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Heat Transfer Characteristics of Insulated Concrete Sandwich Panel Walls

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HEAT TRANSFER CHARACTERISTICS OF INSULATED CONCRETE SANDWICH PANEL WALLS

Final Report

by

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ABSTRACT

Tests were conducted to evaluate thermal performance of three insulated concrete sandwich panel walls. Heat transfer through the walls was measured for steady-state and dynamic temperature conditions. The objective of the test program was to investigate effects of ties connecting wall layers on thermal properties of insulated sandwich panel walls.

The three walls tested were similar except for the type of connectors joining the insulation and concrete layers. Each wall consisted of 2-in. (50-mm) of extruded polystyrene insulation board sandwiched between two 3-in. (75-mm) normal weight concrete layers. The first wall, a control wall, contained no ties. Layers of the second wall were connected using stainless steel ties and anchors. Layers of the third wall were connected using high-tensile fiberglass-composite ties.

Walls were tested in the calibrated hot box facility (ASTM Designation: C976) at Construction Technology Laboratories, Inc. (CTL). Steady-state tests were used to measure thermal resistance (R_T) and thermal transmittance (U). A comparison of results from steady-state tests on the control wall and the wall with stainless steel connectors showed that stainless steel connectors reduced wall thermal resistance by 7%. A comparison of results from steady-state tests on the control wall and the wall with high-tensile fiberglass-composite ties showed that the ties did not reduce wall thermal resistance.

Dynamic calibrated hot box tests provided a measure of thermal response under selected temperature ranges. Heat storage capacities of the walls delayed heat flows through specimens. Average thermal lag values ranged from 5 to 6 hours for the three walls.

Thermal resistances of insulations used in the walls were measured using a guarded hot plate (ASTM Designation: C177. Wall resistances measured in a calibrated hot box were compared to resistances calculated from wall material properties.

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EXECUTIVE SUMMARY

A significant amount of energy is lost from conditioned environments of buildings through thermal bridges. Heat transfer measurements of building components with thermal bridges are needed to assess the severity of heat loss through particular bridges so that remedial measures may be used, if necessary. Heat transfer measurements are also used to verify analytical methods of predicting heat losses through thermal bridges.

Tests were conducted to evaluate thermal performance of three insulated concrete sandwich panel walls. Heat transfer through the walls was measured for steady-state and dynamic temperature conditions in a calibrated hot box. The three walls tested were similar except for the type of connectors joining the insulation and concrete layers. Each wall consisted of 2-in. (50-mm) of extruded polystyrene insulation board sandwiched between two 3-in. (75-mm) normal weight concrete layers. The first wall, a control wall, contained no ties. Layers of the second wall were connected using stainless steel ties and anchors. Layers of the third wall were connected using high-tensile fiberglass-composite ties.

The objective of the test program was to investigate thermal effects of metal and non-metal ties connecting wall layers on thermal properties of insulated sandwich panel walls.

The program was conducted at Construction Technology Laboratories, Inc. (CTL). Work was performed as part of a project sponsored jointly by the U.S. Department of Energy (Office of Buildings and Community Systems), Amoco Foam Products Company, and the Portland Cement Association.

Construction and testing of the control wall and the wall with stainless steel connectors was performed as part of a subcontract with Martin Marietta Energy Systems for the U.S. Department of Energy. This work was co-sponsored by the Portland Cement Association and is part of the Building Thermal Envelope Systems and Materials Program (BTESM) at Oak Ridge National Laboratory.

Construction and testing of the wall with high-tensile fiberglass-composite ties were sponsored by Amoco Foam Products Company. Guarded hot plate tests of insulations used in the walls were also sponsored by Amoco Foam Products Company.

A guarded hot plate was used to measure thermal resistances of the two brands of extruded polystyrene insulation used to construct the three test walls. Thermal resistances were determined at CTL in accordance with ASTM Designation: C 177 "Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate." Nominal specimen dimensions were 2x12x12 in. (50x300x300 mm). Average measured thicknesses of the two brands of insulation were 1.99 and 1.94 in. (49.8 and 48.5 mm), respectively. Thermal resistances were determined at specimen mean temperatures ranging from 34 to 121°F (1 to 50°C) for one brand and 36 to 116°F (2 to 47°C) for the second brand.

Insulation thermal resistances at specimen mean temperature of 75°F (24°C) were interpolated from measured values. The two brands, respectively, had thermal resistances of 8.92 and 9.02 hr•ft^2•°F/Btu (1.57 and 1.59 m^2•K/W) at a specimen mean temperature of 75°F (24°C).

Walls were tested in the calibrated hot box facility (ASTM Designation: C976) at CTL. Test specimens were 8-ft 7-in. (2.6 m) sq. Steady-state tests were used to measure thermal resistance (R) and thermal transmittance (U). Wall thermal resistances were measured at mean temperatures of approximately 105°F (40°C) and 35°F (2°C), and air-to-air temperature differentials, respectively, of 60°F (33°C) and 75°F (42°C).

A comparison of results from steady-state tests on the control wall and the wall with stainless steel connectors showed that stainless steel connectors reduced wall thermal resistance by 7%. A comparison of results from steady-state tests on the control wall and the wall with high-tensile fiberglass-composite ties showed that the ties did not reduce wall thermal resistance.

Design total thermal resistances for Walls P1, P2, and P3 were within 6% of calibrated hot box test results. The isothermal planes method of calculating total wall resistance predicted performance of the wall with stainless steel connectors. A 5% decrease in total thermal resistance for the wall with stainless steel connectors, compared to the control wall, was predicted. A 7% decrease was measured.

Comparing results from the control wall and the wall with stainless steel ties shows that the three-dimensional finite difference technique performed by Mr. K. W. Childs, ORNL, accurately predicted steady-state thermal performance of the stainless steel torsion anchors. A 6% decrease in wall thermal resistance due to the connectors was predicted. A 7% decrease was measured.

Calibrated hot box indoor and outdoor air temperatures, indoor and outdoor wall surface temperatures, and the two concrete-insulation interface temperatures were measured using 16 thermocouples in each of the six planes. Additional thermocouples were used to evaluate the effects of ties on surface temperatures. Steady-state test results showed that wall surface temperatures adjacent to stainless steel ties are not significantly different from surface temperatures between ties.

Dynamic calibrated hot box tests were performed on the three test specimens. Dynamic tests are a means of evaluating thermal response under controlled conditions that simulate temperature changes actually encountered by building envelopes. For these tests, the calibrated hot box indoor air temperatures were held constant while outdoor air temperatures were cycled over a pre-determined temperature versus time relationship.

Three 24-hour (diurnal) temperature cycles were performed on each wall in this investigation. The cycles had mean temperatures of approximately 58, 68, and 78°F (14, 20, and 26°C) and temperature swings of about 60°F (33°C). Average indoor air temperature over the 24-hour period for each cycle was approximately 72°F (22°C).

Dynamic calibrated hot box tests were used to determine dynamic thermal properties of thermal lag, reduction in amplitude, and total heat flow ratio. As indicated by thermal lag, heat storage capacities of insulated concrete sandwich panel walls delayed heat flow through specimens. Average thermal lag values ranged from 5 to 6 hours for the three walls.

As indicated by the damping effect, heat storage capacities of the walls reduced peak heat flows through specimens for dynamic temperature conditions when compared to predictions based on steady-state thermal resistances (R-values). Reduction in amplitude values ranged from 34 to 46% for the control wall, 42 to 48% for the wall with stainless steel connectors, and 44 to 69% for the wall with high-tensile fiberglass-composite ties.

For the three diurnal temperature cycles applied to the test walls, total heat flow for a 24-hour period were less than would be predicted by steady-state R-values. Total measured heat flows for the 24-hour cycles ranged from 43 to 81% of those predicted by steady-state analysis for the three walls. These reductions in total heat flow are attributed to wall storage capacity and reversals in heat flow.

Transient test data were collected during calibrated hot box testing of the three test specimens. Results of a transient test are determined from data collected in the period of time between two steady-state tests. After a wall is in a steady-state condition, the outdoor chamber temperature setting is changed. The transient test continues until the wall reaches equilibrium heat flow for the new outdoor chamber air temperature. The initial wall mean temperature for the tests was 73°F (27°C). The final wall mean temperature was approximately 33°F (1°C).

Transient test results indicated that heat storage capacities of the three insulated concrete sandwich panel walls delayed heat flow through the specimens. The amount of time required for the walls to reach 63% of a final heat flow were approximately 3-1/2 times greater than predicted by steady-state calculations based on measured surface temperatures.

Calibrated hot box test results presented in this report are limited to the specimens and temperature cycles used in this investigation. It is anticipated that results would differ for walls with different insulation thicknesses, for tie systems with different cross-sectional areas, or when insulation is not tightly packed around ties as it was in this test program.

Results described in this report provide data on thermal response of concrete-insulation sandwich panel walls subjected to steady-state and diurnal sol-air temperature cycles. A complete analysis of building energy requirements must include consideration of the entire building envelope, building orientation, building operation, and yearly weather conditions. Data developed in this experimental program provide a quantitative basis for modeling the building envelope, which is part of the overall energy analysis process.

HEAT TRANSFER CHARACTERISTICS OF INSULATED CONCRETE SANDWICH PANEL WALLS

by

M. G. Van Geem and S. T. Shirley*

INTRODUCTION

Tests were conducted to evaluate thermal performance of three insulated concrete sandwich panel walls. Heat transfer through the walls was measured for steady-state and dynamic temperature conditions. The objective of the test program was to investigate effects of ties connecting wythes on thermal properties of sandwich panel walls.

The three walls tested were similar except for the type of connectors joining the insulation and concrete layers. Each wall consisted of 2-in. (50-mm) of extruded polystyrene insulation board sandwiched between two 3-in. (75-mm) normal weight concrete wythes as shown in Fig. 1. The first wall, a control wall, contained no ties. Layers of the second wall were connected using stainless steel ties and anchors. Layers of the third wall were connected using high-tensile fiberglass-composite ties.

Walls were tested in the calibrated hot box facility at Construction Technology Laboratories, Inc. (CTL). Steady-state tests were used to obtain average heat transmission coefficients, including total thermal resistance (R_T), and thermal transmittance (U). Dynamic tests provided a measure of thermal response for selected temperature ranges. A simulated sol-air

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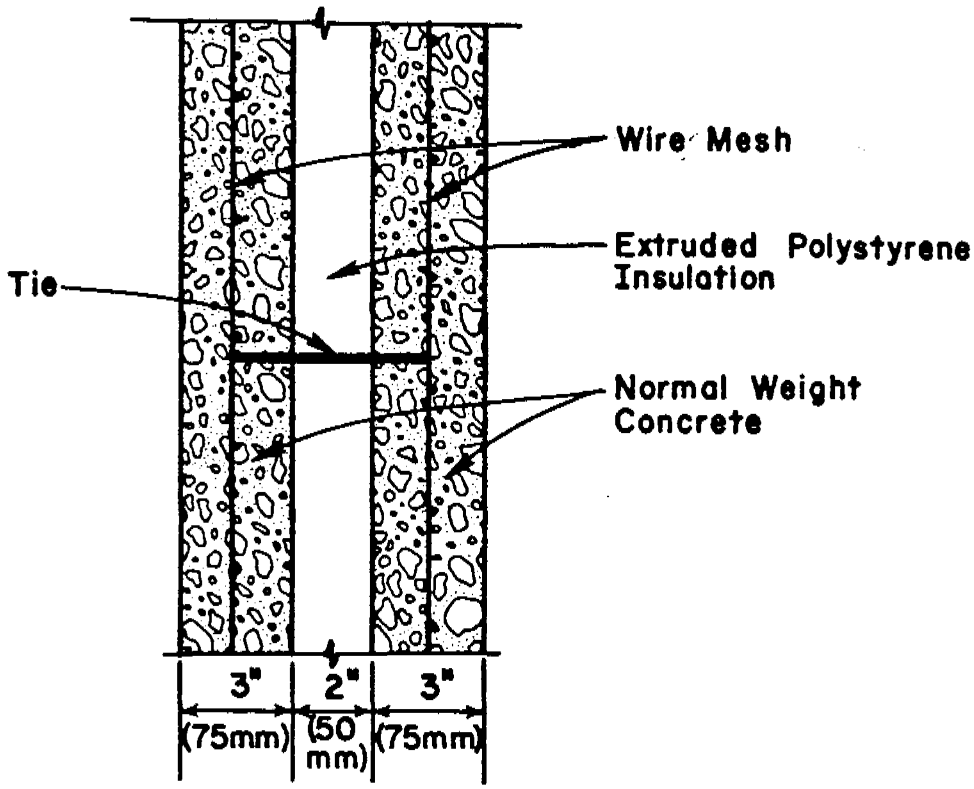


Fig. 1 Cross Section of Insulated Sandwich Panel Walls

dynamic cycle was selected to permit comparison of results with those obtained in previous investigations.(1-8)* Results from tests on walls with ties are compared to those from the wall with no ties.

Thermal resistances of insulations used in the walls were measured using a guarded hot plate. Wall resistances measured in a calibrated hot box are compared to resistances calculated from material properties.

BACKGROUND

One method of insulating structural concrete walls is to provide a layer of insulation between two layers of concrete as shown in Fig. 1. Ties or other fasteners are used to connect the three layers. Ties are often necessary for stability and load transfer, as either or both concrete layers may be designed to be load bearing.

Ties or other elements that penetrate an insulation layer act as thermal bridges when their conductivity is large compared to insulation. Heat losses are concentrated at the location of conductive elements because heat will flow through the path of least resistance, as illustrated in Fig. 2. Metal ties connecting layers of insulated concrete sandwich panel walls reduce the thermal resistance of a wall assembly.

Materials other than metal may be used for connectors if they provide enough strength to resist the connector design loads. High-tensile fiberglass-composite ties, such as those manufactured by Amoco Foam Products, have been developed to reduce thermal bridging through insulation. The conductivity of the fiberglass-composite material is approximately 1/100 that of stainless steel.

*Superscript numbers in parentheses refer to references listed at the end of this report.

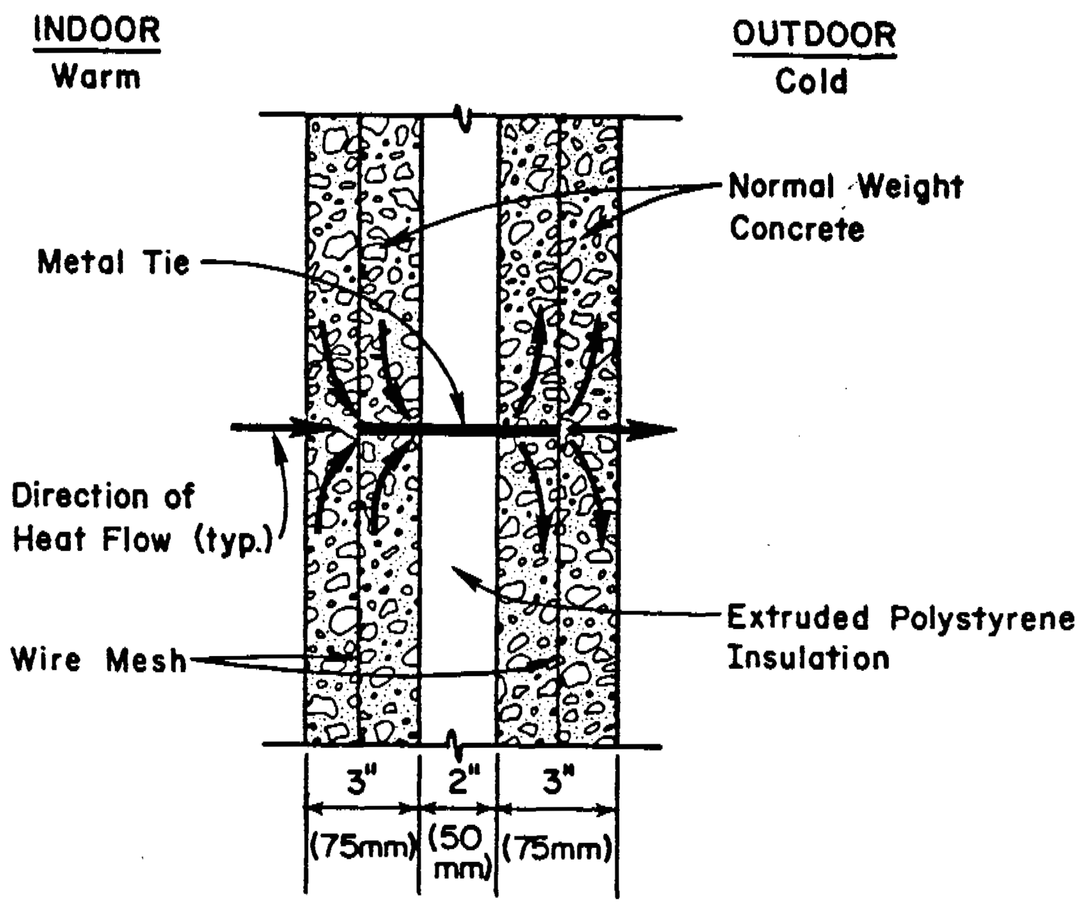


Fig. 2 Thermal Bridge Due to Metal Tie Penetrating Insulation

The guarded hot plate test method [ASTM Designation: C177[9]] is the most widely accepted method of measuring thermal resistance of building materials. Generally, tests are performed using relatively small samples of homogeneous materials. Sample sizes generally range from 0.2 to 4 sq ft (0.02 to 0.4 m^2), depending on the hot plate used. Overall thermal resistance of a system containing a thermal bridges such as a stainless steel tie cannot be measured using a guarded hot plate.

The calibrated hot box [ASTM Designation: C976[9]] and the guarded hot box [ASTM Designation: C236[9]] are used to measure thermal performance of full scale wall assemblies.[9] Specimens may be constructed of homogeneous materials, such as concrete, or composite systems, such as insulated frame walls, masonry walls, or panels with metal connectors. The CTL calibrated hot box is used to measure performance for steady-state or dynamic temperature conditions. Dynamic testing is particularly important for massive envelope components that store as well as transmit heat. Test results are used to evaluate performance of comparative wall systems and to verify analytical models. Heat transfer characteristics of building elements must be known to evaluate energy losses through a building envelope.

TEST SPECIMENS

Three insulated concrete sandwich panel walls were constructed by CTL and subsequently tested in a calibrated hot box. Walls consisted of insulation board sandwiched between normal weight concrete layers as shown in Fig. 1. Overall nominal dimensions of each wall were 103x103 in. (2.62x2.62 m). Nominal dimensions of concrete and insulation layers were 3 in. (75 mm) and 2 in. (50 mm), respectively.

The first wall, designated Wall P1, was constructed of board insulation sandwiched between two concrete layers. The light blue colored board insulation was identified as Dow Styrofoam extruded polystyrene insulation. Wall P1 was constructed without any ties bridging between two concrete layers.

The second wall, designated Wall P2, was also constructed with Dow Styrofoam insulation board identified as, sandwiched between two concrete layers. Wall P2 was constructed with stainless steel ties and torsion anchors bridging the two concrete layers.

The third wall, designated Wall P3, was identified by Amoco Foam Products Company as the Amoco-Thermomass Wall System. It consisted of light green colored board insulation, identified as Amofoam*-CM extruded polystyrene, sandwiched between two concrete layers. The two concrete layers were bridged with plastic ties, identified by Amoco Foam Products Company as high-tensile fiberglass-composite ties.

Wall Construction

Walls were reinforced with a single layer of 6x6-in. (150x150-mm) W1.4xW1.4 welded wire fabric located at the center of each 3-in. (75-mm) concrete layer, as detailed in Fig. 3. Walls were oriented horizontally for casting. The wire mesh was supported at a distance of 1.5 in. (38 mm) from the face of the wythe by concrete chairs. These chair supports, shown in Fig. 4, raised the wire mesh off of the formwork base before and during concrete placement. Chair supports were also used to raise wire mesh above the insulation prior to casting the second concrete wythe. Chair supports were

*Styrofoam and Amofoam, respectively, are trademarks of Dow Chemical Company and Amoco Foam Products Company.

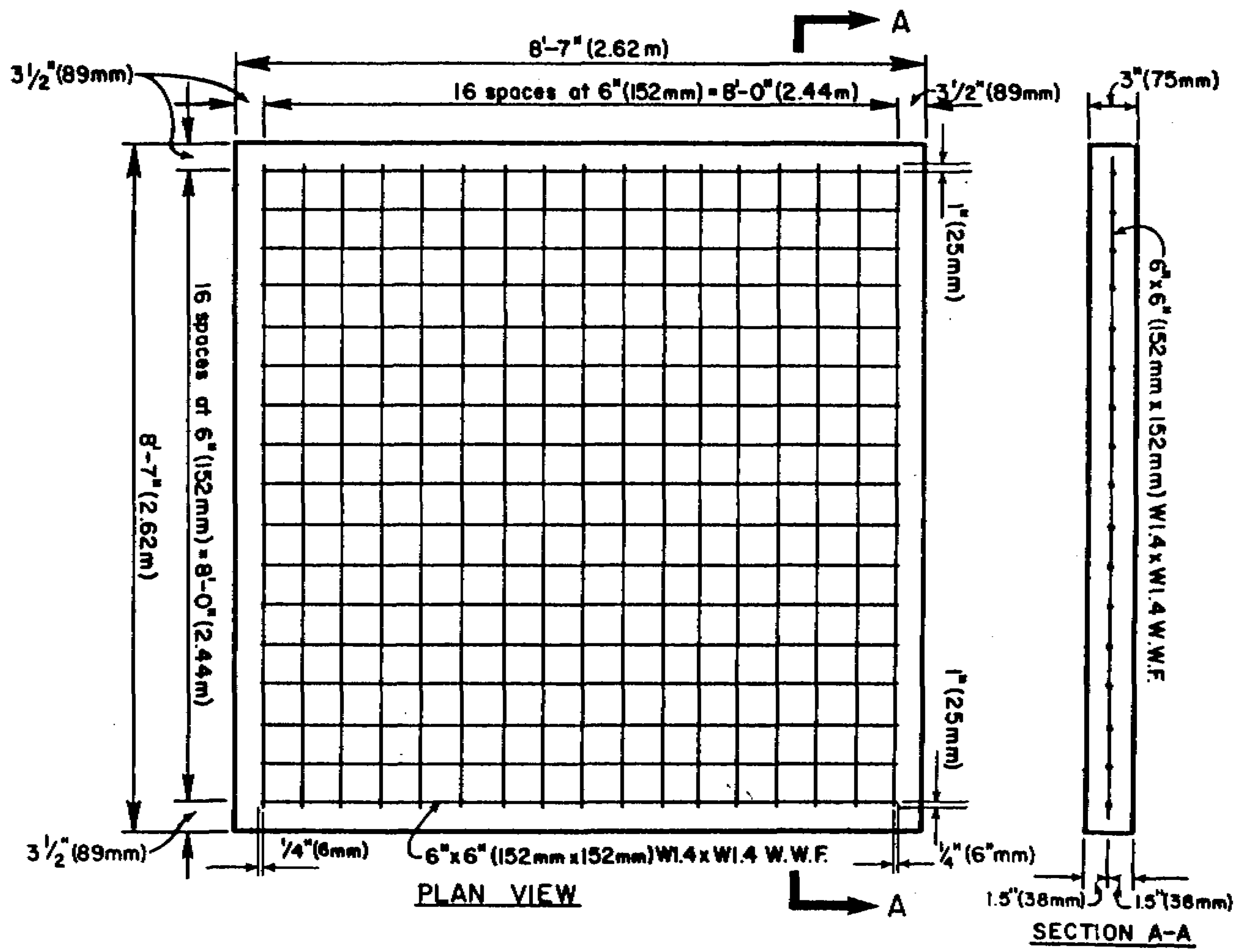


Fig. 3 Reinforcement Detail for Concrete Layers

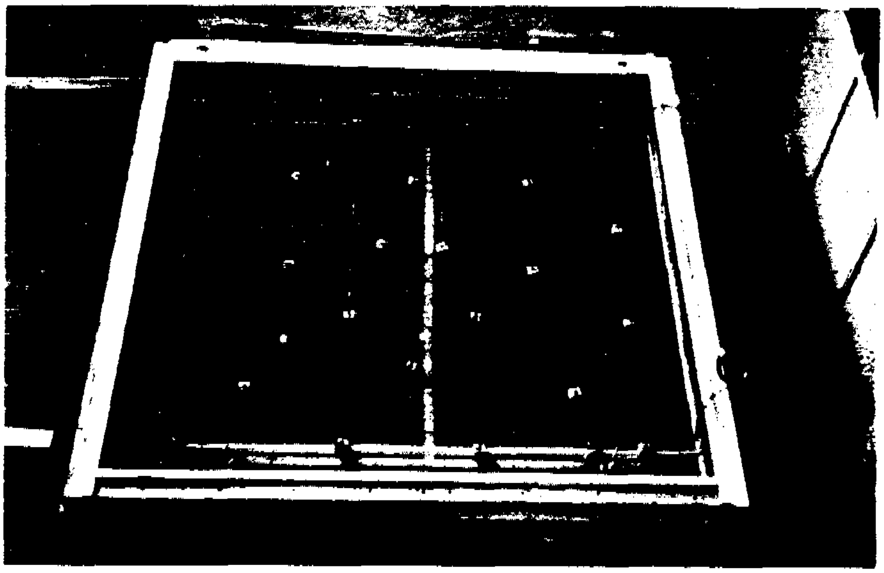


Fig. 4 Location of Concrete Chairs Supporting Wire Mesh for Wall P1

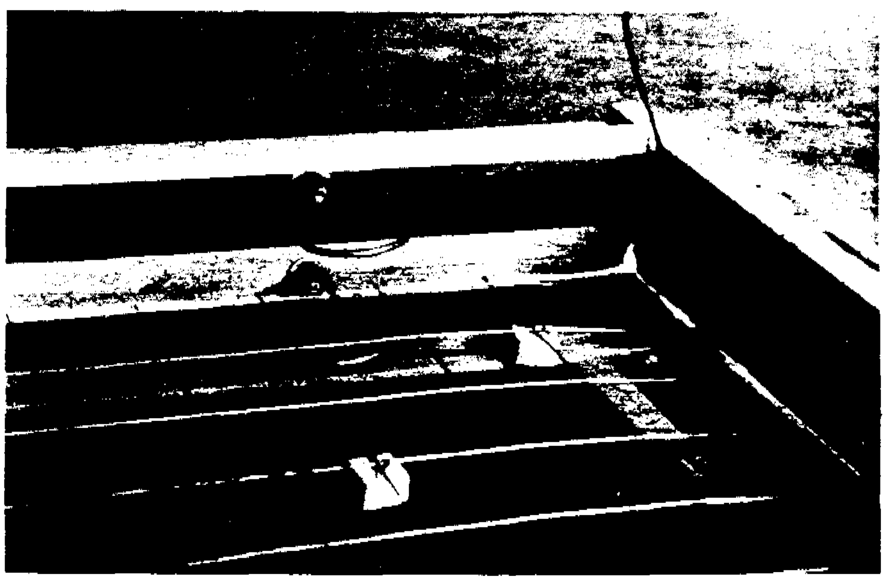


Fig. 5 Lifting Lugs for Wall P1

made of the same concrete used for wall construction. Concrete, rather than steel or plastic chairs, were used to eliminate potential thermal bridging caused by supports.

Threaded inserts were cast into Walls P1, P2, and P3 at mid-thickness of the top edge of each wythe, as shown in Fig. 5. The steel loop-type inserts were used to transport each wall after the concrete had attained the necessary strength.

The mix design for concrete used to construct Walls P1, P2, and P3 is given in Table 1. Elgin coarse and fine aggregates were used in the concrete for all walls. The nominal maximum size of the coarse gravel was 3/4 in. (20 mm). Aggregates from Elgin are considered dolomitic.(10)

Laboratory test results for measured slump, air content, and unit weight of the fresh concrete are summarized in Table 2. The water-cement ratio of concrete used for each of the three walls was 0.57.

Details of construction procedures for each of the three walls are described in the following sections.

<u>Wall P1</u>

The 2-in. (50-mm) thick Dow Styrofoam insulation used for Wall P1 was obtained from Dow Chemical U.S.A. in nominal 4x8-ft (1.22x2.44-m) sheets. Insulation was pieced together to form an 8-ft 7-in. (2.62-m) square panel as shown in Fig. 6. Insulation pieces were secured at joints using continuous strips of duct tape on each surface. Taping of the seams prevented infiltration of concrete paste during placement. Wall P1 had 25-ft 2-1/4 in. (7.68 m) of insulation seams.

Measured thickness and density of the Dow Styrofoam insulation was 2 in. (50 mm) and 1.87 pcf (29.9 kg/m^3), respectively.

TABLE 1 - CONCRETE MIX DESIGN FOR WALLS P1, P2, and P3

Material	Quantities per cu yd of concrete
Type I Cement	454 lb (206 kg)
Water	258 lb (117 kg)
Elgin Coarse Gravel, 3/8" to 3/4" SSD* (2.04% MC**)	872 lb (395 kg)
Elgin Fine Gravel, No. 4 to 3/8" SSD (2.25% MC**)	872 lb (395 kg)
Elgin Sand, SSD (1.79% MC**)	1431 lb (649 kg)
Vinol Resin - 2.2% Solution (Air-Entraining Admixture)	1.5 ml/lb cement (3.30 ml/kg)

*Saturated surface dry; neither absorbing water from nor contributing water to the concrete mix[11]
**Moisture content, by ovendry weight

TABLE 2 - MEASURED PROPERTIES OF FRESH CONCRETE

Wall Designation	Average Slump, in. (mm)	Average Air Content, %	Average Unit Weight, pcf (kg/m^3)
P1	3.7 (94)	7.3	144.1 (2308)
P2	3.2 (81)	6.1	144.9 (2321)
P3	2.9 (74)	7.8	143.3 (2296)

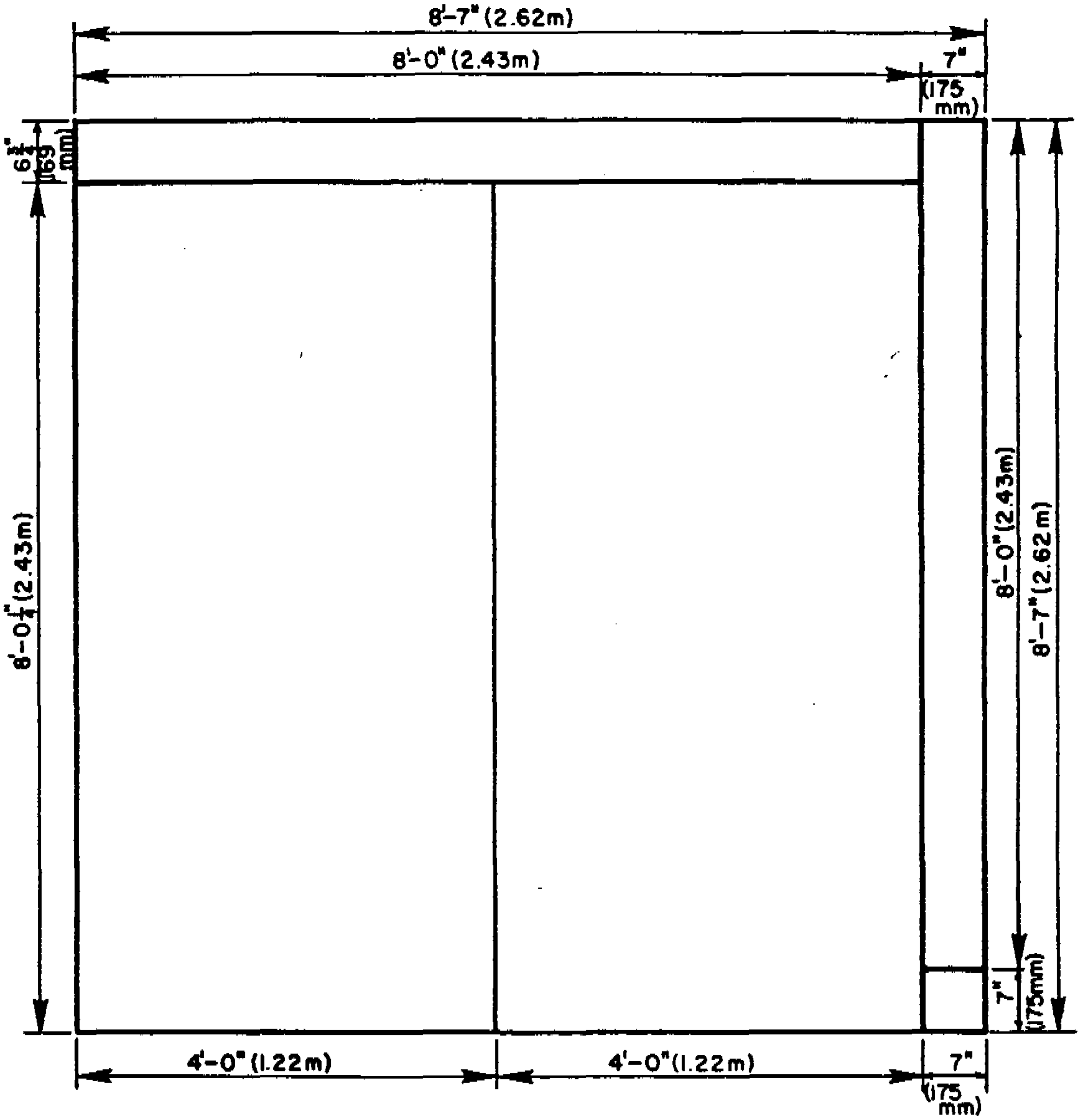


Fig. 6 Location and Length of Insulation Seams for Wall P1

Ten 6-cu-ft (0.17-m^3) batches of concrete were prepared for casting of Wall P1. Concrete was mixed by a 6-cu-ft (0.17-m^3) pan-type concrete mixer and transported by wheelbarrow to the casting site. Placement of concrete to form the first 3-in. (75-mm) thick concrete layer was performed initially. Concrete was consolidated using a vibrating pad as shown in Fig. 7. Concrete was screeded to obtain a uniform 3-in. (75-mm) thickness. Insulation board with thermocouple wires attached was then placed on top of the concrete.

After the insulation board and thermocouples were positioned, construction procedures described above were repeated for the second concrete layer. The top layer of concrete was troweled to obtain a uniform surface. Both concrete layers were cast within a 3-hour period. Figure 8 shows the finished surface of Wall P1.

Wall P1 was allowed to cure in formwork for 15 days. After removing formwork, the wall was allowed to air dry in the laboratory at a temperature of 73±5°F (23±3°C) and 45±15% RH for approximately 3 months.

Prior to testing, the faces of Wall P1 were coated with a cementitious waterproofing material to seal minor surface imperfections. A textured, non-cementitious paint was subsequently used as a finish coat. These coatings provided a white, uniform surface for both wall faces. Wall edges were left uncoated.

Wall P2

Torsion anchors and ties, identified as stainless steel, were used to connect concrete layers of Wall P2. Locations of the four torsion anchors and sixteen metal ties are shown in Fig. 9. A Type A-3 tie consists of a 0.118-in. (3-mm) diameter bar with a nominal height of 5 in. (125 mm). Dimensions of Type A and Type B torsion anchors are shown in Fig. 10. Connectors were manufactured by The Burke Company and were installed per manufacturer's instructions.

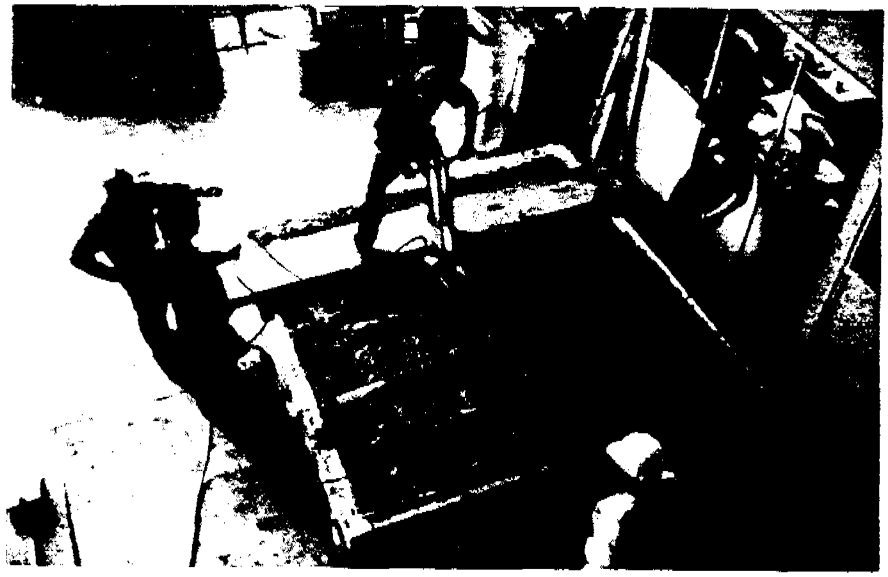


Fig. 7 Concrete Consolidation for Wall P1 Using Vibrating Pad

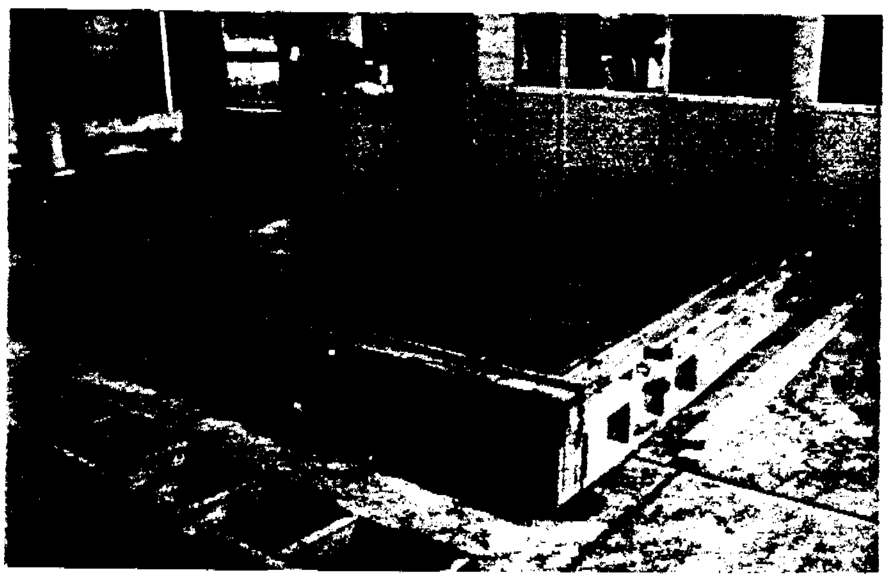


Fig. 8 Finished Surface Wall P1

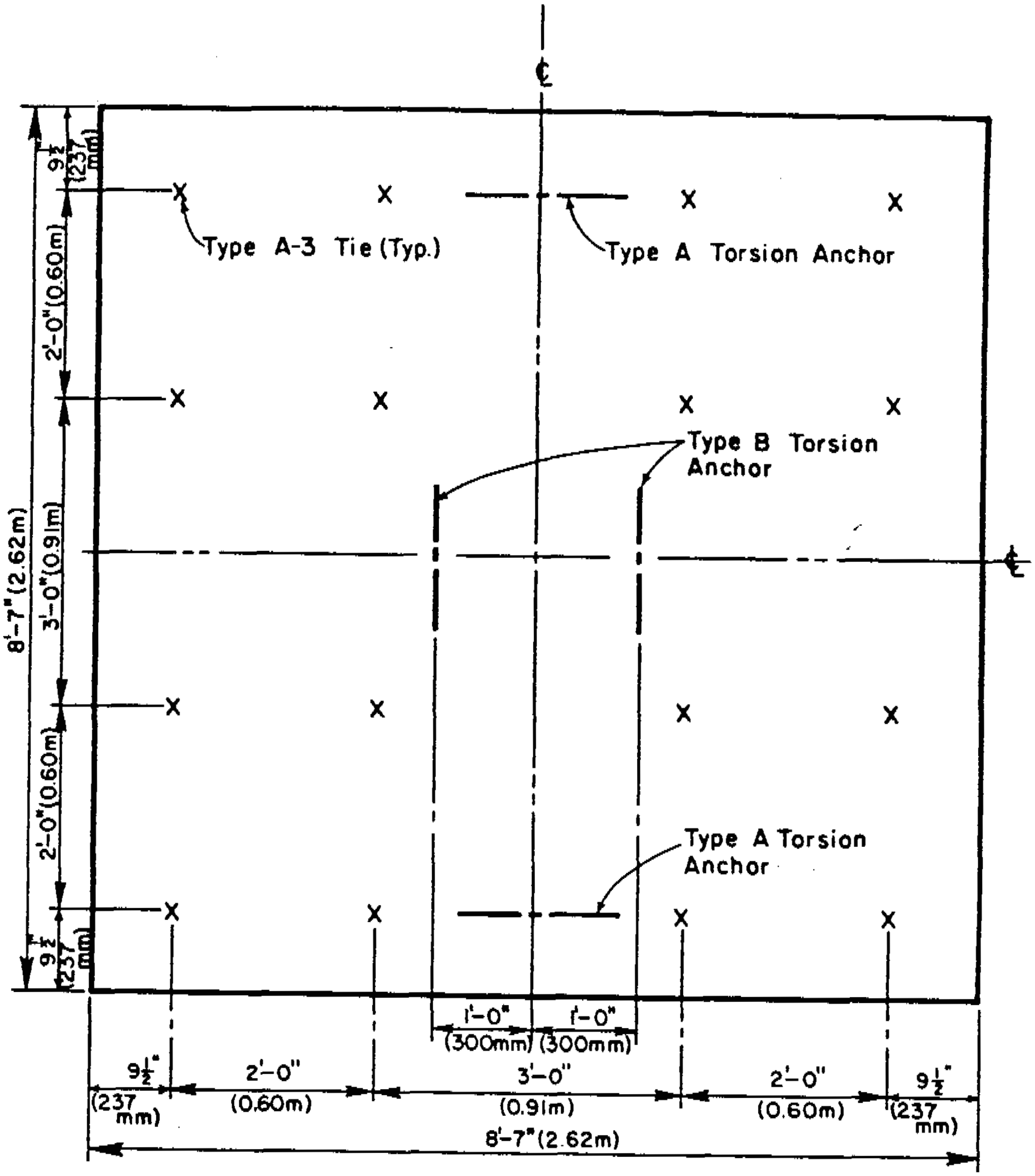


Fig. 9 Location of Stainless Steel Torsion Anchors and Ties in Wall P2

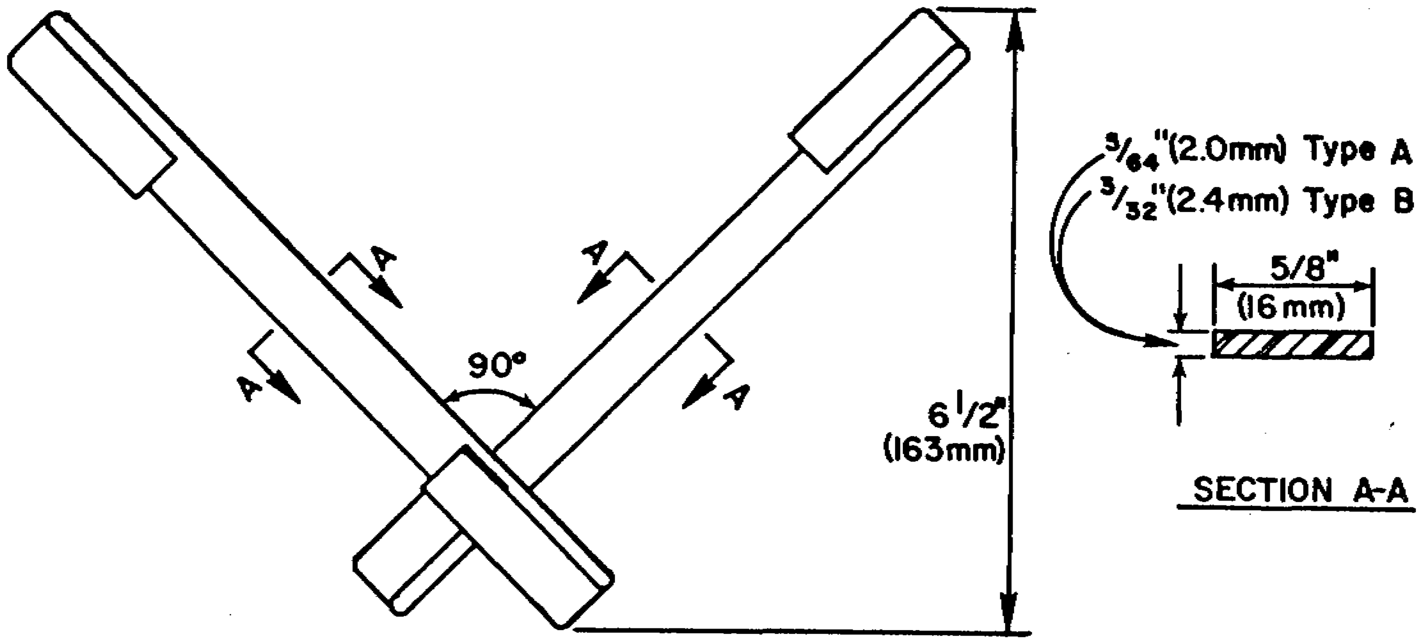


Fig. 10 Dimensions of Type A and Type B Torsion Anchors

Figures 11 and 12, respectively show ties and torsion anchors attached directly to the wire mesh of the lower layer before concrete was placed. Two 28-in. (700-mm) long No. 2 bars were installed at the location of each torsion anchor, as shown in Fig. 13.

The Dow Styrofoam insulation used for Wall P2 was obtained in nominal 4x8-ft (1.22x2.44-m) sheets. Insulation was cut to form three sections as shown in Fig. 14. Sections were chosen to facilitate placement of insulation around ties and torsion anchors. Individual pieces of insulation sections were joined using duct tape. Joints of each surface were continuously taped, except at the location of torsion anchors.

Sections of insulation were cut out at locations of ties and torsion anchors. Figure 15 shows insulation in place with a tie penetrating the cut-out section. Cut-out sections were saved and replaced, as shown in Fig. 16, after insulation board was placed on the first concrete layer. Seams of cut-out sections and the three sections of insulation shown in Fig. 14 were taped on the top surface using duct tape.

Measured thickness and density of the Dow Styrofoam insulation used for Wall P2 was 2.0 in. (50 mm) and 1.86 pcf (29.8 kg/m^3), respectively.

Ten 6-cu-ft (0.17-m^3) batches of concrete were prepared for casting of Wall P2. Concrete was mixed using a 6-cu-ft (0.17-m^3) revolving-drum-type mixer and was transported in a concrete bucket by forklift to the casting site. The concrete bucket was lifted above formwork by an overhead crane and concrete was placed in the formwork. Concrete was placed in each 3-in. (75-mm) thickness from one side of the wall to the opposite side. Concrete in each layer was consolidated using a vibrating screed as shown in Fig. 17. Polystyrene insulation was placed on top of the first concrete layer after the concrete was placed.

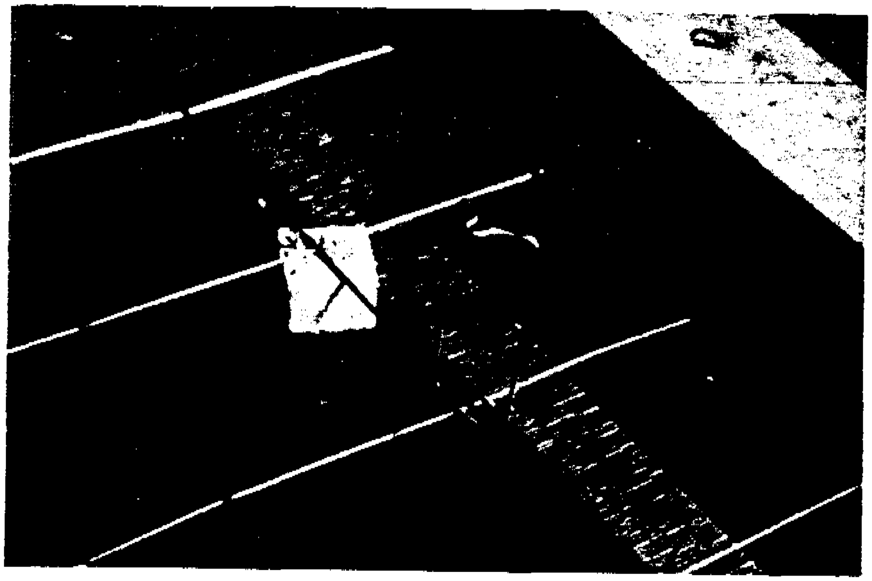


Fig. 11 Mounting of Type A-3 Metal Tie to Wire Mesh for Wall P2

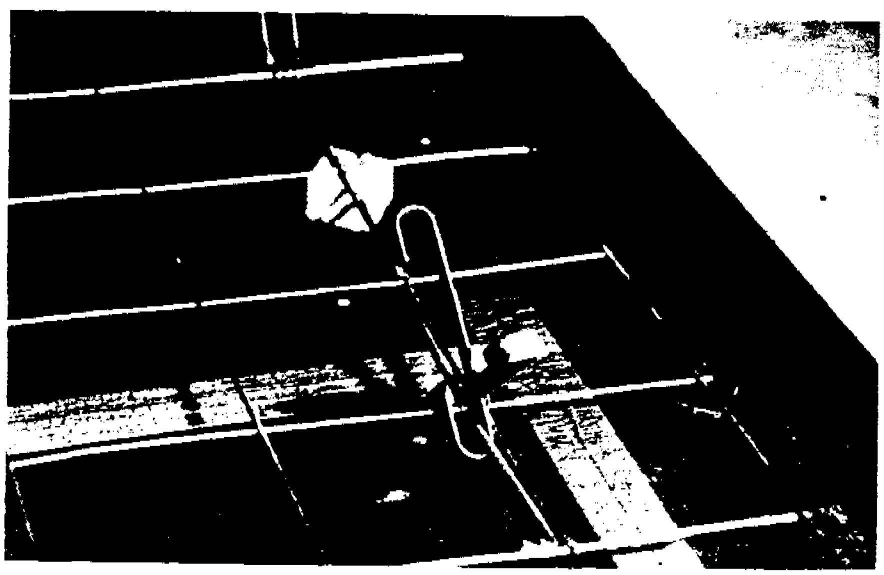


Fig. 12 Mounting of Torsion Anchor to Wire Mesh for Wall P2

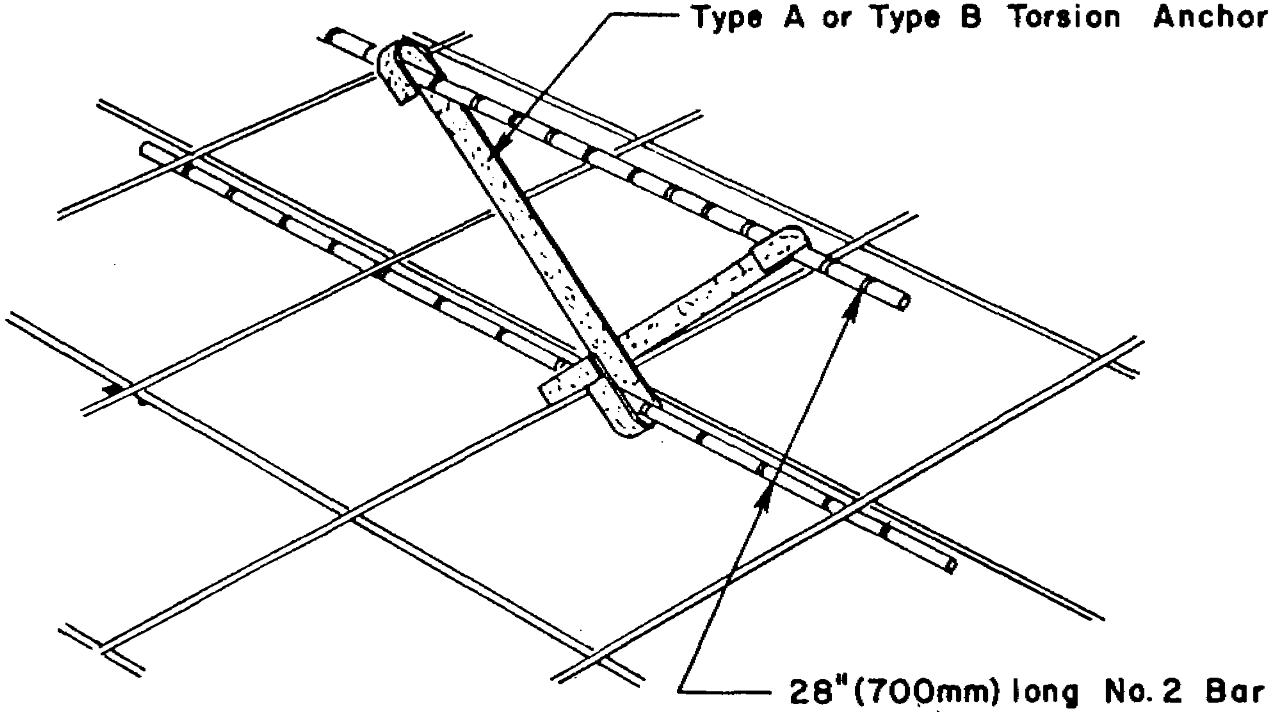


Fig. 13 Torsion Anchor Installation Detail

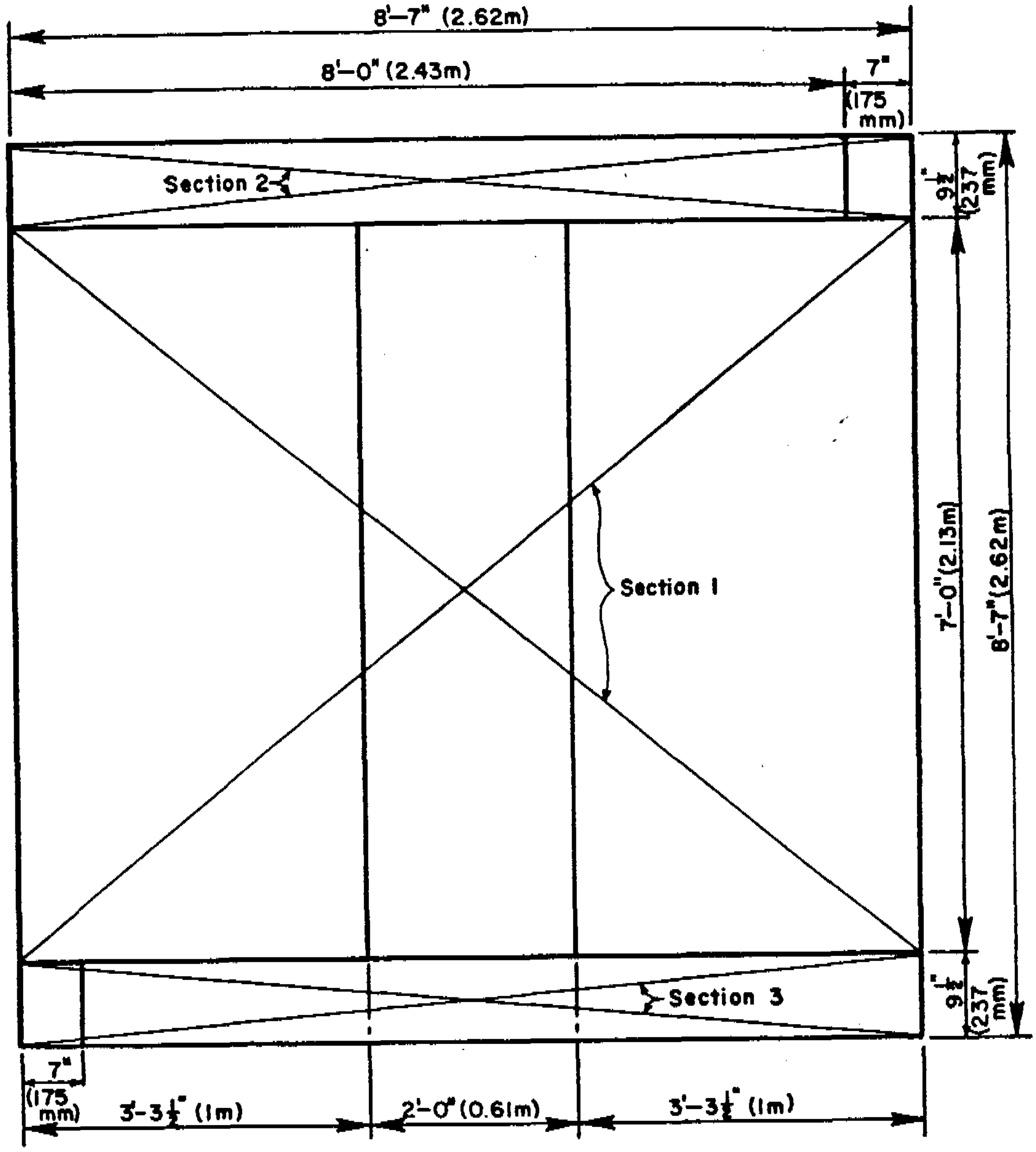


Fig. 14 Location and Length of Insulation Seams for Wall P2

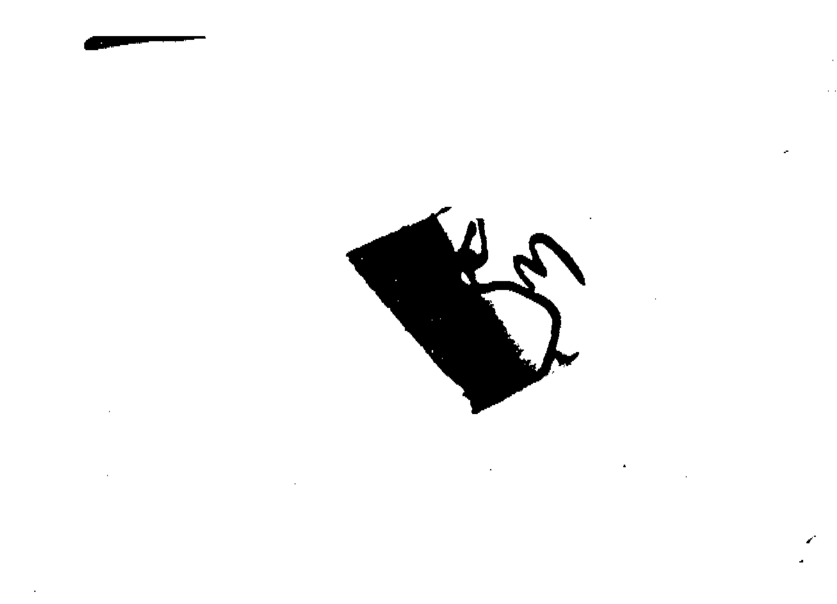


Fig. 15 Insulation Cut-Out for Wall P2 to Allow Penetration of Metal Tie

Fig. 16 Insulation Replaced Around Metal Tie

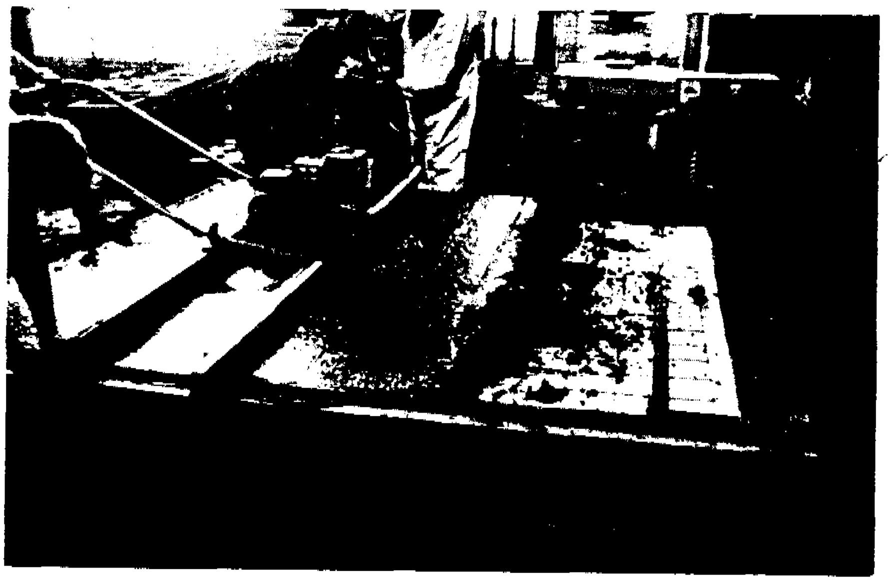


Fig. 17 Concrete Consolidation for Wall P2 Using Vibrating Screed

The top surface of the second concrete layer was troweled to obtain a uniform surface.

Wall P2 was allowed to cure in formwork for 14 days. After removing formwork, the wall was allowed to air dry in the laboratory at a temperature of 73±5°F (23±°C) and 45±15% RH for approximately 3 months.

Prior to testing, the faces of Wall P2 were coated and painted in the same manner as Wall P1.

Wall P3

Ties, described as high-tensile fiberglass-composite, were used to connect concrete layers of Wall P3. Locations of the thirty-six ties are shown in Fig. 18. Connectors, shown in Fig. 19, were manufactured by Thermomass Technology Inc. and were installed per manufacturer's instructions. Dimensions of the 6-in. (150-mm) long connectors are shown in Fig. 20.

The Amofoam insulation was obtained in nominal 4x8-ft (1.22x2.44-m) sheets. Insulation was cut to form an 8-ft 7-in. (2.62 m) square panel as shown in Fig. 21. Insulation pieces were joined using continuous strips of transparent cellophane tape on each surface. Tape was provided by Amoco Foam Products. Wall P3 had 25 ft 2 in. (7.67 m) of insulation seams.

Prior to placing the insulation on the concrete, 15/32-in. (12-mm) holes were drilled through the insulation at the location of ties.

Polystyrene insulation was placed on top of the first concrete layer after the concrete was placed. High-tensile fiberglass-composite ties were pushed through the predrilled holes in the insulation into the lower concrete layer, as shown in Fig. 22.

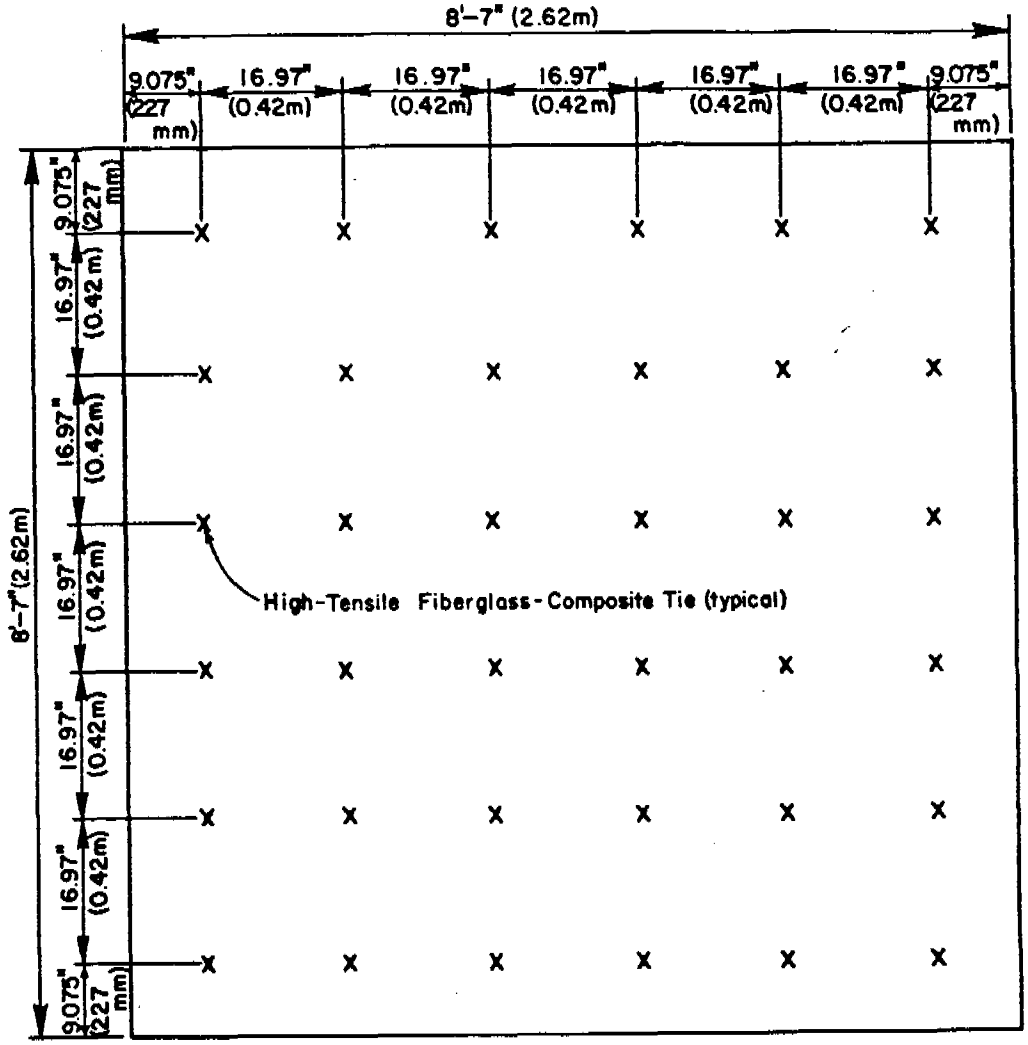


Fig. 18 Location of High-Tensile Fiberglass-Composite Ties in Wall P3

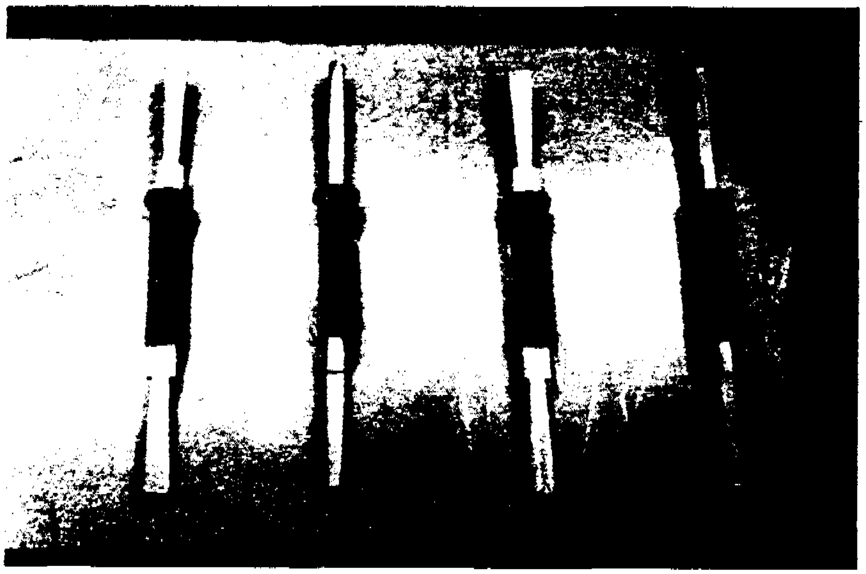


Fig. 19 High-Tensile Fiberglass-Composite Ties

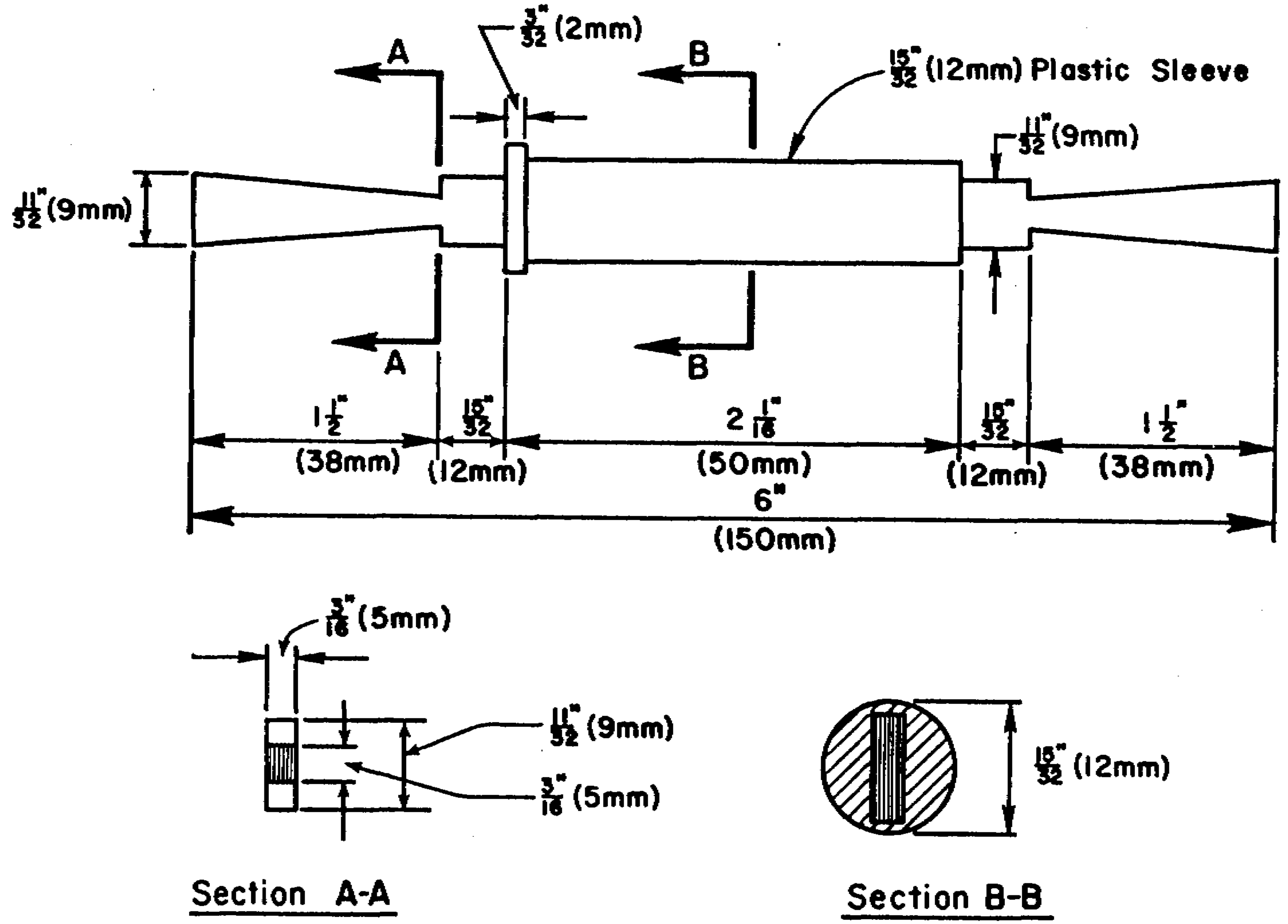


Fig. 20 Dimensions of High-Tensile Fiberglass-Composite Tie

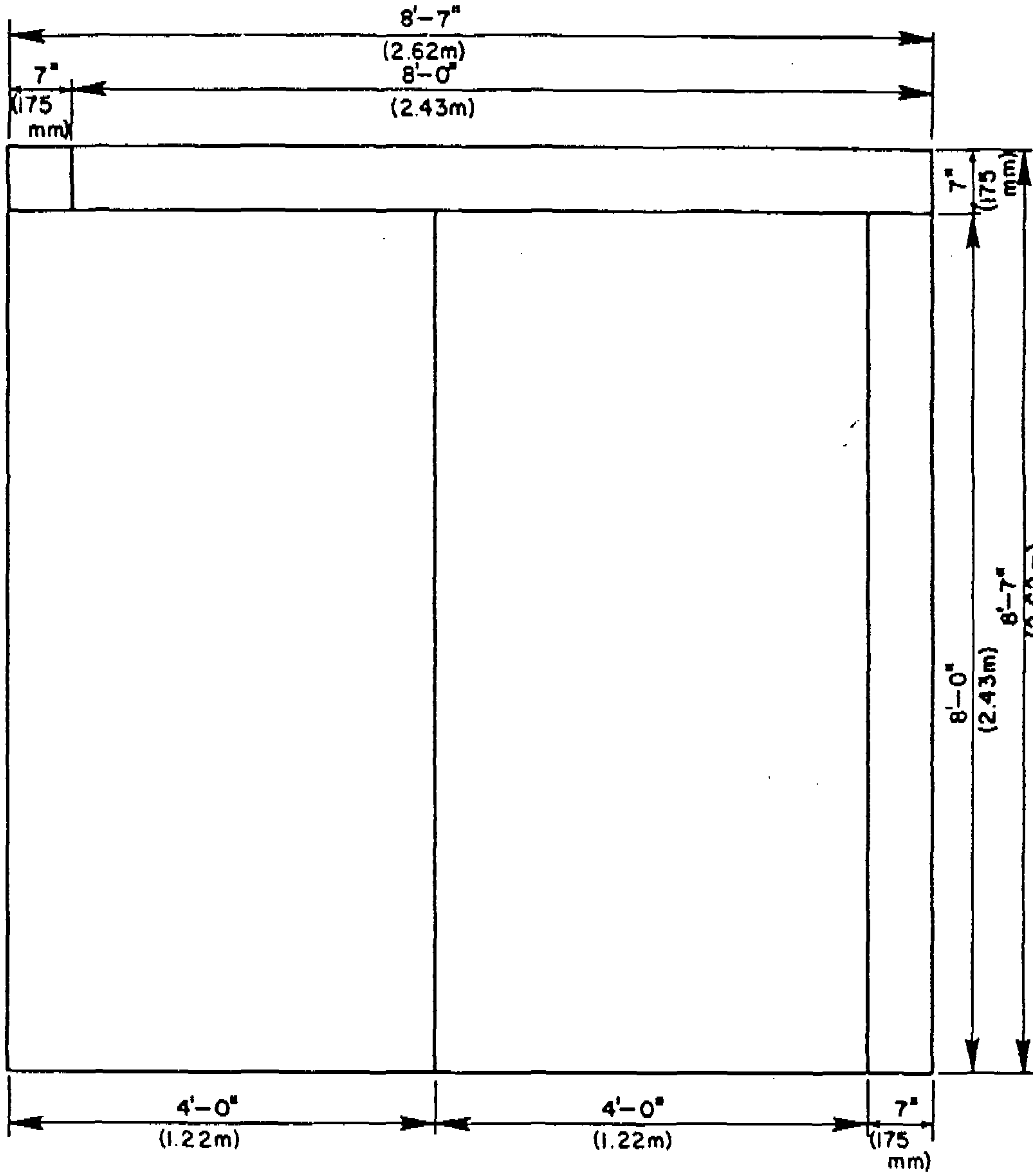


Fig. 21 Location and Length of Insulation Seams for Wall P3

The Amofoam insulation used for Wall P3 had a measured thickness of 2 in. (50 mm) and a density of 2.08 pcf (33.3 kg/m^3).

Ten 6-cu-ft (0.17-m^3) batches of concrete were prepared for casting of Wall P3. Concrete was mixed using a 6-cu-ft (0.17-m^3) revolving-drum-type concrete mixer and was transported in a concrete bucket by forklift to the casting site. The concrete bucket was lifted above formwork by an overhead crane and concrete was placed in the formwork. Concrete was placed in each 3-in. (75-mm) thick layer from one side of the wall to the opposite side. The concrete was consolidated using the same vibrating screed used in construction of Wall P2. To reduce the chance of voids in the concrete, ties were touched gently with an immersion vibrator as shown in Fig. 23.

The top surface of the second concrete wythe was troweled to obtain a uniform surface.

Wall P3 was allowed to cure in formwork for fourteen days. After removing formwork, Wall P3 was allowed to air dry in the laboratory at a temperature of 73±5°F (23±3°C) and 45±15% RH for approximately 3 months.

Prior to testing, the faces of Wall P3 were coated and painted in the same manner as Walls P1 and P2.

Physical Properties of Walls

Measured unit weights, thicknesses, and surface areas of Walls P1, P2, and P3 are summarized in Table 3. Insulation thicknesses and densities for Walls P1, P2, and P3 are also listed in Table 3.

Instrumentation

Ninety-six thermocouples, corresponding to ASTM Designation: E230, "Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples,"[9] Type T, were used to measure temperatures during thermal testing. For each

Fig. 22 High-Tensile Fiberglass-Composite Tie Placed in Insulation and Lower Layer of Concrete for Wall P3

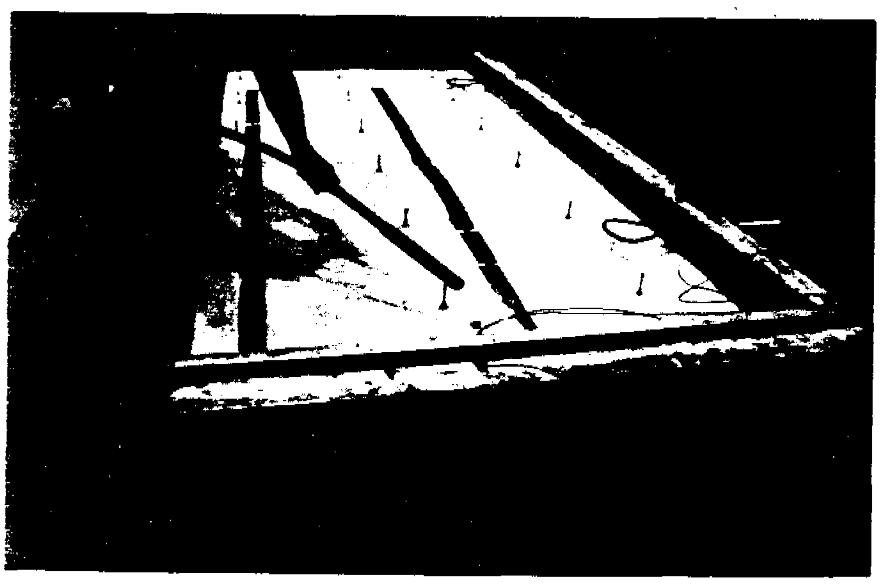


Fig. 23 Vibration of High-Tensile Fiberglass-Composite Tie

TABLE 3 - SUMMARY OF PHYSICAL PROPERTIES FOR WALLS P1, P2, and P3

Property	Measured Value		
	Wall P1	Wall P2	Wall P3
Unit Weight of Wall, lb/ft^2 (kg/m^2)	77.1** (376)	74.5* (364)	75.1* (366)
Average Wall Thickness, in. (mm)	8.20 (208)	8.20 (208)	8.19 (208)
Wall Area, ft^2 (m^2)	73.90 (6.86)	73.94 (6.87)	74.09 (6.88)
Insulation Thickness, in. (mm)	2 (50)	2 (50)	2 (50)
Insulation Density, lb/ft^3 (kg/m^3)	1.87 (29.9)	1.86 (29.8)	2.08 (33.3)

*Measured before calibrated hot box testing.
**Measured after calibrated hot box tests were completed.

test wall, 16 thermocouples were located in the air space on each side of the test specimen, 16 on each face of the test wall, and 16 at each of the two concrete/insulation interfaces. The 16 thermocouples in each plane were spaced 20-3/5-in. (525-mm) apart in a 4x4 grid over the wall area.

Thermocouples measuring temperatures in the air space of each chamber of the calibrated hot box were located approximately 3 in. (75 mm) from the face of the test wall.

Surface thermocouples were securely attached to the wall with duct tape for a length of approximately 4 in. (100 mm). The tape covering the sensors was painted the same color as the test wall surface. Thermocouples attached to indoor and outdoor surfaces of Wall P1 are shown in Figs. 24 and 25, respectively.

Internal thermocouples placed at the concrete/insulation interfaces were taped directly to the insulation board prior to placement in the wall, as shown in Fig. 26. This technique ensured desirable thermocouple location during concrete placement. Thermocouples were wired to form a thermopile, such that an electrical average of 4 thermocouple junctions, located along a horizontal line across the grid, was obtained.

Additional thermocouples were also used to monitor temperatures on and near ties bridging concrete layers for Walls P2 and P3. Two stainless steel ties in Wall P2 were monitored. Each tie was located 2-ft 9-1/2 in. (0.85 m) from the top of the wall and 2-ft 9-1/2 in. (0.85 m) from the side of the wall. Thermocouple locations in a typical cross-section of the wall are shown in Fig. 27. Thermocouple sensors were taped to each end of the monitored tie, on concrete surfaces directly across from the monitored tie, and on concrete surfaces 6 in. (150 mm) and 12 in. (300 mm) above the

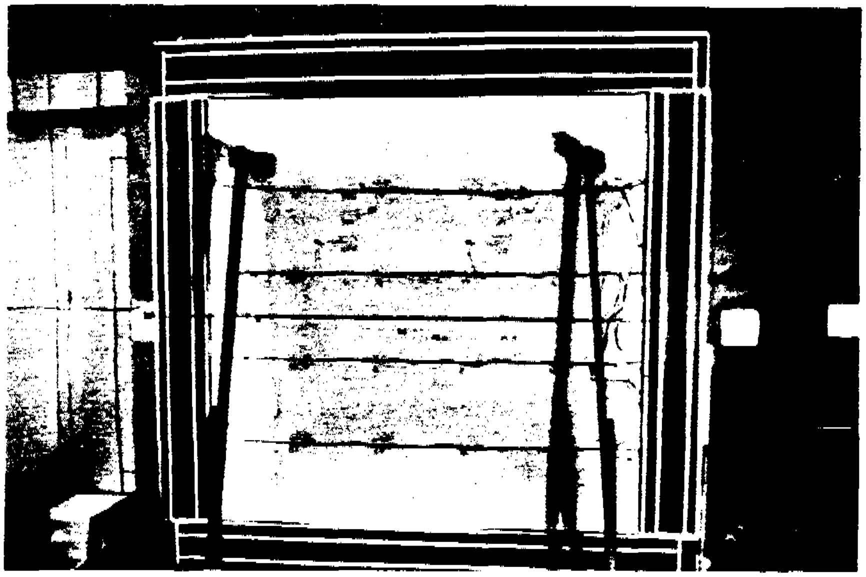


Fig. 24 Indoor Surface of Wall P1 Before Calibrated Hot Box Testing

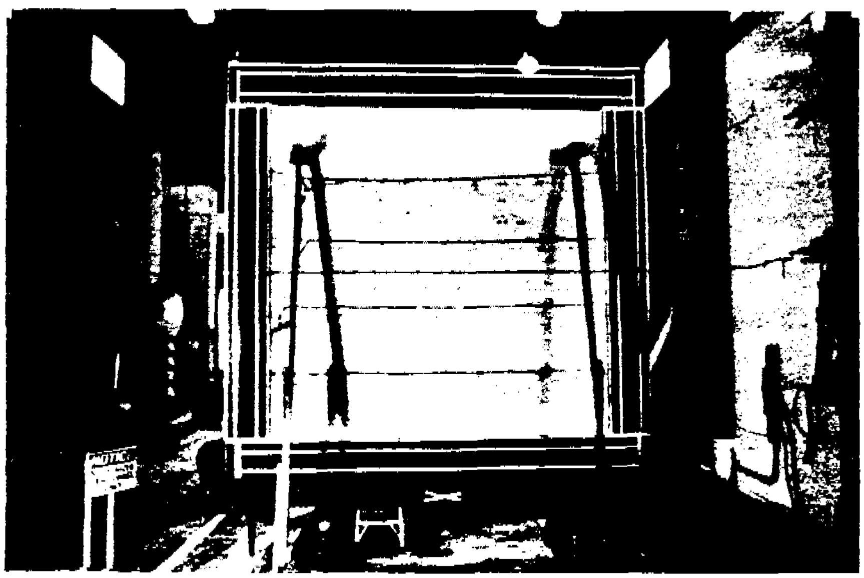


Fig. 25 Outdoor Surface of Wall P1 Before Calibrated Hot Box Testing

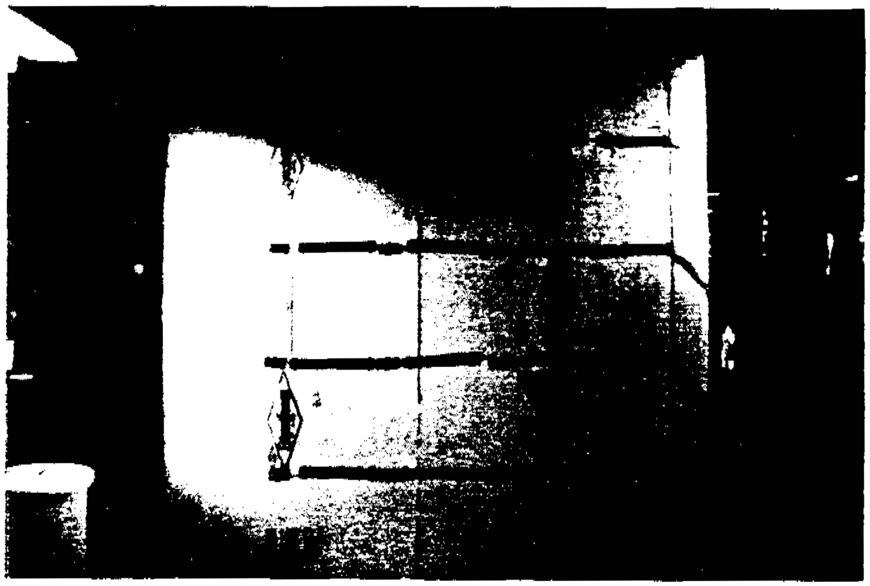


Fig. 26 Thermocouples Taped to Insulation Board for Wall P1

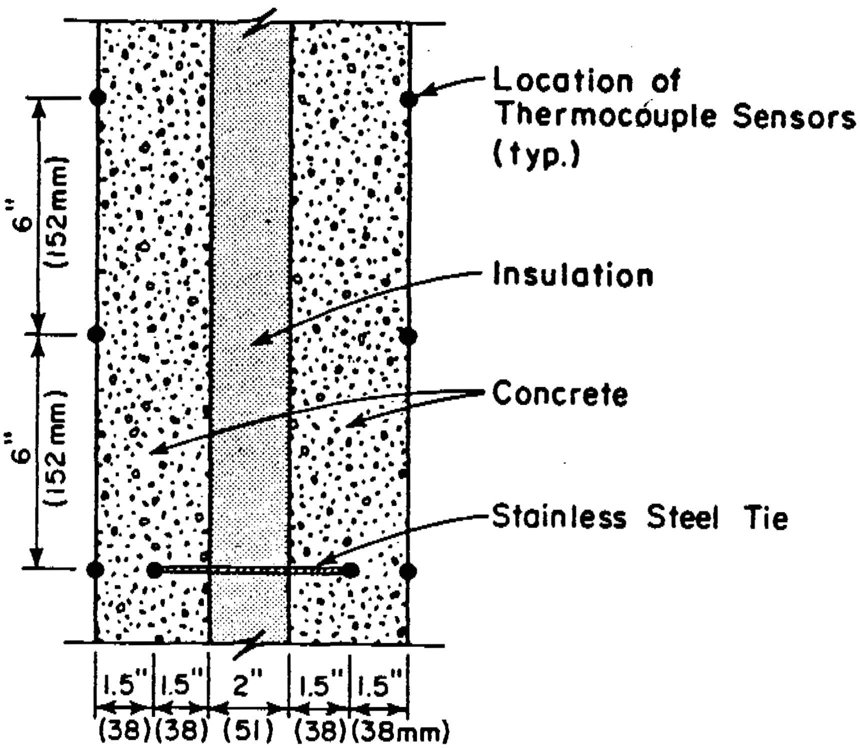


Fig. 27 Locations of Thermocouples in Vicinity of Stainless Steel Tie

monitored tie. The thermocouples located 12 in. (300 mm) above the monitored tie are midway between two ties. Reported temperatures are average readings of two similarly located thermocouples at the monitored ties.

Thermocouples were placed in Wall P1 at the same locations as those placed in Wall P2 to monitor stainless steel ties. Comparisons of measurements from thermocouples on Walls P1 and P2 show effects of ties on concrete temperatures.

One high-tensile fiberglass-composite tie in Wall P3 was also monitored. The tie was located 26 in. (650 mm) from the top of the wall and 26 in. (650 mm) from the side of the wall. Thermocouple locations are shown in Fig. 28. Thermocouple sensors were taped 1-1/2 in. (68 mm) from the insulation along the longitudinal axis the monitored tie, as shown in Fig. 29. Thermocouples were also taped to concrete surfaces directly across from the monitored tie, and on concrete surfaces 4-1/4 in. (106 mm) and 8-1/2 in. (212 mm) below the monitored tie. The thermocouples located 8-1/2 in. (212 mm) below the monitored tie are midway between two ties.

Wires for thermocouples mounted on ties and insulation were routed through side formwork prior to casting the second concrete wythe of each wall.

Heat flux transducers measuring 4x4-in. (100x100-mm) were mounted near the center of the indoor and outdoor surfaces of the test walls. Sensors were located near the center of the walls at wall mid-height. The surface of the heat flux transducer in contact with a wall surface was coated with a thin layer of high-conductivity silicon grease. The silicon grease provided uniform contact between the heat flux transducer and wall surface. Duct tape was used to secure heat flux transducers to the wall surfaces. The duct tape was painted the same color as the test wall surface. Heat flux

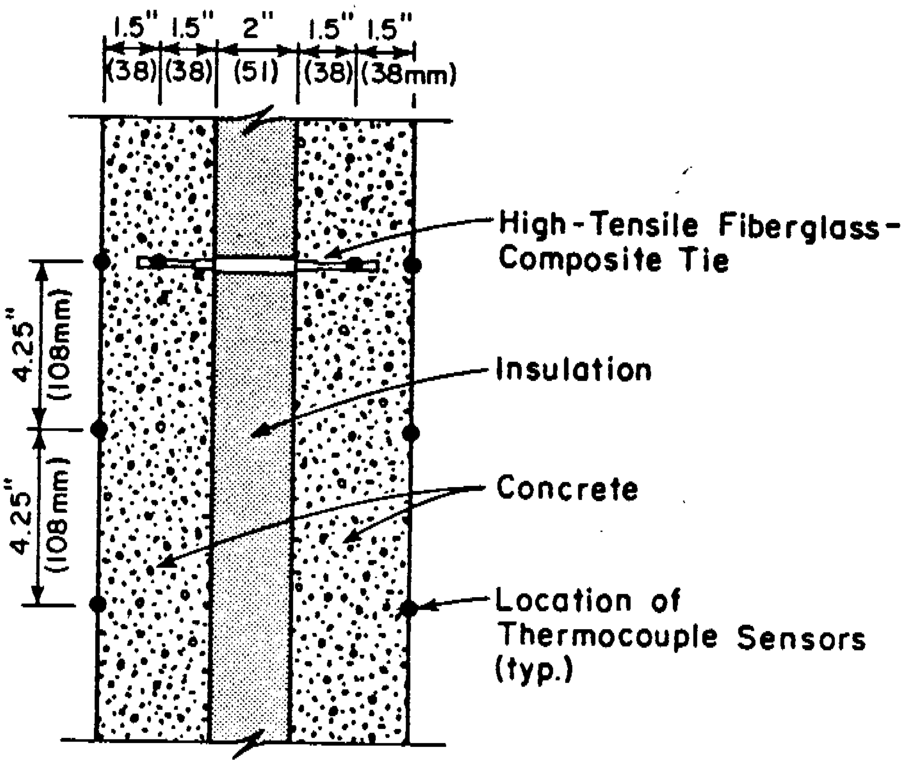


Fig. 28 Locations of Thermocouples in Vicinity of High-Tensile Fiberglass-Composite Tie

Fig. 29 Thermocouple Attached Directly to High-Tensile Fiberglass-Composite Tie

transducers were calibrated using results from steady-state calibrated hot box tests on the insulated concrete walls.

PHYSICAL PROPERTIES OF CONCRETE

At the time each wall was cast, companion control specimens were made for measurement of selected physical properties. Concrete for control specimens was sampled from each of the 10 batches required to cast each wall. Each specimen was cast in individual 6x12-in. (150x300-mm) cylinder molds.

Unit weight, moisture content, compressive strength, and tensile splitting strength of 6x12-in. (150x300-mm) cylinders were determined. Measured physical properties are summarized in Table 4.

Unit Weight

Weights of the 6x12-in. (150x300-mm) cylinders were determined periodically while specimens were air drying. Volume of each cylinder was calculated from cylinder weights in air and immersed in water. Unit weights were calculated from measured weights and volumes.

Unit weights of the concrete cylinders are summarized in Table 5. As shown in the table, unit weights decreased with time for the first two months and then remained fairly constant thereafter. The reduction in unit weight is due to evaporation of free water from the concrete.

Moisture Content

Average moisture content of concrete in each wall at the time of calibrated hot box tests was estimated using air dry and ovendry unit weights of 6x12-in. (150x300-mm) cylinders. Estimated moisture content for the concrete in each wall are listed in Table 4.

TABLE 4 - SUMMARY OF PHYSICAL PROPERTIES OF CONCRETE FOR WALLS P1, P2, and P3

Property	Measured Value		
	Wall P1	Wall P2	Wall P3
Unit Weight of Fresh Concrete, lb/ft^3 (kg/m^3)	144.1 (2310)	144.9 (2320)	143.3 (2300)
Estimated Moisture Content of Concrete, %, Ovendry Weight	1.8	2.3	2.2
Concrete Compressive Strength, psi (MPa)			
Moist cured*	4715 (32.5)	4820 (33.2)	4630 (31.9)
Air cured	5580** (38.4)	5660*** (39.0)	5520**** (38.0)
Concrete Splitting Tensile Strength, psi (MPa)			
Moist cured*	479 (3.30)	454 (3.13)	471 (3.25)
Air cured	498** (3.43)	500*** (3.45)	495**** (3.41)

*Cured in molds for first 24 hours, moist cured for 27 days
**Cured in molds for first 7 days, air cured for 147 days
***Cured in molds for first 7 days, air cured for 133 days
****Cured in molds for first 7 days, air cured for 124 days

TABLE 5 - UNIT WEIGHT OF SITE-CURED CONTROL SPECIMENS

Age, Days	Average for Cylinders, lb/ft^3 (kg/m^3)		
	Wall P1	Wall P2	Wall P3
0	144.1 (2310)*	144.9 (2320)*	143.3 (2300)*
14	--	--	146.5 (2350)
16	146.2 (2340)	--	--
17	--	146.7 (2350)	--
21	--	145.7 (2330)	--
22	145.2 (2330)	--	--
28	144.9 (2320)	145.1 (2320)	144.7 (2320)
35	144.6 (2320)	--	--
42	--	144.5 (2320)	--
46	--	--	144.4 (2310)
57	144.0 (2310)	--	--
62	--	--	144.3 (2310)
63	--	143.9 (2310)	--
70	143.8 (2300)	--	--
84	143.4 (2300)	--	143.6 (2300)
98	--	143.5 (2300)	--
112	143.0 (2290)	--	--
154	142.6 (2280)	--	--
175	142.6 (2280)	--	--

*Unit weight of fresh concrete

Compressive Strength

Compressive strengths of 6x12-in. (150x300-mm) concrete cylinders were determined in accordance with ASTM Designation: C39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." Two sets of compressive strength data were obtained for each wall as follows:

1. Twenty-eight day compressive strengths of 5 cylinders cured for 24 hours in molds, and then moist cured at 73±3°F (23±1.7°C) and 100% RH the remaining 27 days.
2. Compressive strengths of 5 cylinders cured in molds for 7 days, and then air cured at 73±5°F (23±3°C) and 45±15% RH until each wall was midway through thermal tests.

Compressive strength was measured on 5 moist-cured cylinders and 5 air-cured cylinders. Average compressive strengths for both sets of cylinders are shown in Table 4.

Splitting Tensile Strength

Splitting tensile strengths of 6x12 in.-(150x300-mm) concrete cylinders were determined in accordance with ASTM Designation: C496 "Standard Test method for Splitting Tensile Strength of Cylindrical Concrete Specimens." Cylinders were cured in the same two ways as compressive strength cylinders. Splitting tensile strength was measured on 5 moist-cured cylinders and 5 air-cured cylinders. Average strengths for both sets of cylinders are shown in Table 4.

THERMAL RESISTANCE OF INSULATION

A guarded hot plate was used to measure thermal resistances of Styrofoam insulation, used for Walls P1 and P2, and Amofoam insulation, used for Wall P3. Tests on Styrofoam insulation were performed in August and September 1985. Tests on Amofoam insulation were performed in October 1985.

Test Procedure

Thermal resistances were determined at CTL in accordance with ASTM Designation: C 177 "Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate."[9]

Guarded hot plate specimens were cut from the same lot of insulation board as that used in the concrete-insulation sandwich walls. Two specimens were cut from each type of insulation. Nominal specimen dimensions were 2x12x12 in. (50x300x300 mm). Measured thicknesses of both Styrofoam insulation specimens was 1.99 in. (49.8 mm). Measured thickness of Amofoam insulation was 1.94 in. (48.5 mm).

Insulation densities were determined from measured weights and dimensions. Densities of Styrofoam and Amofoam were 1.8 lb/ft^3 (28.8 kg/m^3) and 2.2 lb/ft^3 (35.2 kg/m^3), respectively.

Using a guarded hot plate, two identical samples of the material to be tested are placed on either side of a horizontal flat plate heater assembly consisting of a 5.88 in. (149.4 mm) square inner (main) heater surrounded by a separately controlled guard heater to form a 12-in. (300-mm) square assembly. The function of the guard heater is to eliminate lateral heat flow to or from the main heater thereby forcing all heat generated in the main heater to flow in the direction of the two test samples. Liquid cooled heat sinks are also placed in contact with the samples producing a uniform and constant temperature on the outside of each sample.[12]

The rate of heat flow through the specimens is determined from measuring heat input into the heater plate. The thermal resistance of the test samples is determined from measurements of the final surface temperatures after steady-state has been reached, the power input to the main heater, and the geometry of the test samples.

Test specimen temperatures are measured by chromel/alumel thermocouples placed in contact with the specimen surfaces. For each of the two surfaces of the two specimens, three thermocouples were located in the region of the main heater, and two were located in the region of the guard heater.

After steady-state heat flow and temperatures are reached, the test is continued for 3 hours. Thermal resistance is calculated from three sets of measured data collected after equilibrium is reached. Data sets are collected at time intervals of not less than 30 minutes. Power input to the main heater and surface temperatures within the region of the main heater are used to determine thermal resistance.

Test Results

Thermal resistances were determined for 4 mean temperatures of the Styrofoam insulation and 5 mean temperatures of the Amofoam insulation. Measured resistances are listed in Table 6.

Specimen mean temperature, also listed in Table 6, is the average temperature of the cold and hot surfaces for the two test samples. The average temperature differential across the specimens, from the hot surface to the cold surface, is denoted ΔT in Table 6.

A plot of thermal resistance versus mean specimen temperature is presented in Fig. 30. Thermal resistance decreases with increasing mean temperature for both types of insulation.

Thermal resistances at specimen mean temperatures of 75°F (24°C) were interpolated from measured values. Styrofoam and Amofoam insulations, respectively, had thermal resistances of 8.92 and 9.02 $hr \cdot ft^2 \cdot °F/Btu$ (1.57 and 1.59 $m^2 \cdot K/W$) at a specimen mean temperature of 75°F (24°C). Apparent thermal conductivities of Styrofoam and Amofoam insulations, respectively, were 0.223 and 0.215 $Btu \cdot in./hr \cdot ft^2 \cdot °F$ (0.032 and 0.030 $W/m \cdot K$).

TABLE 6 - MEASURED THERMAL RESISTANCES OF STYROFOAM AND AMOFOAM INSULATIONS

Type of Insulation	Test No.	Specimen Mean Temp., °F (°C)	ΔT, Temperature Differential, °F (°C)	R, Thermal Resistance, hr•ft^2•°F/Btu (m^2•K/W)
Styrofoam*	1	33.9 (1.1)	29.5 (16.3)	9.87 (1.74)
Styrofoam	2	52.6 (11.5)	45.0 (25.0)	9.36 (1.65)
Styrofoam	3	98.5 (33.8)	41.0 (22.8)	8.56 (1.51)
Styrofoam	4	121.3 (49.6)	38.5 (21.4)	8.05 (1.42)
Amofoam**	1	36.0 (2.2)	29.5 (16.4)	9.91 (1.74)
Amofoam	2	46.2 (7.9)	28.1 (15.5)	9.37 (1.65)
Amofoam	3	70.2 (21.2)	27.3 (15.1)	9.18 (1.62)
Amofoam	4	88.3 (31.2)	25.9 (14.3)	8.69 (1.53)
Amofoam	5	115.7 (46.5)	24.1 (13.4)	8.13 (1.43)

*Average measured thickness of Styrofoam insulation was 1.99 in. (49.8 mm).
**Average measured thickness of Amofoam insulation was 1.94 in. (48.5 mm).

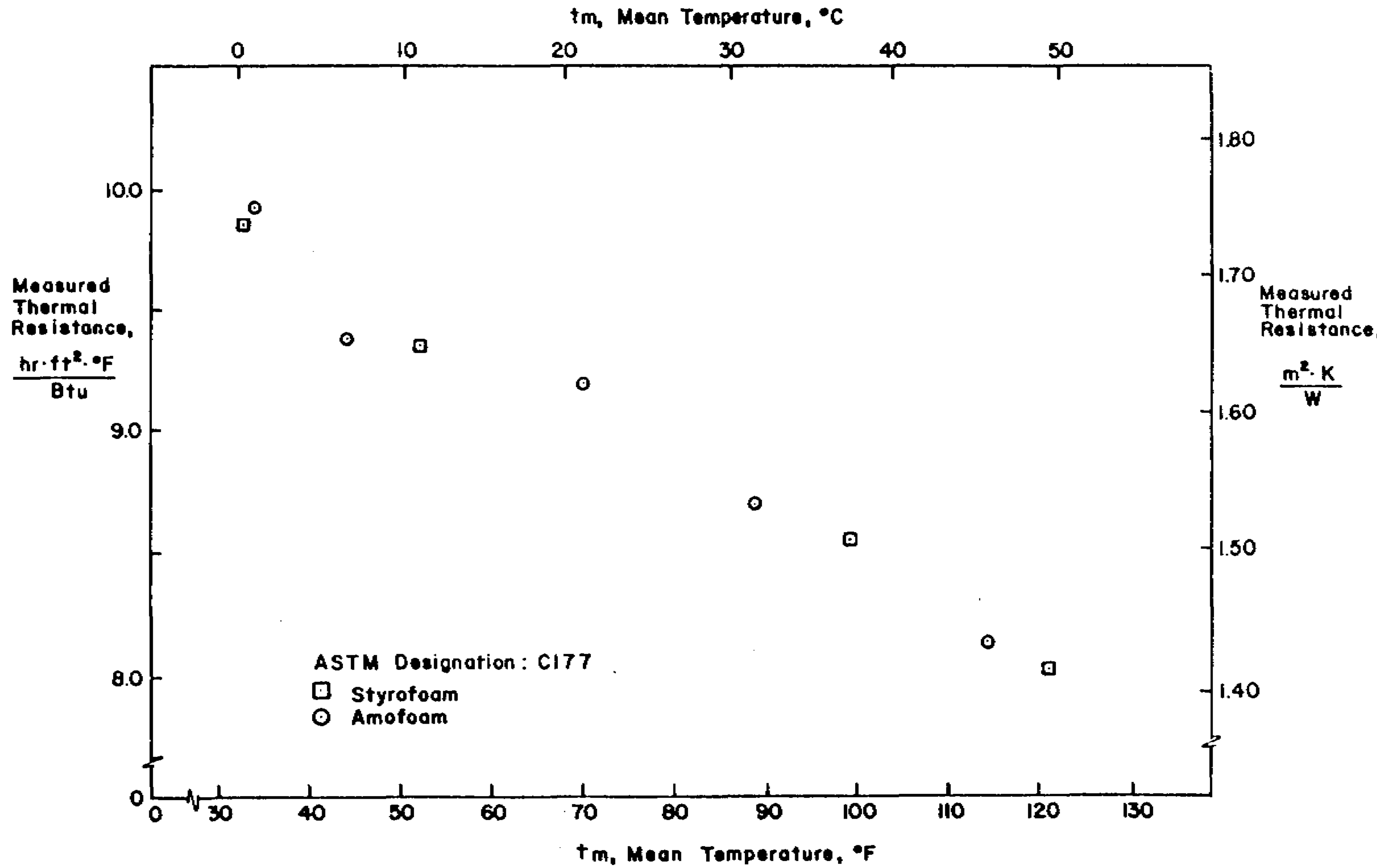


Fig. 30 Measured Thermal Resistances of Styrofoam and Amofoam Insulations

CALIBRATED HOT BOX TEST FACILITY

Heat flow through Walls P1, P2, and P3 was measured for steady-state and dynamic temperature conditions. Tests were conducted in the calibrated hot box facility shown in Figs. 31 and 32. Tests were performed in accordance with ASTM Designation: C 976, "Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box."[11]

The following is a brief description of the calibrated hot box. Instrumentation and calibration details are described in Appendix A and Reference 13.

The facility consists of two highly insulated chambers as shown in Fig. 32. Walls, ceiling, and floors of each chamber are insulated with foamed urethane sheets to obtain a nominal thickness of 12 in. (300 mm). During tests, the chambers are clamped tightly against an insulating frame that surrounds the test wall. Air in each chamber is conditioned by heating and cooling equipment to obtain desired temperatures on each side of the test wall.

The outdoor (climatic) chamber can be held at a constant temperature or cycled within the range -15 to 130°F (-26 to 54°C). Temperatures can be programmed for a 24-hour cycle to obtain the desired temperature-time relationship. The indoor (metering) chamber, which simulates an indoor environment, can be maintained at a constant room temperature between 65 and 80°F (18 and 27°C).

The specimen is oriented vertically in the CTL calibrated hot box. Therefore, heat flows horizontally through the wall. The facility was designed to accommodate walls with thermal resistance values ranging from 1.5 to 20 $hr \cdot ft^2 \cdot °F/Btu$ (0.26 to 3.52 $m^2 \cdot K/W$).

The pressure in both the indoor and outdoor chambers is atmospheric.

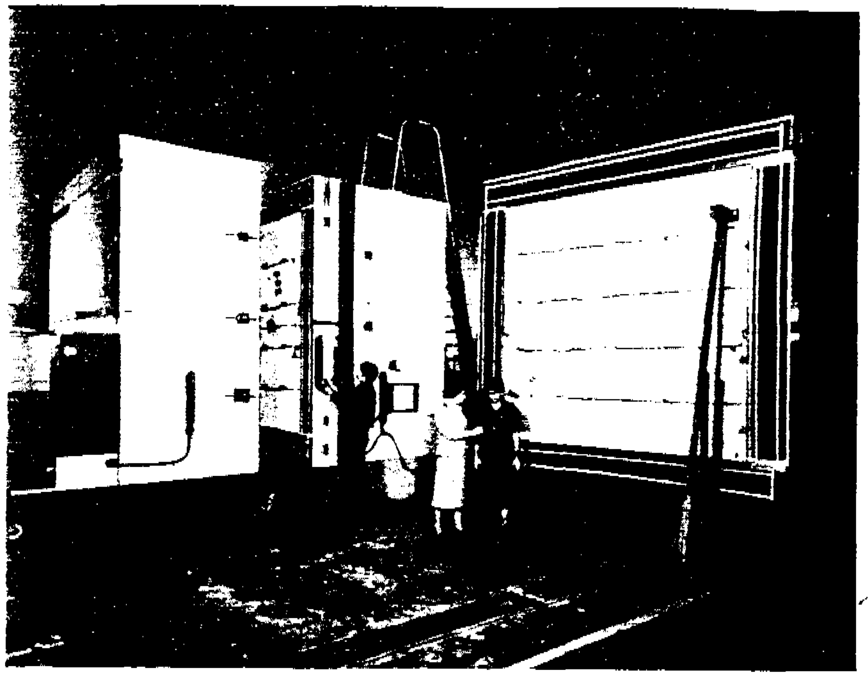


Fig. 31 Calibrated Hot Box Test Facility

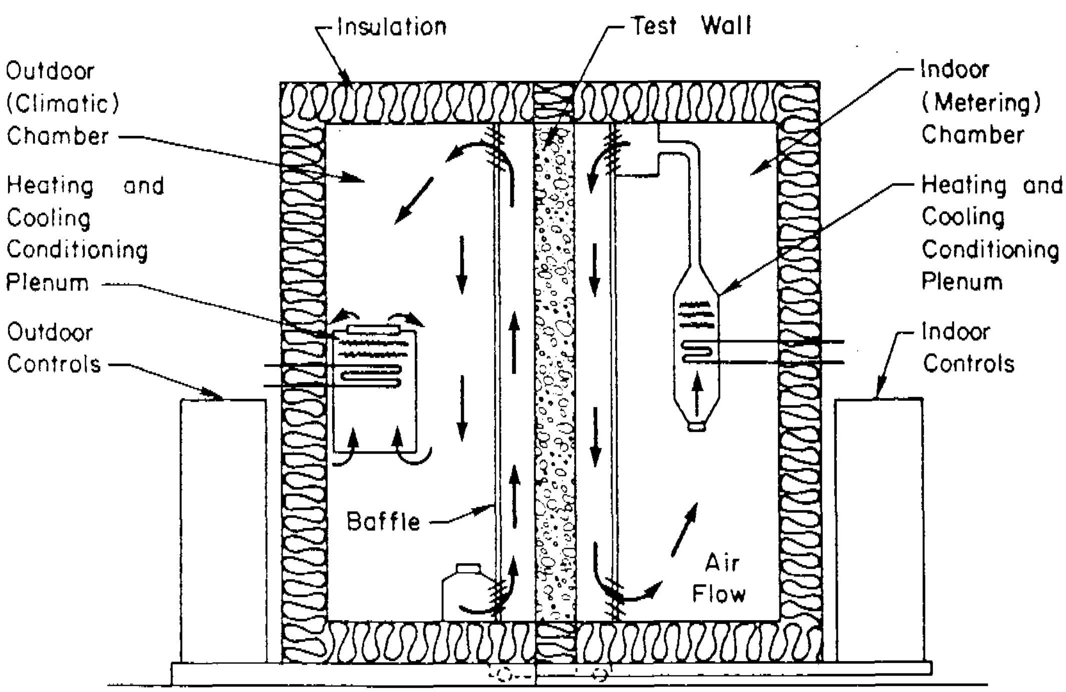


Fig. 32 Schematic of Calibrated Hot Box

THERMAL RESISTANCE OF WALLS

Two steady-state calibrated hot box tests were performed on each of the Walls P1, P2, and P3. Heat flow and temperature measurements were used to determine average thermal properties of total thermal resistance (R_T) and transmittance (U).

Design heat transmission coefficients are calculated for the walls and compared to measured values. Test results are also compared to results from a three-dimensional modeling of a torsion anchor used in Wall P2.

Design Heat Transmission Coefficients

Design values are calculated in accordance with procedures established by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.[14] Wall configurations and thermal conductivities of wall materials are used to calculate design values.

Material Properties

Thermal conductivities used to calculate design heat transmission coefficients are listed in Table 7. Values of all materials are for temperature of 75°F (24°C).

A thermal conductivity value of 16.0 Btu•in/hr•ft^2•°F (2.31 W/m•K) was used for normal weight concrete.[8]

Thermal conductivities of Styrofoam and Amofoam insulations were determined from guarded hot plate test results, discussed in the section titled "Thermal Resistance of Insulation."

Stainless steel torsion anchors and ties were used to bridge concrete layers of Wall P2. A thermal conductivity of 182 Btu•in/hr•ft^2•°F (26.2 W/m•K) was used for stainless steel.[15]

TABLE 7 - THERMAL CONDUCTIVITIES USED TO CALCULATE DESIGN HEAT TRANSMISSION COEFFICIENTS

Material	Thermal Conductivity*		Source
	$\frac{Btu \cdot in}{hr \cdot ft^2 \cdot °F}$	W/m•K	
Normal Weight Concrete	16.0	2.31	Ref. 8
Styrofoam Insulation	0.223	0.0322	Interpolated for a mean temperature of 75°F from guarded hot plate test results.
Amofoam Insulation	0.215	0.0310	Interpolated for a mean temperature of 75°F from guarded hot plate test results.
Stainless Steel	182	26.2	Ref. 15
High-Tensile Fiberglass-Composite Tie	2.1	0.303	Ref. 16

*Values are for material temperatures of 75°F (24°C).

The ties incorporated into Wall P3 were fiberglass and a thermal conductivity of 2.1 Btu•in/hr•ft^2•°F (0.303 W/m•K) was used for calculation purposes. This value was obtained from the manufacturer's literature.[16]

Wall P1

Design values of total resistance and transmittance for Wall P1 are shown in Table 8. Figure 33 shows locations of layers used for calculations.

Wire mesh, such as shown in Fig. 33, is commonly used in construction of wall systems, but was not considered in thermal calculations because its effect is considered insignificant.

Total resistance values, R_T, include standard surface resistances equal to 0.68 hr•ft^2•°F/Btu (0.12 m^2•K/W) for indoor surfaces and 0.17 hr•ft^2•°F/Btu (0.03 m^2•K/W) for outdoor surfaces. These values are commonly used in design and are considered to represent still air on the indoor wall surface and an air flow of 15 mph (24 km/hr) on the outdoor wall surface. Actual surface resistances may be calculated using measured temperatures and heat flux presented in the calibrated hot box portion of the "Thermal Resistance of Walls" section of this report. Thermal transmittance, U, is equal to the reciprocal of total thermal resistance, R_T.

Calculated total thermal resistance of Wall P1 is 10.15 hr•ft^2•°F/Btu (1.79 m^2•K/W).

Wall P2

Calculations of design heat transmission coefficients for Wall P2 were made using the isothermal planes method also designated the series parallel method.[17,18] This method of calculation is applicable for wall assemblies in which heat can flow laterally in any continuous layer. Lateral heat flow in continuous layers is assumed to result in isothermal

TABLE 8 - DESIGN HEAT TRANSMISSION COEFFICIENTS FOR WALL P1

Component	R Thermal Resistance, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)
1. Outside Air Film	0.17* (0.03)
2. 3.0-in. (76.2-mm) Normal Weight Concrete	0.19 (0.03)
3. 1.99-in. (50.5-mm) Dow Styrofoam Insulation	8.92 (1.57)
4. 3.0-in. (76.2-mm) Normal Weight Concrete	0.19 (0.03)
5. Inside Air Film	0.68* (0.12)
Total R	10.15 (1.79)
Total U**	0.098 (0.559)

*Source: ASHRAE Handbook - 1985 Fundamentals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1985, Chapter 23.

**Units for thermal transmittance are $Btu/hr \cdot ft^2 \cdot °F$ ($W/m^2 \cdot K$)

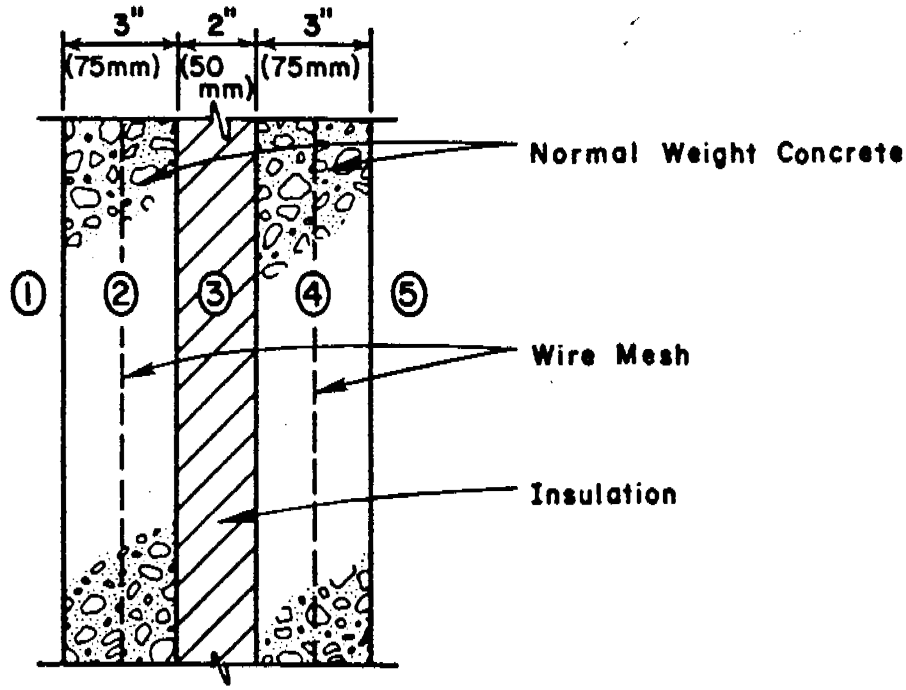


Fig. 33 Layers Assumed for Calculating Design Heat Transmission Coefficients for Wall P1

planes. These planes provide a means for heat flow towards areas with higher thermal conductivities. In this case the ties used to bridge concrete layers in Wall P2 act as heat sinks or thermal bridges.

Parallel combinations of the highly conductive bridge and insulation are assumed to act in series with concrete layers. The calculated total thermal resistance, R_T, of Wall P2 is the sum of seven individual resistances:

$$R_T = R_i + R_c + \frac{R_r R_c}{a_c R_r + a_r R_c} + \frac{R_{rr} R_p}{a_p R_{rr} + a_r R_p} + \frac{R_r R_c}{a_c R_r + a_r R_c} + R_c + R_o \quad (1)$$

where

R_T = Total thermal resistance based on isothermal planes (series-parallel heat flow paths), $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)

R_i = thermal resistance of inside air surface film, assumed to be 0.68 $hr \cdot ft^2 \cdot °F/Btu$ (0.12 $m^2 \cdot K/W$)

R_c = thermal resistance of 1.5-in. (38-mm) thick concrete layer, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)

R_r = thermal resistance of 1.5-in. (38-mm) long segment of stainless steel rod that penetrates concrete, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)

R_{rr} = thermal resistance of 2-in. (50-mm) segment of stainless steel rod that penetrates insulation layer, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)

R_p = thermal resistance of insulation, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)

a_r = area of stainless steel rods transverse to heat flow divided by total wall area

a_c = $1-a_r$, area of 1.5-in. (38-mm) thick concrete layer between welded-wire fabric and insulation that is transverse to heat flow, divided by total wall area

a_p = $1-a_r$, area of insulation transverse to heat flow divided by total wall area

This equation for total thermal resistance can be reduced to:

$$R_T = R_i + R_o + 2R_c + \frac{2R_rR_c}{a_cR_r + a_rR_c} + \frac{R_{rr}R_p}{a_pR_{rr} + a_rR_p} \qquad (2)$$

For homogeneous materials, thermal resistance is equal to thickness in the direction of heat flow divided by thermal conductivity.

Figure 34 shows regions represented by terms described in Eqs. 1 and 2. The seven component resistances for Wall P2 are listed in Table 9. Wall layers are identified by numerals in Fig. 34. The outer portion of the concrete layers, where no ties were present, were treated separately from inner portions containing ties.

The sixteen stainless steel ties penetrating the insulation of Wall P2 had an aggregate cross-sectional area of 0.351 sq in. (226 mm^2). The four torsion anchors had an aggregate cross-sectional area of 0.430 sq in. (277 mm^2). Total cross-sectional area of stainless steel in Wall P2 was 0.781 sq in. (504 mm^2).

Total thermal resistance of Wall P2 calculated using the isothermal planes method is 9.64 hr·ft^2·°F/Btu (1.70 m^2·K/W). This value is 5% less than the calculated thermal resistance of the wall with no ties, Wall P1.

<u>Wall P3</u>

Design heat transmission coefficients for Wall P3 were calculated using the parallel path method. This method is preferred when the material penetrating the insulation has a lower conductivity than the highly conductive surrounding layer.[17] In this case, the high-tensile fiberglass-composite ties have a lower thermal conductivity than the concrete.

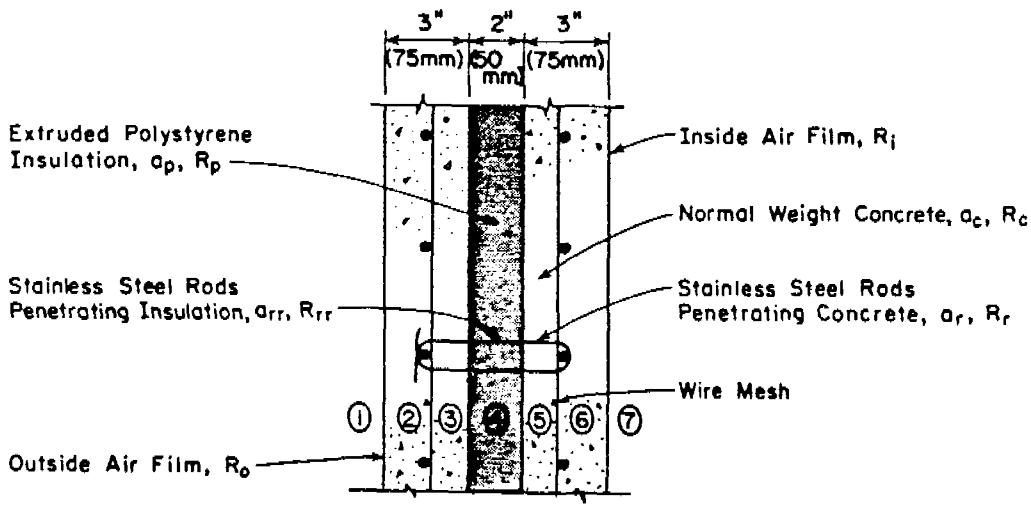


Fig. 34 Layers Assumed for Calculating Design Heat Transmission Coefficients for Wall P2

TABLE 9 - DESIGN HEAT TRANSMISSION COEFFICIENTS FOR WALL P2

Component	R Thermal Resistance, $hr \cdot ft^2 \cdot °F/Btu$ ($m^2 \cdot K/W$)
1. Outside Air Film	0.17* (0.03)
2. 1.5-in. (38.1-mm) Normal Weight Concrete	0.094 (0.015)
3. 1.5-in. (38.1-mm) Normal Weight Concrete with Steel Ties	0.094** (0.015)
4. 1.99-in. (50.5-mm) Dow Styrofoam Insulation with Steel Ties	8.41** (1.48)
5. 1.5-in. (38.1-mm) Normal Weight Concrete with Steel Ties	0.094** (0.015)
6. 1.5-in. (38.1-mm) Normal Weight Concrete	0.094 (0.015)
7. Inside Air Film	0.68* (0.12)
Total R	9.64 (1.70)
Total U***	0.104 (0.589)

*Source: <u>ASHRAE Handbook - 1985 Fundamentals</u>, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1985, Chapter 23.

**Resistance of layer calculated using the isothermal planes method.

***Units for thermal transmittance are $Btu/hr \cdot ft^2 \cdot °F$ ($W/m^2 \cdot K$)

To calculate total thermal resistance using the parallel path method, total resistances are first calculated along a path through a tie, and a path through the insulation. Resistances for individual components along the two paths are listed and summed in Table 10.

Locations of layers are illustrated in Fig. 35. The outer portion of the concrete layers, where no ties were present, were treated separately from inner portions containing ties.

The overall transmittance of the wall determined using the parallel path method is the area-weighted average of the thermal transmittances for the two paths. Total thermal resistance of Wall P3 is the reciprocal of overall transmittance.

Total thermal resistance of Wall P3 calculated using the parallel path method is 10.25 hr•ft^2•°F/Btu (1.81 m^2•K/W). This value is 1% greater than the calculated thermal resistance of the wall with no ties, Wall P1.

Three-Dimensional Modeling of Torsion Anchor

Mr. K.W. Childs of Martin Marietta Energy Systems, Inc. performed a three-dimensional steady-state heat transfer calculation on a portion of Wall P2. The analysis was performed to estimate performance of Wall P2 prior to calibrated hot box tests.

The section of the wall modeled was 40-in. (1.02-m) sq with a Type B torsion anchor located at the center. A Type B torsion anchor was chosen because it provides a greater thermal bridge than a stainless steel tie. Material thermal conductivities assumed for the calculation are listed in Table 11.

For the analysis, an air temperature of 0°F (-18°C) was controlled on one side of the wall and 100°F (38°C) was maintained on the other side.

TABLE 10 - DESIGN HEAT TRANSMISSION COEFFICIENTS FOR WALL P3

Component	R, Thermal Resistance	
	Between Ties hr•ft^2•°F/Btu (m^2•K/W)	At Ties hr•ft^2•°F/Btu (m^2•K/W)
1. Outside Air Film	0.17* (0.03)	0.17* (0.03)
2. 1.0-in. (25-mm) Normal Weight Concrete	0.063 (0.01)	0.063 (0.01)
3. 2.0-in. (50-mm) Normal Weight Concrete	0.125 (0.02)	--
4. 6.0-in. (150-mm) High-Tensile Fiberglass-Composite Tie	--	1.73 (0.30)
5. 1.94-in. (50-mm) Amofoam Insulation	9.02 (1.59)	--
6. 2.0-in. (50-mm) Normal Weight Concrete	0.125 (0.02)	--
7. 1.0-in. (25-mm) Normal Weight Concrete	0.063 (0.01)	0.063 (0.01)
8. Inside Air Film	0.68* (0.12)	0.68* (0.12)
Total R	10.25 (1.81)	2.71 (0.48)
Total U**	0.098 (0.55)	0.370 (2.10)

Adjust for Ties (<1%)

$U = (0.9994)(0.098) + (5.86 \times 10^{-4})(0.370)$

$= 0.098$ Btu/hr•ft^2•°F (0.55 W/m^2•K)

$R = 1/U = 10.23$ hr•ft^2•°F/Btu (1.81 m^2•K/W)

*Source: ASHRAE Handbook - 1985 Fundamentals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1985, Chapter 23.

**Units for thermal transmittance are Btu/hr•ft^2•°F (W/m^2•K)

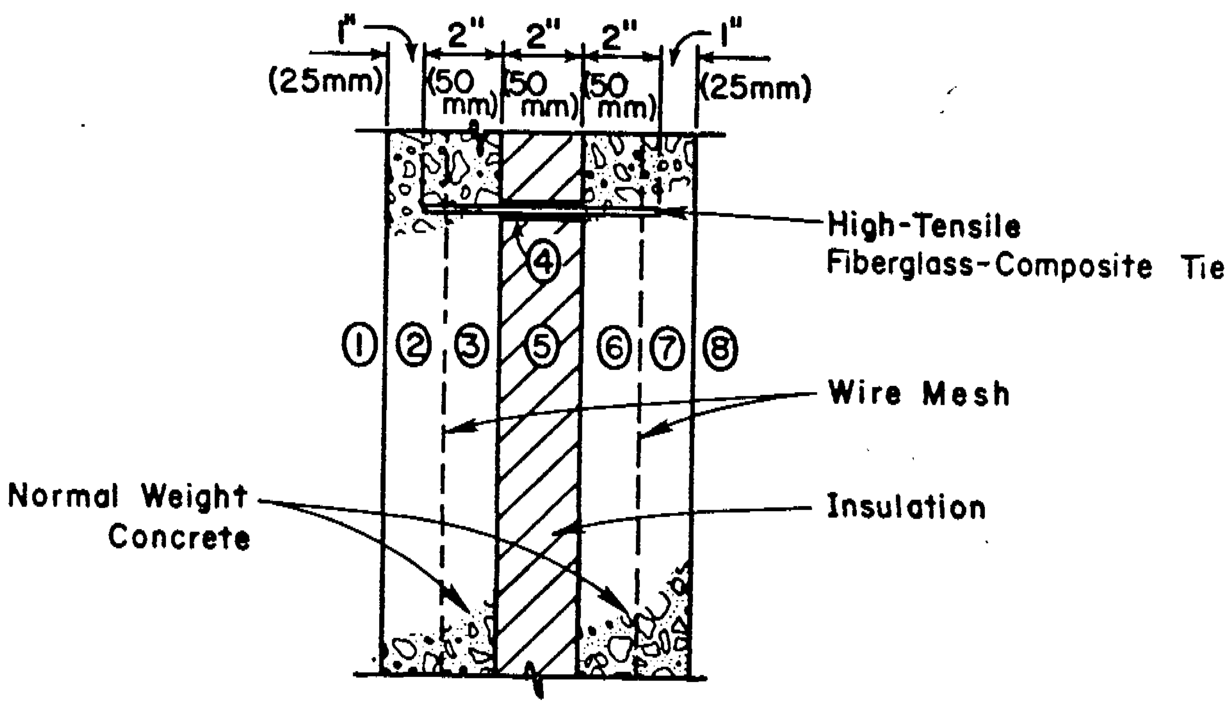


Fig. 35 Layers Assumed for Calculating Design Heat Transmission Coefficients for Wall P3

TABLE 11 - THERMAL CONDUCTIVITIES OF MATERIALS FOR THREE-DIMENSIONAL STEADY-STATE HEAT TRANSFER CALCULATION

Material	Thermal Conductivity	
	Btu•in/hr•ft^2•°F	W/m•K
Concrete	12	1.73
Insulation	0.20	0.029
Steel	360	52
Stainless Steel	240	35

Since the anchors have two lines of approximate symmetry when viewed from the surface of the wall, only one fourth of the anchor was modeled.

Detailed results from the analysis are given in Appendix B. Figures B1 and B2, respectively, show locations of isotherms on the warm and cold sides of the modeled region of the wall. Because a constant heat transfer coefficient was used at the wall surfaces, isotherms radiating from the center of the anchor also represent lines of constant heat flux.

An integrated average of the heat flux over the 40x40-in. (1.02x1.02-m) area shows an increase in total heat flow of 6% due to a single Type B torsion anchor compared to the same wall without ties or torsion anchors.

Results from the three-dimensional analysis were extrapolated to estimate performance for the entire 8-ft 7-in. x 8-ft-7-in. (2.62 m x 2.62 m) wall used in the CTL experimental study. A Type B torsion anchor with 0.117 sq in. (75.6 mm^2) of stainless steel penetrating the insulation causes an increase in heat flow of 6% for a 40-in. (1.02-m) sq area. It is assumed that 6.67 times that amount of steel, or 0.781 sq in. (504 mm^2), will cause a 6% increase in heat flow for an area 6.67 times as large, or 8 ft 7 in. (2.62 m) sq. Therefore, computations indicate that 0.781 sq in. (504 mm^2) of stainless steel in Wall P2 will cause an increase in heat flow of approximately 6% averaged over the wall area.

Calibrated Hot Box Test Results

Test Procedures

Steady-state calibrated hot box tests were conducted by maintaining constant indoor and outdoor chamber temperatures. Results are calculated from data collected when specimen temperatures reach equilibrium and the rate of heat flow through the test wall is constant. Steady-state tests were run at two temperature differentials. For the first case, indoor air temperature was maintained at approximately 73°F (23°C) while outdoor air temperature was maintained at approximately 134°F (56°C). This provided a nominal temperature differential of approximately 61°F (34°C) and mean wall temperature of approximately 104°F (40°C). In the second case, indoor air temperature was maintained at approximately 71°F (22°C) while outdoor air temperature was maintained at approximately -4°F (-20°C). This provided a nominal temperature differential of 75°F (42°C) and a mean wall temperature of approximately 34°F (1°C).

Steady-state calibrated hot box tests on Wall P1 were performed in March and April 1985. Tests on Wall P2 were performed in June and July 1985. Tests on Wall P3 were performed in September 1985.

Test Results

Steady-state results from calibrated hot box tests on Walls P1, P2, and P3 are summarized in Table 12. Data are averages for 16 consecutive hours of testing. Wall mean temperature, heat flow, total thermal resistance, and thermal transmittance are listed for steady-state test conditions applied to each wall.

The first column of Table 12 lists the mean wall temperature, t_m, during each steady-state test. Wall mean temperature is determined from the average of the indoor and outdoor wall surface temperatures.

The second column shows wall heat flow determined from each calibrated hot box test. The third and fourth columns list total thermal resistance and transmittance coefficients calculated using measured values of heat flow and standard surface resistance coefficients of 0.68 hr•ft^2•°F/Btu (0.12 m^2•K/W) for outdoor and 0.17 hr•ft^2•°F/Btu (0.03 m^2•K/W) for indoor. Design heat

TABLE 12 - STEADY-STATE RESULTS FROM CALIBRATED HOT BOX TESTS

Wall Designation	Nominal Test Condition	q* Heat Flow, $\frac{Btu}{hr \cdot ft^2}$ (W/m^2)	R_T**, $\frac{hr \cdot ft^2 \cdot F}{Btu}$ ($m^2 \cdot K/W$)	U**, $\frac{Btu}{hr \cdot ft^2 \cdot F}$ ($W/m^2 \cdot K$)	Relative Humidity		Laboratory Air Temperature	
					Indoor Chamber, %	Outdoor Chamber, %	Max. °F (°C)	Min. °F (°C)
P1	t_m=104°F (40°C)	6.97 (22.0)	8.89 (1.57)	0.112 (0.636)	22	21	77 (25)	76 (24)
P1	t_m=34°F (1°C)	-6.99 (-22.0)	10.95 (1.94)	0.091 (0.517)	23	22	77 (25)	73 (23)
P1	Design+ Values	--	10.15 (1.79)	0.098 (0.559)	--	--	--	--
P2	t_m=103°F (39°C)	7.46 (23.5)	8.27 (1.46)	0.121 (0.686)	33	15	76 (24)	75 (24)
P2	t_m=34°F (1°C)	-7.44 (-23.5)	10.31 (1.82)	0.097 (0.551)	37	23	74 (23)	73 (23)
P2	Design+ Values	--	9.64 (1.70)	0.1066 (0.6053)	--	--	--	--
P3	t_m=105°F (41°C)	6.17 (19.5)	10.55 (1.85)	0.095 (0.538)	***	9	75 (24)	75 (24)
P3	t_m=35°F (2°C)	-6.39 (-20.2)	11.30 (1.99)	0.088 (0.502)	***	20	75 (24)	74 (23)
P3	Design+ Values	--	10.25 (1.81)	0.0976 (0.554)	--	--	--	--

*Measured by the calibrated hot box.

**Total thermal resistance, R_T, and transmittance, U, for steady-state tests were calculated using the design surface resistance coefficients and measured values of heat flow.

***Not available.

+Values computed for t_m = 75°F (24°C).

transmission coefficients from Tables 8, 9, and 10 are shown in the last row of each section in Table 12 for comparison. The design values for each wall were calculated at a mean wall temperature of 75°F (24°C).

Measured relative humidity within the indoor and outdoor chambers of the CTL calibrated hot box is listed in Table 12.

Maximum and minimum laboratory air temperatures obtained during each steady-state test are also listed in Table 12. The laboratory acts as a guard for the indoor chamber during tests conducted in CTL's calibrated hot box.

Thermal Resistance Comparisons

Wall P1 is a control wall for this test program. Since Walls P1 and P2 were constructed using the same concrete mix and insulation differences in thermal performances of the walls can be attributed to stainless steel torsion anchors and ties in Wall P2. Walls P1 and P3 were constructed with the same concrete mix but different brands of extruded polystyrene insulations. Differences in thermal performance of Walls P1 and P3 can be attributed to the insulations or the high-tensile fiberglass-composite ties in Wall P3.

Figure 36 shows measured and design thermal resistances for Walls P1, P2, and P3 as a function of mean temperature. At a mean wall temperature of approximately 104°F (40°C) the measured total thermal resistance of Wall P1 was 8.89 hr•ft^2•°F/Btu (1.57 m^2•K/W). At this same mean temperature Walls P2 and P3 had measured total thermal resistances of 8.27 and 10.55 hr•ft^2•°F/Btu (1.46 and 1.85 m^2•K/W), respectively.

At a mean wall temperature of approximately 34°F (1°C) the measured total thermal resistance of Wall P1 was 10.95 hr•ft^2•°F/Btu (1.94 m^2•K/W). At this

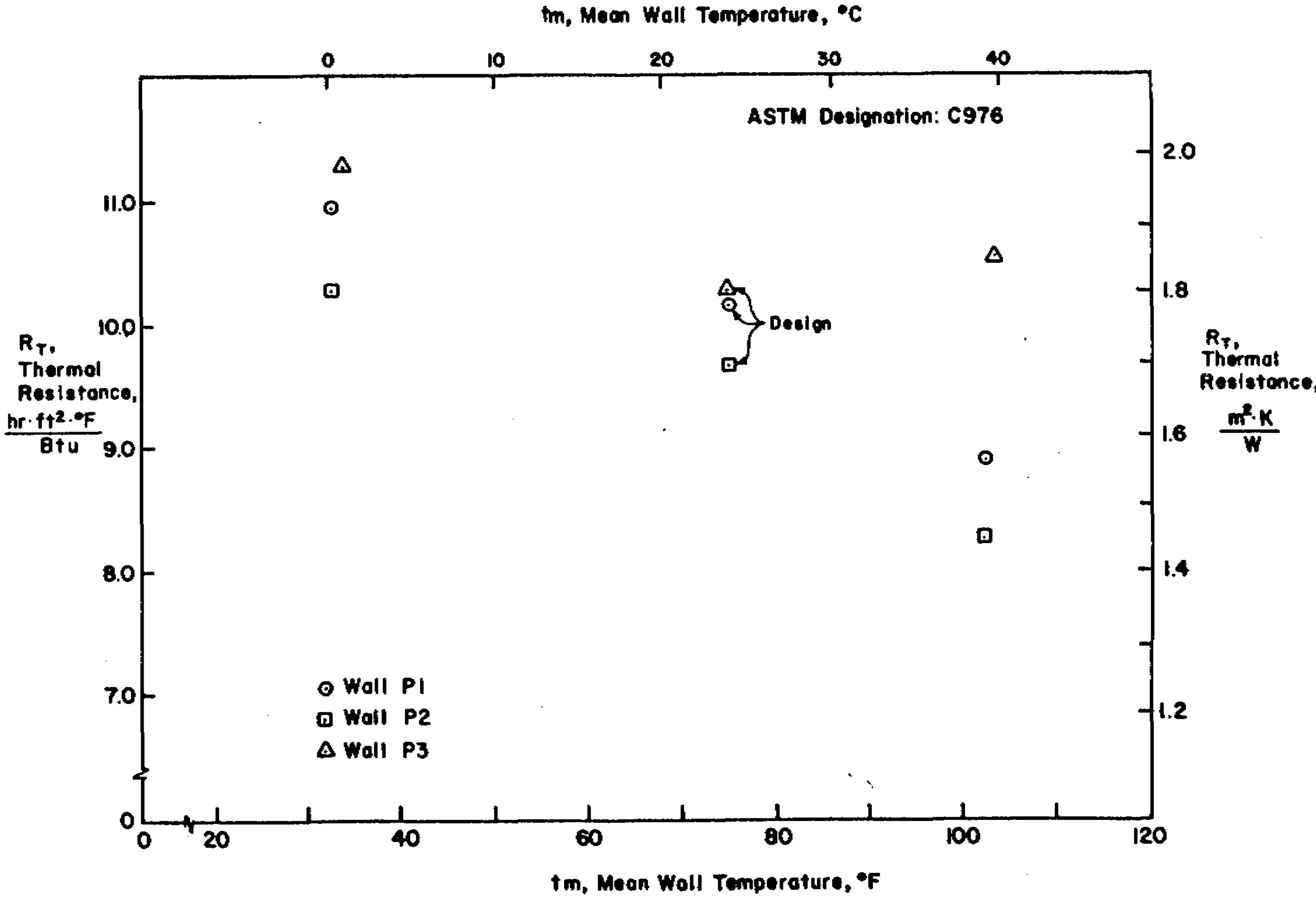


Fig. 36 Total Thermal Resistance as a Function of Wall Mean Temperature

same mean temperature Walls P2 and P3 had measured total thermal resistances of 10.31 and 11.30 hr•ft^2•°F/Btu (1.82 and 1.99 m^2•K/W), respectively.

Walls P1 and P2

For steady-state tests at a mean wall temperatures of 104°F (40°C), and 34°F (1°C), respectively, total thermal resistances of Wall P2 were 7 and 6% less than for Wall P1. This reduction in thermal resistance is due to greater heat flow through stainless steel ties and torsion anchors in Wall P2.

The design thermal resistance of Wall P2 calculated at a mean wall temperature of 75°F (24°C) using the isothermal planes method is 5% less than that for Wall P1. The calculation is consistent with the measured decrease in thermal resistance of Wall P2.

Using results from the three-dimensional analysis performed by Mr. K. W. Childs, a 6% increase in heat flow through Wall P2 was predicted. This calculated method also accurately predicted the decrease in thermal resistance of Wall P2.

Walls P1 and P3

For steady-state tests at mean wall temperatures of 104°F (40°C) and 34°F (1°C), respectively, total thermal resistances of Wall P3 were 19 and 3% greater than for Wall P1. The design thermal resistance for Wall P3 was 1% greater than that for Wall P1.

The magnitude of the higher resistance of Wall P3 at a mean temperature of 104°F (40°C) was not predicted. The increase in resistance cannot be attributed to the high-tensile fiberglass-composite ties because of the small percentage of gross wall area represented by the ties. Ties represent less than 0.06% of the wall area perpendicular to heat flow. The increase in resistance cannot be attributed to the concrete because the concrete contributes less than 4% to the wall's thermal resistance. More research is needed to determine the reason for the increase in resistance of Wall P3 at a mean temperature of 104°F (40°C). For example, thermal resistance of Wall P3 could be measured at 10°F (6°C) intervals of mean temperature to better define thermal resistance as a function of mean temperature. Thermal resistance of concrete and insulation portions of the wall could be measured at selected mean temperatures using a guarded hot plate. Results on the full size wall assembly, Wall P3, could then be compared to results from the materials tests.

Total thermal resistances of Walls P1, P2, and P3 at 75°F (24°C) mean temperatures were estimated to be 9.74, 9.10, and 10.87 $hr \cdot ft^2 \cdot °F/Btu$ (1.72, 1.60, and 1.91 $m^2 \cdot K/W$), respectively. Values were interpolated from measured resistances at 104°F (40°C) and 34°F (1°C).

Interpolated thermal resistances for Walls P1 and P2, respectively, at 75°F (24°C) mean temperatures were 4% and 6% less than design resistances. Interpolated resistance for Wall P3 at a 75°F (24°C) mean temperature was 6% greater than the design resistance.

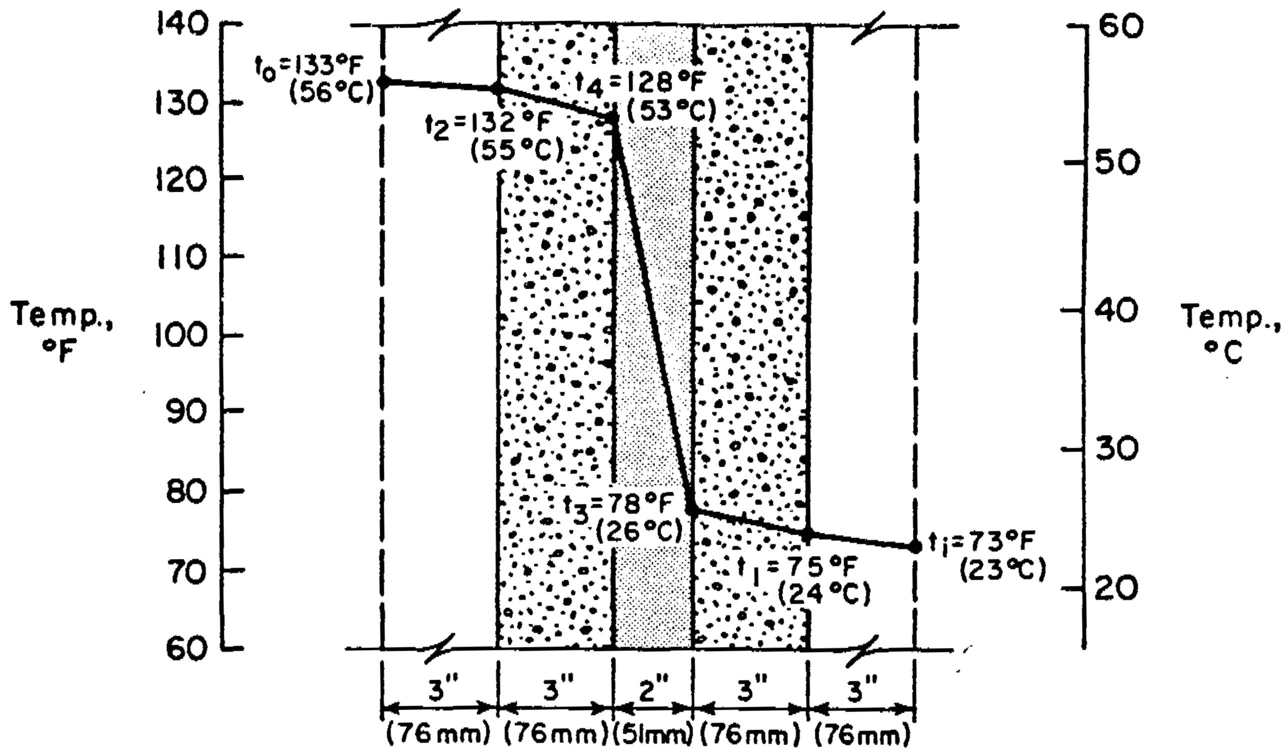
Steady-State Temperature Profiles

Temperature profiles across Walls P1, P2, and P3 for the steady-state tests are illustrated in Figures 37, 38, and 39. The following notation is used to designate average measured temperatures:

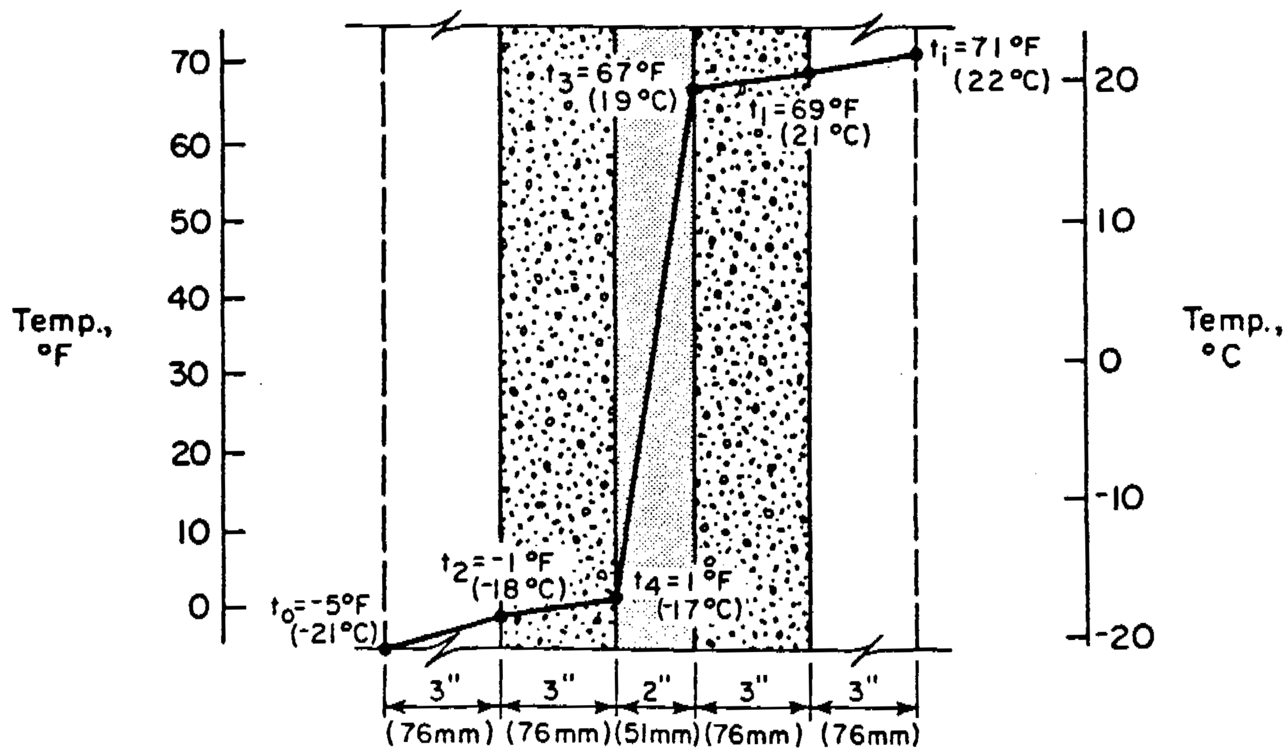
t_0 = outdoor air temperature

t_2 = wall surface temperature, outdoor side

t_4 = internal wall temperature at the interface of concrete and insulation on the outdoor side

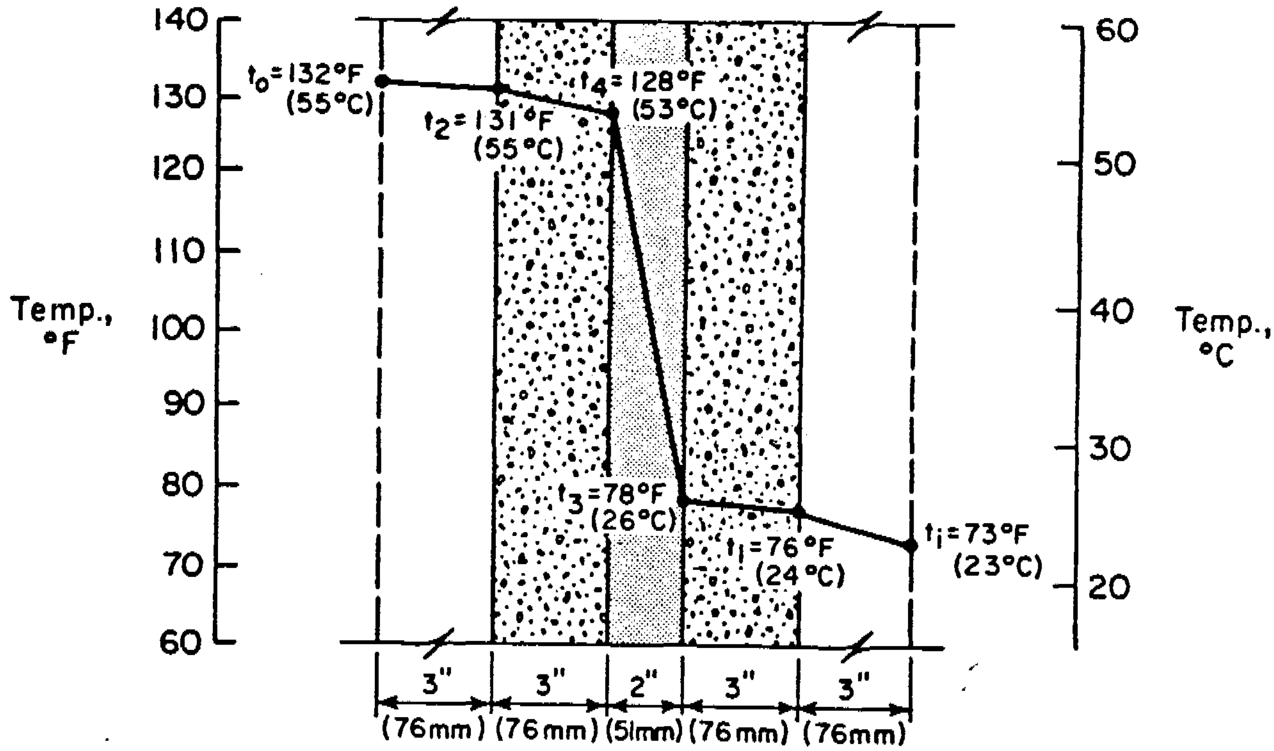


(a) Mean Wall Temperature = 104°F (40°C)

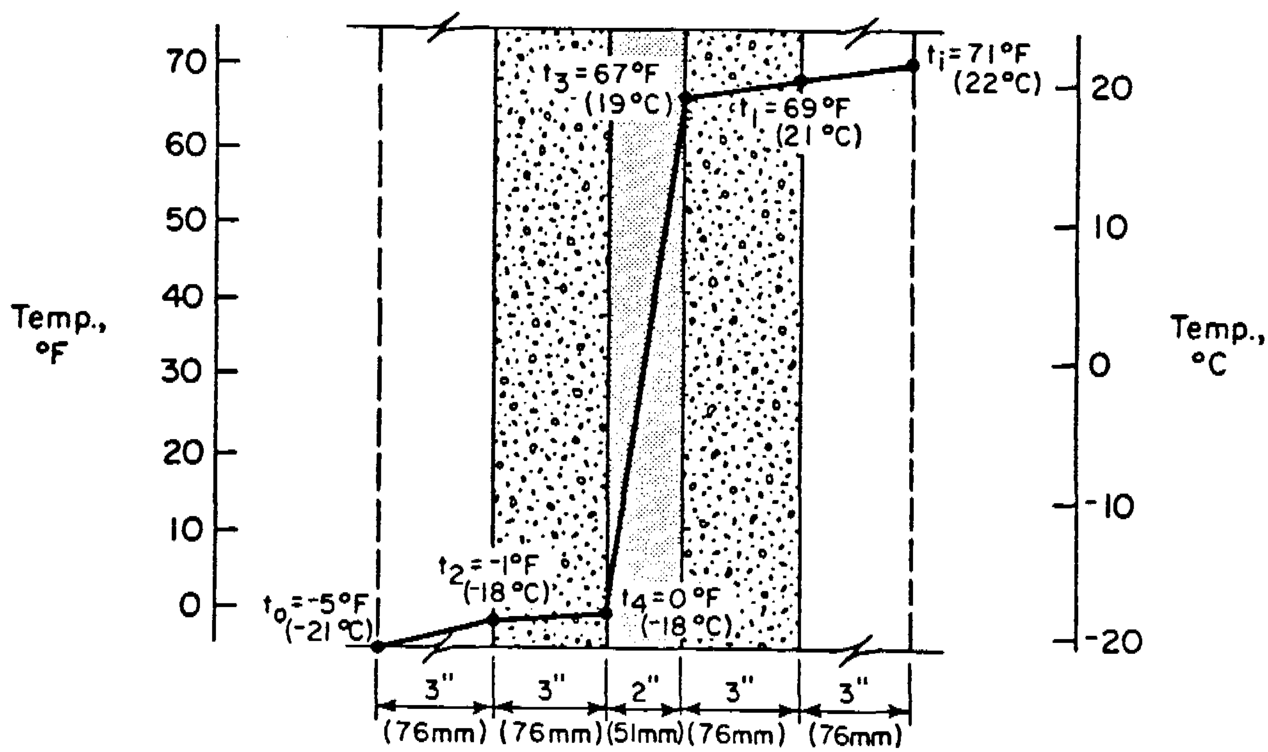


(b) Mean Wall Temperature = 34°F (1°C)

Fig. 37 Steady-State Temperature Profiles Across Wall P1

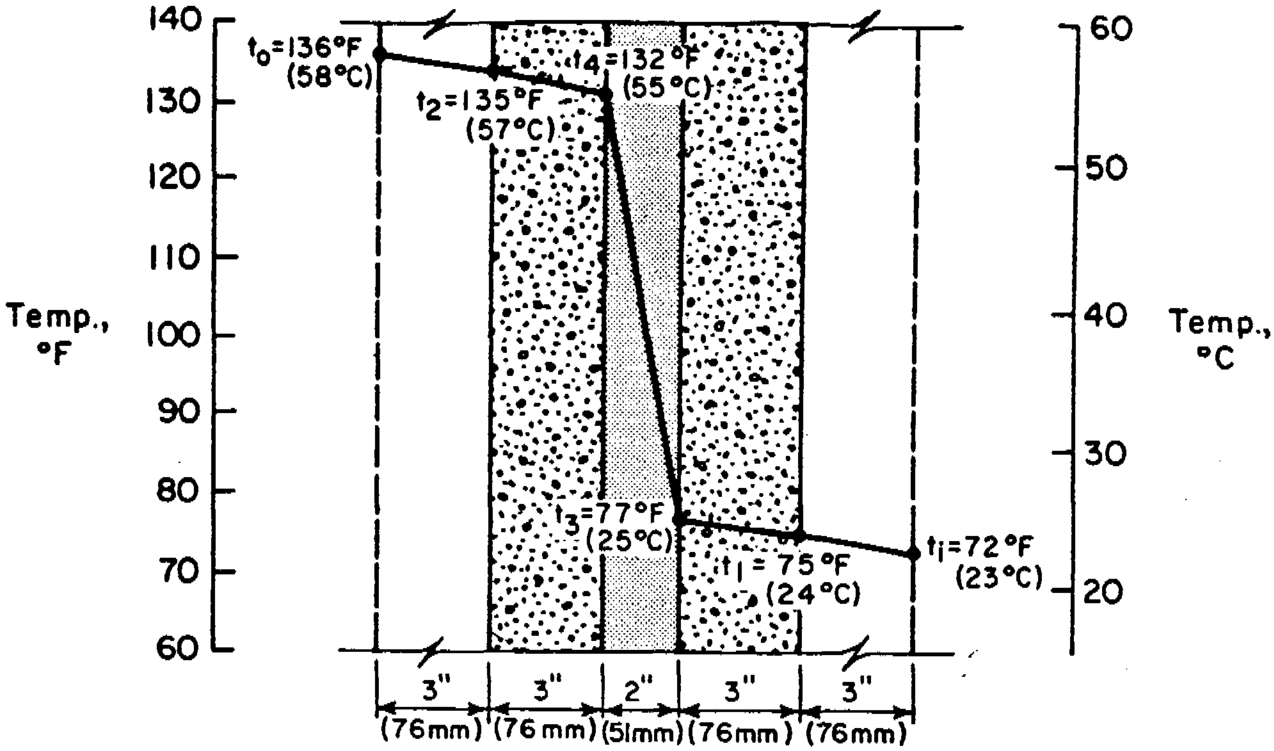


(a) Mean Wall Temperature = 103°F (39°C)

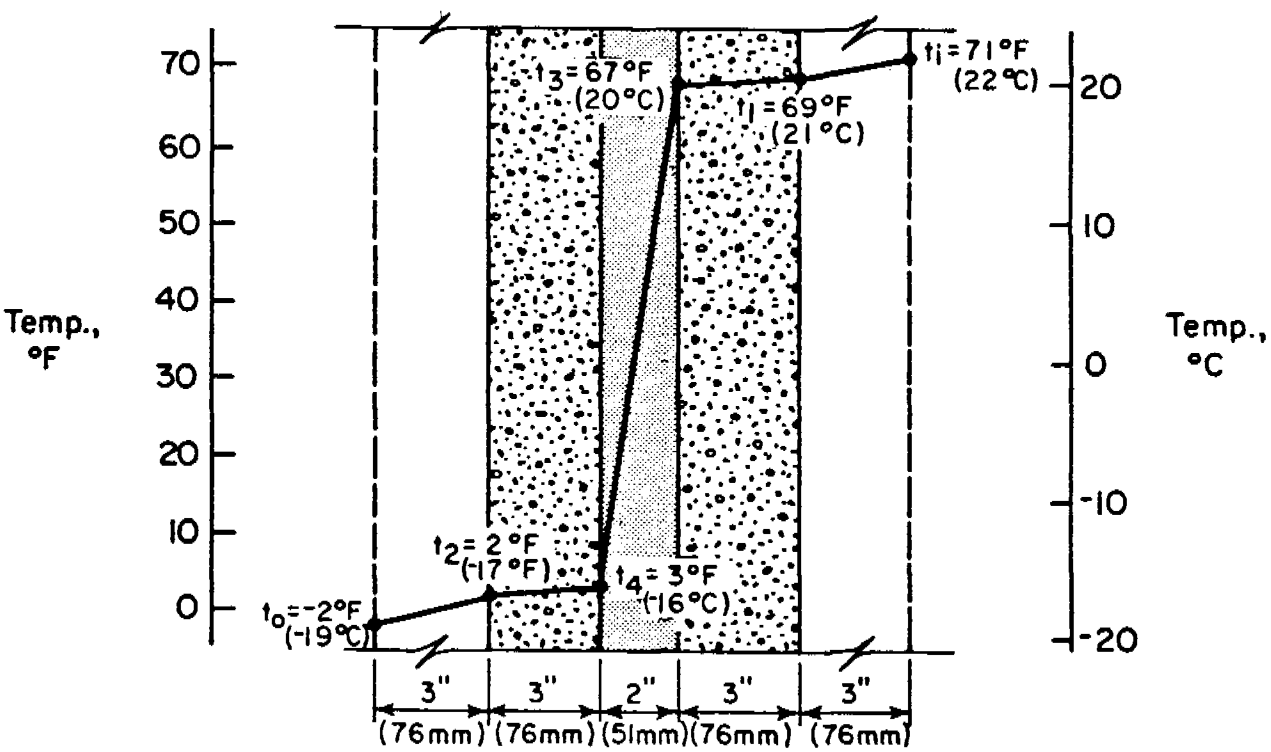


(b) Mean Wall Temperature = 34°F (1°C)

Fig. 38 Steady-State Temperature Profiles Across Wall P2



(a) Mean Wall Temperature = 105°F (41°C)



(b) Mean Wall Temperature = 35°F (2°C)

Fig. 39 Steady-State Temperature Profiles Across Wall P3

t_3 = internal wall temperature at the interface of concrete and insulation on the indoor side

t_1 = wall surface temperature, indoor side

t_i = indoor air temperature

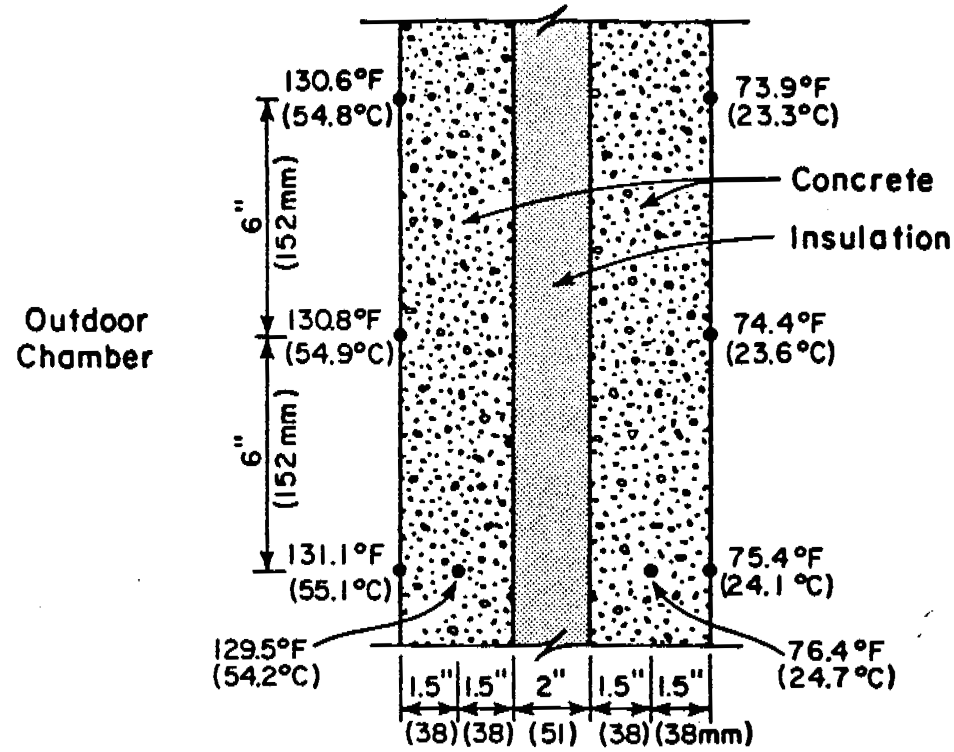
All temperatures are averages from the 16 thermocouples located in each plane as previously described in the "Instrumentation" section of this report.

A comparison of Figs. 37, 38, and 39 shows that temperature profiles are similar for each of the three walls. The presence of stainless steel connectors, used in Wall P2, and high-tensile fiberglass-composite ties, used in Wall P3, does not significantly affect average temperatures at the wall surfaces and concrete/insulation interfaces.

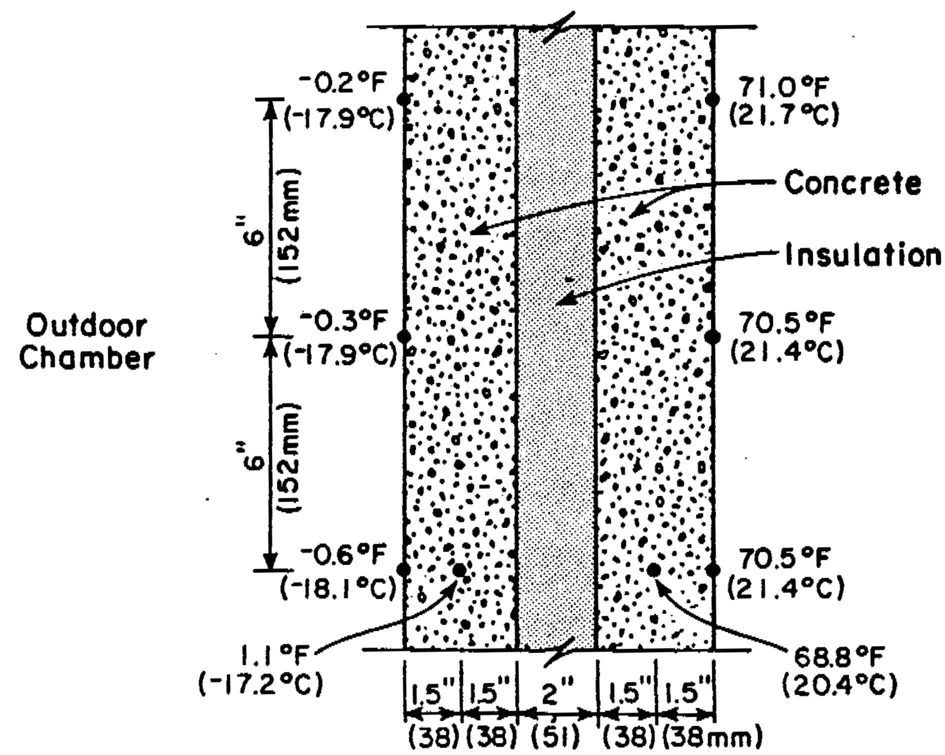
As described in the section on "Instrumentation" additional thermocouples were located on and near the ties in Walls P2 and P3. Wall P1 also had additional thermocouples although no ties were present.

Figures 40, 41, and 42 present measured temperatures at locations of these additional thermocouples for each steady-state test applied to Walls P1, P2, and P3, respectively. A comparison of Figs. 40 and 41 shows that wall surface temperatures monitored in vicinity of a stainless steel tie on Wall P2 are not significantly different from surface temperatures on Wall P1. Figure 41 shows that surface temperatures directly across from the monitored tie are not significantly different from those 12 in. (300 mm) away from the tie. The point 12 in. (300 mm) from the monitored tie is midway between two ties spaced 2 ft (0.6 m) apart. These data indicate that the stainless steel tie does not significantly affect wall surface temperatures.

Similarly, Fig. 42 shows that the presence of a high-tensile fiberglass-composite tie does not significantly affect wall surface temperatures.

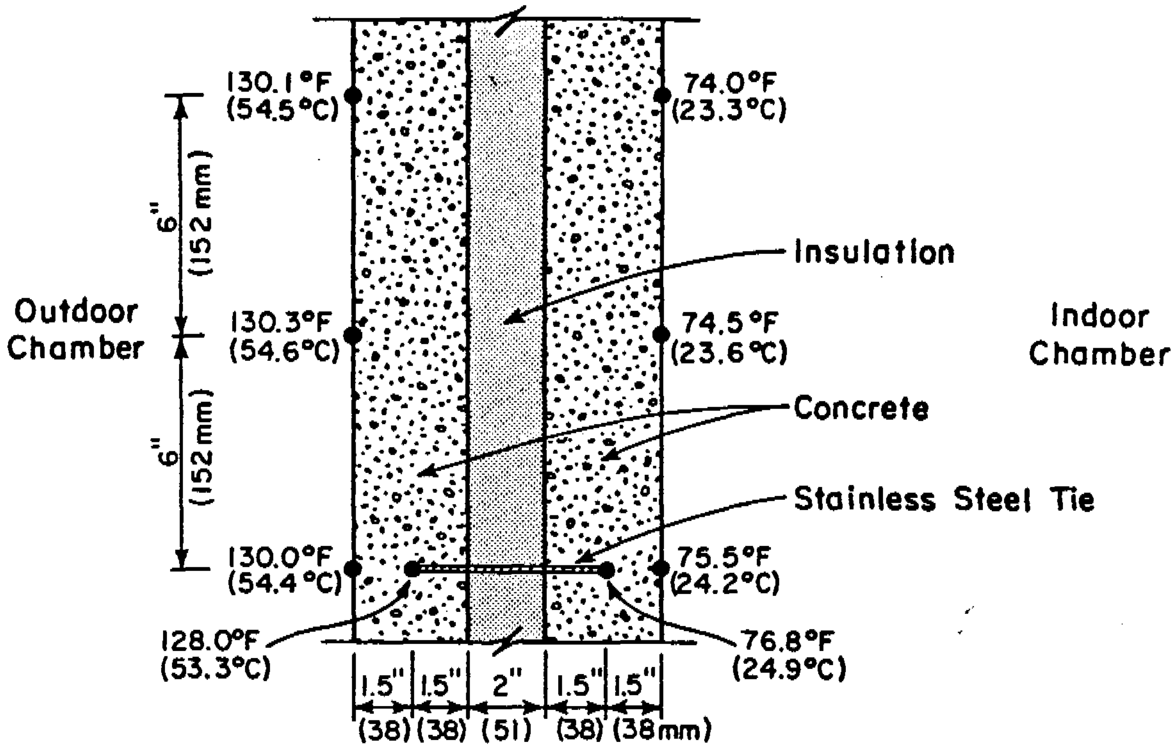


(a) Mean Wall Temperature = 104°F (40°C)

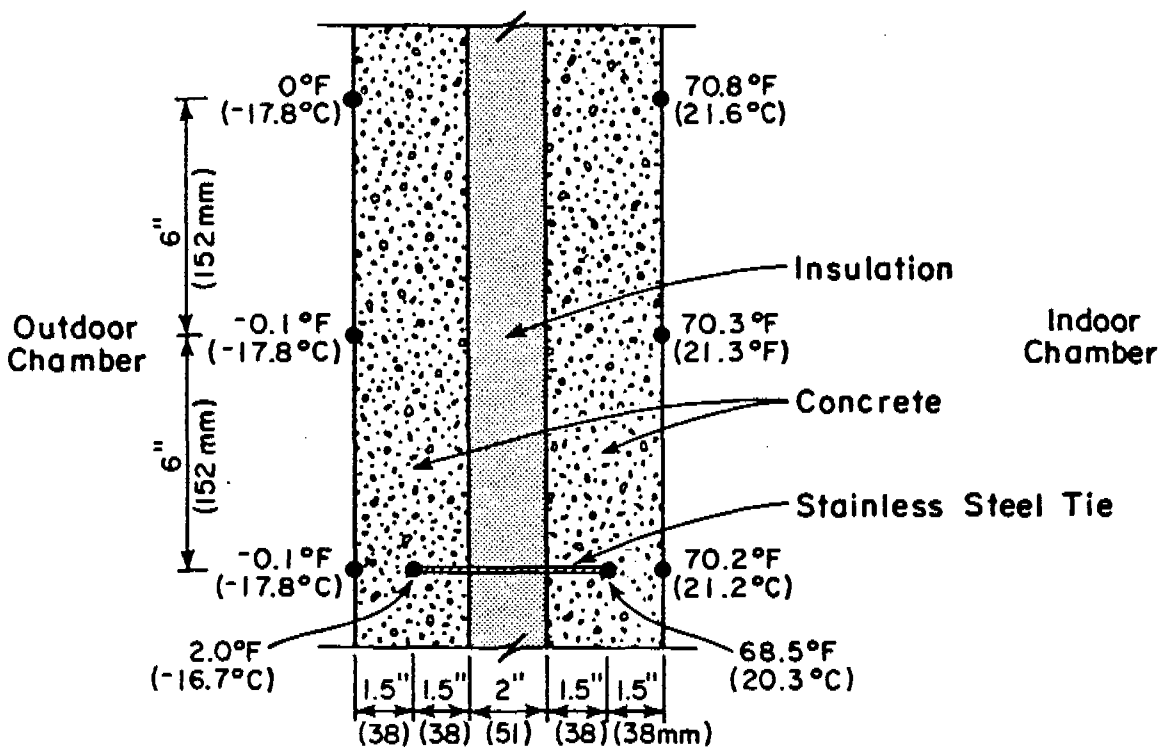


(b) Mean Wall Temperature = 34°F (1°C)

Fig. 40 Temperatures at Thermocouples in Vicinity of Ties for Wall P1

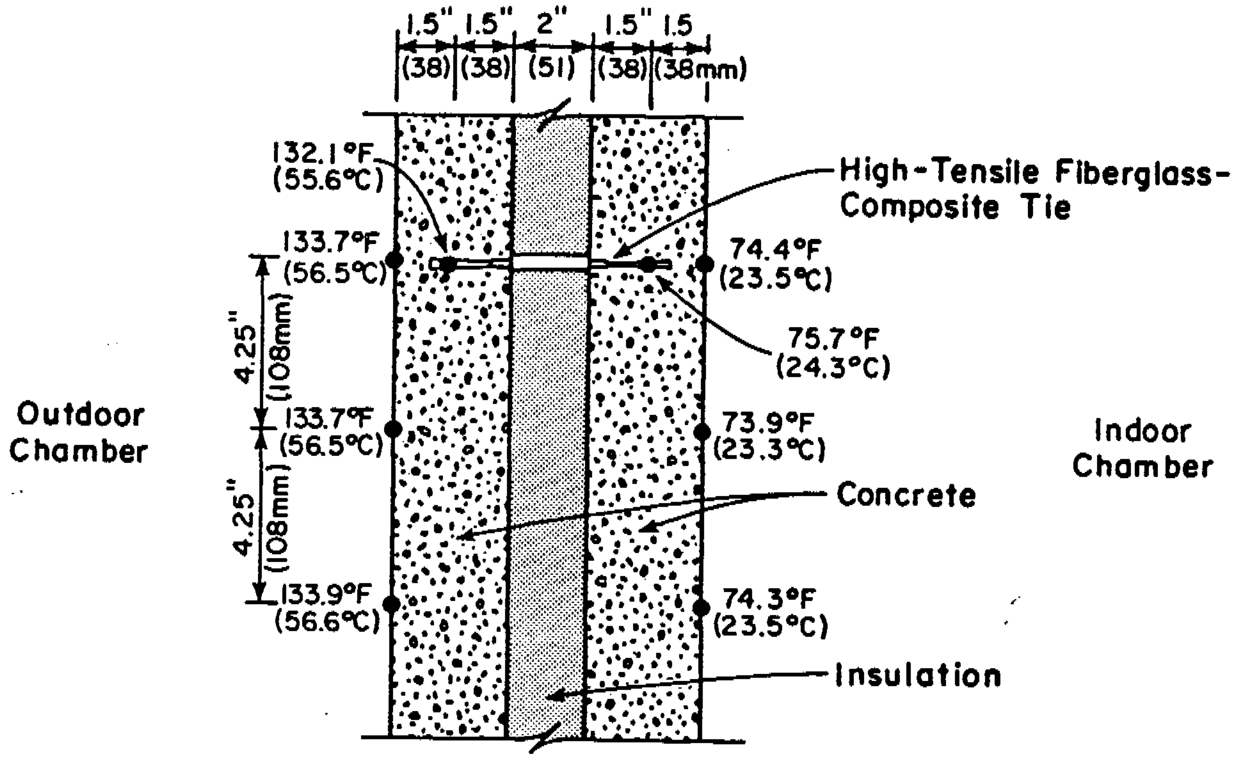


(a) Mean Wall Temperature = 103°F (39°C)

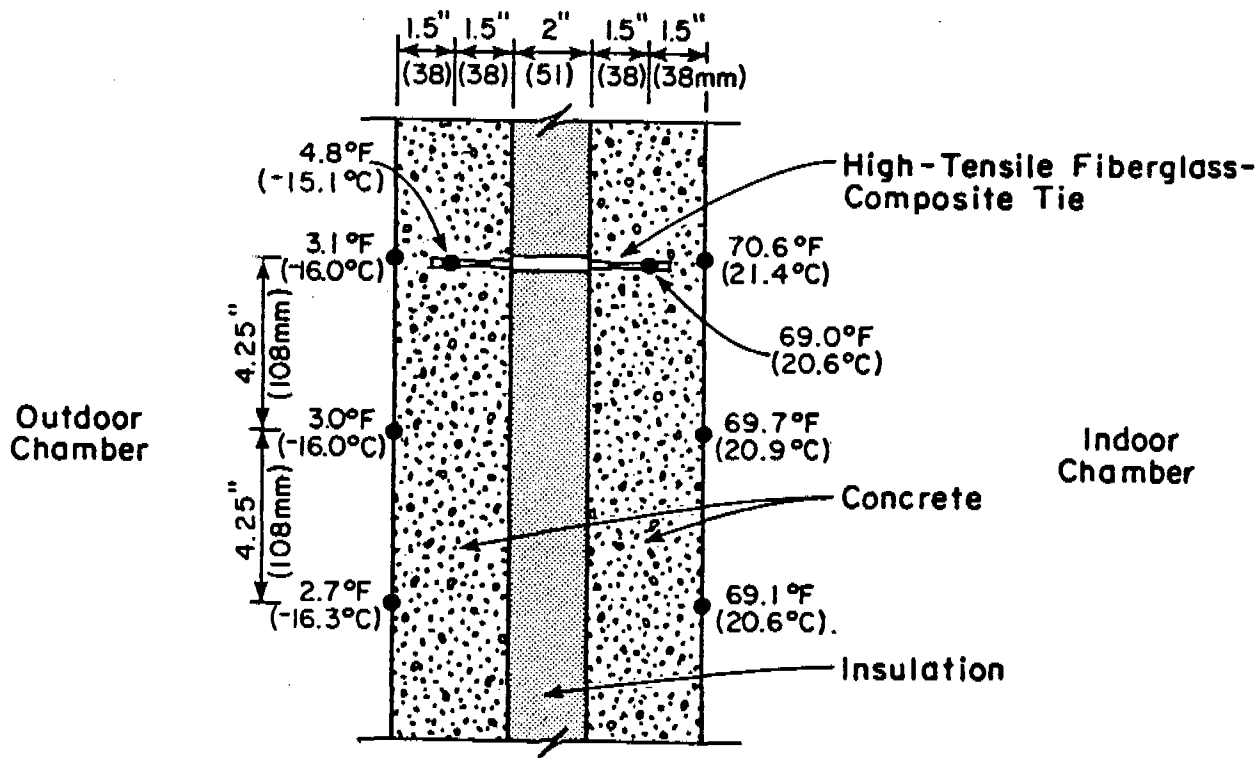


(b) Mean Wall Temperature = 34°F (1°C)

Fig. 41 Temperatures at Thermocouples in Vicinity of Ties for Wall P2



(a) Mean Wall Temperature = 105°F (41°C)



(b) Mean Wall Temperature = 36°F (2°C)

Fig. 42 Temperatures at Thermocouples in Vicinity of Ties for Wall P3

Surface temperatures directly across from the monitored tie are not significantly different from those 8-1/2 in. (215 mm) away from the tie. The point 8-1/2 in. (215 mm) from the monitored tie is midway between two ties spaced 17 in. (430 mm) apart.

DYNAMIC CALIBRATED HOT BOX TESTS

Exterior building walls are seldom subjected to steady-state thermal conditions. Outdoor air temperatures and solar effects cause cyclic changes in outdoor surface temperatures. Generally, indoor surface temperatures are relatively constant compared to outdoor surface temperatures.

Dynamic tests are a means of evaluating thermal response under controlled conditions that simulate temperature changes actually encountered in building envelopes. The heat flow through walls as a response to temperature changes is a function of both thermal resistance and thermal storage capacity.

Test Procedures

Dynamic tests were conducted on Walls P1, P2, and P3 in the CTL calibrated hot box. For these tests, the calibrated hot box indoor air temperatures were held constant while outdoor air temperatures were cycled over a pre-determined time versus temperature relationship. The rate of heat flow through a test specimen was determined from hourly averages of data.

Three 24-hour (diurnal) temperature cycles were used on each wall in this investigation. The first cycle, denoted the NBS Test Cycle, has been used in previous studies using the CTL calibrated hot box. This periodic cycle is based on a simulated sol-air* cycle used by the National Bureau of Standards

*Sol-air temperature is that temperature of outdoor air that, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange, and convective heat exchange with outdoor air.(14)

in their evaluation of dynamic thermal performance of an experimental masonry building.[19] It represents a large variation in outdoor temperature over a 24-hour period. The mean outdoor temperature of the cycle is approximately equal to the mean indoor temperature.

Two additional sol-air temperature cycles were run with mean outdoor temperatures approximately 10°F (6°C) above and 10°F (6°C) below the indoor temperature. The test cycle designated "NBS+10" was derived by increasing hourly outdoor temperatures of the NBS Test Cycle by 10°F (6°C). The test cycle designated "NBS-10" was derived by decreasing hourly outdoor temperatures by 10°F (6°C).

Outdoor chamber air temperatures for the three actual test cycles applied to Walls P1, P2, and P3 are illustrated in Fig. 43. Outdoor air temperatures represent the average from the 16 thermocouples located 3 in. (75 mm) from the test specimen surface in the outdoor chamber. Average indoor air temperature over the 24-hour period for each cycle was approximately 72°F (22°C).

For all tests, dynamic cycles were repeated until conditions of equilibrium were obtained. Equilibrium conditions were evaluated by consistency of applied temperatures and measured energy response. After equilibrium conditions were reached, each test was continued for a period of three days. Results are based on average readings for three consecutive 24-hour cycles. Each test required a total of approximately eight days for completion.

Dynamic calibrated hot box tests were performed on Wall P1 in April and May 1985. Tests were performed on Wall P2 in July and August 1985. Tests were performed on Wall P3 in October and November 1985.

Test Results

Measured temperatures, temperature differentials, and heat flow for dynamic temperature cycles for each wall are presented in Appendix C. Brief

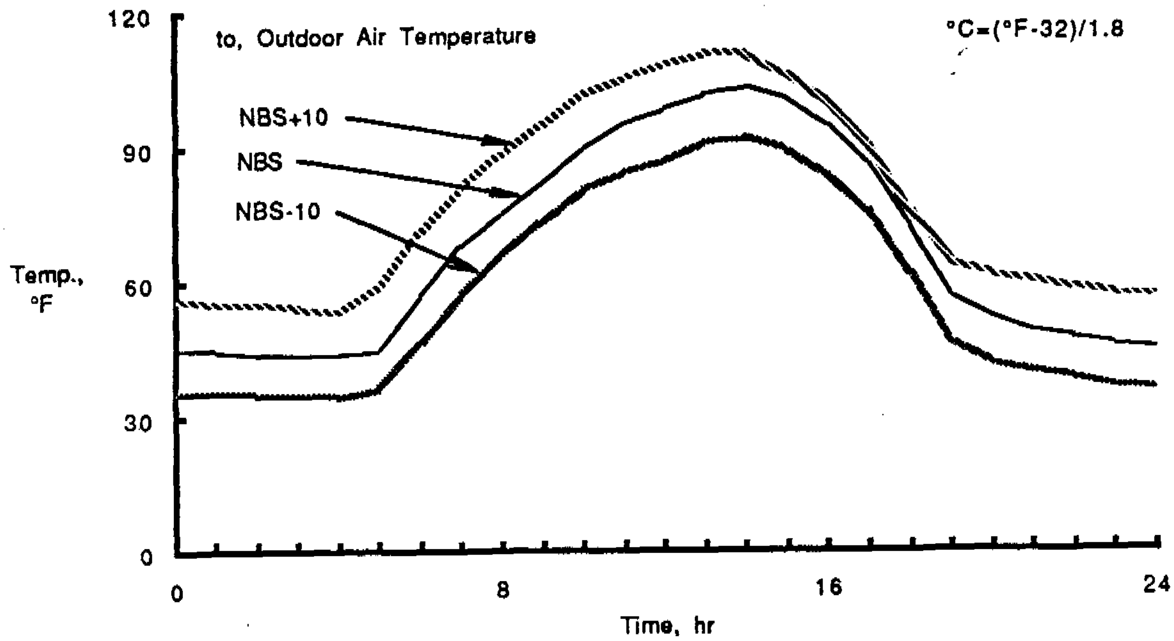


Fig. 43 Outdoor Chamber Air Temperatures for Dynamic Temperature Cycles

descriptions of symbols used in test result figures and tables are listed in Table 13. Symbols are described in detail in the following paragraphs.

Measured Temperatures and Temperature Differentials

For Walls P1, P2, and P3, outdoor air (t_0), indoor air (t_1), outdoor surface (t_2), indoor surface (t_1), and internal wall (t_3,t_4) temperatures are average readings of the 16 thermocouples placed as described in the "Instrumentation" section of this report. Internal concrete/insulation interface temperatures on the indoor and outdoor sides, (t_3) and (t_4), respectively, are average readings of thermocouples placed on each side of the insulation board. Figure 44 shows a wall cross-section illustrating the location of measured temperatures.

Heat Flow

Heat flow is designated positive when heat flows from the calibrated hot box outdoor chamber to the indoor chamber. Heat flow determined from calibrated hot box tests is denoted q_w.

Heat flow measurements from heat flux transducers located on indoor and outdoor wall surfaces were denoted q_{hft} and q'_{hft}, respectively. For each wall, heat flux transducer data were calibrated using results from steady-state calibrated hot box tests.

Heat flow predicted by steady-state data analysis is denoted q_{ss}. Values were calculated on an hourly basis from wall surface temperatures using the following equation:

$$q_{ss} = (t_2 - t_1)/R \qquad (3)$$

where

q_{ss} = heat flow through wall predicted by steady-state analysis, Btu/hr•ft^2(W/m^2)

TABLE 13 - ABBREVIATIONS FOR HEAT FLOW AND TEMPERATURE

q_{hft}	=	heat flow measured by heat flux transducer mounted on indoor wall surface
q'_{hft}	=	heat flow measured by heat flux transducer mounted on outdoor wall surface
q_{ss}	=	heat flow predicted from steady-state analysis
q_w	=	heat flow measured by calibrated hot box
t_i	=	indoor air temperature
t_1	=	wall surface temperature, indoor side
t_3	=	concrete/insulation interface temperature on the indoor side
t_4	=	concrete/insulation interface temperature on the outdoor side
t_2	=	wall surface temperature, outdoor side
t_o	=	outdoor air temperature
t_m	=	average of wall surface temperatures on indoor and outdoor side

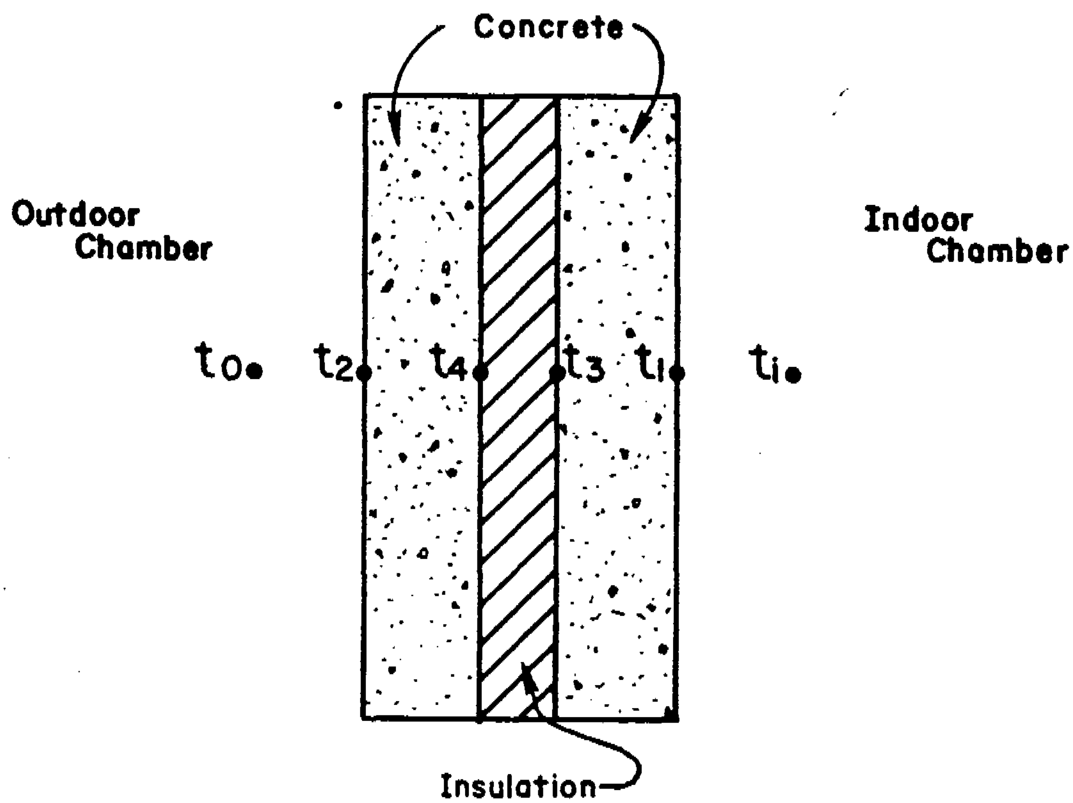


Fig. 44 Location of Measured Temperatures

R = average thermal resistance, $hr \cdot ft^2 \cdot {}^\circ F/Btu$ ($m^2 \cdot K/W$)

t_2 = average temperature of outdoor wall surface, °F (°C)

t_1 = average temperature of indoor wall surface, °F (°C)

Thermal resistances for each wall are dependent on wall mean temperature and were derived from steady-state calibrated hot box test results.

Appendix C tables also footnote calibrated hot box indoor and outdoor chamber relative humidities, and maximum and minimum laboratory air temperatures measured during tests.

Discussion of Test Results

Heat Flow Comparisons

Figure 45 shows measured and calculated heat flows through Walls P1, P2, and P3 for the NBS Temperature Cycle. Heat flows measured by the calibrated hot box, q_w, and calculated from steady-state resistances using Eq. 3, q_{ss}, are shown. Figures 46 and 47, respectively, show measured and calculated heat flows through Walls P1, P2, and P3 for the NBS+10 and NBS-10 Temperature Cycles.

Measured heat flow curves, q_w, for Walls P1, P2, and P3 show significantly reduced and delayed peaks compared to calculated heat flows, q_{ss}. This is shown for all three temperature cycles in Figs. 45, 46, and 47.

The amplitudes of calculated heat flows, q_{ss}, for Wall P2 are greater than those for Wall P1 due to the decreased resistance of Wall P2. The amplitudes of calculated heat flow, q_{ss}, for Wall P3 are less than those for Wall P1 due to the increased resistance of Wall P3. Thermal resistances of Walls P1, P2, and P3 are discussed in the "Thermal Resistance Comparisons" section of this report.

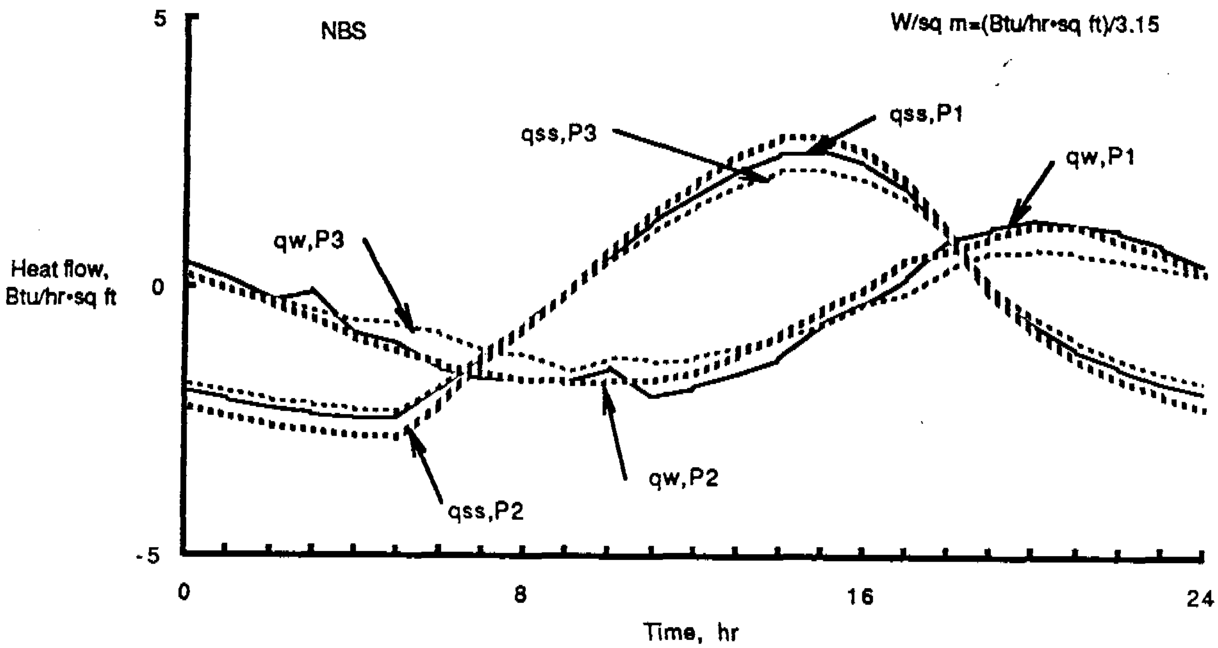


Fig. 45 Heat Flow for NBS Test Cycle Applied to Walls P1, P2, and P3

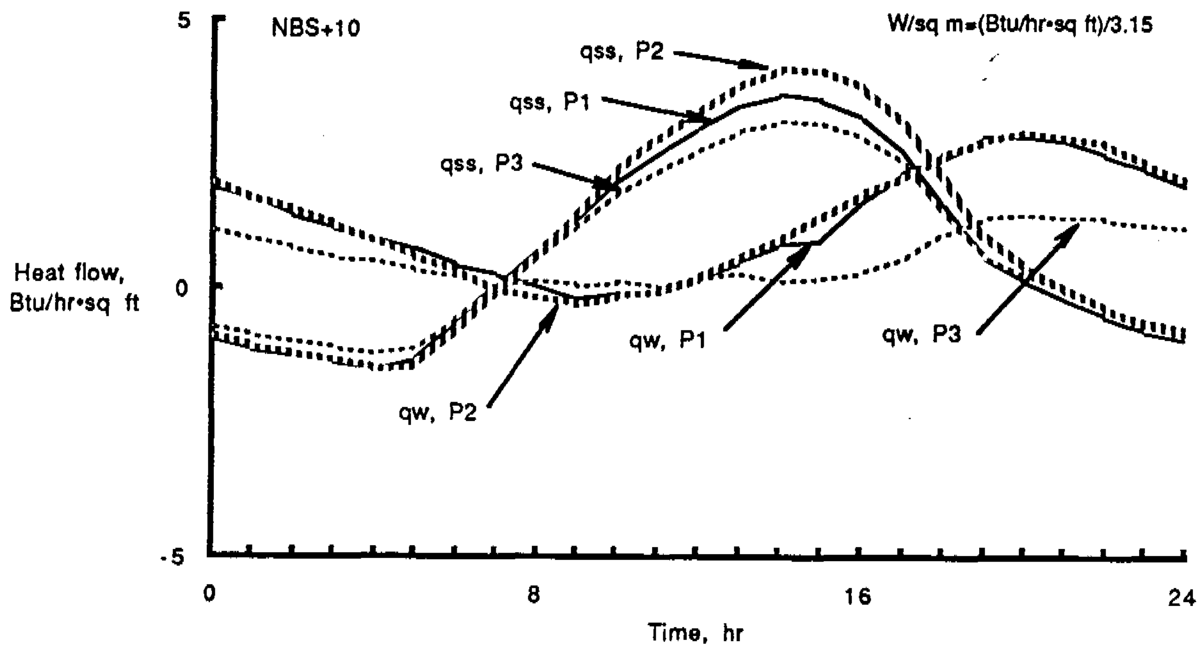


Fig. 46 Heat Flow for NBS+10 Test Cycle Applied to Walls P1, P2, and P3

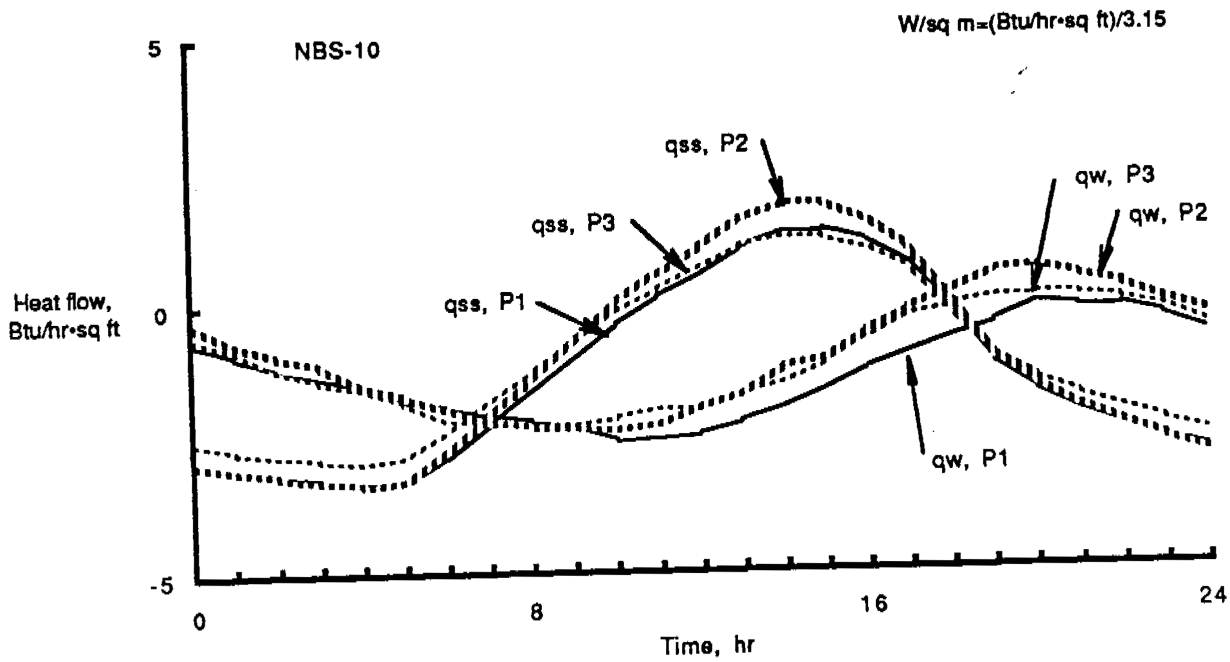


Fig. 47 Heat Flow for NBS-10 Test Cycle Applied to Walls P1, P2, and P3

Measured heat flows, q_w, for the NBS Test Cycle applied to Walls P1, P2 and P3 are not significantly different. Figure 47 shows that measured heat flows for the NBS-10 Test Cycle applied to the three walls were similar.

For the NBS+10 Test Cycle, amplitudes of measured heat flow, q_w, were less for Wall P3 than for Walls P1 and P2. The NBS+10 Test Cycle was the warmest of the three dynamic temperature cycles applied to the walls. The high resistance of Wall P3 for the steady-state test at a mean temperature of 104°F (40°C) may be related to the low heat flow measured for the wall during the NBS+10 Test Cycle.

Thermal Lag

One measure of dynamic thermal performance is thermal lag. Thermal lag is a measure of the response of indoor surface temperatures and heat flow to fluctuations in outdoor air temperatures. Lag is dependent on thermal resistance and heat storage capacity of the test specimen, since both of these factors influence the rate of heat flow.

For each dynamic test cycle, Table 14 lists thermal lags determined from calibrated hot box test results and measured heat flux transducer readings. Calibrated hot box thermal lag is quantified by two methods. In one measure, denoted t_o vs t_1, lag is calculated as the time required for the maximum or minimum indoor surface temperature to be reached after the maximum or minimum outdoor air temperature is attained. In the second measure, denoted q_{ss} vs q_w, lag is calculated as the time required for the maximum or minimum heat flow rate, q_w, to be reached after the maximum or minimum heat flow rate based on steady-state predictions, q_{ss}, is attained. The second measure is illustrated in Figure 48 for the NBS Test Cycle applied to Wall P3. Both measures give similar results. The second measure was also used to determine thermal lag for heat flux transducer data.

TABLE 14 - THERMAL LAG

Wall Designation	Test Cycle	Measured Thermal Lag, hrs							
		Calibrated Hot Box					Heat Flux Trans.		
		t_o vs t_1		q_{ss} vs q_w		Avg.	q_{ss} vs q_{hft}		Avg.
		@ Max.	@ Min.	@ Max.	@ Min.		@ Max.	@ Min.	
P1	NBS	6	5	5	6	5.5	6	5	5.5
P2	NBS	6	4.5	6	4	5	6	4.5	5.5
P3	NBS	6	4.5	5	4	5.5	6	4	5
P1	NBS+10	6	4	5.5	6	5.5	6.5	5	6
P2	NBS+10	5.5	4	6	5	5	7	5.5	6.5
P3	NBS+10	6.5	5	6	5	5.5	6	5	5.5
P1	NBS-10	6	4.5	5	6	5	6	5.5	6
P2	NBS-10	6.5	4.5	6	6	6	7	5	6
P3	NBS-10	6.5	4.5	6	3.5	5	6	5	5.5

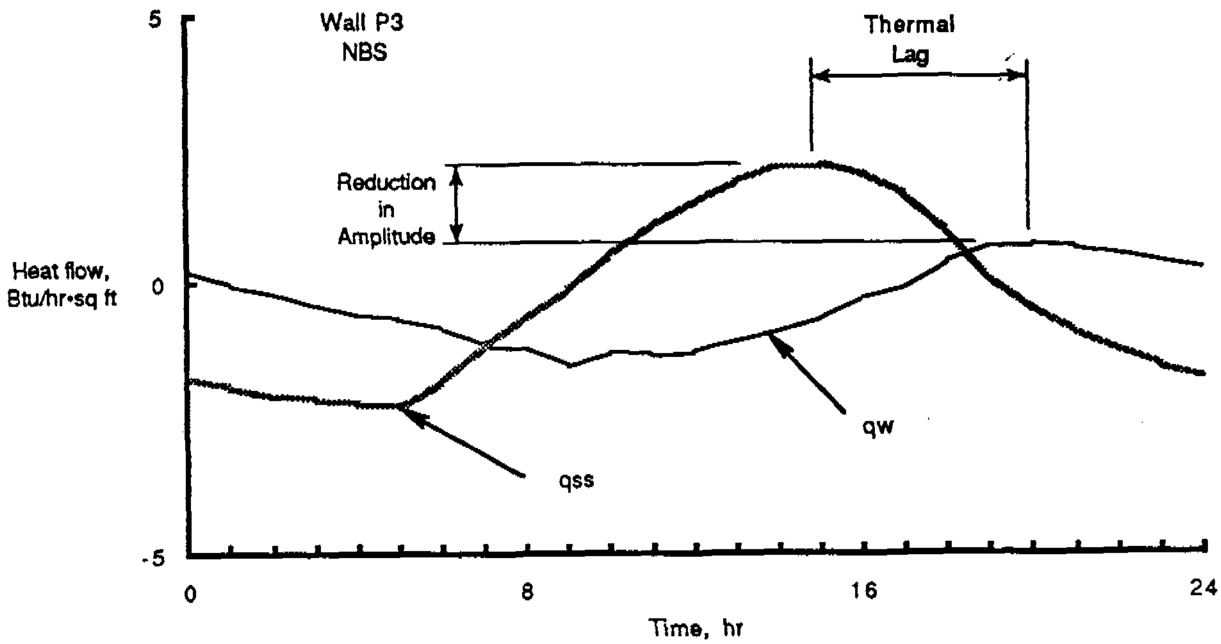


Fig. 48 Definition of Thermal Lag and Reduction in Amplitude

Average thermal lag values for Walls P1, P2, and P3 were between 5 and 6 hours. Thermal lag values for each wall are relatively constant regardless of the temperature cycle applied to the wall. Thermal lags for Walls P2 and P3 are not significantly different from those for Wall P1, the control wall. Thermal lags exhibited by the three walls are predominately due to the thermal storage capacity of the concrete and the thermal resistance of the insulation board. The tie systems present in Walls P2 and P3 did not significantly affect thermal lag of the wall systems.

Thermal lag is of interest because the time of occurrence of peak heat flows will have an effect on overall response of the building envelope. If the envelope can be effectively used to delay the occurrence of peak loads, it may be possible to improve overall energy efficiency. The "lag effect" is also of interest for passive solar applications.

Reduction in Amplitude

Reduction in amplitude is a second measure of dynamic thermal performance. Reduction in amplitude, as well as thermal lag, is influenced by both wall thermal resistance and heat storage capacity. Reduction in amplitude is dependent on the temperature cycle applied to the test specimen.

Reduction in amplitude is defined as the percent reduction in peak heat flow when compared to peak heat flow calculated using steady-state theory. Reduction in amplitude is illustrated in Fig. 45. Values for reduction in amplitude were calculated using the following equation:

$$A = [1 - (q' - \bar{q})/(q'_{ss} - \bar{q}_{ss})] \cdot 100 \qquad (4)$$

where

A = reduction in amplitude, %

q' = maximum or minimum heat flow through wall

$\bar{q}$ = mean heat flow through wall

q'_{ss} = maximum or minimum heat flow through wall predicted by steady-state analysis

$\bar{q}_{ss}$ = mean heat flow through wall predicted by steady-state analysis

Table 15 lists reduction in amplitude values for each dynamic temperature cycle applied to Walls P1, P2, and P3. Average reduction in amplitude values for heat flow measured by the calibrated hot box, q_w, range from 34 to 69% for Walls P1, P2, and P3. Reduction in amplitude values from heat flux transducer measurements range from 57 to 63% for the three walls.

Reduction in amplitude values for Walls P2 and P3 are not consistently greater or less than those for Wall P1, the control wall. Amplitude reductions exhibited by the three walls are predominantly due to the thermal storage capacity of the concrete and the thermal resistance of the insulation board. The tie systems present in Walls P2 and P3 did not significantly affect amplitude reductions of the wall systems.

Amplitudes for heat flux transducer data, q_{hft}, are generally not the same as those for measured heat flow, q_w. Heat flow amplitudes differ because of the physical presence of the instrument mounted on a wall. A wall's thermal properties are locally altered by the heat flux transducer. In addition, heat flux transducer calibration using steady-state results may not fully correct for dynamic effects of the instrument location.

Actual maximum heat flow through a wall is important in determining the peak energy load for a building envelope. Test results show anticipated peak energy demands based on actual heat flow are less than those based on steady-state predictions for walls with thermal storage capacity. Calculations based on steady-state analysis overestimate peak heat flow for the three dynamic temperature cycles applied to Walls P1, P2, and P3.

TABLE 15 - REDUCTION IN AMPLITUDE

Wall Designation	Test Cycle	Measured, %					
		Calibrated Hot Box			Heat Flux Trans.		
		@ Max.	@ Min.	Avg.	@ Max.	@ Min.	Avg.
P1	NBS	39	28	34	64	56	60
P2	NBS	49	47	48	63	57	60
P3	NBS	54	45	50	62	56	59
P1	NBS+10	44	37	41	64	59	62
P2	NBS+10	47	36	42	66	59	63
P3	NBS+10	66	71	69	62	57	60
P1	NBS-10	50	41	46	63	55	59
P2	NBS-10	45	40	43	62	56	59
P3	NBS-10	46	42	44	60	54	57

Total and Net Heat Flow

Results of dynamic tests are also compared using measures of total heat flow through a specimen for a 24-hr temperature cycle.

Total measured heat flow is illustrated in Fig. 49 for the NBS Test Cycle applied to Wall P3. The curve marked "q_w" is measured heat flow through the test wall. Areas enclosed by the measured heat flow curve and the line for zero heat flow are total heat flow through a wall. The sum of the areas above and below the horizontal axis is total measured heat flow for a 24-hour period, denoted as q_w^T.

A similar procedure is used to calculate total heat flow for a 24-hour period from measured heat flux transducer data, q_{hfm}, and predictions based on steady-state analysis, q_{ss}.

Table 16 lists total heat flow values for the NBS, NBS+10, and NBS-10 Test Cycles applied to Walls P1, P2, and P3. Values measured by the calibrated hot box, measured by heat flux transducers, and calculated using steady-state thermal resistances are denoted q_w^T, q_{hft}^T, and q_{ss}^T, respectively. "Total Heat Flow Comparisons" listed in Table 16 show measured total heat flow as a percentage of predicted heat flow based on steady-state analysis.

As shown in the "Total Heat Flow Comparisons" column of Table 16, total heat flow measured by the calibrated hot box ranges from 43 to 81% of total heat flow calculated using steady-state analysis. The ratio of total measured heat flow to steady-state predictions depends on the outdoor air temperature cycle applied to the wall. Particularly for massive walls, greater reductions in actual heat flow, compared to steady-state predictions, occur for temperature cycles which produce heat flow reversals through a wall.

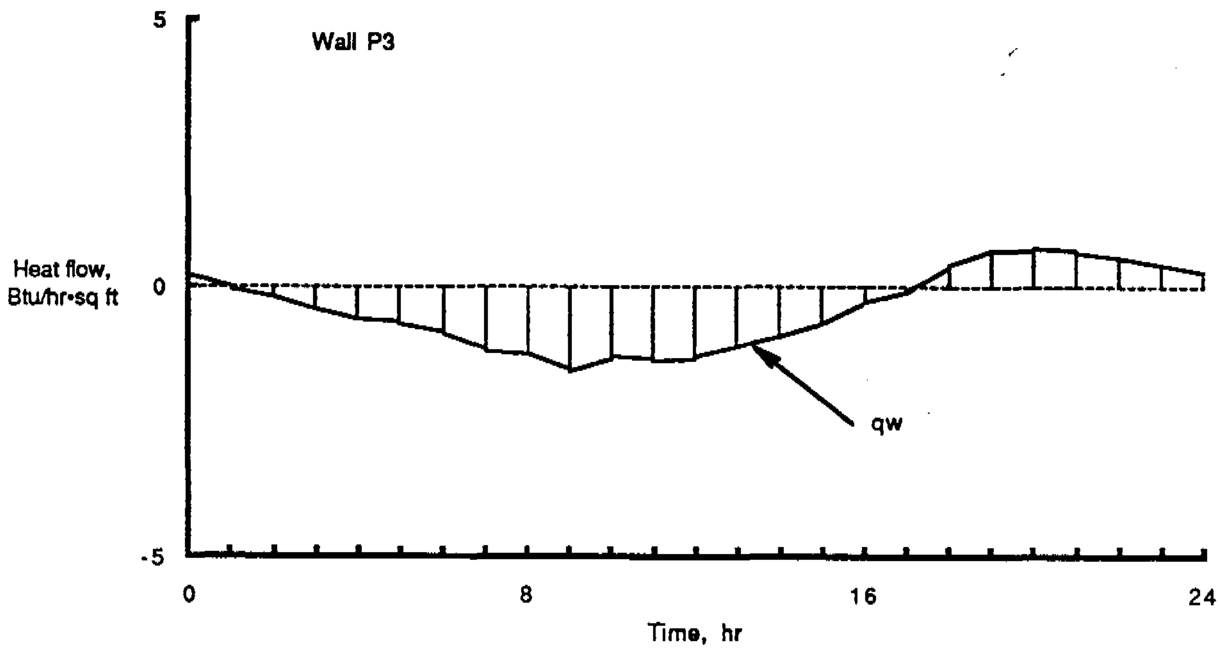


Fig. 49 Definition of Total Measured Heat Flow

TABLE 16 - TOTAL HEAT FLOW

Wall Designation	Test Cycle	Total Heat Flow, Btu/ft^2 (W•hr/m^2)			Total Heat Flow Comparisons, %	
		Measured		Calculated	$\frac{q_w^T}{q_{ss}^T}$	$\frac{q_{hft}^T}{q_{ss}^T}$
		q_w^T	q_{hft}^T	q_{ss}^T		
P1	NBS	25.1 (79.0)	14.9 (46.9)	38.2 (120.5)	66	39
P2	NBS	23.3 (73.6)	17.2 (54.1)	43.5 (137.3)	54	39
P3	NBS	17.3 (54.7)	17.1 (53.8)	34.6 (109.3)	50	49
P1	NBS+10	30.2 (95.3)	21.6 (68.1)	37.3 (117.7)	81	58
P2	NBS+10	31.4 (99.0)	25.1 (79.1)	41.4 (130.5)	76	61
P3	NBS+10	13.7 (43.4)	14.2 (44.7)	31.6 (99.8)	43	45
P1	NBS-10	33.4 (105.3)	26.0 (82.1)	43.0 (135.6)	78	61
P2	NBS-10	28.2 (89.1)	23.9 (75.3)	44.8 (141.4)	63	53
P3	NBS-10	28.0 (88.5)	33.6 (105.9)	37.7 (118.9)	74	89

It should be noted that comparison of total measured heat flow values for the test walls is limited to specimens and dynamic cycles evaluated in this program. Results are for three particular diurnal test cycles and should not be arbitrarily assumed to represent annual heating and cooling loads. In addition, results are for individual opaque wall assemblies. As such, they are representative of only one component of the building envelope.

Total heat flux is the cumulative or integrated heat flux for a given period of time. Net heat flux is the average heat flux for a given period of time, multiplied by the length of the time period. Total heat flux is equal to net heat flux for time periods with no reversals in heat flow through the specimen.

Net heat flow for a 24-hour periodic cycle is equal to the sum of hourly measured rates of heat flow. These values can be determined by totaling values of "q" from columns of Heat Flow Tables in the "Test Results" section. Net heat flow values are denoted by the superscript "N" and are presented in Table 17.

The column "Net Heat Flow Comparisons" in Table 17 lists measured heat flow as a percentage of predicted heat flow based on steady-state analysis. Measured calibrated hot box net heat flow theoretically should be equal to net heat flow based on steady-state predictions.

TRANSIENT TEST RESULTS

Time required for a wall to reach a steady-state condition can be determined from transient tests. This time is affected by both thermal resistance and thermal storage capacity of the test wall.

TABLE 17 - NET HEAT FLOW

Wall Designation	Test Cycle	Net Heat Flow, Btu/ft^2 (W•hr/m^2) Measured q_w^N	Measured q_{hft}^N	Calculated q_{ss}^N	Net Heat Flow Comparisons, % q_w^N / q_{ss}^N	q_{hft}^N / q_{ss}^N
P1	NBS	-10.7 (-33.9)	-2.4 (-7.5)	-6.7 (-21.1)	161	35
P2	NBS	-10.7 (-33.7)	-5.1 (-16.2)	-8.1 (-25.6)	132	63
P3	NBS	-10.2 (-32.1)	-14.3 (-45.2)	-6.7 (-21.2)	152	214
P1	NBS+10	29.4 (92.9)	21.5 (67.9)	18.2 (57.5)	161	118
P2	NBS+10	30.0 (94.5)	25.1 (79.1)	23.1 (72.9)	130	109
P3	NBS+10	13.7 (43.4)	9.3 (29.5)	17.1 (54.1)	80	54
P1	NBS-10	-33.4 (-105.3)	-26.0 (-82.1)	-31.1 (-98.2)	107	84
P2	NBS-10	-24.6 (-77.6)	-23.2 (-73.2)	-26.7 (-84.2)	92	87
P3	NBS-10	-27.7 (-87.4)	-33.6 (-105.9)	-26.1 (-82.4)	106	128

Test Procedures

Results of a transient test are determined from data collected in the period of time between two steady-state tests. After a wall is in a steady-state condition, denoted time 0, the outdoor chamber temperature setting is changed. The transient test continues until the wall reaches equilibrium heat flow for the new outdoor chamber air temperature. The rate of heat flow through a test specimen is determined from hourly averages of data.

Transient test data were collected during calibrated hot box testing of Walls P1, P2, and P3. The initial wall mean temperature for the tests was 73°F (23°C). The final wall mean temperature was approximately 33°F (1°C).

Test Results

Results from transient tests are presented in Appendix D. Values are shown as a function of time. Table 13 in the "Test Results" portion of the "Dynamic Calibrated Hot Box Tests" section lists brief descriptions of symbols used in test data figures and tables.

Heat flows through Walls P1, P2, and P3 for the transient tests are compared in Fig. 50. Heat flows measured by the calibrated hot box, denoted q_w, are delayed compared to heat flows calculated from steady-state resistances, q_{ss}. Calculated heat flows, q_{ss}, were determined using Eq. (3). Values of q_{ss} change dramatically during the first portion of a transient test because of changes in oudoor surface temperatures.

Table 18 lists time required to reach 99.5, 95, 90, and 63% of the final steady-state heat flow achieved during the transient tests for Walls P1, P2, and P3. Table 18(a) lists values measured by the calibrated hot box. Table 18(b) lists values predicted using steady-state analysis.

Performance of the three walls was similar. Steady-state analysis predicted for all three walls that 63% of the final heat flow would be reached

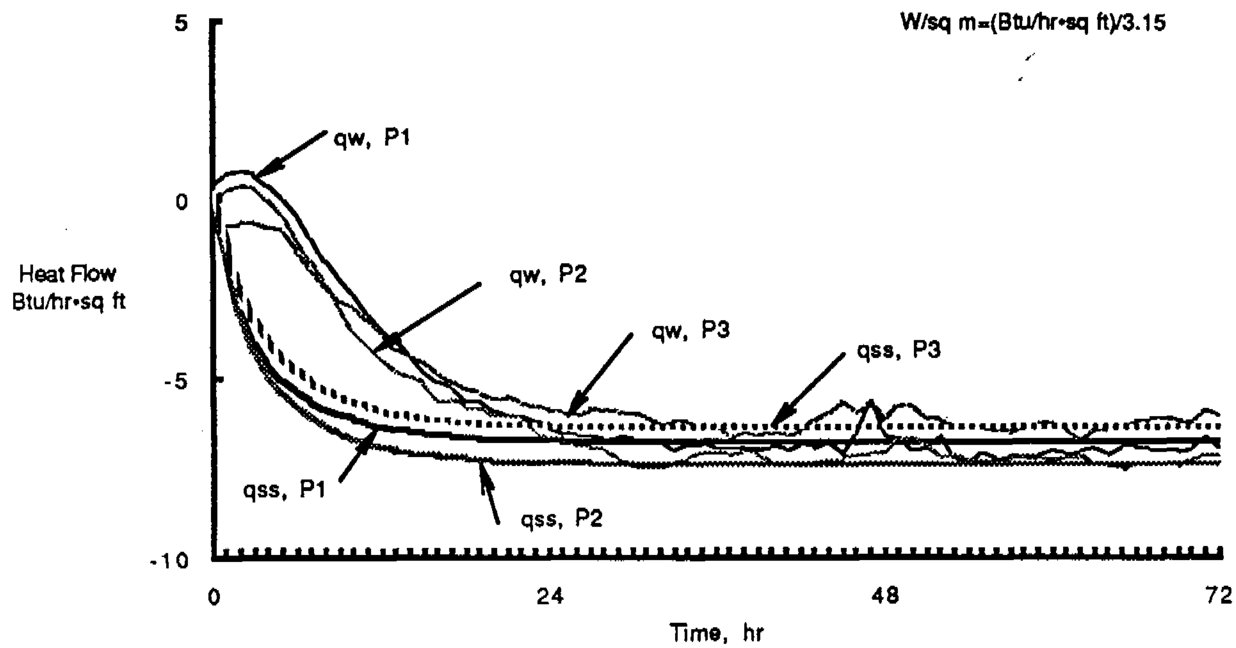


Fig. 50 Heat Flow for Transient Tests on Walls P1, P2, and P3

TABLE 18 - SUMMARY OF TRANSIENT TEST RESULTS FOR WALLS P1, P2 AND P3

(a) Results Measured by the Calibrated Hot Box

Heat Flow	Wall P1		Wall P2		Wall P3	
	q_w, Btu/hr•ft^2 (W/m^2)	Time to Reach q_w, hr	q_w, Btu/hr•ft^2 (W/m^2)	Time to Reach q_w, hr	q_w, Btu/hr•ft^2 (W/m^2)	Time to Reach q_w, hr
99.5% of Final Heat Flow	-6.96 (-21.9)	36	-7.40 (-23.4)	30	-6.35 (-20.1)	36
95% of Final Heat Flow	-6.64 (-21.0)	27	-7.07 (-22.3)	28	-6.07 (-19.2)	31
90% of Final Heat Flow	-6.29 (-19.8)	24	-6.70 (-21.1)	24	-5.75 (-18.1)	23
63% of Final Heat Flow	-4.40 (-13.9)	14	-4.69 (-14.8)	15	-4.03 (-12.7)	13

(b) Results Calculated by Steady-State Analysis

Heat Flow	Wall P1		Wall P2		Wall P3	
	q_{ss}, Btu/hr•ft^2 (W/m^2)	Time to Reach q_{ss}, hr	q_{ss}, Btu/hr•ft^2 (W/m^2)	Time to Reach q_{ss}, hr	q_{ss}, Btu/hr•ft^2 (W/m^2)	Time to Reach q_{ss}, hr
99.5% of Final Heat Flow	-6.76 (-21.3)	24	-7.37 (-23.3)	26	-6.38 (-20.1)	24
95% of Final Heat Flow	-6.46 (-20.4)	13	-7.04 (-22.2)	13	-6.09 (-19.2)	15
90% of Final Heat Flow	-6.12 (-19.3)	10	-6.67 (-21.0)	10	-5.77 (-18.2)	10
63% of Final Heat Flow	-4.28 (-13.5)	4	-4.67 (-14.7)	4	-4.04 (-12.7)	4

after 4 hours. Calibrated hot box test results show that 63% of the final heat flow is reached after 14 hours for Wall P1, 15 hours for Wall P2, and 13 hours for Wall P3. The times required for Walls P1, P2, and P3, respectively, to reach 63% of the final heat flow were 3.5, 3.75, and 3.25 greater than steady-state predictions. Similarly, the times required for Walls P1, P2, and P3 to reach 90% of the final heat flow were 2.3 to 2.4 times greater than steady-state predictions.

As shown by the data, massive walls, such as Walls P1, P2, and P3, "damp out" effects of a sudden change in temperature.

SUMMARY AND CONCLUSIONS

This report presents results of an experimental investigation of heat transmission characteristics of three concrete-insulation sandwich panel walls. Wall P1 contained no ties connecting layers. Layers of Wall P2 were connected using stainless steel ties and torsion anchors. Layers of Wall P3 were connected using high-tensile fiberglass-composite ties. Walls were tested for steady-state and dynamic temperature conditions using a calibrated hot box.

The following conclusions are based on results obtained in this investigation.

Steady-State Temperature Conditions

1. Measured thermal conductivity of extruded polystyrene used in construction of Walls P1 and P2 was 0.22 Btu•in/hr•ft^2•°F (0.032 W/m•K) for a specimen mean temperature of 75°F (24°C). Measured thermal conductivity of extruded polystyrene used in construction of Wall P3 was 0.21 Btu•in/hr•ft^2•°F (0.030 W/m•K) for a specimen mean temperature of 75°F (24°C). Values were interpolated from steady-state guarded hot plate test results.

2. Total thermal resistances, R_T, for Walls P1, P2, and P3 were 9.7, 9.1, and 10.9 hr•ft^2•°F/Btu (1.72, 1.60, and 1.91 m^2•K/W). Resistances are for a wall mean temperature of 75°F (24°C) and were interpolated from steady-state calibrated hot box test results. Values include standard surface film resistances.

3. A comparison of steady-state calibrated hot box test results from Walls P1 and P2 shows that stainless steel connectors reduced total wall resistance by 7%.

4. A comparison of steady-state calibrated hot box test results from Walls P1 and P3 shows that use of high-tensile fiberglass-composite ties did not reduce total wall thermal resistance.

5. The isothermal planes method of calculating total wall thermal resistance predicted performance of Wall P2. A 5% decrease in total resistance for Wall P2, compared to Wall P1, was predicted. A 7% decrease was measured.

6. Comparing results from Walls P1 and P2 shows that the three-dimensional analysis performed by Mr. K. W. Childs, ORNL, accurately predicted thermal performance of torsion anchors. A 6% decrease in total thermal resistance for Wall P2, compared to Wall P1, was predicted. A 7% decrease was measured.

7. Design total thermal resistances for Walls P1, P2, and P3 were within 6% of calibrated hot box test results.

8. Wall surface temperatures adjacent to stainless steel ties are not significantly different from surface temperatures between ties.

Dynamic Temperature Conditions

1. As indicated by thermal lag, heat storage capacities of insulated concrete sandwich panel walls delayed heat flow through specimens. Average thermal lag values ranged from 5 to 6 hours for Walls P1, P2, and P3.

2. As indicated by the damping effect, heat storage capacities of the walls reduced peak heat flows through specimens for dynamic temperature conditions when compared to steady-state predictions. Reduction in amplitude values ranged from 34 to 46% for Wall P1, 42 to 48% for Wall P2, and 44 to 69% for Wall P3.

3. For the three diurnal temperature cycles applied to Walls P1, P2 and P3, total heat flow for a 24-hr period were less than would be predicted by steady-state analysis. Total measured heat flows for the 24-hour cycles ranged from 43 to 81% of those predicted by steady-state analysis for the three walls. These reductions in total heat flow are attributed to wall storage capacity and reversals in heat flow.

Transient Temperature Conditions

1. Transient test results indicated that heat storage capacities of Walls P1, P2, and P3 delay heat flow through the specimens. The amount of time required for Walls P1, P2, and P3 to reach 63% of a final heat flow were approximately 3-1/2 times greater than predicted by steady-state calculations based on measured surface temperatures.

Limitations

Calibrated hot box test results presented in this report are limited to the test specimens and temperature cycles used in this investigation. It is anticipated that results would differ for walls with different insulation thicknesses, for tie systems with different cross-sectional areas, or when insulation is not packed tightly around ties as it was in this test program.

Results described in this report provide data on thermal response of concrete-insulation sandwich panel walls subjected to steady-state and diurnal sol-air temperature cycles. A complete analysis of building energy requirements must include consideration of the entire building envelope, building orientation, building operation, and yearly weather conditions. Data developed in this experimental program provide a quantitative basis for modeling the building envelope, which is part of the overall energy analysis process.

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Mr. Ken Childs, ORNL, performed the three-dimensional analysis of a torsion anchor used in Wall P2.

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Mr. S. C. Larson, Structural Engineer, Analytical Design Section of the Structural Development Department, monitored calibrated hot box tests of Walls P1, P2, and P3, and performed analysis of Wall P1. Mr. D. C. Discher helped with analysis of Walls P2 and P3, and with the preparation of tables and figures for this report.

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Ms. E. M. Ringquist provided editorial assistance. The manuscript was typed by personnel of the Construction Technology Laboratories' (CTL) Word Processing Department. Mr. C. Steer and Mr. M. Whiteside drafted the figures.

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APPENDIX A - CALIBRATED HOT BOX INSTRUMENTATION AND CALIBRATION

Calibrated hot box tests were performed according to ASTM Designation: C976, "Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box."(11)

Instrumentation

Instrumentation was designed to monitor temperatures inside and outside the indoor chamber, air and surface temperatures on both sides of the test wall, internal wall temperatures, and heating energy input to the indoor chamber. Additional measurements monitor indoor chamber cooling system performance. Basically, the instrumentation provides a means of monitoring the energy required to maintain constant temperature in the indoor chamber while temperatures in the outdoor chamber held constant or are varied. This energy, when corrected for thermal losses, provides a measure of heat flow through the test wall.

Thermocouples corresponding to ASTM Designation: E230, "Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples,"(11) 20 gauge, Type T, were used to measure temperatures in the air space of each chamber. Thermocouples were uniformly distributed on a 20-3/5-in. (525-mm) square grid over the wall area. Thermocouples were located approximately 3 in. (75 mm) from the face of the test wall.

Thermocouples used to measure air and test specimen temperatures are described in the "Instrumentation" portion of the "Test Specimens" section of this report.

Laboratory and interior surface temperatures of the indoor chamber sides were measured. These temperatures provided data for evaluating heat transfer between the chamber and the laboratory. Temperature data were supplemented with heat flux transducer measurements on chamber surfaces.

A digital humidity and temperature measurement system was used to measure relative humidity and temperature in air streams on each side of the test wall. Probes were located in the air streams approximately at the specimen mid-point.

A watt-hour transducer was used to measure cumulative electrical energy input to the indoor chamber.

Measurements were monitored with a programmable digital data acquisition system capable of sampling and recording up to 124 independent channels of data at preselected time intervals. The data acquisition system is interfaced with a microcomputer that is programmed to reduce and store data. Channels were scanned every two minutes. Average temperature and supplementary data were obtained from average readings for one hour. The cumulative watt-hour transducer output was scanned every hour.

Air flow rates in each chamber were measured with air flow meters located approximately at the wall geometric center. Each flow rate meter was mounted perpendicular to the air flow. Air flow is vertical on both sides of the specimen. Air velocity is uniform and averages 20 ft/min. (0.10 m/s). Data for air flow meters were monitored periodically and were not part of the automated data acquisition apparatus. Reference 13 gives more information on instrumentation of CTL's calibrated hot box.

Calibration Procedure

Heat flow through a test wall is determined from measurements of the amount of energy input to the indoor chamber to maintain a constant temperature. The measured energy input must be adjusted for heat losses. Figure A1 shows sources of heat losses and gains by the indoor chamber where:

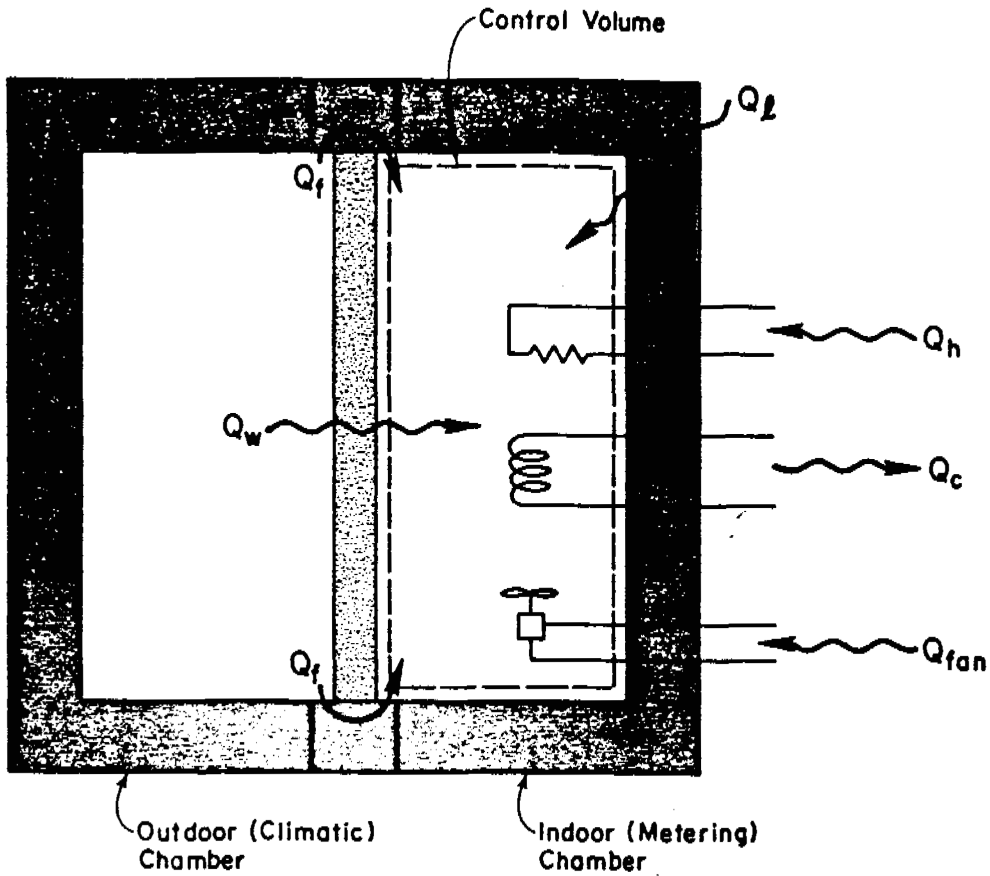

Fig. A1 Indoor (Metering) Chamber Energy Balance

Q_w = heat transfer through test wall

Q_c = heat removed by indoor chamber cooling

Q_h = heat supplied by indoor electrical resistance heaters

Q_{fan} = heat supplied by indoor circulation fan

Q_ℓ = heat loss/gain from laboratory

Q_f = heat loss/gain from flanking path around specimen

The directions of arrows in Fig. A1 indicate positive heat flow.

Since net energy into the control volume of the indoor chamber equals zero, heat transfer through the test wall can be expressed by the following energy balance equation:

$$Q_w = Q_c - Q_h - Q_{fan} - Q_\ell - Q_f \qquad \text{(A1)}$$

The need for cooling in the indoor chamber results from requirements for dynamic tests. In cases where outdoor temperatures exceed indoor temperatures, cooling capacity is required to maintain indoor temperature control.

Indoor chamber cooling equipment operates continuously and is designed to remove heat at a constant rate. Control of indoor chamber temperature is obtained by varying the amount of input heat required to balance the amount of heat removed by the refrigeration system, the amount of heat that flows through the test specimen, and the amount of heat lost to laboratory space.

Steady-state calibrated hot box tests on two "standard" calibration specimens were used to refine calculations of heat removed by indoor chamber cooling, Q_c, and flanking losses, Q_f. The first calibration specimen, S1, has a relatively low thermal resistance of 6.8 hr•ft^2•°F/Btu (1.2 m^2•K/W). It consists of 1-3/8-in. (35-mm) thick fiberglass and was specially fabricated to insure uniformity.

The second calibration wall, S2, has a relatively high thermal resistance of 16.8 hr•ft^2•°F/Btu (3.0 m^2•K/W). Material for specimen S2 was selected as part of the ASTM Committee C16 Hot Box Round Robin program. It consists of expanded polystyrene board that is specially produced and cut to insure uniformity. Board faces are coated to provide surfaces suitable for attachment of instrumentation.

Heat removed by indoor chamber cooling, Q_c, was calculated from refrigerant enthalpy and mass flow rate, assuming an ideal basic vapor compression refrigeration cycle. Results from steady-state calibrated hot box tests on the two "standard" calibration specimens were used to adjust for inefficiencies in the actual refrigeration cycle.

Losses from the indoor chamber to the laboratory, Q_ℓ, were calculated from thermal properties of component materials making up walls and ceilings of the indoor chamber and temperature conditions on the inner and outer surfaces of the indoor chamber. Heat flux transducers mounted on the inside surface of the indoor chamber were used to check calculations. Indoor chamber air and laboratory air temperatures were generally maintained at the same nominal value, 72°F (22°C), to minimize laboratory losses. Thus, the value of Q_ℓ is small relative to other terms of the energy balance equation.

A watt-hour transducer was used to measure heat supplied to the indoor chamber by heaters and a fan, $Q_h + Q_{fan}$.

Heat loss or gain from flanking around the test specimen, Q_f, was determined from steady-state tests of the "standard" calibration walls. Since thermal conductance of each standard calibration wall is known, Q_w for a given steady-state test can be calculated using the following equation:

$$Q_w = A \cdot C \cdot (t_2 - t_1) \qquad \text{(A2)}$$

where

Q_w = heat transfer through test wall, Btu/hr (W•hr/hr)

A = area of wall surface normal to heat flow, ft^2 (m^2)

C = average thermal conductance, Btu/hr•ft^2•°F (W/m^2•K)

t_2 = average temperature of outside wall surface, °F (°C)

t_1 = average temperature of inside wall surface, °F (°C)

Thus, Q_f was determined from Eq. (A1) using calculated values of Q_w, Q_c, and Q_ℓ, and measured values of Q_h and Q_{fan}.

For both standard calibration walls, values of Q_f were observed to follow the empirical relationship:

$$Q_f = 0.802\ (t_2 - t_1) \quad \text{U.S. units} \tag{A3}$$

$$Q_f = 0.131\ (t_2 - t_1) \quad \text{(SI units)}$$

where

Q_f = heat loss or gain from flanking around test specimen, Btu/hr (W•hr/hr)

t_2 = average temperature of outside wall surface, °F (°C)

t_1 = average temperature of inside wall surface, °F (°C)

Since Q_f is the residual from Eq. (A1), it may include other undetermined losses from the indoor chamber.

A round robin to include both calibrated (ASTM Designation: C976) and guarded (ASTM Designation: C236) hot boxes has been organized under ASTM Subcommittee C16.30 which, when completed, will provide information on the precision of the calibrated hot box test method.

APPENDIX B - RESULTS OF A THREE-DIMENSIONAL ANALYSIS OF A TORSION ANCHOR

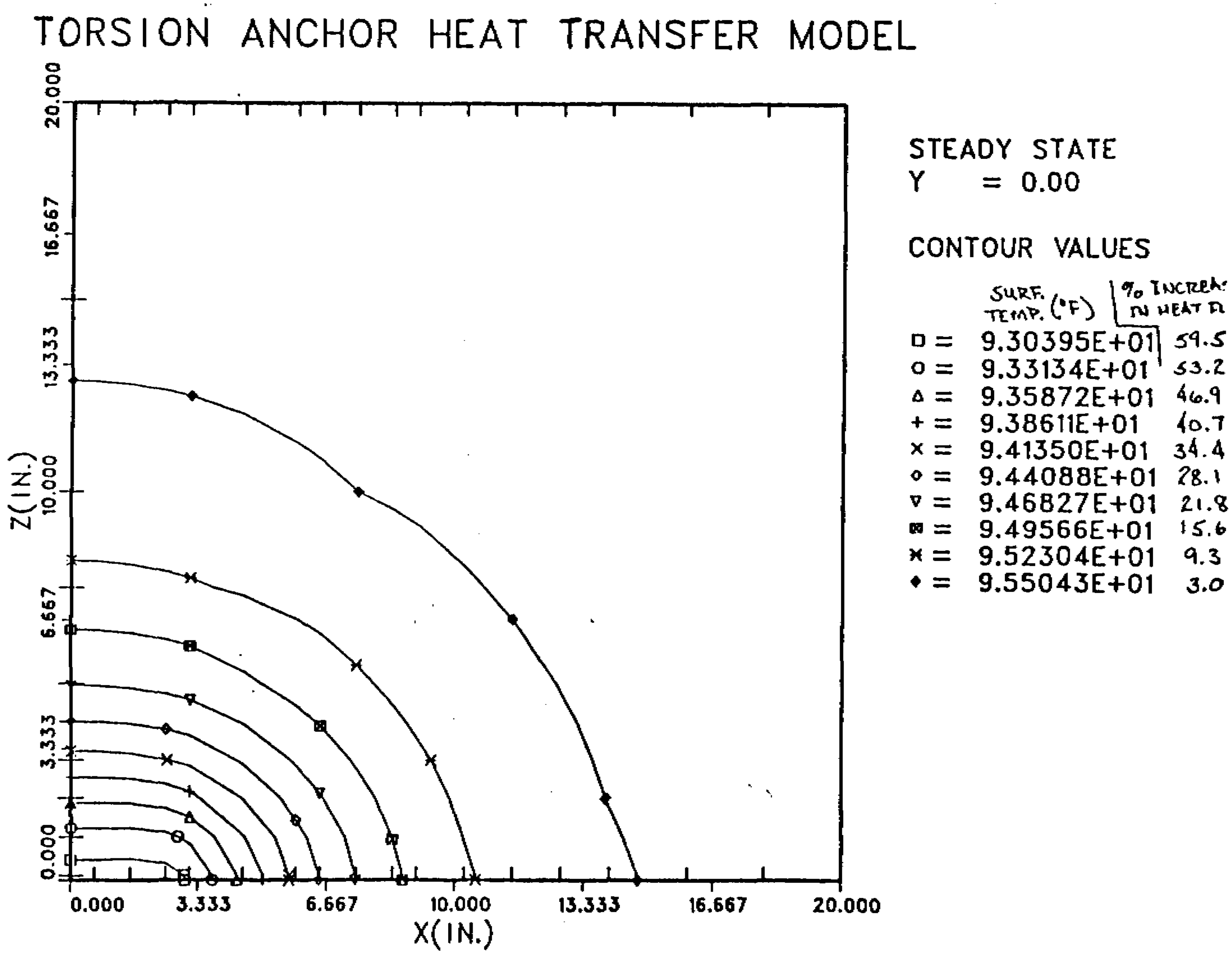

Fig. B1 Location of Isotherms on Warm Side of Wall

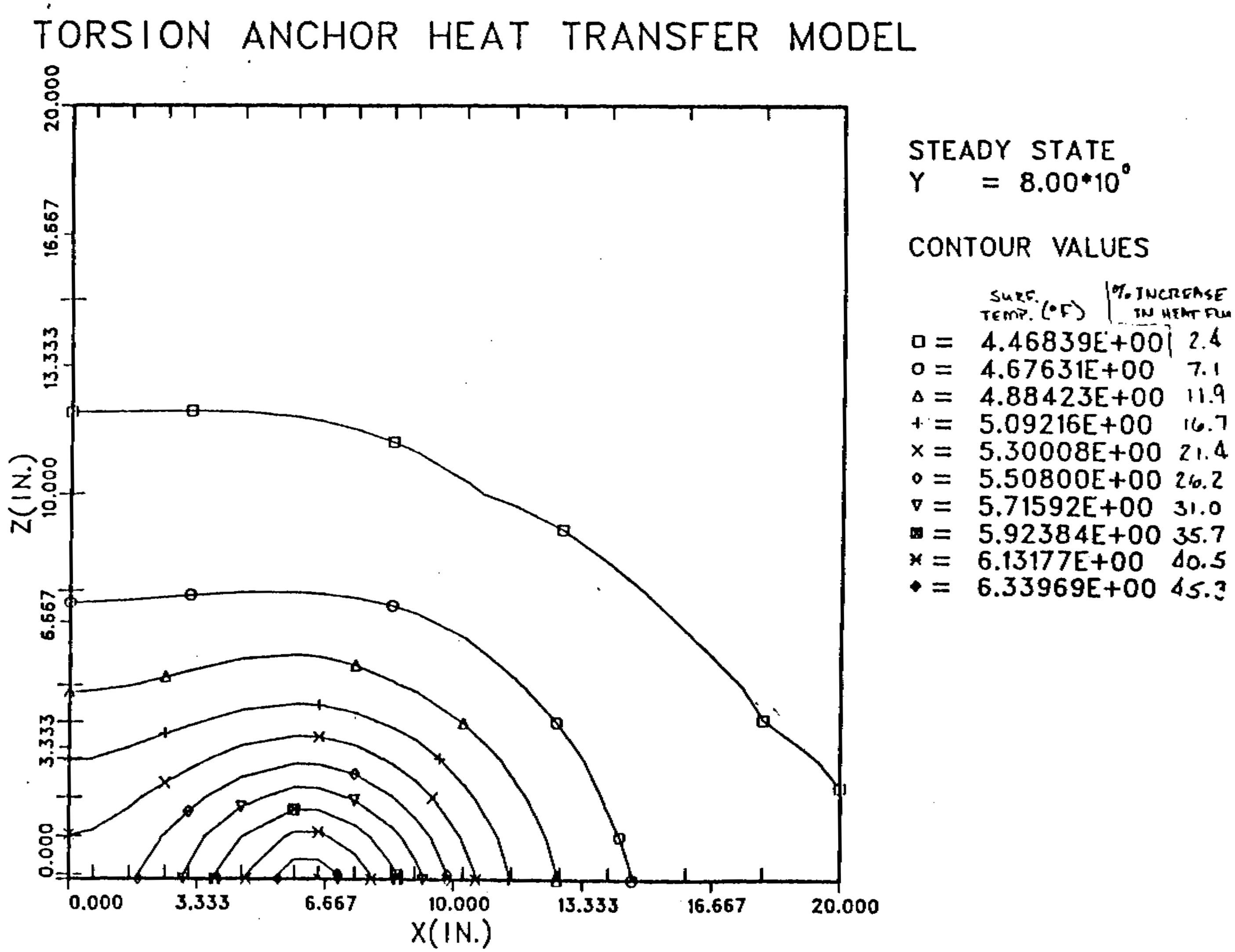

Fig. B2 Location of Isotherms on Cold Side of Wall

APPENDIX C - DYNAMIC TEMPERATURE TEST RESULTS

Measured temperatures, temperature differentials, and heat flow for dynamic temperature cycles for each wall are presented in Figs. C1 through C27 and listed in Tables C1 through C18. Data for Wall P1 is followed by data for Wall P2 and Wall P3. For each wall, data for the NBS Test Cycle is presented first, followed by results for the NBS+10 Test Cycle and the NBS-10 Test Cycle.

Tables C1 through C18 denoted (a) and (b), respectively, list hourly test data in U.S. and SI units.

Symbols used in these figures and tables are described in detail in the "Test Results" portion of the "Dynamic Calibrated Hot Box Tests" section of this report.

Measured temperatures are listed in Tables C1, C3, and C5 for Wall P1; Tables C7, C9, and C11 for Wall P2; and Tables C13, C15, and C17 for Wall P3. Values are illustrated in Figs. C1, C4, and C7 for Wall P1; Figs. C10, C13, and C16 for Wall P2; and Figs. C19, C22, and C25 for Wall P3.

Air-to-air (t_o-t_i), surface-to-surface (t_2-t_1), and surface-to-air (t_o-t_2, t_1-t_i) temperature differentials are illustrated in Figs. C2, C5, and C8 for Wall P1; Figs. C11, C14, and C17 for Wall P2; and Figs. C20, C23, and C26 for Wall P3.

Measured and calculated heat flows are listed in Tables C2, C4, and C6 for Wall P1; Tables C8, C10, and C12 for Wall P2; and Tables C14, C16, and C18 for Wall P3. Values are illustrated in Figs. C3, C6, and C9 for Wall P1; Figs. C12, C15, and C18 for Wall P2; and Figs. C21, C24, and C27 for Wall P3.

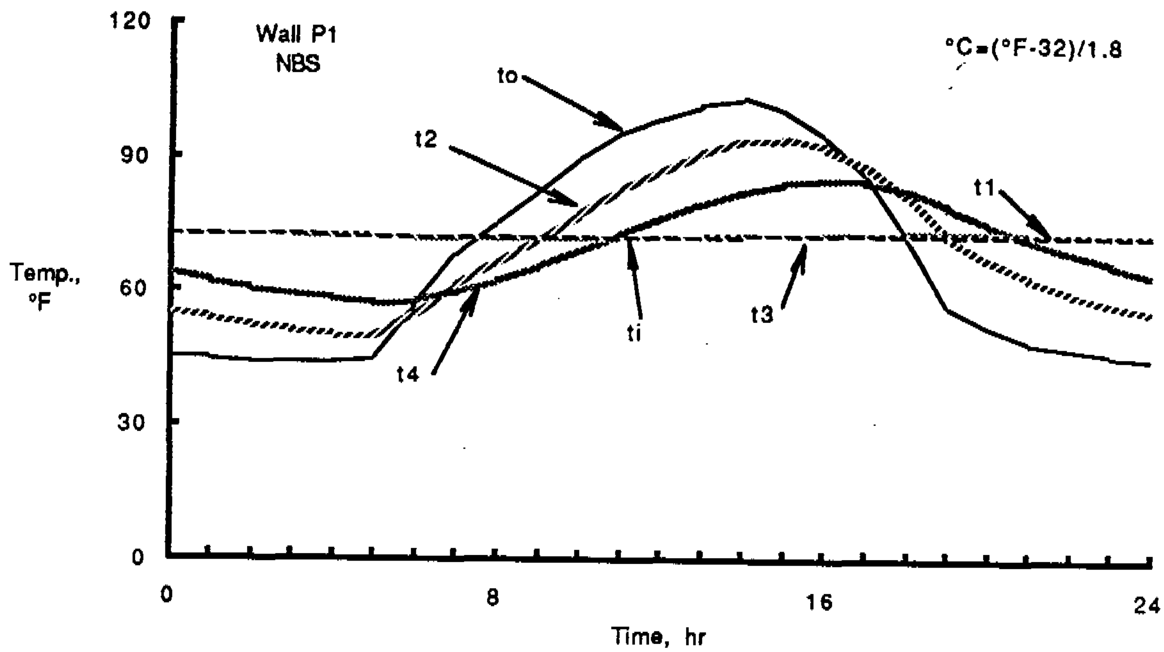

Fig. C1 Measured Temperatures for NBS Test Cycle Applied to Wall P1

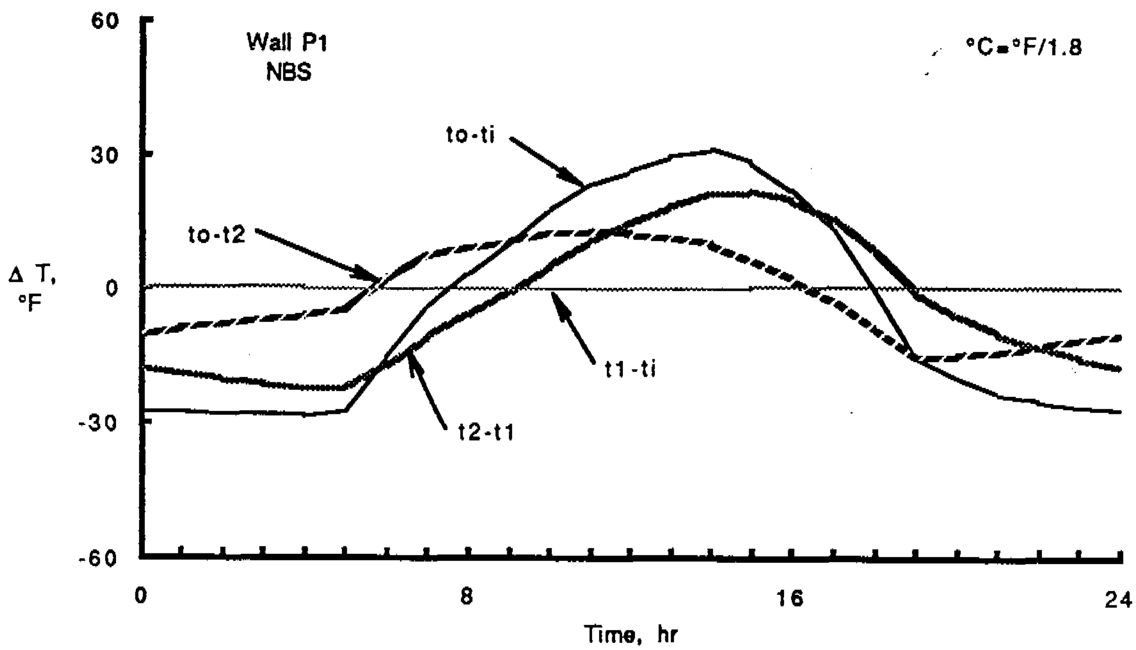

Fig. C2 Temperature Differentials for NBS Test Cycle Applied to Wall P1

TABLE C1(a) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	44.6	53.5	62.0	72.6	72.7	72.3
2	44.0	51.9	60.4	72.4	72.5	72.3
3	44.3	51.0	59.1	72.2	72.7	72.3
4	43.9	50.0	58.0	72.0	72.3	72.2
5	45.0	49.7	57.1	71.8	72.2	72.2
6	57.0	54.9	57.8	71.7	72.1	72.2
7	68.2	61.1	59.8	71.6	72.1	72.2
8	75.3	66.2	62.5	71.6	72.0	72.2
9	81.9	71.3	65.5	71.6	72.0	72.1
10	89.5	77.2	68.9	71.7	72.0	72.1
11	95.1	82.5	72.6	71.8	72.1	72.2
12	98.4	86.6	76.0	72.0	72.2	72.2
13	101.7	90.6	79.3	72.3	72.3	72.2
14	103.2	93.6	82.1	72.5	72.5	72.3
15	100.3	94.0	84.1	72.7	72.6	72.3
16	94.3	92.2	84.9	73.0	72.8	72.3
17	85.7	88.2	84.4	73.2	72.9	72.4
18	72.2	81.3	82.5	73.4	73.0	72.4
19	56.9	72.2	78.9	73.4	73.0	79.3
20	52.5	67.2	75.2	73.4	73.1	72.4
21	48.7	62.9	71.7	73.2	73.0	72.4
22	47.4	59.9	68.7	73.1	73.0	72.4
23	45.8	57.2	66.0	72.9	72.9	72.4
24	45.1	55.1	63.8	72.7	72.8	72.3
Mean	68.4	69.6	70.1	72.4	72.5	72.6

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 31%
Outdoor Chamber - 24%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 73°F (23°C)

TABLE C1(b) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	tl Indoor Air
1	7.0	11.9	16.7	22.5	22.6	22.4
2	6.7	11.1	15.8	22.4	22.5	22.4
3	6.8	10.6	15.0	22.3	22.6	22.4
4	6.6	10.0	14.5	22.2	22.4	22.3
5	7.2	9.8	14.0	22.1	22.3	22.3
6	13.9	12.7	14.3	22.0	22.3	22.3
7	20.1	16.1	15.4	22.0	22.3	22.3
8	24.1	19.0	16.9	22.0	22.2	22.3
9	27.7	21.8	18.6	22.0	22.2	22.3
10	32.0	25.1	20.5	22.1	22.2	22.3
11	35.1	28.1	22.6	22.1	22.3	22.3
12	36.9	30.4	24.5	22.2	22.3	22.3
13	38.7	32.6	26.3	22.4	22.4	22.4
14	39.6	34.2	27.8	22.5	22.5	22.4
15	38.0	34.5	28.9	22.6	22.6	22.4
16	34.6	33.4	29.4	22.8	22.7	22.4
17	29.8	31.2	29.1	22.9	22.7	22.4
18	22.3	27.4	28.1	23.0	22.8	22.5
19	13.9	22.3	26.1	23.0	22.8	26.3
20	11.4	19.6	24.0	23.0	22.8	22.5
21	9.3	17.2	22.0	22.9	22.8	22.5
22	8.5	15.5	20.4	22.8	22.8	22.4
23	7.7	14.0	18.9	22.7	22.7	22.4
24	7.3	12.8	17.7	22.6	22.7	22.4
Mean	20.2	20.9	21.1	22.5	22.5	22.5

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 31%
Outdoor Chamber - 24%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 73°F (23°C)

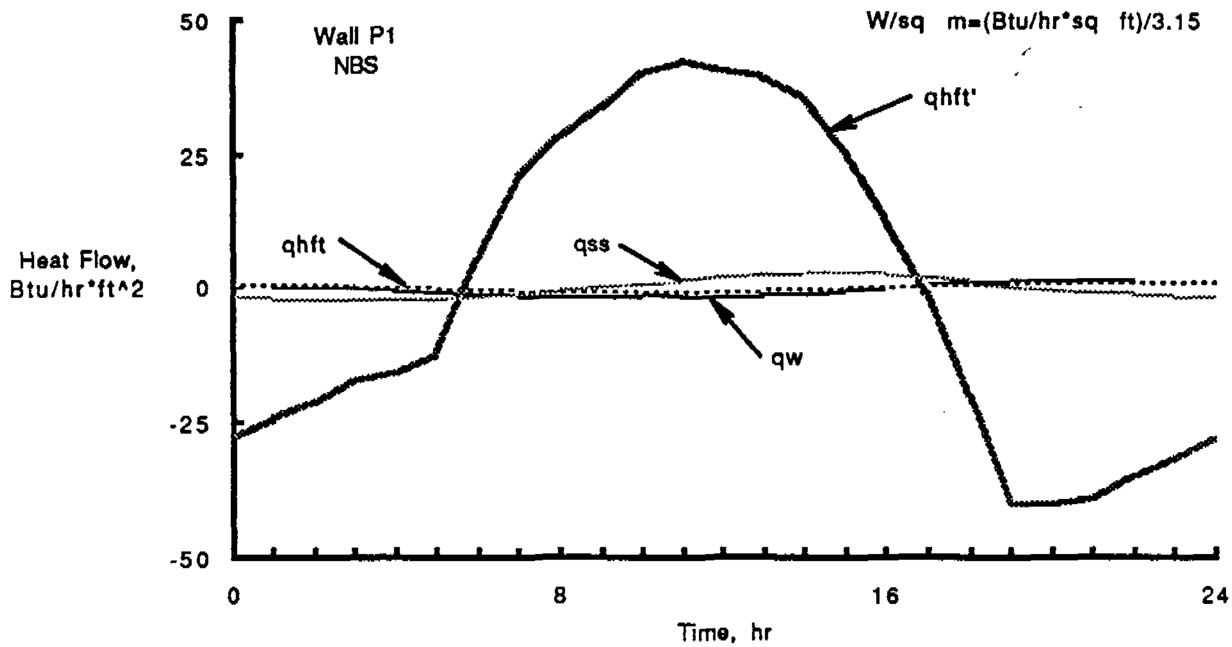

Fig. C3 Heat Flow for NBS Test Cycle Applied to Wall P1

TABLE C2(a) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	0.17	0.38	-24.16	-2.10
2	-0.23	0.19	-21.29	-2.25
3	-0.06	-0.03	-17.13	-2.36
4	-0.84	-0.26	-15.68	-2.42
5	-1.03	-0.48	-12.15	-2.45
6	-1.50	-0.69	5.50	-1.89
7	-1.71	-0.86	20.53	-1.23
8	-1.73	-0.97	27.83	-0.66
9	-1.72	-1.00	33.39	-0.08
10	-1.45	-1.05	39.96	0.59
11	-2.01	-1.00	42.20	1.21
12	-1.85	-0.87	40.21	1.69
13	-1.58	-0.70	38.99	2.15
14	-1.28	-0.48	35.16	2.51
15	-0.64	-0.22	25.22	2.54
16	-0.26	0.09	12.61	2.30
17	0.21	0.31	-1.43	1.80
18	0.90	0.54	-20.50	0.97
19	1.12	0.76	-39.89	-0.09
20	1.28	0.89	-40.14	-0.66
21	1.18	0.90	-38.97	-1.13
22	1.05	0.86	-34.71	-1.45
23	0.79	0.75	-31.52	-1.73
24	0.46	0.57	-27.63	-1.94
Mean	-0.45	-0.10	-0.15	-0.28

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 31%
Outdoor Chamber - 24%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 73°F (23°C)

TABLE C2(b) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Heat Flux, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	0.53	1.20	-76.23	-6.64
2	-0.73	0.60	-67.17	-7.10
3	-0.20	-0.09	-54.05	-7.45
4	-2.66	-0.81	-49.47	-7.63
5	-3.25	-1.50	-38.32	-7.72
6	-4.74	-2.17	17.37	-5.97
7	-5.40	-2.72	64.76	-3.87
8	-5.45	-3.06	87.79	-2.07
9	-5.42	-3.17	105.34	-0.24
10	-4.56	-3.33	126.08	1.87
11	-6.35	-3.16	133.15	3.82
12	-5.84	-2.76	126.85	5.32
13	-4.99	-2.21	123.01	6.80
14	-4.03	-1.52	110.93	7.91
15	-2.02	-0.69	79.56	8.01
16	-0.81	0.27	39.80	7.24
17	0.66	0.99	-4.52	5.69
18	2.83	1.71	-64.68	3.05
19	3.53	2.41	-125.86	-0.29
20	4.04	2.80	-126.63	-2.08
21	3.73	2.85	-122.96	-3.57
22	3.33	2.73	-109.52	-4.57
23	2.50	2.35	-99.44	-5.47
24	1.44	1.81	-87.16	-6.12
Mean	-1.41	-0.31	-0.47	-0.88

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 31%
Outdoor Chamber - 24%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 73°F (23°C)

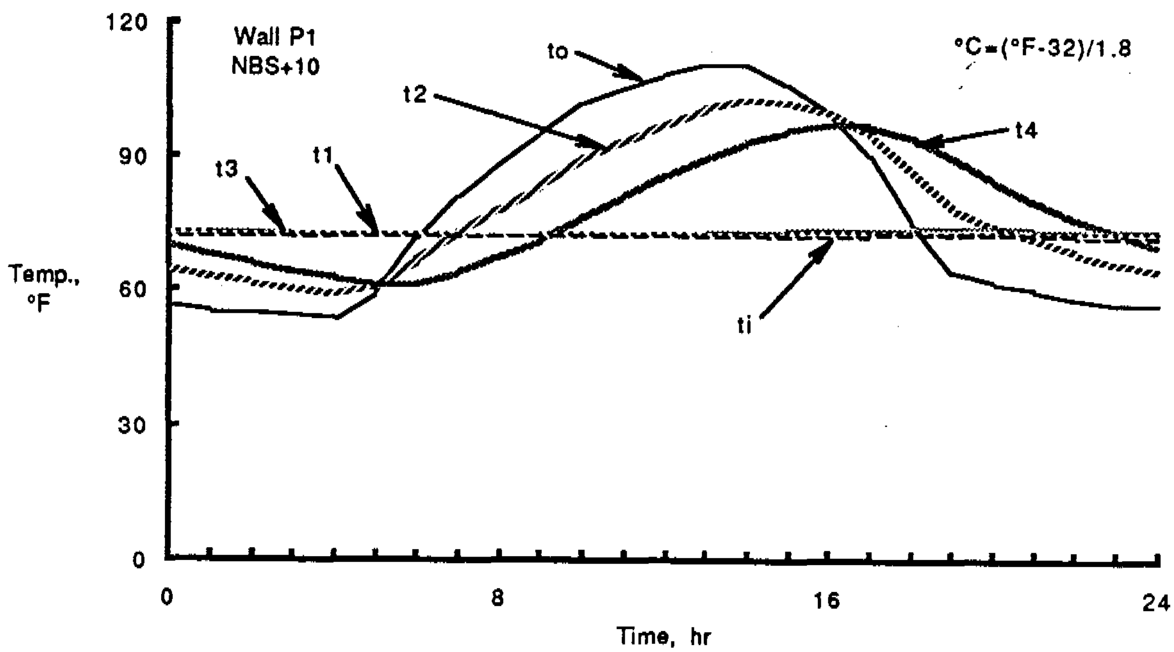

Fig. C4 Measured Temperatures for NBS+10 Test Cycle Applied to Wall P1

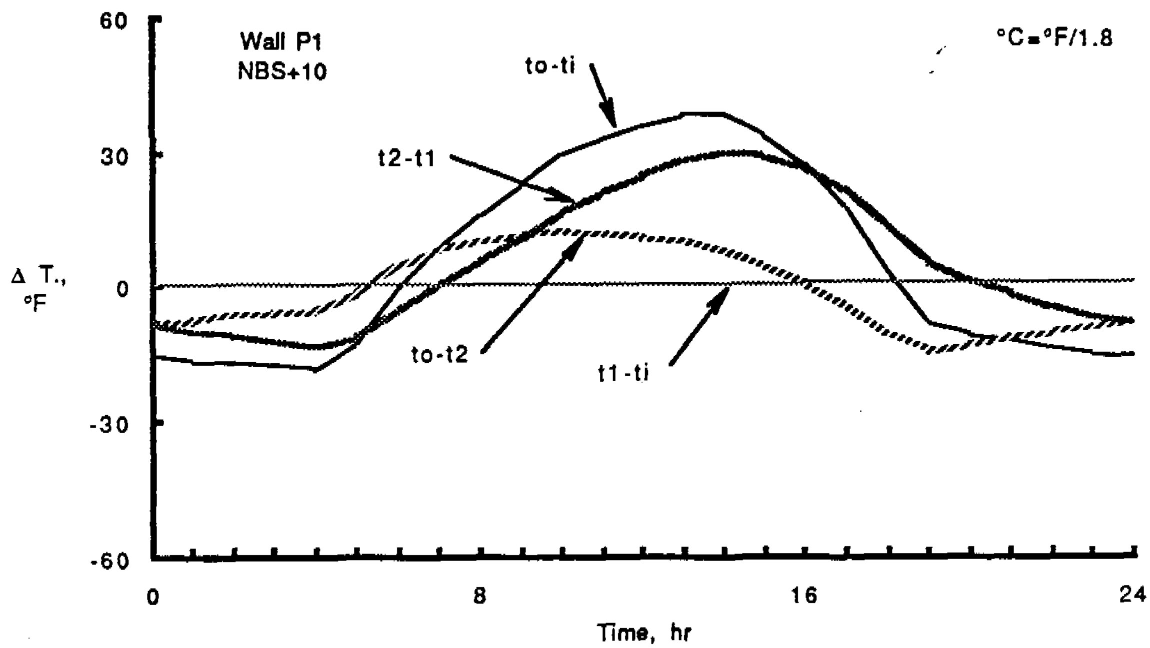

Fig. C5 Temperature Differentials for NBS+10 Test Cycle Applied to Wall P1

TABLE C3(a) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	55.3	62.7	67.7	73.1	72.8	72.2
2	55.3	61.6	65.6	73.0	72.7	72.1
3	54.4	60.3	63.9	72.8	72.6	72.1
4	53.6	59.1	62.4	72.6	72.5	72.1
5	59.3	60.9	61.2	72.5	72.4	72.1
6	71.4	66.8	61.4	72.3	72.3	72.0
7	80.8	72.6	64.1	72.2	72.3	72.0
8	88.0	77.9	67.6	72.3	72.3	72.0
9	94.8	83.2	71.4	72.3	72.3	72.0
10	101.5	89.0	76.1	72.4	72.3	72.0
11	104.9	93.3	81.0	72.6	72.4	72.0
12	107.9	97.2	85.4	72.8	72.5	72.1
13	110.6	100.7	89.5	73.0	72.6	72.1
14	110.3	102.6	93.1	73.3	72.8	72.1
15	105.8	101.8	95.8	73.5	72.9	72.2
16	99.6	99.4	96.9	73.7	73.0	72.2
17	89.9	94.5	96.5	73.9	73.2	72.3
18	75.4	86.4	94.2	74.0	73.3	72.4
19	64.1	78.5	89.6	74.1	73.3	72.4
20	61.6	74.5	84.5	74.0	73.3	72.3
21	60.0	71.5	80.0	73.8	73.2	72.3
22	58.3	68.6	76.0	73.6	73.1	72.3
23	57.1	66.3	72.9	73.5	73.0	72.2
24	56.6	64.6	70.1	73.3	72.9	72.2
Mean	78.2	78.9	77.8	73.1	72.8	72.2

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 33%
Outdoor Chamber - 18%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 70°F (21°C)

TABLE C3(b) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	12.9	17.0	19.8	22.8	22.7	22.3
2	12.9	16.4	18.6	22.8	22.6	22.3
3	12.5	15.7	17.7	22.7	22.6	22.3
4	12.0	15.0	16.9	22.6	22.5	22.3
5	15.1	16.1	16.2	22.5	22.5	22.3
6	21.9	19.4	16.4	22.4	22.4	22.2
7	27.1	22.5	17.8	22.4	22.4	22.2
8	31.1	25.5	19.8	22.4	22.4	22.2
9	34.9	28.4	21.9	22.4	22.4	22.2
10	38.6	31.7	24.5	22.5	22.4	22.2
11	40.5	34.0	27.2	22.5	22.4	22.2
12	42.2	36.2	29.7	22.7	22.5	22.3
13	43.7	38.2	31.9	22.8	22.6	22.3
14	43.5	39.2	34.0	22.9	22.6	22.3
15	41.0	38.8	35.4	23.1	22.7	22.3
16	37.6	37.4	36.1	23.2	22.8	22.4
17	32.2	34.7	35.8	23.3	22.9	22.4
18	24.1	30.2	34.5	23.3	22.9	22.4
19	17.8	25.8	32.0	23.4	22.9	22.4
20	16.4	23.6	29.2	23.3	22.9	22.4
21	15.6	21.9	26.7	23.2	22.9	22.4
22	14.6	20.4	24.4	23.1	22.9	22.4
23	14.0	19.0	22.7	23.0	22.8	22.4
24	13.7	18.1	21.1	22.9	22.7	22.3
Mean	25.7	26.1	25.4	22.8	22.6	22.3

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 33%
Outdoor Chamber - 18%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 70°F (21°C)

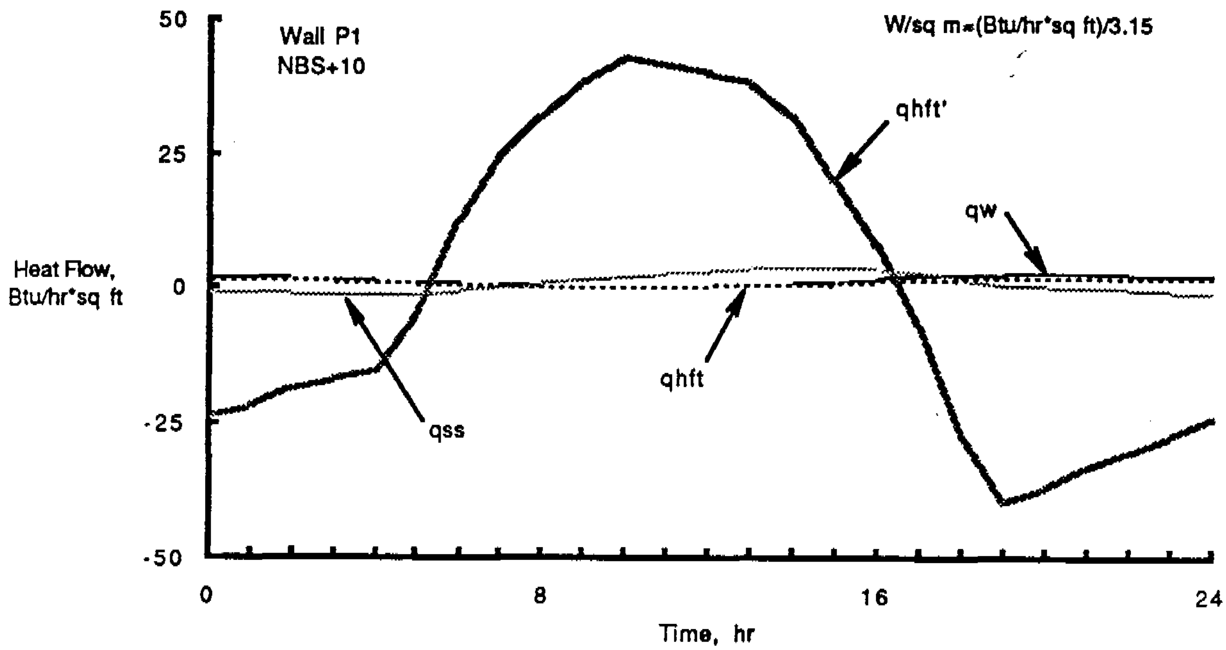

Fig. C6 Heat Flow for NBS+10 Test Cycle Applied to Wall P1

TABLE C4(a) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	1.69	1.33	-21.92	-1.13
2	1.33	1.10	-18.48	-1.24
3	1.11	0.87	-16.90	-1.37
4	0.89	0.64	-15.51	-1.49
5	0.71	0.43	-5.36	-1.28
6	0.39	0.26	12.52	-0.62
7	0.25	0.14	24.45	0.03
8	0.06	0.00	31.77	0.65
9	-0.19	-0.03	37.98	1.26
10	-0.09	-0.01	42.37	1.96
11	-0.10	0.07	40.99	2.48
12	0.19	0.19	39.28	2.95
13	0.51	0.34	37.73	3.38
14	0.81	0.58	31.56	3.60
15	0.87	0.87	19.66	3.48
16	1.60	1.12	7.71	3.16
17	2.13	1.36	-7.13	2.54
18	2.42	1.61	-27.23	1.54
19	2.81	1.80	-39.51	0.60
20	2.82	1.91	-36.92	0.14
21	2.72	1.91	-33.06	-0.20
22	2.45	1.82	-30.20	-0.51
23	2.20	1.69	-27.29	-0.76
24	1.89	1.52	-23.70	-0.94
Mean	1.23	0.90	0.95	0.76

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 33%
Outdoor Chamber - 18%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 70°F (21°C)

TABLE C4(b) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	5.32	4.18	-69.15	-3.57
2	4.20	3.48	-58.32	-3.92
3	3.50	2.74	-53.32	-4.31
4	2.80	2.03	-48.92	-4.71
5	2.22	1.36	-16.91	-4.03
6	1.23	0.81	39.50	-1.95
7	0.78	0.43	77.14	0.10
8	0.19	0.01	100.22	2.04
9	-0.60	-0.09	119.84	3.99
10	-0.29	-0.03	133.69	6.18
11	-0.33	0.22	129.33	7.81
12	0.61	0.60	123.92	9.29
13	1.61	1.07	119.03	10.66
14	2.54	1.84	99.59	11.36
15	2.75	2.74	62.02	10.98
16	5.06	3.53	24.34	9.98
17	6.71	4.29	-22.51	8.01
18	7.65	5.08	-85.92	4.86
19	8.86	5.68	-124.66	1.88
20	8.88	6.02	-116.47	0.45
21	8.58	6.01	-104.30	-0.63
22	7.72	5.74	-95.29	-1.60
23	6.94	5.34	-86.09	-2.39
24	5.95	4.80	-74.77	-2.96
Mean	3.87	2.83	3.00	2.40

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 33%
Outdoor Chamber - 18%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 70°F (21°C)

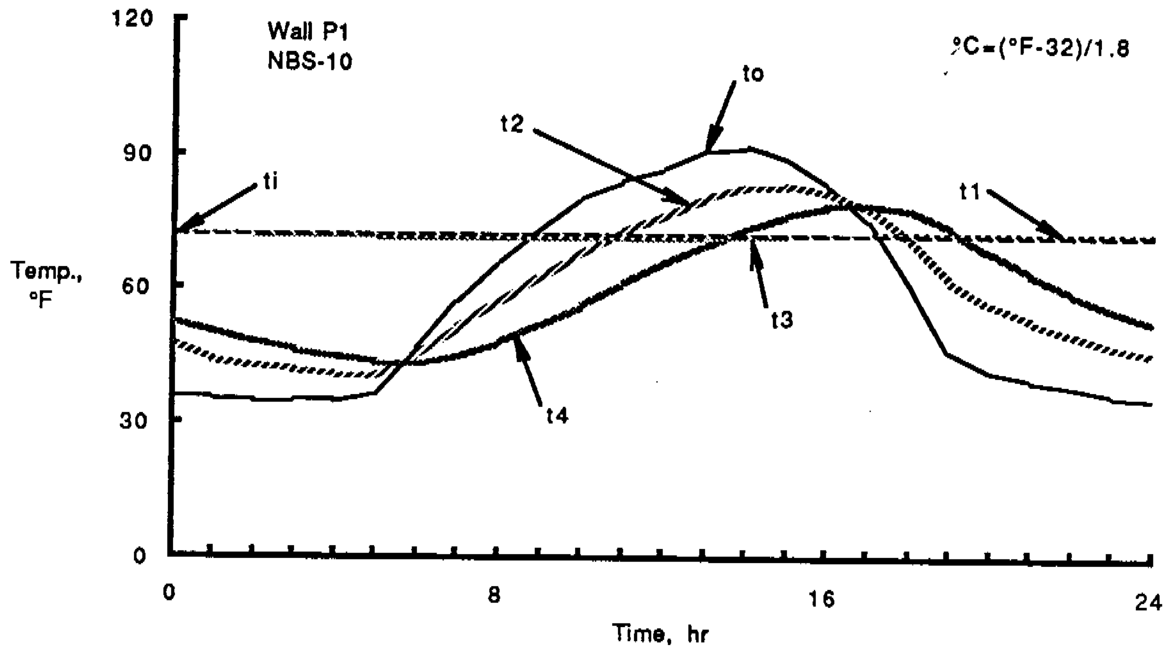

Fig. C7 Measured Temperatures for NBS-10 Test Cycle Applied to Wall P1

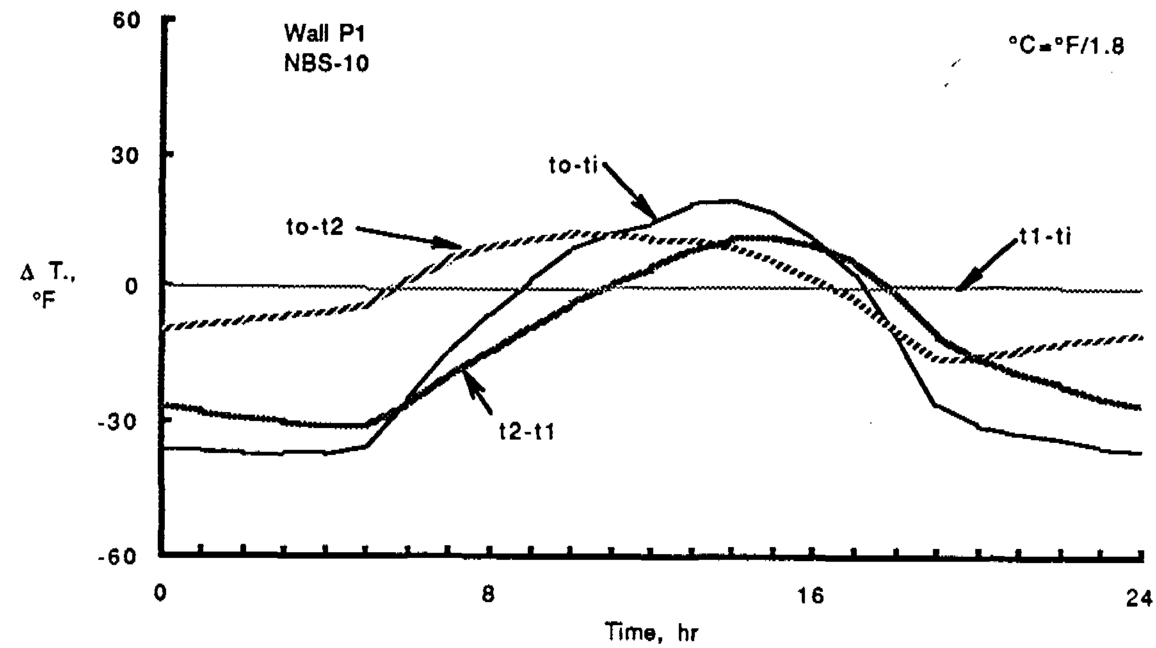

Fig. C8 Temperature Differentials for NBS-10 Test Cycle Applied to Wall P1

TABLE C5(a) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	35.3	43.9	50.2	71.8	72.1	72.1
2	34.9	42.5	48.0	71.6	72.0	72.1
3	35.0	41.6	46.1	71.4	71.9	72.0
4	34.7	40.6	44.6	71.2	71.8	72.0
5	36.5	40.7	43.4	71.0	71.7	72.0
6	46.7	45.2	43.2	70.9	71.6	72.0
7	57.4	51.2	44.9	70.8	71.5	71.9
8	66.1	57.1	48.1	70.8	71.5	71.9
9	73.4	62.6	52.2	70.8	71.5	71.9
10	80.3	68.1	56.3	70.9	71.5	71.8
11	84.1	72.5	61.1	71.0	71.6	71.9
12	86.6	76.1	65.6	71.2	71.6	71.9
13	90.9	80.3	69.7	71.4	71.8	72.0
14	91.7	82.9	73.6	71.6	71.9	72.0
15	88.9	83.3	76.7	71.9	72.1	72.1
16	83.2	81.5	78.6	72.1	72.2	72.1
17	75.4	78.1	78.9	72.3	72.3	72.2
18	61.6	71.1	77.5	72.5	72.4	72.2
19	46.2	61.9	73.6	72.5	72.5	72.2
20	41.7	56.9	68.3	72.5	72.5	72.2
21	39.8	53.3	63.4	72.4	72.5	72.2
22	38.6	50.6	59.4	72.3	72.4	72.2
23	36.6	47.7	55.8	72.1	72.3	72.1
24	35.7	45.6	52.8	71.9	72.2	72.1
Mean	58.4	59.8	59.7	71.6	72.0	72.0

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 32%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 71°F (22°C)

TABLE C5(b) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	1.8	6.6	10.1	22.1	22.3	22.3
2	1.6	5.8	8.9	22.0	22.2	22.3
3	1.7	5.3	7.9	21.9	22.2	22.2
4	1.5	4.8	7.0	21.8	22.1	22.2
5	2.5	4.9	6.4	21.7	22.0	22.2
6	8.2	7.3	6.2	21.6	22.0	22.2
7	14.1	10.7	7.1	21.6	22.0	22.2
8	18.9	13.9	8.9	21.6	21.9	22.2
9	23.0	17.0	11.2	21.6	21.9	22.1
10	26.8	20.1	13.5	21.6	21.9	22.1
11	28.9	22.5	16.2	21.7	22.0	22.1
12	30.4	24.5	18.7	21.8	22.0	22.2
13	32.7	26.8	20.9	21.9	22.1	22.2
14	33.2	28.3	23.1	22.0	22.2	22.2
15	31.6	28.5	24.9	22.2	22.3	22.3
16	28.4	27.5	25.9	22.3	22.3	22.3
17	24.1	25.6	26.0	22.4	22.4	22.3
18	16.4	21.7	25.3	22.5	22.5	22.3
19	7.9	16.6	23.1	22.5	22.5	22.3
20	5.4	13.8	20.2	22.5	22.5	22.4
21	4.3	11.9	17.5	22.4	22.5	22.3
22	3.6	10.3	15.2	22.4	22.4	22.3
23	2.6	8.7	13.2	22.3	22.4	22.3
24	2.1	7.5	11.5	22.2	22.3	22.3
Mean	14.7	15.4	15.4	22.0	22.2	22.2

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 32%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 71°F (22°C)

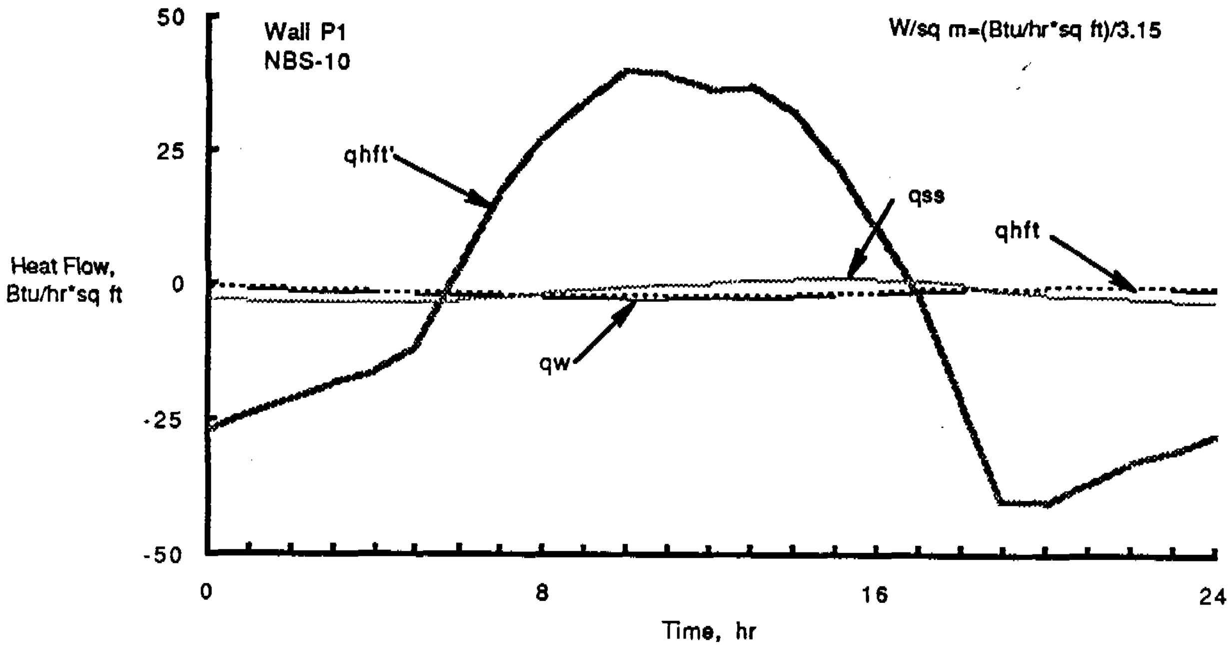

Fig. C9 Heat Flow for NBS-10 Test Cycle Applied to Wall P1

TABLE C6(a) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P1, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.94	-0.60	-24.03	-3.02
2	-1.19	-0.82	-21.08	-3.15
3	-1.35	-1.02	-17.96	-3.23
4	-1.53	-1.23	-15.96	-3.31
5	-1.80	-1.43	-11.50	-3.29
6	-1.90	-1.63	3.07	-2.83
7	-2.08	-1.81	17.09	-2.21
8	-2.21	-1.92	27.04	-1.59
9	-2.30	-1.98	33.84	-0.99
10	-2.57	-1.99	39.55	-0.38
11	-2.50	-1.92	38.78	0.11
12	-2.42	-1.82	36.20	0.51
13	-2.21	-1.65	37.05	0.99
14	-1.96	-1.46	32.37	1.27
15	-1.63	-1.22	22.78	1.30
16	-1.26	-0.96	10.87	1.08
17	-0.98	-0.71	-1.53	0.67
18	-0.68	-0.47	-21.09	-0.15
19	-0.42	-0.27	-40.08	-1.19
20	-0.10	-0.16	-40.32	-1.72
21	-0.17	-0.11	-36.65	-2.09
22	-0.16	-0.15	-32.85	-2.37
23	-0.35	-0.25	-30.60	-2.66
24	-0.67	-0.42	-27.34	-2.86
Mean	-1.39	-1.08	-0.93	-1.30

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 32%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 71°F (22°C)

TABLE C6(b) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P1, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-2.96	-1.90	-75.80	-9.53
2	-3.76	-2.58	-66.51	-9.95
3	-4.25	-3.22	-56.65	-10.19
4	-4.81	-3.88	-50.34	-10.44
5	-5.69	-4.52	-36.28	-10.37
6	-5.99	-5.15	9.70	-8.93
7	-6.56	-5.70	53.91	-6.96
8	-6.98	-6.07	85.31	-5.01
9	-7.27	-6.26	106.75	-3.11
10	-8.12	-6.27	124.79	-1.21
11	-7.88	-6.06	122.35	0.35
12	-7.63	-5.75	114.22	1.61
13	-6.96	-5.22	116.88	3.11
14	-6.18	-4.62	102.13	4.01
15	-5.16	-3.85	71.87	4.11
16	-3.96	-3.04	34.30	3.41
17	-3.09	-2.23	-4.84	2.10
18	-2.15	-1.48	-66.52	-0.48
19	-1.34	-0.86	-126.45	-3.74
20	-0.30	-0.50	-127.22	-5.42
21	-0.54	-0.36	-115.64	-6.60
22	-0.52	-0.48	-103.63	-7.49
23	-1.11	-0.79	-96.56	-8.39
24	-2.10	-1.31	-86.25	-9.04
Mean	-4.39	-3.42	-2.94	-4.09

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 32%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 81°F (27°C)
Min. - 71°F (22°C)

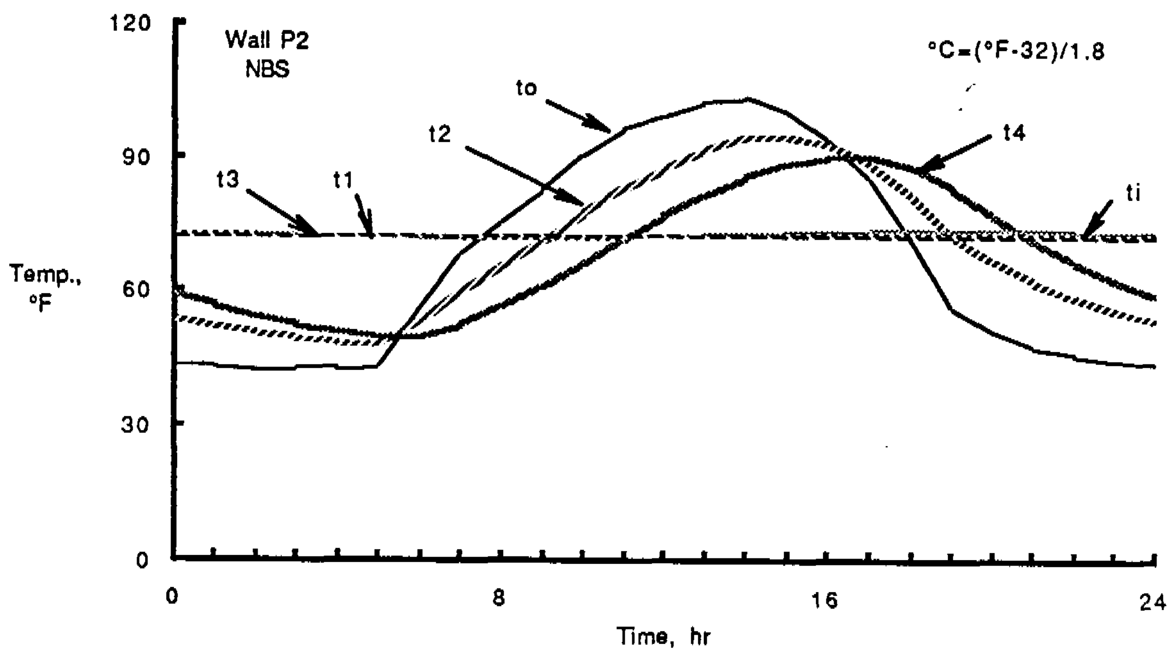

Fig. C10 Measured Temperatures for NBS Test Cycle Applied to Wall P2

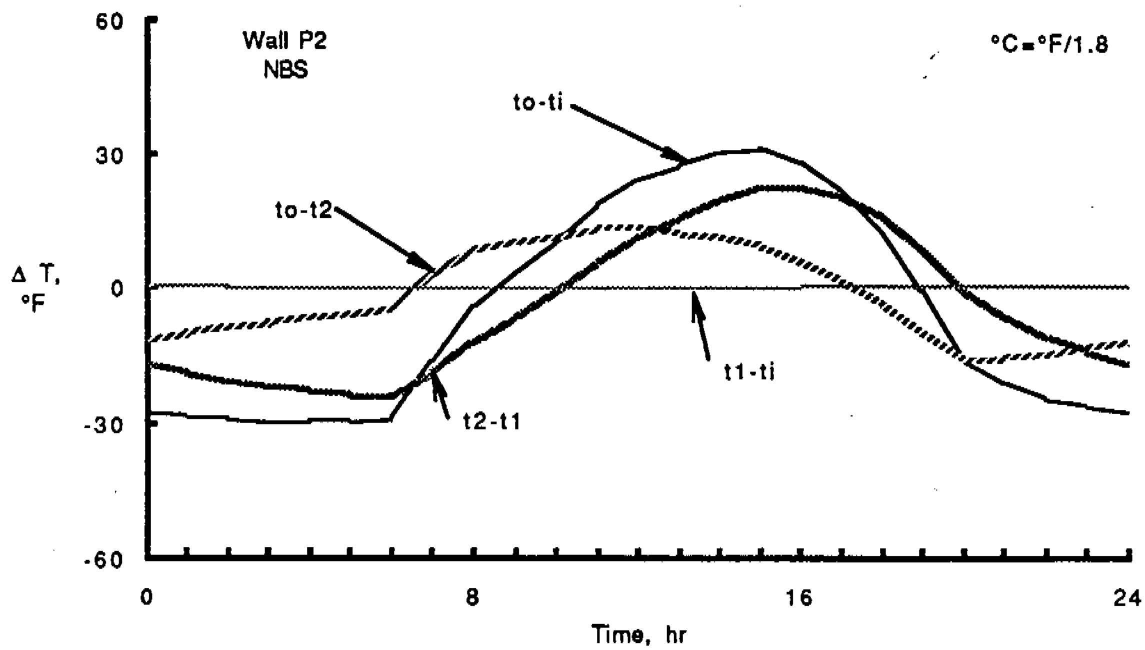

Fig. C11 Temperature Differentials for NBS Test Cycle Applied to Wall P2

TABLE C7(a) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	43.2	51.8	56.3	72.6	72.3	72.1
2	42.5	50.3	54.1	72.4	72.2	72.1
3	42.8	49.3	52.2	72.1	72.1	72.0
4	42.5	48.3	50.8	72.0	72.0	72.0
5	43.5	47.9	49.6	71.8	71.9	72.0
6	56.1	53.2	49.6	71.7	71.8	71.9
7	68.2	59.9	52.3	71.6	71.7	71.9
8	75.3	65.3	56.4	71.6	71.6	71.9
9	82.2	70.8	60.8	71.6	71.6	71.9
10	90.2	77.1	65.8	71.7	71.7	71.9
11	96.1	82.8	71.3	71.9	71.8	71.9
12	99.1	87.2	76.5	72.1	71.9	72.0
13	102.2	91.2	81.1	72.4	72.0	72.0
14	103.3	94.1	85.3	72.7	72.1	72.0
15	99.8	94.3	88.3	73.0	72.3	72.1
16	93.5	92.3	89.9	73.2	72.4	72.1
17	84.8	88.3	89.7	73.4	72.6	72.2
18	71.5	81.2	87.4	73.6	72.7	72.2
19	56.4	72.1	82.8	73.6	72.7	72.2
20	51.3	66.6	76.8	73.5	72.8	72.2
21	47.5	62.0	71.2	73.4	72.7	72.2
22	45.9	58.7	66.4	73.2	72.6	72.2
23	44.5	55.8	62.3	73.0	72.5	72.2
24	43.7	53.6	59.0	72.8	72.4	72.1
Mean	67.7	68.9	68.2	72.5	72.2	72.0

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 40%
Outdoor Chamber - 20%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 70°F (21°C)

TABLE C7(b) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	6.2	11.0	13.5	22.5	22.4	22.3
2	5.9	10.1	12.3	22.4	22.3	22.3
3	6.0	9.6	11.2	22.3	22.3	22.2
4	5.9	9.1	10.5	22.2	22.2	22.2
5	6.4	8.8	9.8	22.1	22.1	22.2
6	13.4	11.8	9.8	22.0	22.1	22.2
7	20.1	15.5	11.3	22.0	22.1	22.2
8	24.0	18.5	13.5	22.0	22.0	22.1
9	27.9	21.5	16.0	22.0	22.0	22.2
10	32.4	25.1	18.8	22.1	22.0	22.1
11	35.6	28.2	21.8	22.2	22.1	22.2
12	37.3	30.6	24.7	22.3	22.1	22.2
13	39.0	32.9	27.3	22.4	22.2	22.2
14	39.6	34.5	29.6	22.6	22.3	22.2
15	37.7	34.6	31.3	22.8	22.4	22.3
16	34.2	33.5	32.2	22.9	22.5	22.3
17	29.3	31.3	32.0	23.0	22.5	22.3
18	21.9	27.3	30.8	23.1	22.6	22.3
19	13.5	22.3	28.2	23.1	22.6	22.3
20	10.7	19.2	24.9	23.1	22.6	22.4
21	8.6	16.7	21.8	23.0	22.6	22.3
22	7.7	14.8	19.1	22.9	22.6	22.3
23	6.9	13.2	16.9	22.8	22.5	22.3
24	6.5	12.0	15.0	22.7	22.5	22.3
Mean	19.9	20.5	20.1	22.5	22.3	22.2

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 40%
Outdoor Chamber - 20%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 70°F (21°C)

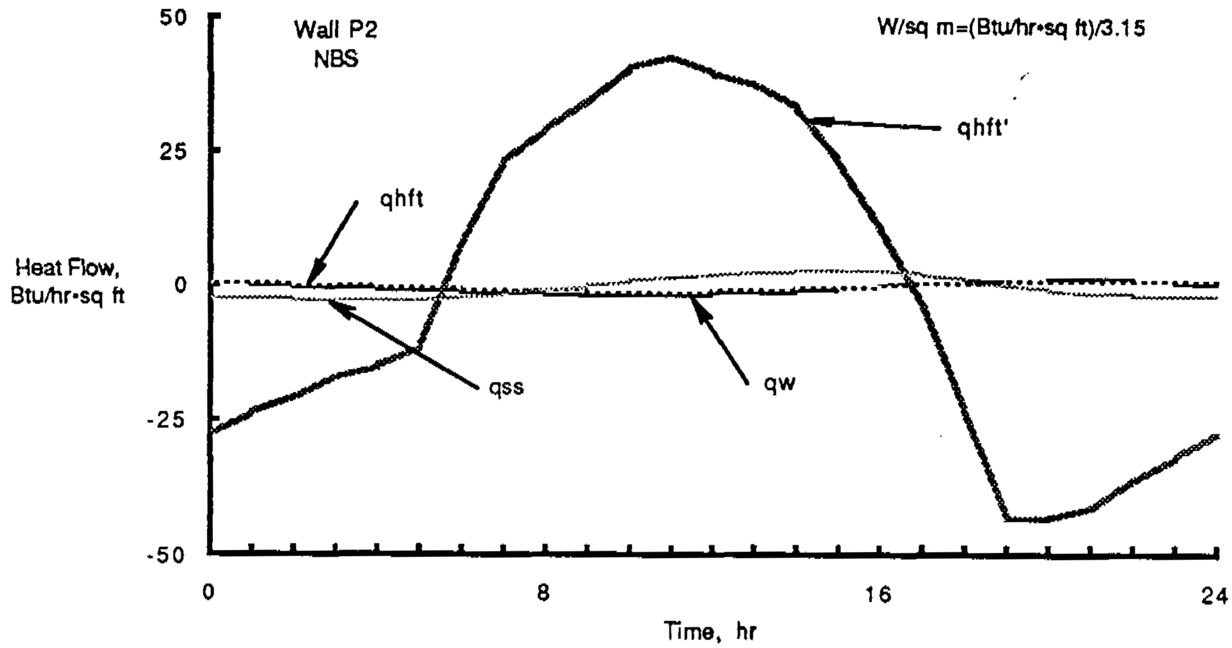

Fig. C12 Heat Flow for NBS Test Cycle Applied to Wall P2

TABLE C8(a) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.04	0.33	-23.77	-2.42
2	-0.29	0.12	-20.85	-2.59
3	-0.57	-0.12	-17.20	-2.68
4	-0.93	-0.39	-14.97	-2.78
5	-1.17	-0.63	-11.41	-2.81
6	-1.42	-0.86	7.58	-2.20
7	-1.57	-1.05	22.92	-1.41
8	-1.71	-1.17	28.83	-0.77
9	-1.75	-1.29	33.87	-0.11
10	-1.72	-1.28	40.18	0.68
11	-1.74	-1.25	42.07	1.39
12	-1.57	-1.16	39.08	1.94
13	-1.21	-0.92	37.15	2.45
14	-0.85	-0.65	32.77	2.82
15	-0.41	-0.35	22.73	2.83
16	-0.05	-0.03	10.69	2.54
17	0.52	0.27	-3.54	1.99
18	0.71	0.51	-23.57	1.07
19	0.97	0.76	-43.17	-0.09
20	1.17	0.89	-43.35	-0.75
21	1.18	0.95	-41.37	-1.29
22	0.87	0.89	-36.21	-1.68
23	0.64	0.75	-32.02	-2.00
24	0.27	0.54	-27.71	-2.24
Mean	-0.45	-0.21	-0.89	-0.34

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 40%
Outdoor Chamber - 20%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 70°F (21°C)

TABLE C8(b) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.12	1.03	-74.99	-7.65
2	-0.92	0.39	-65.79	-8.16
3	-1.81	-0.37	-54.26	-8.47
4	-2.93	-1.24	-47.23	-8.76
5	-3.70	-2.00	-36.01	-8.87
6	-4.49	-2.72	23.91	-6.93
7	-4.96	-3.31	72.32	-4.46
8	-5.40	-3.69	90.97	-2.43
9	-5.51	-4.06	106.85	-0.34
10	-5.41	-4.05	126.78	2.13
11	-5.49	-3.95	132.73	4.39
12	-4.94	-3.66	123.30	6.11
13	-3.83	-2.89	117.22	7.74
14	-2.69	-2.03	103.40	8.89
15	-1.30	-1.10	71.71	8.91
16	-0.15	-0.08	33.74	8.02
17	1.64	0.84	-11.17	6.29
18	2.23	1.60	-74.37	3.37
19	3.07	2.41	-136.19	-0.27
20	3.69	2.80	-136.78	-2.38
21	3.72	3.01	-130.54	-4.08
22	2.75	2.80	-114.23	-5.29
23	2.01	2.36	-101.03	-6.30
24	0.84	1.71	-87.42	-7.06
Mean	-1.40	-0.68	-2.79	-1.07

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 40%
Outdoor Chamber - 20%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 70°F (21°C)

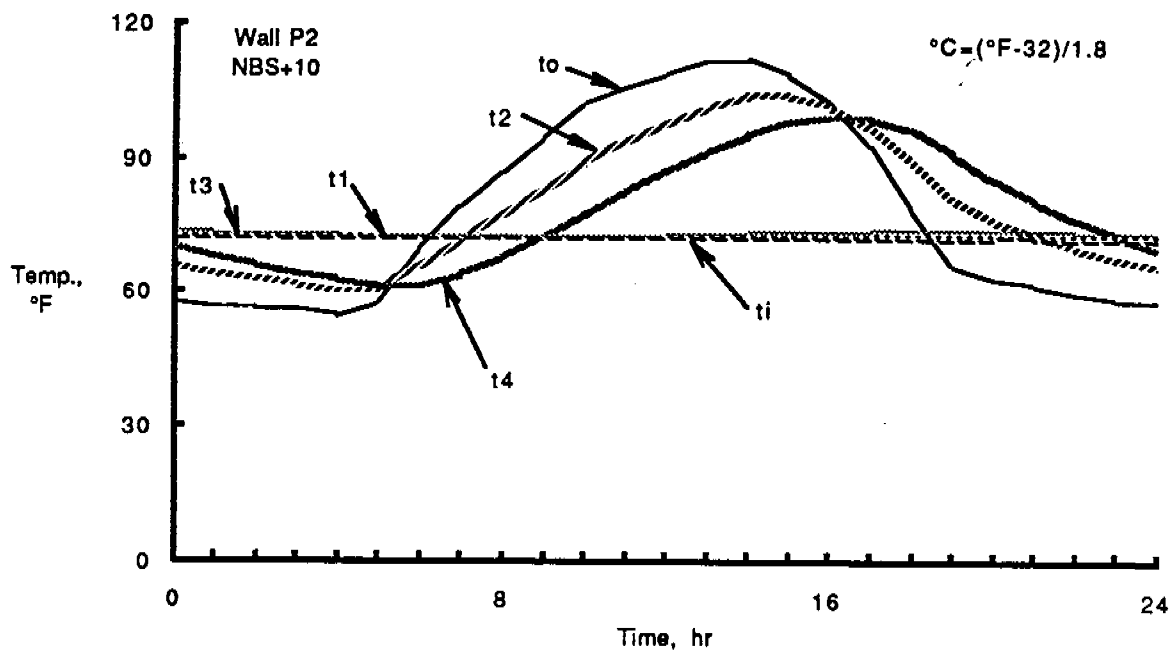

Fig. C13 Measured Temperatures for NBS+10 Test Cycle Applied to Wall P2

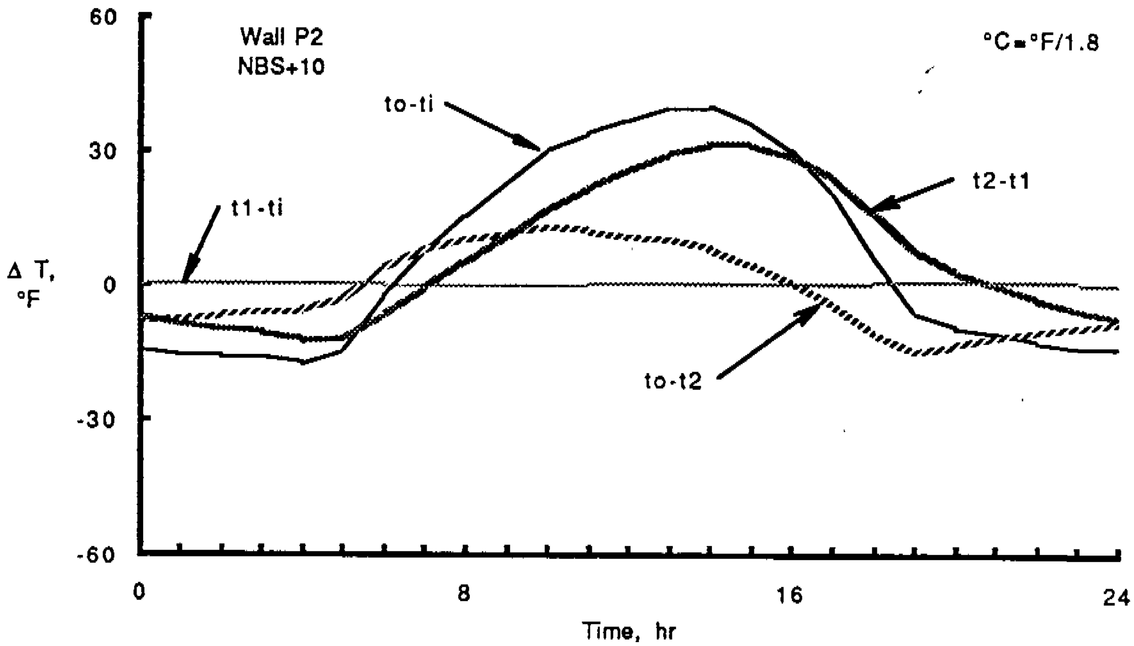

Fig. C14 Temperature Differentials for NBS+10 Test Cycle Applied to Wall P2

TABLE C9(a) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	56.6	63.9	67.7	73.3	72.7	72.1
2	56.3	62.7	65.8	73.1	72.6	72.1
3	55.9	61.6	64.1	72.9	72.5	72.1
4	54.7	60.1	62.6	72.8	72.4	72.0
5	57.6	60.6	61.3	72.5	72.2	72.0
6	69.5	65.8	61.6	72.4	72.1	71.9
7	79.3	71.5	64.0	72.3	72.1	71.9
8	87.0	77.0	67.9	72.4	72.0	71.8
9	94.5	82.7	72.4	72.5	72.1	71.9
10	102.0	89.0	77.4	72.6	72.1	71.9
11	105.7	93.7	82.5	72.8	72.2	71.9
12	108.5	97.7	87.1	73.0	72.3	72.0
13	111.5	101.5	91.4	73.2	72.4	72.0
14	111.8	103.8	95.2	73.4	72.6	72.1
15	108.1	103.5	98.0	73.6	72.7	72.1
16	102.0	101.4	99.2	73.8	72.8	72.2
17	92.7	96.9	98.7	74.0	72.9	72.2
18	78.7	89.2	96.1	74.2	73.1	72.3
19	66.2	80.8	91.0	74.2	73.1	72.3
20	63.1	76.3	85.3	74.2	73.1	72.3
21	61.6	73.1	80.5	74.1	73.1	72.3
22	59.9	70.2	76.5	73.9	73.0	72.2
23	58.4	67.6	73.0	73.7	72.9	72.2
24	57.9	65.8	70.1	73.5	72.8	72.1
Mean	79.1	79.8	78.7	73.3	72.6	72.1

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 39%
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 69°F (21°C)

TABLE C9(b) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	13.7	17.7	19.8	22.9	22.6	22.3
2	13.5	17.1	18.8	22.9	22.6	22.3
3	13.3	16.4	17.8	22.7	22.5	22.3
4	12.6	15.6	17.0	22.6	22.4	22.2
5	14.2	15.9	16.3	22.5	22.3	22.2
6	20.9	18.8	16.4	22.4	22.3	22.2
7	26.3	21.9	17.8	22.4	22.3	22.1
8	30.6	25.0	19.9	22.4	22.2	22.1
9	34.7	28.2	22.4	22.5	22.3	22.2
10	38.9	31.7	25.2	22.6	22.3	22.2
11	40.9	34.3	28.1	22.6	22.3	22.2
12	42.5	36.5	30.6	22.8	22.4	22.2
13	44.1	38.6	33.0	22.9	22.5	22.2
14	44.4	39.9	35.1	23.0	22.5	22.3
15	42.3	39.7	36.7	23.1	22.6	22.3
16	38.9	38.5	37.3	23.2	22.7	22.3
17	33.7	36.1	37.0	23.3	22.7	22.3
18	25.9	31.8	35.6	23.4	22.8	22.4
19	19.0	27.1	32.8	23.4	22.9	22.4
20	17.3	24.6	29.6	23.4	22.9	22.4
21	16.4	22.8	27.0	23.4	22.8	22.4
22	15.5	21.2	24.7	23.3	22.8	22.4
23	14.7	19.8	22.8	23.2	22.7	22.3
24	14.4	18.8	21.2	23.0	22.7	22.3
Mean	26.2	26.6	26.0	22.9	22.5	22.3

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 39%
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 69°F (21°C)

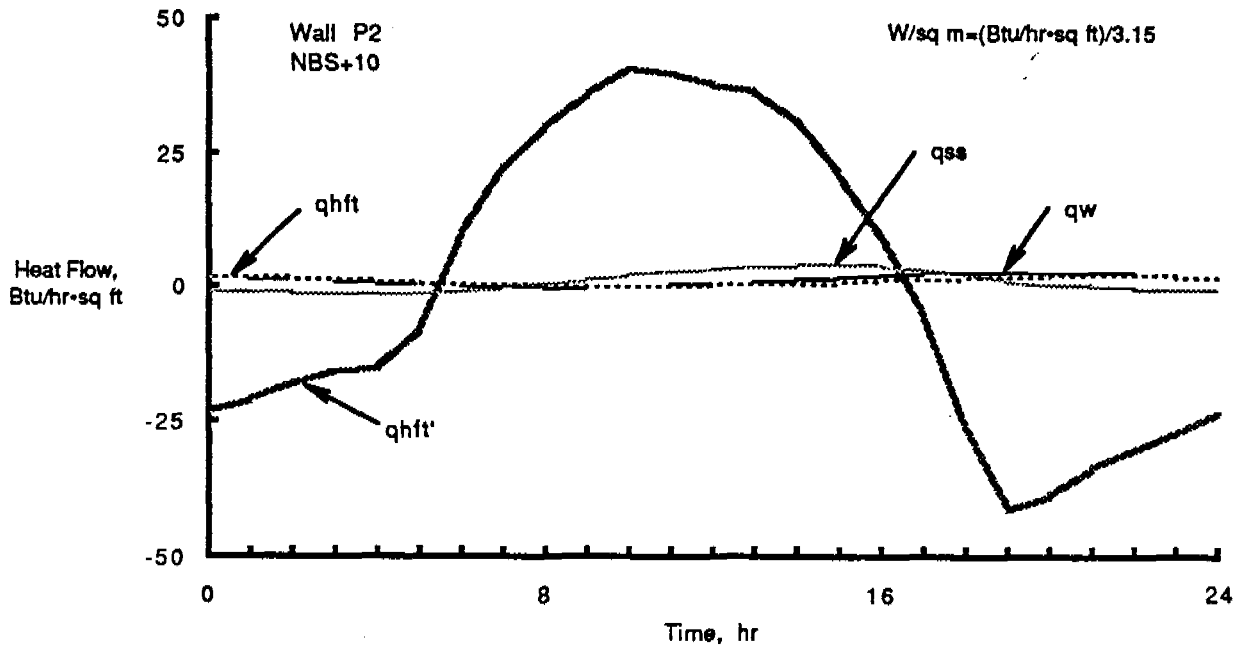

Fig. C15 Heat Flow for NBS+10 Test Cycle Applied to Wall P2

TABLE C10(a) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	1.64	1.58	-20.99	-1.06
2	1.44	1.34	-18.05	-1.20
3	1.18	1.10	-15.62	-1.31
4	0.90	0.85	-14.88	-1.47
5	0.58	0.63	-8.08	-1.40
6	0.31	0.43	10.18	-0.77
7	-0.01	0.26	22.30	-0.07
8	-0.18	0.15	29.82	0.61
9	-0.31	0.05	35.57	1.34
10	-0.14	0.04	40.56	2.15
11	-0.06	0.10	39.37	2.76
12	0.19	0.21	37.15	3.28
13	0.54	0.38	35.87	3.78
14	0.87	0.61	30.62	4.08
15	1.31	0.89	20.77	4.03
16	1.76	1.22	9.26	3.72
17	2.07	1.50	-5.59	3.09
18	2.48	1.76	-26.34	2.06
19	2.74	1.96	-41.18	0.96
20	2.90	2.09	-38.54	0.40
21	2.78	2.12	-33.79	0.00
22	2.67	2.06	-30.40	-0.35
23	2.31	1.96	-27.12	-0.64
24	2.00	1.78	-23.03	-0.85
Mean	1.25	1.04	0.33	0.96

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 39%
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 69°F (21°C)

TABLE C10(b) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	5.18	4.98	-66.23	-3.36
2	4.54	4.24	-56.94	-3.78
3	3.71	3.46	-49.28	-4.15
4	2.83	2.69	-46.96	-4.64
5	1.83	1.98	-25.49	-4.42
6	0.97	1.35	32.10	-2.43
7	-0.04	0.83	70.36	-0.23
8	-0.56	0.48	94.07	1.93
9	-0.99	0.15	112.24	4.22
10	-0.45	0.14	127.96	6.78
11	-0.20	0.33	124.20	8.70
12	0.61	0.65	117.22	10.33
13	1.72	1.19	113.18	11.91
14	2.75	1.92	96.62	12.86
15	4.13	2.80	65.54	12.70
16	5.56	3.85	29.21	11.72
17	6.54	4.72	-17.63	9.75
18	7.83	5.55	-83.09	6.49
19	8.65	6.20	-129.92	3.03
20	9.15	6.59	-121.61	1.25
21	8.78	6.68	-106.61	-0.01
22	8.41	6.51	-95.91	-1.10
23	7.30	6.20	-85.57	-2.02
24	6.30	5.60	-72.66	-2.69
Mean	3.94	3.30	1.03	3.04

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 39%
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 71°F (22°C)
Min. - 69°F (21°C)

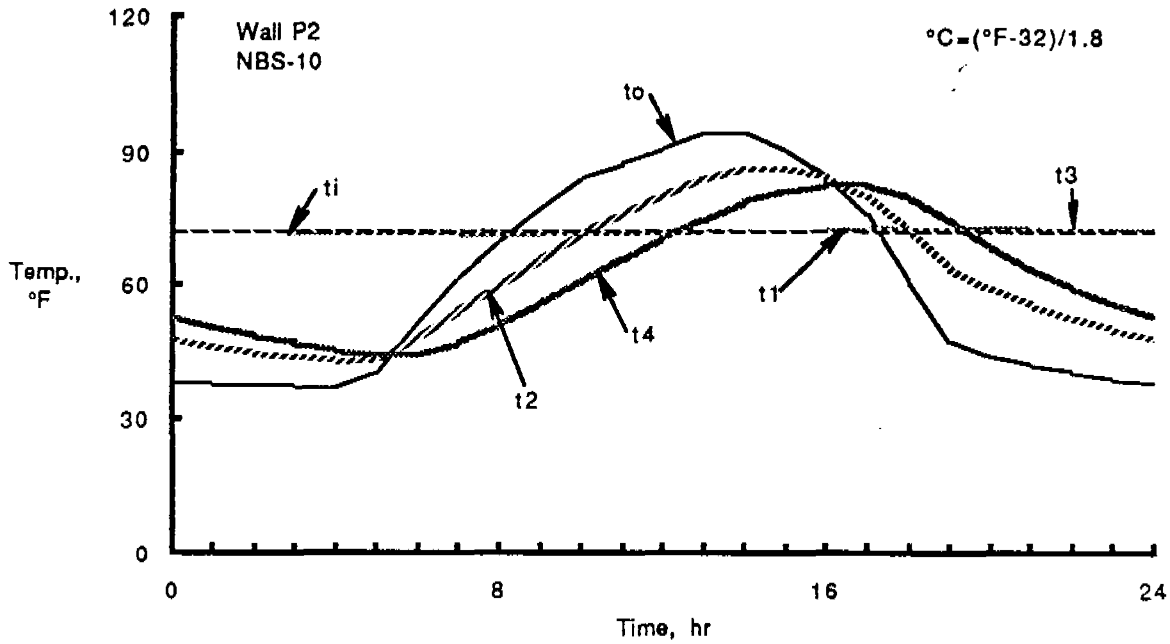

Fig. C16 Measured Temperatures for NBS-10 Test Cycle Applied to Wall P2

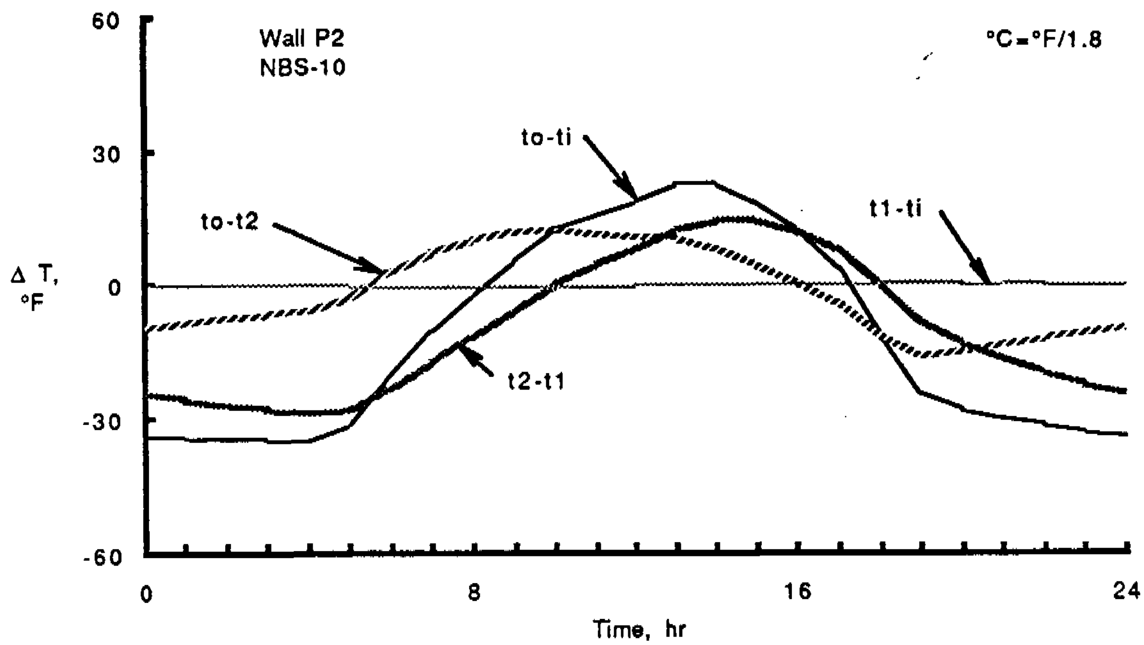

Fig. C17 Temperature Differentials for NBS-10 Test Cycle Applied to Wall P2

TABLE C11(a) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	37.4	45.8	50.1	72.0	72.0	72.1
2	37.3	44.5	48.0	71.8	72.0	72.1
3	37.1	43.5	46.4	71.6	71.8	72.0
4	36.9	42.6	45.1	71.5	71.7	72.0
5	40.4	43.4	44.1	71.4	71.7	72.0
6	51.4	48.4	44.6	71.2	71.6	72.0
7	61.6	54.3	47.2	71.1	71.5	71.9
8	69.6	59.8	51.0	71.1	71.5	71.9
9	77.2	65.7	55.6	71.2	71.5	71.9
10	84.2	71.7	60.7	71.4	71.5	71.9
11	87.2	75.9	65.9	71.5	71.6	71.9
12	90.4	79.8	70.4	71.7	71.7	72.0
13	94.2	83.9	74.7	72.0	71.8	72.0
14	94.1	86.1	78.6	72.2	71.9	72.0
15	90.2	86.0	81.3	72.3	72.1	72.1
16	84.2	83.9	82.4	72.7	72.2	72.1
17	75.7	79.9	82.0	72.9	72.3	72.1
18	60.7	72.3	79.6	72.8	72.4	72.2
19	47.3	63.6	74.5	73.0	72.4	72.2
20	43.8	59.0	68.6	72.9	72.4	72.2
21	41.9	55.4	63.5	72.8	72.4	72.2
22	40.2	52.3	59.3	72.6	72.4	72.2
23	38.8	49.6	55.6	72.4	72.3	72.1
24	37.9	47.5	52.6	72.2	72.2	72.1
Mean	60.8	62.3	61.7	72.0	71.9	72.0

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 42%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 73°F (23°C)
Min. - 73°F (23°C)

TABLE C11(b) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	3.0	7.7	10.1	22.2	22.2	22.3
2	3.0	7.0	8.9	22.1	22.2	22.3
3	2.9	6.4	8.0	22.0	22.1	22.2
4	2.7	5.9	7.3	21.9	22.1	22.2
5	4.7	6.3	6.7	21.9	22.0	22.2
6	10.8	9.1	7.0	21.8	22.0	22.2
7	16.4	12.4	8.4	21.7	21.9	22.2
8	20.9	15.4	10.5	21.7	21.9	22.2
9	25.1	18.7	13.1	21.8	21.9	22.2
10	29.0	22.0	16.0	21.9	21.9	22.2
11	30.7	24.4	18.8	21.9	22.0	22.2
12	32.4	26.6	21.3	22.1	22.0	22.2
13	34.6	28.8	23.7	22.2	22.1	22.2
14	34.5	30.1	25.9	22.4	22.2	22.2
15	32.3	30.0	27.4	22.4	22.3	22.3
16	29.0	28.8	28.0	22.6	22.3	22.3
17	24.3	26.6	27.8	22.7	22.4	22.3
18	15.9	22.4	26.5	22.7	22.5	22.3
19	8.5	17.6	23.6	22.8	22.5	22.3
20	6.6	15.0	20.3	22.7	22.5	22.3
21	5.5	13.0	17.5	22.7	22.5	22.3
22	4.6	11.3	15.1	22.6	22.4	22.3
23	3.8	9.8	13.1	22.5	22.4	22.3
24	3.3	8.6	11.5	22.3	22.3	22.3
Mean	16.0	16.8	16.5	22.2	22.2	22.2

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 42%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 73°F (23°C)
Min. - 73°F (23°C)

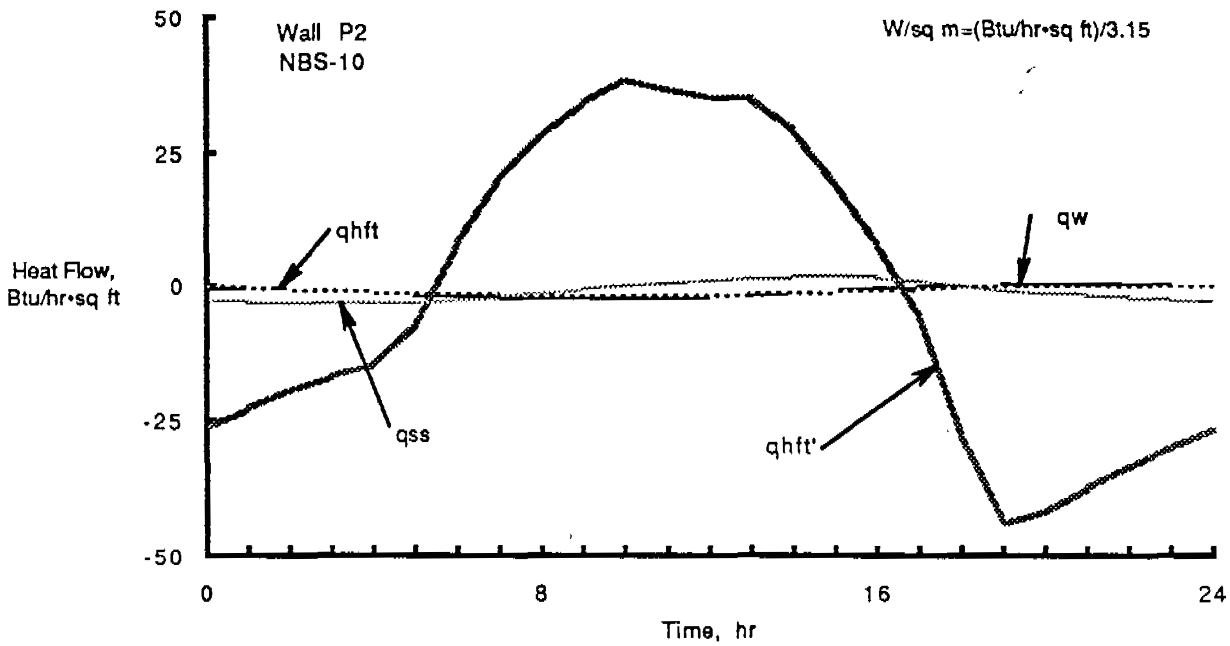

Fig. C18 Heat Flow for NBS-10 Test Cycle Applied to Wall P2

TABLE C12(a) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P2, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.69	-0.50	-22.65	-3.07
2	-0.96	-0.75	-19.22	-3.19
3	-1.12	-0.96	-16.55	-3.29
4	-1.50	-1.19	-14.51	-3.38
5	-1.70	-1.44	-7.42	-3.28
6	-1.94	-1.63	8.05	-2.72
7	-2.19	-1.81	20.05	-2.04
8	-2.31	-1.94	27.99	-1.41
9	-2.30	-1.97	33.86	-0.70
10	-2.37	-1.97	38.09	0.02
11	-2.28	-1.92	36.08	0.54
12	-1.93	-1.75	34.62	1.01
13	-1.70	-1.58	34.19	1.53
14	-1.23	-1.28	28.41	1.79
15	-1.06	-1.06	18.75	1.75
16	-0.57	-0.76	7.62	1.47
17	-0.18	-0.47	-5.93	0.95
18	0.14	-0.22	-28.18	-0.02
19	0.50	-0.01	-44.03	-1.07
20	0.57	0.12	-41.55	-1.61
21	0.39	0.15	-37.43	-2.03
22	0.22	0.06	-33.42	-2.37
23	-0.06	-0.06	-29.71	-2.67
24	-0.31	-0.26	-26.26	-2.90
Mean	-1.02	-0.97	-1.63	-1.11

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 42%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 73°F (23°C)
Min. - 73°F (23°C)

TABLE C12(b) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P2, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-2.17	-1.56	-71.46	-9.67
2	-3.02	-2.36	-60.64	-10.08
3	-3.54	-3.04	-52.22	-10.39
4	-4.72	-3.77	-45.79	-10.65
5	-5.37	-4.53	-23.42	-10.35
6	-6.12	-5.15	25.40	-8.59
7	-6.89	-5.70	63.25	-6.44
8	-7.28	-6.11	88.31	-4.43
9	-7.27	-6.22	106.84	-2.22
10	-7.49	-6.22	120.19	0.06
11	-7.19	-6.05	113.84	1.69
12	-6.09	-5.51	109.21	3.20
13	-5.37	-4.97	107.87	4.81
14	-3.89	-4.05	89.62	5.66
15	-3.36	-3.36	59.17	5.53
16	-1.79	-2.40	24.05	4.64
17	-0.57	-1.47	-18.71	3.00
18	0.44	-0.70	-88.91	-0.05
19	1.59	-0.03	-138.92	-3.36
20	1.78	0.38	-131.10	-5.08
21	1.23	0.46	-118.10	-6.41
22	0.69	0.20	-105.45	-7.48
23	-0.20	-0.19	-93.74	-8.41
24	-0.99	-0.83	-82.84	-9.14
Mean	-3.23	-3.05	-5.15	-3.51

Calibrated Hot Box Relative Humidity:
Indoor Chamber - 42%
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 73°F (23°C)
Min. - 73°F (23°C)

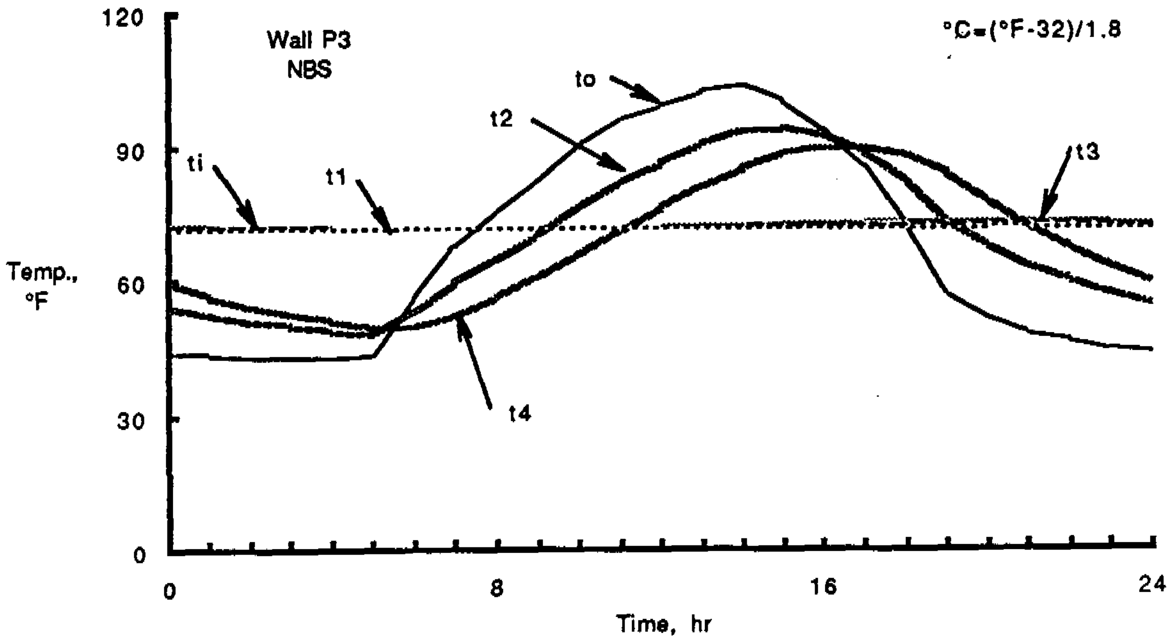

Fig. C19 Measured Temperatures for NBS Test Cycle Applied to Wall P3

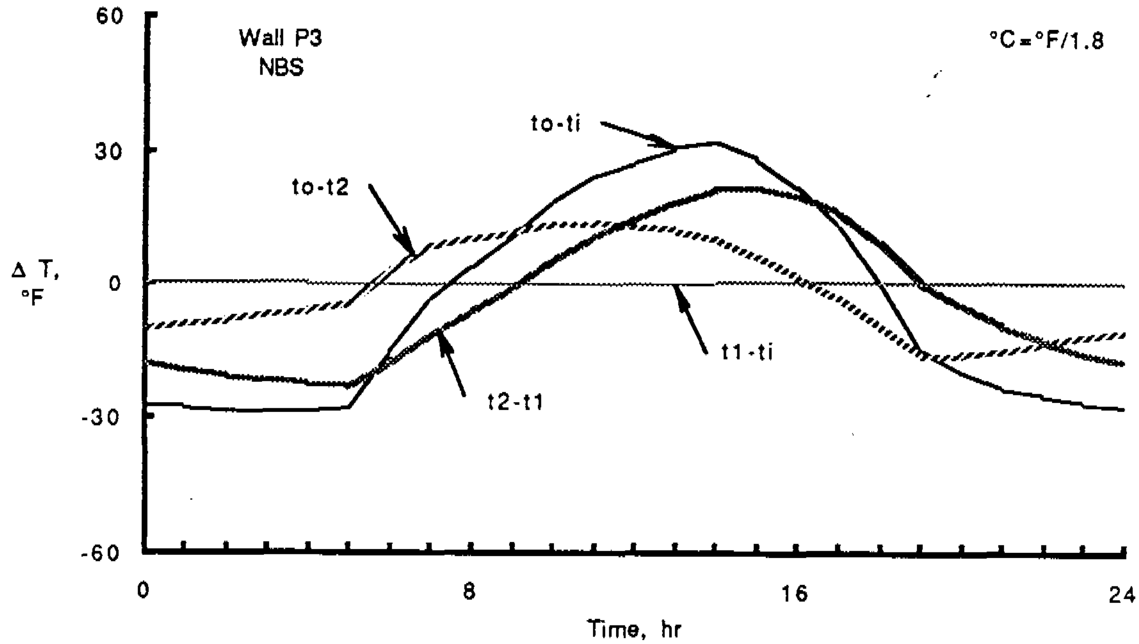

Fig. C20 Temperature Differentials for NBS Test Cycle Applied to Wall P3

TABLE C13(a) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	43.6	52.6	56.6	72.3	72.0	71.6
2	42.9	50.9	54.4	72.1	71.9	71.6
3	43.1	49.9	52.6	71.9	71.8	71.5
4	42.8	48.9	51.1	71.7	71.7	71.5
5	43.6	48.4	49.8	71.5	71.5	71.4
6	56.1	53.3	49.7	71.4	71.4	71.4
7	67.8	59.5	52.1	71.3	71.3	71.4
8	75.1	64.8	56.1	71.2	71.3	71.4
9	82.0	70.2	60.5	71.3	71.3	71.3
10	90.0	76.4	65.5	71.4	71.3	71.4
11	95.7	81.8	70.8	71.6	71.4	71.4
12	98.7	86.1	76.0	71.8	71.5	71.4
13	101.9	90.2	80.6	72.0	71.7	71.5
14	103.1	93.2	84.8	72.3	71.8	71.5
15	99.6	93.6	87.9	72.6	72.0	71.6
16	93.5	92.0	89.5	72.8	72.1	71.6
17	85.0	88.3	89.4	73.0	72.3	71.7
18	72.1	81.7	87.4	73.2	72.4	71.7
19	56.9	72.9	83.1	73.2	72.4	71.7
20	51.7	67.5	77.2	73.2	72.5	71.7
21	47.9	62.9	71.6	73.1	72.4	71.7
22	46.5	59.6	66.8	72.9	72.4	71.7
23	44.8	56.7	62.8	72.7	72.3	71.7
24	44.0	54.4	59.4	72.5	72.1	71.6
Mean	67.8	69.0	68.2	72.2	71.9	71.5

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 74°F (23°C)
Min. - 70°F (21°C)

TABLE C13(b) - MEASURED TEMPERATURES FOR NBS TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	6.4	11.4	13.7	22.4	22.2	22.0
2	6.1	10.5	12.4	22.3	22.2	22.0
3	6.2	10.0	11.4	22.1	22.1	22.0
4	6.0	9.4	10.6	22.1	22.0	21.9
5	6.4	9.1	9.9	22.0	22.0	21.9
6	13.4	11.8	9.8	21.9	21.9	21.9
7	19.9	15.3	11.2	21.8	21.9	21.9
8	24.0	18.2	13.4	21.8	21.8	21.9
9	27.8	21.2	15.9	21.8	21.8	21.9
10	32.2	24.6	18.6	21.9	21.9	21.9
11	35.4	27.7	21.6	22.0	21.9	21.9
12	37.1	30.1	24.4	22.1	22.0	21.9
13	38.9	32.3	27.0	22.2	22.0	21.9
14	39.5	34.0	29.3	22.4	22.1	21.9
15	37.5	34.2	31.1	22.5	22.2	22.0
16	34.1	33.3	31.9	22.7	22.3	22.0
17	29.5	31.3	31.9	22.8	22.4	22.0
18	22.3	27.6	30.8	22.9	22.4	22.1
19	13.8	22.7	28.4	22.9	22.5	22.1
20	10.9	19.7	25.1	22.9	22.5	22.1
21	8.8	17.2	22.0	22.8	22.5	22.1
22	8.0	15.4	19.3	22.7	22.4	22.1
23	7.1	13.7	17.1	22.6	22.4	22.0
24	6.7	12.4	15.2	22.5	22.3	22.0
Mean	19.9	20.5	20.1	22.3	22.1	22.0

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 74°F (23°C)
Min. - 70°F (21°C)

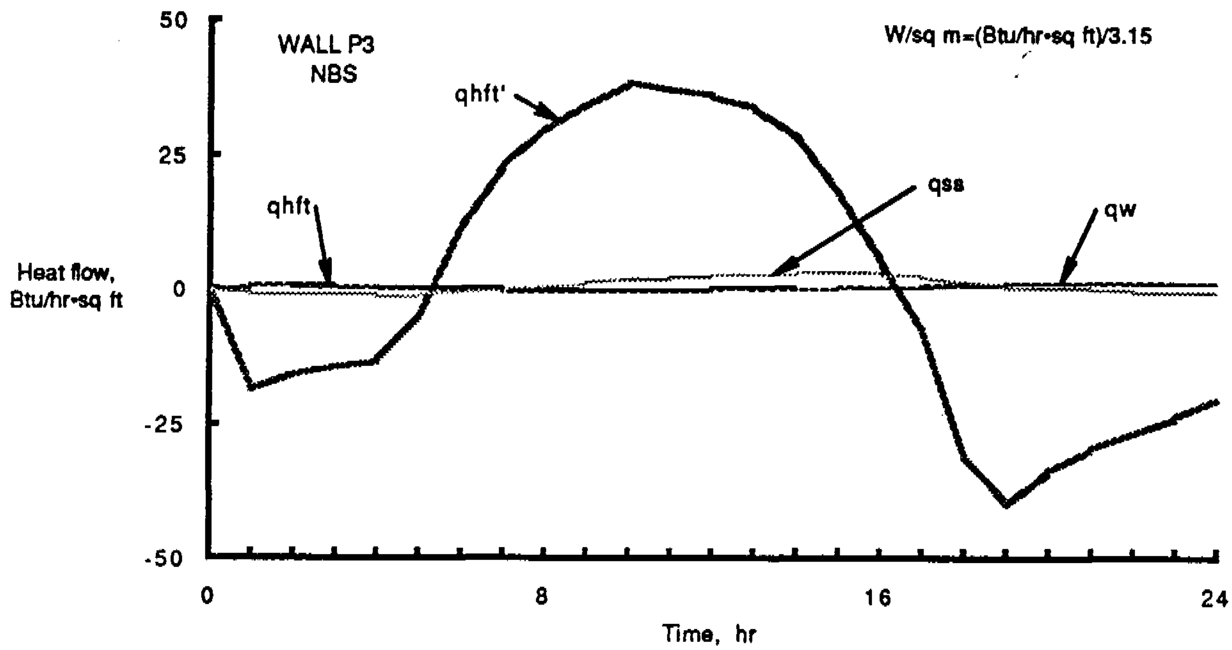

Fig. C21 Heat Flow for NBS Test Cycle Applied to Wall P3

TABLE C14(a) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.03	-0.15	-22.01	-1.94
2	-0.19	-0.32	-19.37	-2.10
3	-0.41	-0.53	-16.16	-2.19
4	-0.62	-0.74	-14.09	-2.28
5	-0.70	-0.93	-11.07	-2.32
6	-0.88	-1.12	6.18	-1.81
7	-1.17	-1.29	20.82	-1.19
8	-1.24	-1.42	26.90	-0.65
9	-1.54	-1.50	32.05	-0.11
10	-1.30	-1.48	38.09	0.51
11	-1.36	-1.43	39.26	1.05
12	-1.28	-1.33	37.01	1.48
13	-1.09	-1.15	35.62	1.88
14	-0.91	-0.94	31.07	2.18
15	-0.67	-0.69	21.20	2.20
16	-0.30	-0.43	9.57	2.02
17	-0.08	-0.23	-3.75	1.63
18	0.38	0.01	-20.88	0.95
19	0.68	0.21	-38.50	0.05
20	0.71	0.31	-38.83	-0.51
21	0.65	0.34	-36.85	-0.96
22	0.54	0.28	-32.47	-1.28
23	0.39	0.18	-29.28	-1.56
24	0.22	0.03	-25.33	-1.78
Mean	-0.42	-0.60	-0.45	-0.28

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 74°F (23°C)
Min. - 70°F (21°C)

TABLE C14(b) - HEAT FLOW FOR NBS TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.09	-0.48	-69.44	-6.13
2	-0.59	-1.00	-61.10	-6.62
3	-1.30	-1.66	-50.98	-6.90
4	-1.94	-2.34	-44.47	-7.18
5	-2.22	-2.94	-34.91	-7.31
6	-2.79	-3.53	19.49	-5.73
7	-3.71	-4.07	65.69	-3.74
8	-3.92	-4.48	84.86	-2.05
9	-4.85	-4.72	101.11	-0.35
10	-4.10	-4.68	120.16	1.60
11	-4.28	-4.52	123.87	3.32
12	-4.04	-4.21	116.76	4.68
13	-3.44	-3.64	112.38	5.94
14	-2.86	-2.98	98.01	6.88
15	-2.12	-2.18	66.87	6.95
16	-0.94	-1.36	30.19	6.37
17	-0.24	-0.71	-11.84	5.14
18	1.21	0.04	-65.89	3.00
19	2.15	0.67	-121.46	0.14
20	2.25	0.99	-122.50	-1.59
21	2.06	1.07	-116.28	-3.03
22	1.69	0.87	-102.44	-4.04
23	1.22	0.56	-92.37	-4.93
24	0.70	0.09	-79.92	-5.61
Mean	-1.34	-1.88	-1.43	-0.88

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 74°F (23°C)
Min. - 70°F (21°C)

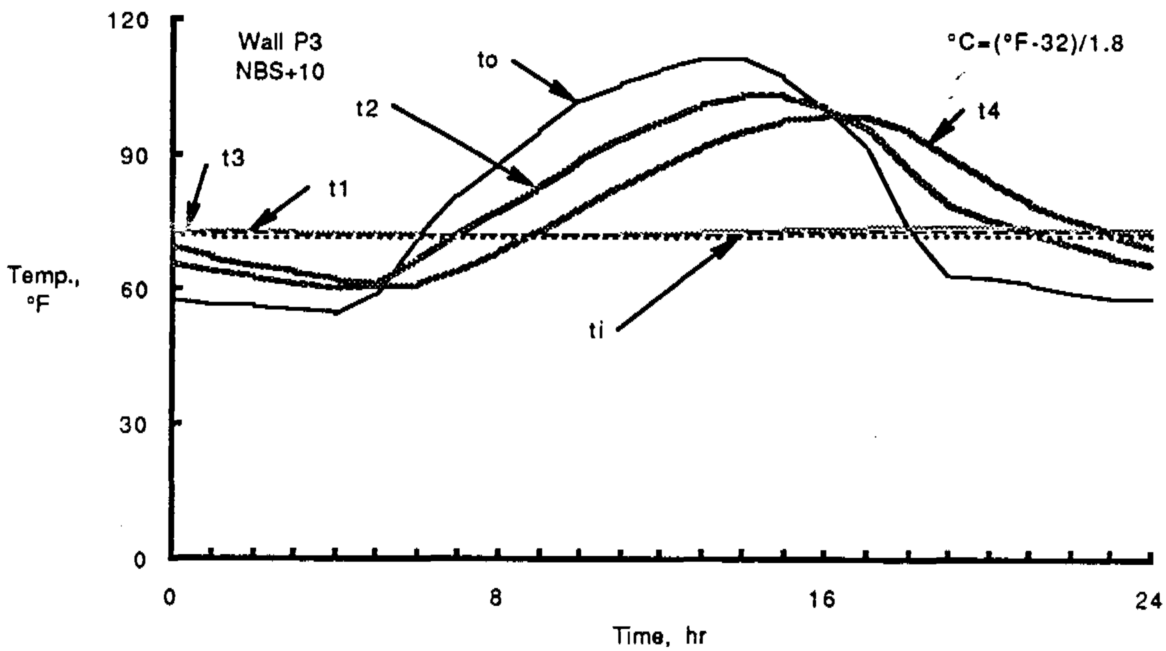

Fig. C22 Measured Temperatures for NBS+10 Test Cycle Applied to Wall P3

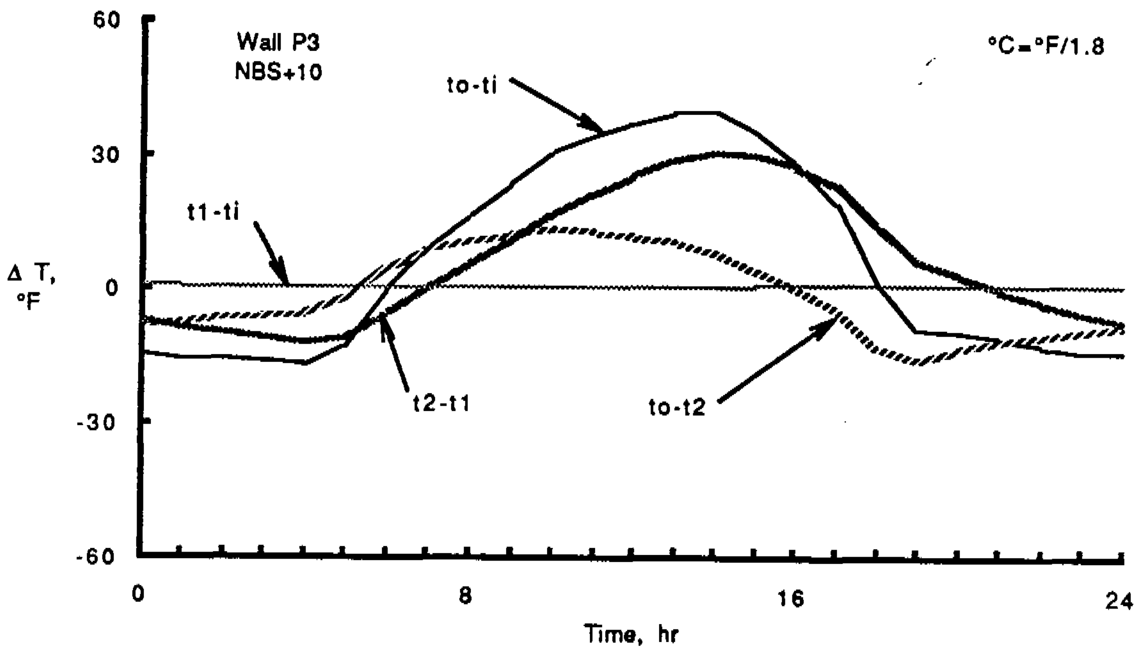

Fig. C23 Temperature Differentials for NBS+10 Test Cycle Applied to Wall P3

TABLE C15(a) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	56.5	63.8	67.0	73.1	72.5	71.7
2	56.3	62.6	65.1	72.9	72.4	71.7
3	55.6	61.4	63.5	72.7	72.2	71.7
4	54.7	60.1	62.1	72.5	72.1	71.7
5	59.1	61.2	61.0	72.3	72.0	71.6
6	71.3	66.5	61.5	72.2	71.9	71.6
7	81.0	72.2	64.3	72.1	71.8	71.5
8	88.1	77.4	68.2	72.1	71.8	71.5
9	94.8	82.7	72.7	72.1	71.7	71.4
10	101.9	88.6	77.6	72.2	71.8	71.4
11	105.4	93.1	82.7	72.4	71.9	71.4
12	108.5	97.1	87.2	72.6	72.0	71.5
13	111.1	100.7	91.4	72.9	72.1	71.5
14	110.9	102.7	95.0	73.2	72.4	71.7
15	106.6	102.3	97.6	73.5	72.6	71.8
16	100.0	99.9	98.5	73.7	72.7	71.8
17	91.2	95.9	97.9	73.9	72.9	71.9
18	73.6	86.7	95.0	74.0	72.9	71.9
19	63.1	79.0	89.0	74.1	73.0	71.9
20	62.5	75.7	83.7	74.0	73.0	71.9
21	61.1	72.6	79.1	73.8	72.9	71.9
22	59.4	69.8	75.3	73.7	72.8	71.9
23	58.1	67.4	72.0	73.4	72.7	71.8
24	57.7	65.6	69.3	73.3	72.6	71.8
Mean	78.7	79.4	78.2	73.0	72.4	71.7

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 77°F (25°C)
Min. - 70°F (21°C)

TABLE C15(b) - MEASURED TEMPERATURES FOR NBS+10 TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	13.6	17.7	19.5	22.8	22.5	22.1
2	13.5	17.0	18.4	22.7	22.4	22.1
3	13.1	16.3	17.5	22.6	22.4	22.0
4	12.6	15.6	16.7	22.5	22.3	22.0
5	15.0	16.2	16.1	22.4	22.2	22.0
6	21.8	19.2	16.4	22.3	22.2	22.0
7	27.2	22.3	17.9	22.3	22.1	21.9
8	31.2	25.2	20.1	22.3	22.1	21.9
9	34.9	28.2	22.6	22.3	22.1	21.9
10	38.8	31.4	25.3	22.3	22.1	21.9
11	40.8	33.9	28.2	22.4	22.1	21.9
12	42.5	36.2	30.7	22.6	22.2	22.0
13	43.9	38.2	33.0	22.7	22.3	22.0
14	43.8	39.3	35.0	22.9	22.4	22.0
15	41.4	39.0	36.4	23.0	22.5	22.1
16	37.8	37.7	36.9	23.2	22.6	22.1
17	32.9	35.5	36.6	23.3	22.7	22.2
18	23.1	30.4	35.0	23.4	22.7	22.2
19	17.3	26.1	31.7	23.4	22.8	22.2
20	16.9	24.3	28.7	23.3	22.8	22.2
21	16.2	22.6	26.2	23.2	22.7	22.2
22	15.2	21.0	24.0	23.2	22.7	22.1
23	14.5	19.7	22.2	23.0	22.6	22.1
24	14.3	18.7	20.7	22.9	22.6	22.1
Mean	25.9	26.3	25.7	22.8	22.4	22.0

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 77°F (25°C)
Min. - 70°F (21°C)

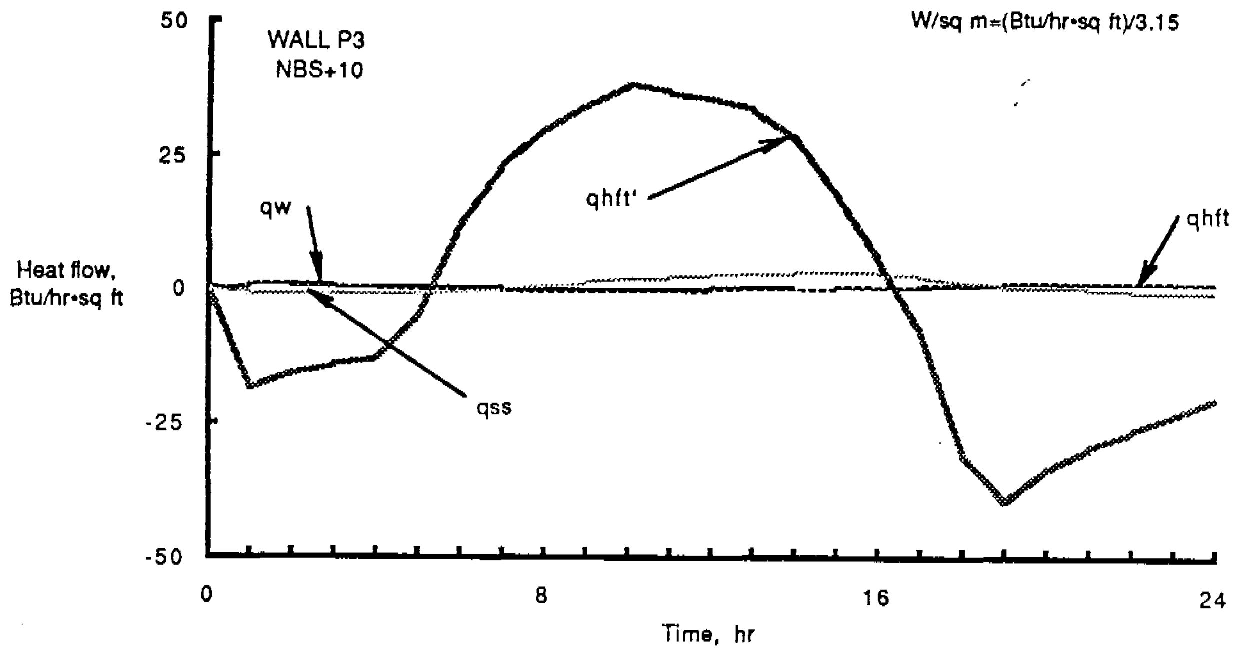

Fig. C24 Heat Flow for NBS+10 Test Cycle Applied to Wall P3

TABLE C16(a) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	0.89	0.77	-18.56	-0.87
2	0.71	0.57	-15.77	-0.98
3	0.57	0.35	-14.25	-1.09
4	0.49	0.16	-13.24	-1.21
5	0.33	-0.04	-5.37	-1.09
6	0.21	-0.20	11.74	-0.55
7	0.02	-0.32	22.96	0.03
8	0.13	-0.39	29.52	0.56
9	0.06	-0.43	34.15	1.12
10	0.11	-0.40	38.20	1.71
11	0.01	-0.33	36.53	2.16
12	0.20	-0.24	35.51	2.57
13	0.29	-0.07	33.26	2.92
14	0.14	0.10	28.05	3.11
15	0.19	0.33	17.37	3.04
16	0.30	0.58	5.26	2.78
17	0.55	0.83	-7.64	2.35
18	1.02	1.06	-30.84	1.40
19	1.31	1.22	-39.89	0.61
20	1.37	1.29	-33.52	0.27
21	1.31	1.28	-29.44	-0.03
22	1.29	1.22	-26.61	-0.30
23	1.17	1.10	-23.77	-0.53
24	1.10	0.95	-20.40	-0.70
Mean	0.57	0.39	0.55	0.72

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 77°F (25°C)
Min. - 70°F (21°C)

TABLE C16(b) - HEAT FLOW FOR NBS+10 TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	2.82	2.41	-58.57	-2.74
2	2.25	1.79	-49.75	-3.09
3	1.78	1.10	-44.94	-3.44
4	1.54	0.49	-41.76	-3.81
5	1.04	-0.12	-16.93	-3.44
6	0.67	-0.64	37.04	-1.72
7	0.07	-1.02	72.45	0.10
8	0.40	-1.24	93.14	1.78
9	0.18	-1.35	107.73	3.52
10	0.36	-1.25	120.51	5.40
11	0.04	-1.04	115.24	6.83
12	0.62	-0.75	112.03	8.10
13	0.91	-0.23	104.93	9.22
14	0.45	0.32	88.49	9.80
15	0.61	1.04	54.80	9.60
16	0.95	1.84	16.58	8.78
17	1.73	2.61	-24.11	7.41
18	3.22	3.33	-97.31	4.43
19	4.15	3.86	-125.86	1.92
20	4.33	4.06	-105.77	0.86
21	4.13	4.02	-92.88	-0.10
22	4.06	3.83	-83.95	-0.96
23	3.70	3.48	-75.00	-1.68
24	3.47	3.01	-64.35	-2.22
Mean	1.81	1.23	1.74	2.27

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 17%

Laboratory Air Temperature:
Max. - 77°F (25°C)
Min. - 70°F (21°C)

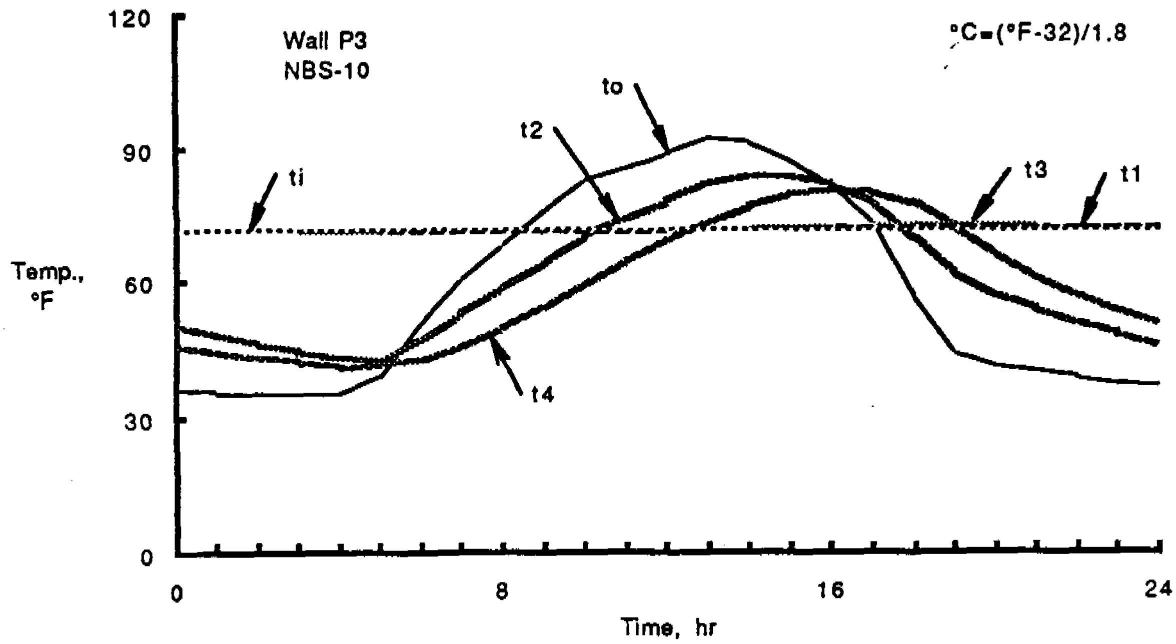

Fig. C25 Measured Temperatures for NBS-10 Test Cycle Applied to Wall P3

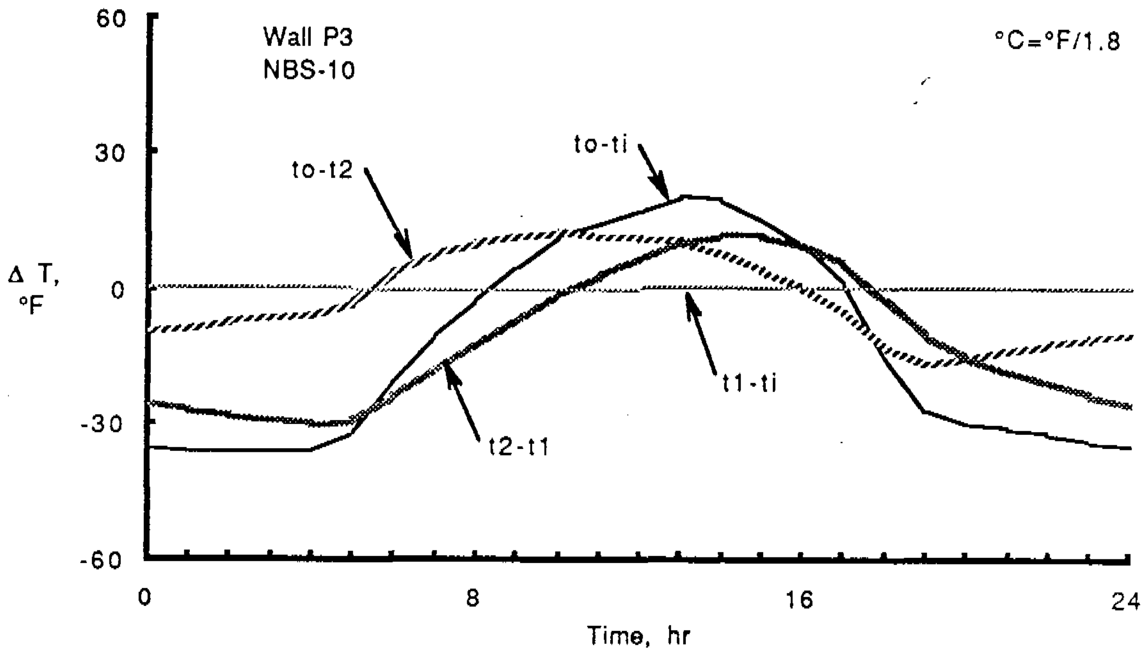

Fig. C26 Temperature Differentials for NBS-10 Test Cycle Applied to Wall P3

TABLE C17(a) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	35.5	44.2	48.1	71.5	71.6	71.4
2	35.5	42.9	46.0	71.3	71.5	71.4
3	35.5	42.1	44.5	71.2	71.4	71.4
4	35.4	41.2	43.1	71.0	71.3	71.3
5	39.4	42.2	42.3	70.9	71.2	71.3
6	50.9	47.3	42.9	70.8	71.1	71.3
7	60.6	53.1	45.7	70.7	71.1	71.3
8	68.3	58.5	49.7	70.7	71.0	71.3
9	75.4	64.0	54.3	70.8	71.0	71.2
10	82.5	69.9	59.3	70.9	71.1	71.2
11	85.2	74.0	64.4	71.1	71.2	71.3
12	88.4	77.7	68.8	71.3	71.2	71.3
13	91.7	81.6	73.0	71.5	71.4	71.3
14	90.8	83.4	76.7	71.8	71.5	71.4
15	86.7	83.1	79.1	72.0	71.6	71.4
16	81.2	81.1	80.2	72.2	71.8	71.5
17	72.5	77.3	79.6	72.3	71.8	71.5
18	56.3	69.2	77.1	72.4	71.9	71.5
19	44.3	61.2	71.8	72.5	72.0	71.6
20	41.2	56.7	65.9	72.4	72.0	71.5
21	40.0	53.5	60.9	72.2	71.9	71.5
22	38.8	50.8	56.9	72.1	71.9	71.5
23	37.3	48.1	53.5	71.9	71.8	71.4
24	36.2	45.9	50.6	71.7	71.7	71.4
Mean	58.7	60.4	59.8	71.5	71.5	71.4

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 74°F (23°C)

TABLE C17(b) - MEASURED TEMPERATURES FOR NBS-10 TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
1	1.9	6.8	9.0	22.0	22.0	21.9
2	2.0	6.1	7.8	21.8	21.9	21.9
3	2.0	5.6	6.9	21.8	21.9	21.9
4	1.9	5.1	6.2	21.7	21.8	21.9
5	4.1	5.7	5.7	21.6	21.8	21.8
6	10.5	8.5	6.0	21.5	21.7	21.8
7	15.9	11.7	7.6	21.5	21.7	21.8
8	20.1	14.7	9.8	21.5	21.7	21.8
9	24.1	17.8	12.4	21.6	21.7	21.8
10	28.0	21.0	15.2	21.6	21.7	21.8
11	29.6	23.3	18.0	21.7	21.8	21.8
12	31.3	25.4	20.4	21.8	21.8	21.8
13	33.2	27.6	22.8	21.9	21.9	21.8
14	32.7	28.6	24.8	22.1	22.0	21.9
15	30.4	28.4	26.2	22.2	22.0	21.9
16	27.3	27.3	26.8	22.3	22.1	21.9
17	22.5	25.2	26.5	22.4	22.1	21.9
18	13.5	20.7	25.0	22.5	22.2	21.9
19	6.8	16.2	22.1	22.5	22.2	22.0
20	5.1	13.7	18.8	22.4	22.2	22.0
21	4.5	11.9	16.1	22.3	22.2	22.0
22	3.8	10.4	13.8	22.3	22.1	21.9
23	2.9	9.0	11.9	22.2	22.1	21.9
24	2.3	7.7	10.3	22.0	22.0	21.9
Mean	14.9	15.8	15.4	22.0	21.9	21.9

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 74°F (23°C)

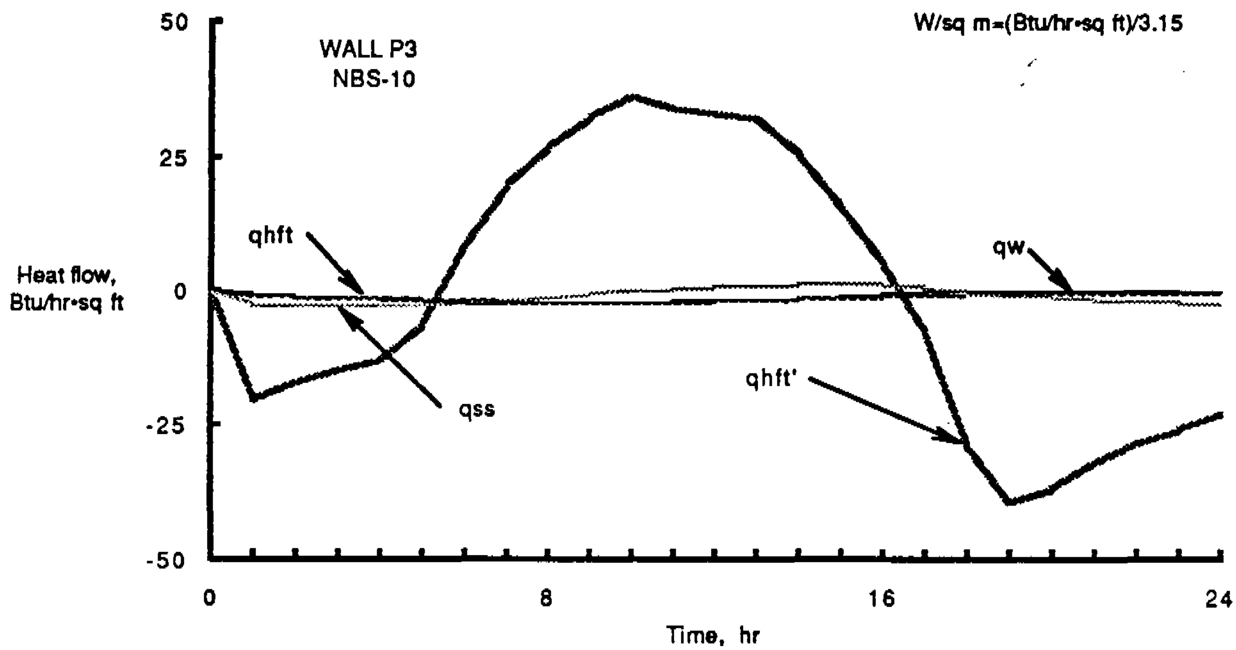

Fig. C27 Heat Flow for NBS-10 Test Cycle Applied to Wall P3

TABLE C18(a) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P3, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-0.79	-1.03	-20.46	-2.69
2	-1.21	-1.25	-17.21	-2.80
3	-1.41	-1.45	-14.89	-2.87
4	-1.56	-1.65	-12.89	-2.95
5	-1.83	-1.84	-6.25	-2.84
6	-2.17	-2.03	8.51	-2.34
7	-2.23	-2.17	19.63	-1.77
8	-2.23	-2.23	26.44	-1.24
9	-2.22	-2.26	31.90	-0.70
10	-2.11	-2.24	35.99	-0.12
11	-1.96	-2.16	33.58	0.28
12	-1.92	-2.04	32.62	0.65
13	-1.71	-1.86	31.46	1.03
14	-1.50	-1.64	24.88	1.19
15	-1.16	-1.41	15.03	1.15
16	-0.70	-1.15	4.72	0.94
17	-0.26	-0.89	-7.99	0.54
18	-0.12	-0.70	-28.87	-0.27
19	0.04	-0.56	-39.59	-1.06
20	0.08	-0.48	-36.99	-1.51
21	0.05	-0.49	-32.11	-1.82
22	-0.04	-0.55	-28.39	-2.08
23	-0.20	-0.67	-25.82	-2.33
24	-0.55	-0.82	-23.07	-2.53
Mean	-1.15	-1.40	-1.24	-1.09

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 74°F (23°C)

TABLE C18(b) - HEAT FLOW FOR NBS-10 TEST CYCLE APPLIED TO WALL P3, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
1	-2.50	-3.25	-64.56	-8.47
2	-3.80	-3.95	-54.31	-8.82
3	-4.44	-4.57	-46.97	-9.05
4	-4.93	-5.20	-40.66	-9.29
5	-5.76	-5.80	-19.72	-8.96
6	-6.85	-6.39	26.84	-7.39
7	-7.05	-6.84	61.92	-5.60
8	-7.02	-7.05	83.41	-3.91
9	-7.00	-7.12	100.64	-2.22
10	-6.66	-7.06	113.54	-0.38
11	-6.20	-6.80	105.95	0.89
12	-6.06	-6.43	102.91	2.05
13	-5.38	-5.86	99.25	3.24
14	-4.72	-5.17	78.49	3.76
15	-3.66	-4.44	47.43	3.62
16	-2.22	-3.64	14.89	2.95
17	-0.81	-2.81	-25.22	1.72
18	-0.37	-2.20	-91.08	-0.84
19	0.13	-1.76	-124.90	-3.35
20	0.26	-1.51	-116.70	-4.75
21	0.15	-1.55	-101.32	-5.74
22	-0.14	-1.75	-89.58	-6.56
23	-0.63	-2.10	-81.47	-7.34
24	-1.72	-2.60	-72.78	-7.98
Mean	-3.64	-4.41	-3.92	-3.43

Calibrated Hot Box Relative Humidity:
Indoor Chamber - not available
Outdoor Chamber - 16%

Laboratory Air Temperature:
Max. - 75°F (24°C)
Min. - 74°F (23°C)

APPENDIX D - TRANSIENT TEMPERATURE TEST RESULTS

Results from transient tests are illustrated in Figs. D1 through D9 and are listed in Tables D1 through D6. Measured temperatures, temperature differentials, and heat flow through Wall P1 are illustrated in Figs. D1 through D3, respectively. Figures D4 through D6 show results for Wall P2. Figures D7 through D9 show results for Wall P3. Values are shown as a function of time. Table 13 in the "Test Results" portion of the "Dynamic Calibrated Hot Box Tests" section lists brief descriptions of symbols used in test data figures and tables.

Hourly values of measured temperatures and heat flow through Wall P1 are listed in Tables D1 and D2, respectively. Tables D3 and D4 list hourly values for Wall P2. Tables D5 and D6 list hourly values for Wall P3. Tables D1 through D6 denoted (a) and (b), respectively, list hourly test data in U.S. and SI units.

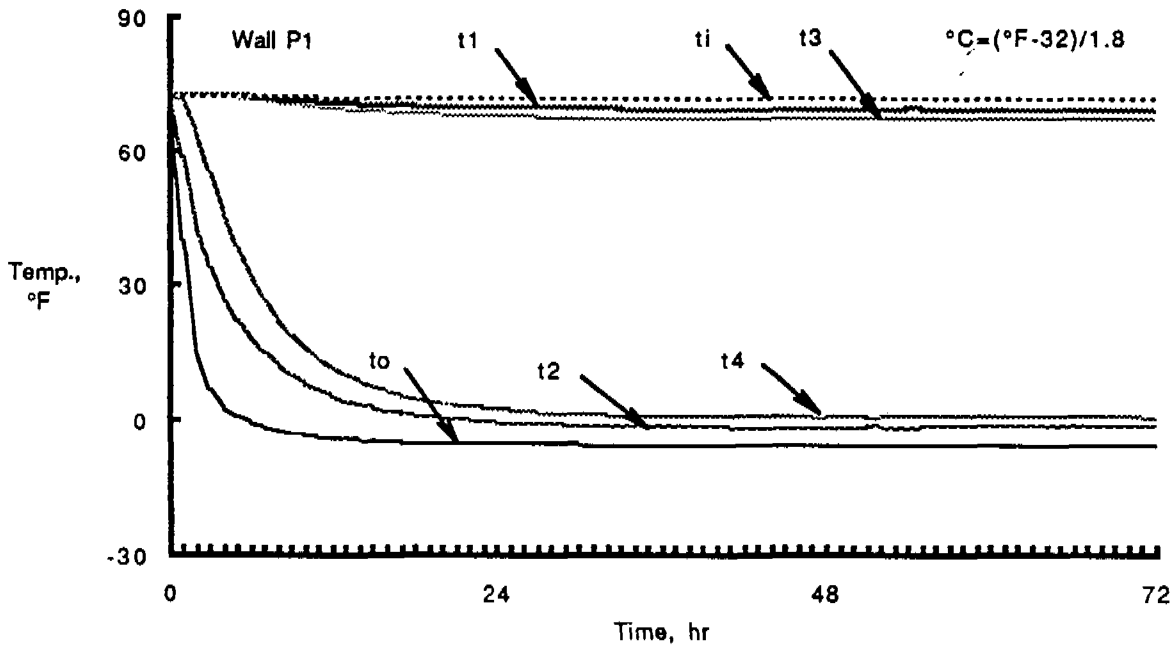

Fig. D1 Measured Temperatures for Transient Test on Wall P1

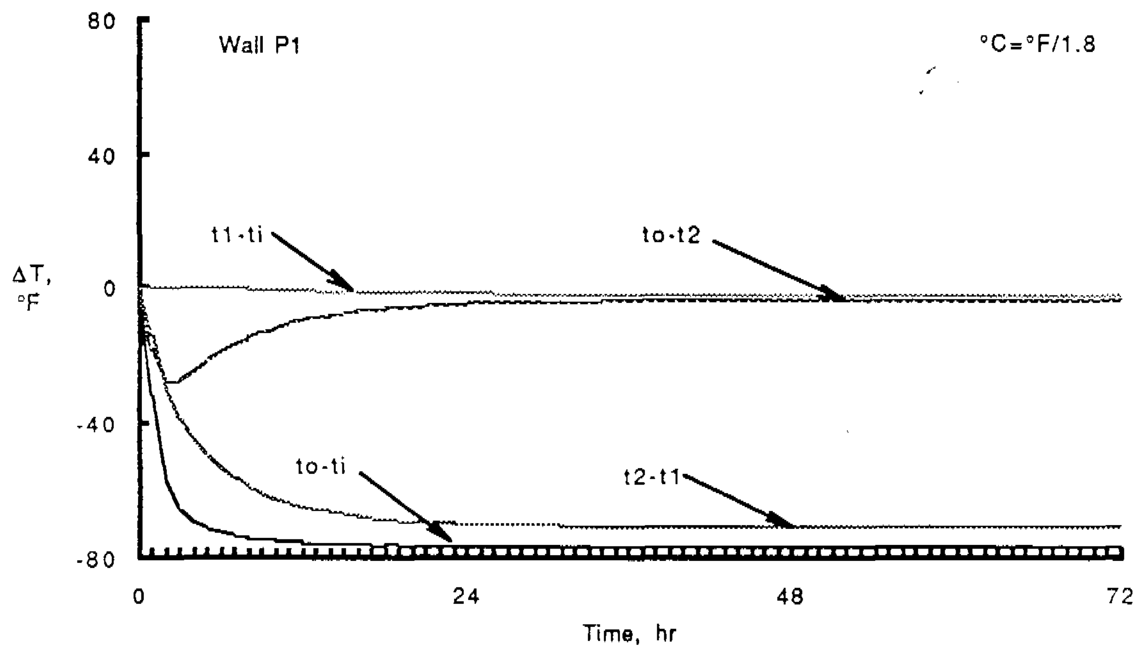

Fig. D2 Temperature Differentials for Transient Test on Wall P1

TABLE D1(a) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P1, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	71.9	72.7	72.0	72.6	72.5	72.3
1	39.9	58.5	70.9	72.6	72.5	72.3
2	15.4	43.1	64.0	72.6	72.5	72.3
3	6.8	34.0	54.8	72.3	72.4	72.3
4	2.8	27.3	46.1	72.1	72.3	72.2
5	0.7	22.3	38.4	71.7	72.1	72.2
6	-0.7	18.3	32.1	71.3	71.9	72.1
7	-1.6	15.0	26.8	71.0	71.7	72.0
8	-2.4	12.3	22.5	70.6	71.5	72.0
9	-2.9	10.1	19.0	70.2	71.2	71.9
10	-3.4	8.3	16.1	69.9	71.0	71.9
11	-3.8	6.7	13.7	69.6	70.9	71.8
12	-4.1	5.5	11.6	69.3	70.7	71.8
13	-4.3	4.4	10.0	69.1	70.5	71.7
14	-4.5	3.5	8.5	68.8	70.4	71.7
15	-4.7	2.8	7.4	68.7	70.3	71.7
16	-4.8	2.1	6.4	68.5	70.1	71.6
17	-4.9	1.6	5.5	68.3	70.0	71.6
18	-5.0	1.1	4.8	68.2	69.9	71.4
19	-5.1	0.7	4.2	68.0	69.9	71.5
20	-5.2	0.4	3.7	68.0	69.8	71.5
21	-5.2	0.1	3.2	67.8	69.7	71.5
22	-5.3	-0.2	2.9	67.8	69.7	71.5
23	-5.3	-0.4	2.6	67.7	69.6	71.5
24	-5.3	-0.5	2.3	67.7	69.6	71.5
26	-5.4	-0.8	1.8	67.5	69.5	71.4
28	-5.3	-1.0	1.6	67.5	69.5	71.4
30	-5.4	-1.1	1.3	67.4	69.4	71.4
32	-5.4	-1.3	1.2	67.3	69.4	71.4
34	-5.4	-1.4	1.0	67.3	69.4	71.4
36	-5.5	-1.4	0.9	67.3	69.3	71.4
38	-5.5	-1.5	0.8	67.2	69.3	71.4
40	-5.6	-1.6	0.8	67.2	69.3	71.4
42	-5.5	-1.6	0.8	67.2	69.3	71.4
44	-5.5	-1.6	0.8	67.2	69.3	71.4
46	-5.6	-1.6	0.7	67.2	69.2	71.4
48	-5.6	-1.7	0.7	67.1	69.2	71.4
50	-5.5	-1.6	0.7	67.2	69.3	71.4
52	-5.5	-1.6	0.7	67.3	69.3	71.4
54	-5.5	-1.6	0.7	67.2	69.4	71.4
56	-5.5	-1.5	0.7	67.2	69.3	71.4
58	-5.5	-1.5	0.7	67.3	69.3	71.4
60	-5.5	-1.5	0.7	67.3	69.3	71.4
62	-5.5	-1.4	0.7	67.3	69.3	71.4
64	-5.5	-1.4	0.7	67.2	69.3	71.4
66	-5.5	-1.5	0.7	67.3	69.3	71.4
68	-5.5	-1.5	0.7	67.2	69.3	71.4
70	-5.5	-1.5	0.8	67.3	69.3	71.4
72	-5.6	-1.6	0.6	67.1	69.2	71.3

TABLE D1(b) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P1, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	22.2	22.6	22.2	22.6	22.5	22.4
1	4.4	14.7	21.6	22.5	22.5	22.4
2	-9.2	6.2	17.8	22.5	22.5	22.4
3	-14.0	1.1	12.7	22.4	22.5	22.4
4	-16.3	-2.6	7.8	22.3	22.4	22.4
5	-17.4	-5.4	3.6	22.1	22.3	22.3
6	-18.1	-7.6	0.0	21.9	22.2	22.3
7	-18.7	-9.4	-2.9	21.6	22.0	22.2
8	-19.1	-10.9	-5.3	21.4	21.9	22.2
9	-19.4	-12.2	-7.2	21.2	21.8	22.2
10	-19.7	-13.2	-8.8	21.1	21.7	22.2
11	-19.9	-14.0	-10.2	20.9	21.6	22.1
12	-20.0	-14.7	-11.3	20.7	21.5	22.1
13	-20.2	-15.4	-12.2	20.6	21.4	22.1
14	-20.3	-15.8	-13.0	20.5	21.3	22.0
15	-20.4	-16.2	-13.7	20.4	21.3	22.0
16	-20.5	-16.6	-14.3	20.3	21.2	22.0
17	-20.5	-16.9	-14.7	20.2	21.1	22.0
18	-20.6	-17.2	-15.1	20.1	21.1	21.9
19	-20.6	-17.4	-15.4	20.0	21.0	22.0
20	-20.7	-17.6	-15.7	20.0	21.0	21.9
21	-20.7	-17.7	-16.0	19.9	21.0	21.9
22	-20.7	-17.9	-16.2	19.9	20.9	21.9
23	-20.7	-18.0	-16.3	19.8	20.9	22.0
24	-20.7	-18.1	-16.5	19.8	20.9	21.9
26	-20.8	-18.2	-16.8	19.7	20.8	21.9
28	-20.7	-18.3	-16.9	19.7	20.8	21.9
30	-20.8	-18.4	-17.0	19.7	20.8	21.9
32	-20.8	-18.5	-17.1	19.6	20.8	21.9
34	-20.8	-18.6	-17.2	19.6	20.8	21.9
36	-20.8	-18.6	-17.3	19.6	20.7	21.9
38	-20.9	-18.6	-17.3	19.6	20.7	21.9
40	-20.9	-18.6	-17.4	19.6	20.7	21.9
42	-20.8	-18.7	-17.3	19.6	20.7	21.9
44	-20.8	-18.7	-17.4	19.6	20.7	21.9
46	-20.9	-18.7	-17.4	19.6	20.7	21.9
48	-20.9	-18.7	-17.4	19.5	20.7	21.9
50	-20.8	-18.7	-17.4	19.6	20.7	21.9
52	-20.9	-18.6	-17.4	19.6	20.7	21.9
54	-20.8	-18.6	-17.4	19.6	20.8	21.9
56	-20.8	-18.6	-17.4	19.6	20.7	21.9
58	-20.8	-18.6	-17.4	19.6	20.7	21.9
60	-20.8	-18.6	-17.4	19.6	20.7	21.9
62	-20.8	-18.6	-17.4	19.6	20.7	21.9
64	-20.8	-18.6	-17.4	19.6	20.7	21.9
66	-20.8	-18.6	-17.4	19.6	20.7	21.9
68	-20.8	-18.6	-17.4	19.6	20.7	21.9
70	-20.8	-18.6	-17.4	19.6	20.7	21.9
72	-20.9	-18.7	-17.4	19.5	20.7	21.8

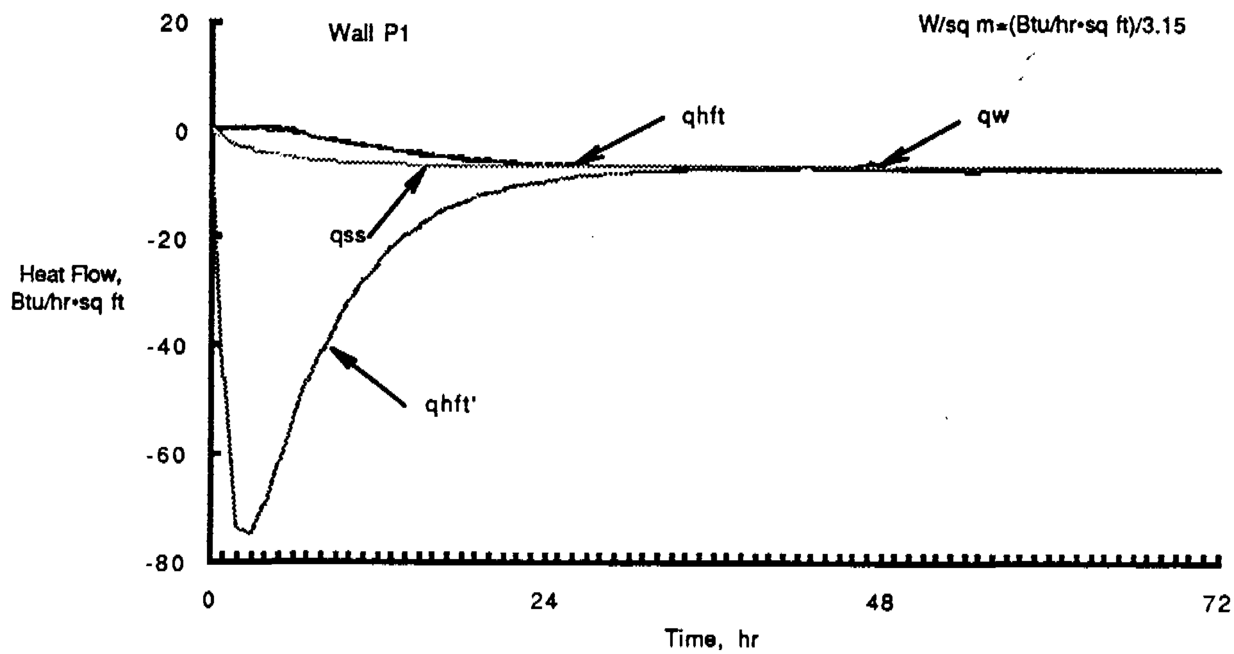

Fig. D3 Heat Flow for Transient Test on Wall P1

TABLE D2(a) - HEAT FLOW FOR TRANSIENT TEST ON WALL P1, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	0.37	0.21	0.09	0.02
1	0.71	0.21	-45.82	-1.56
2	0.79	0.20	-74.02	-3.15
3	0.68	0.08	-75.00	-4.04
4	0.38	-0.16	-69.17	-4.65
5	-0.01	-0.44	-61.06	-5.09
6	-0.48	-0.85	-53.33	-5.43
7	-1.11	-1.23	-46.34	-5.69
8	-1.73	-1.72	-40.79	-5.90
9	-2.25	-2.15	-35.82	-6.07
10	-2.68	-2.62	-31.61	-6.20
11	-3.23	-3.04	-27.76	-6.30
12	-3.67	-3.45	-24.65	-6.39
13	-3.97	-3.84	-21.80	-6.46
14	-4.40	-4.20	-19.54	-6.52
15	-4.82	-4.55	-17.73	-6.57
16	-5.11	-4.83	-16.06	-6.61
17	-5.31	-5.09	-14.57	-6.64
18	-5.67	-5.31	-13.40	-6.66
19	-5.63	-5.49	-12.43	-6.69
20	-5.90	-5.74	-11.73	-6.71
21	-6.07	-5.93	-10.98	-6.72
22	-6.07	-6.08	-10.35	-6.74
23	-6.22	-6.16	-9.80	-6.75
24	-6.38	-6.30	-9.40	-6.76
26	-6.61	-6.49	-8.69	-6.77
28	-6.74	-6.61	-8.16	-6.78
30	-6.74	-6.73	-7.84	-6.78
32	-6.80	-6.83	-7.53	-6.79
34	-6.89	-6.92	-7.35	-6.80
36	-6.98	-6.91	-7.21	-6.80
38	-6.94	-6.99	-7.19	-6.81
40	-6.89	-7.01	-7.13	-6.81
42	-6.84	-6.98	-6.98	-6.81
44	-6.82	-7.02	-7.05	-6.81
46	-6.54	-7.02	-6.95	-6.80
48	-6.63	-7.02	-7.02	-6.81
50	-7.05	-7.06	-6.91	-6.81
52	-6.65	-7.11	-6.81	-6.81
54	-7.45	-7.10	-6.88	-6.82
56	-7.27	-7.04	-6.83	-6.81
58	-7.25	-7.11	-6.87	-6.81
60	-7.05	-7.07	-6.90	-6.80
62	-7.06	-7.12	-6.82	-6.80
64	-7.18	-7.08	-6.90	-6.80
66	-6.94	-7.08	-6.90	-6.81
68	-7.05	-7.08	-6.87	-6.80
70	-6.98	-7.04	-6.81	-6.80
72	-7.00	-7.06	-6.95	-6.80

TABLE D2(b) - HEAT FLOW FOR TRANSIENT TEST ON WALL P1, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	1.15	0.67	0.30	0.06
1	2.23	0.66	-144.55	-4.91
2	2.49	0.62	-233.52	-9.93
3	2.13	0.25	-236.62	-12.74
4	1.21	-0.52	-218.23	-14.68
5	-0.03	-1.38	-192.64	-16.07
6	-1.53	-2.67	-168.27	-17.13
7	-3.52	-3.88	-146.22	-17.96
8	-5.47	-5.41	-128.71	-18.62
9	-7.10	-6.78	-113.00	-19.14
10	-8.46	-8.28	-99.74	-19.56
11	-10.18	-9.60	-87.57	-19.89
12	-11.57	-10.88	-77.77	-20.16
13	-12.52	-12.12	-68.79	-20.39
14	-13.88	-13.25	-61.66	-20.56
15	-15.21	-14.35	-55.93	-20.72
16	-16.12	-15.23	-50.66	-20.84
17	-16.77	-16.06	-45.96	-20.95
18	-17.89	-16.76	-42.27	-21.03
19	-17.75	-17.31	-39.21	-21.11
20	-18.61	-18.11	-37.01	-21.16
21	-19.16	-18.71	-34.64	-21.22
22	-19.16	-19.17	-32.64	-21.26
23	-19.63	-19.44	-30.92	-21.29
24	-20.14	-19.88	-29.64	-21.32
26	-20.86	-20.48	-27.42	-21.36
28	-21.26	-20.86	-25.76	-21.40
30	-21.27	-21.24	-24.75	-21.41
32	-21.44	-21.56	-23.76	-21.43
34	-21.73	-21.83	-23.18	-21.46
36	-22.03	-21.81	-22.73	-21.44
38	-21.89	-22.06	-22.68	-21.48
40	-21.75	-22.12	-22.48	-21.47
42	-21.58	-22.02	-22.02	-21.49
44	-21.50	-22.14	-22.24	-21.48
46	-20.64	-22.14	-21.93	-21.46
48	-20.93	-22.15	-22.14	-21.48
50	-22.26	-22.27	-21.79	-21.48
52	-20.97	-22.44	-21.50	-21.47
54	-23.51	-22.38	-21.70	-21.50
56	-22.93	-22.23	-21.53	-21.48
58	-22.89	-22.44	-21.67	-21.47
60	-22.24	-22.29	-21.77	-21.45
62	-22.28	-22.46	-21.52	-21.46
64	-22.64	-22.35	-21.78	-21.46
66	-21.91	-22.33	-21.76	-21.47
68	-22.26	-22.33	-21.69	-21.46
70	-22.03	-22.21	-21.48	-21.46
72	-22.07	-22.28	-21.94	-21.46

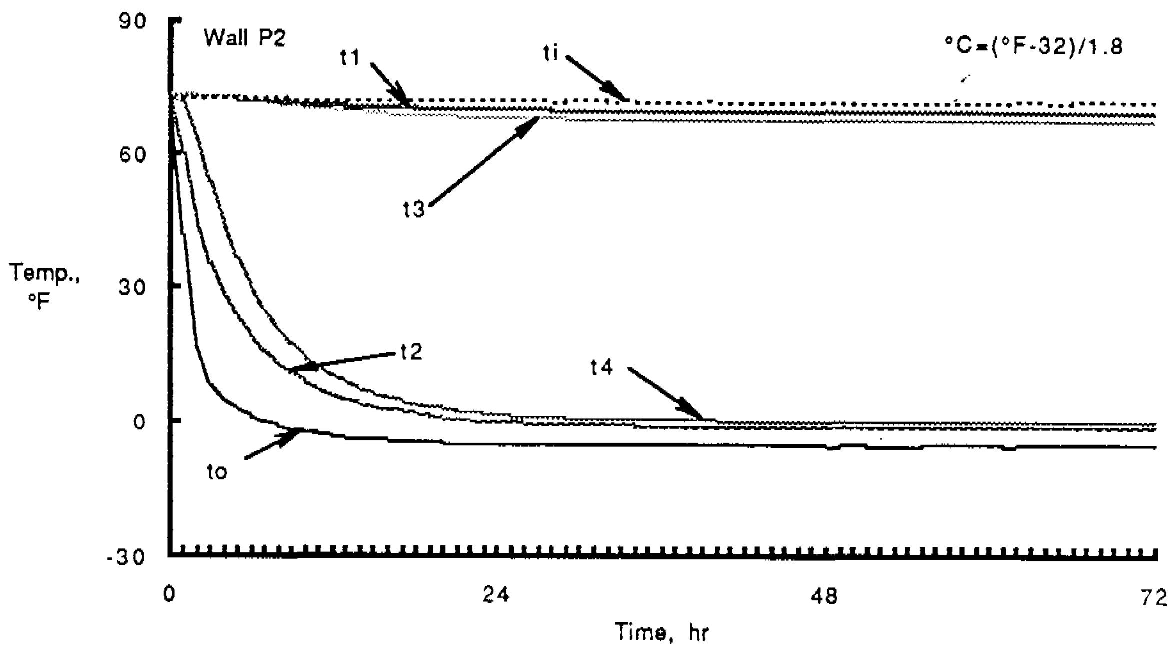

Fig. D4 Measured Temperatures for Transient Test on Wall P2

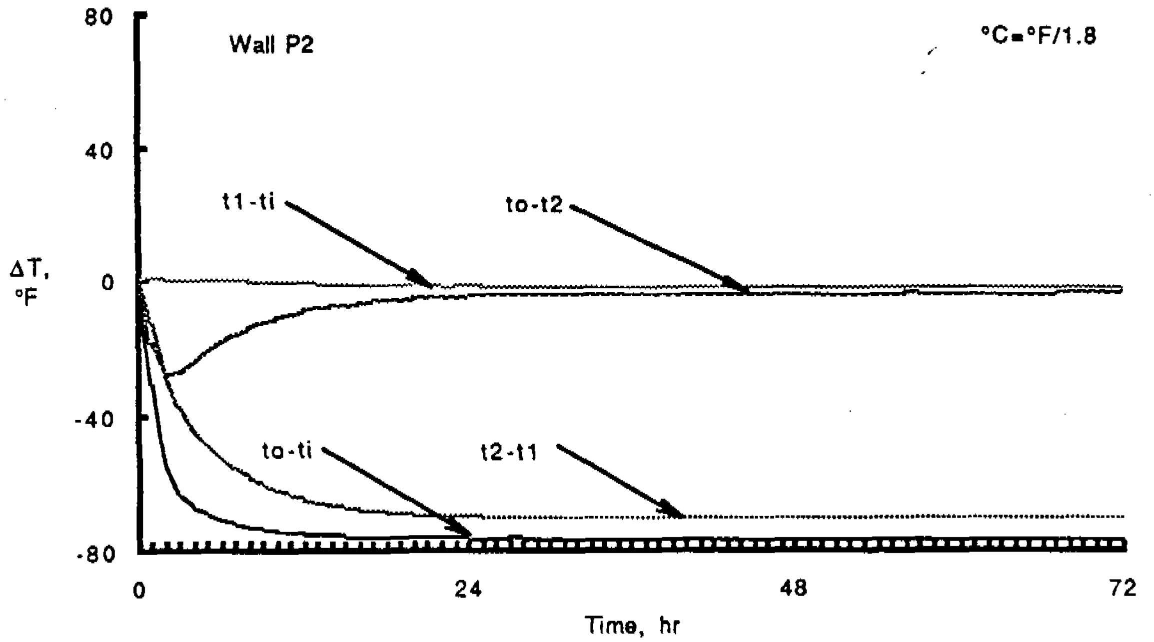

Fig. D5 Temperature Differentials for Transient Test on Wall P2

TABLE D3(a) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P2, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	72.8	73.6	72.7	73.0	72.5	72.2
1	41.7	60.3	71.2	73.0	72.5	72.2
2	17.0	45.0	63.4	72.9	72.5	72.2
3	8.2	35.4	53.4	72.7	72.4	72.2
4	4.7	28.7	44.1	72.3	72.3	72.1
5	2.6	23.4	36.3	71.9	72.1	72.1
6	1.0	19.1	29.9	71.5	71.8	72.0
7	-0.2	15.7	24.5	71.1	71.6	72.0
8	-1.1	12.8	20.5	70.7	71.4	72.0
9	-1.8	10.5	17.1	70.4	71.2	71.8
10	-2.5	8.6	14.3	70.1	71.0	71.8
11	-3.0	7.1	11.9	69.8	70.8	71.7
12	-3.4	5.7	10.0	69.5	70.7	71.7
13	-3.8	4.6	8.4	69.2	70.5	71.6
14	-4.0	3.7	7.0	69.0	70.3	71.6
15	-4.2	2.9	6.0	68.8	70.2	71.6
16	-4.4	2.3	5.1	68.6	70.1	71.4
17	-4.5	1.7	4.3	68.4	69.9	71.5
18	-4.7	1.3	3.6	68.3	69.9	71.5
19	-4.8	0.9	3.0	68.1	69.8	71.5
20	-4.9	0.6	2.6	68.0	69.7	71.4
21	-5.0	0.3	2.2	67.9	69.6	71.4
22	-5.0	0.0	1.8	67.8	69.4	71.4
23	-5.1	-0.2	1.6	67.8	69.5	71.3
24	-5.1	-0.3	1.4	67.7	69.5	71.4
26	-5.1	-0.5	1.0	67.6	69.4	71.4
28	-5.2	-0.7	0.7	67.5	69.3	71.3
30	-5.3	-0.9	0.5	67.5	69.4	71.4
32	-5.3	-1.0	0.3	67.4	69.3	71.3
34	-5.3	-1.0	0.3	67.4	69.3	71.3
36	-5.3	-1.1	0.2	67.4	69.3	71.3
38	-5.3	-1.1	0.1	67.4	69.3	71.3
40	-5.3	-1.1	0.1	67.4	69.2	71.3
42	-5.3	-1.2	0.1	67.4	69.2	71.3
44	-5.3	-1.2	0.1	67.4	69.2	71.3
46	-5.4	-1.2	0.0	67.3	69.2	71.3
48	-5.4	-1.2	0.0	67.4	69.2	71.3
50	-5.4	-1.2	0.1	67.3	69.2	71.3
52	-5.4	-1.2	0.0	67.3	69.2	71.3
54	-5.4	-1.3	0.0	67.3	69.2	71.3
56	-5.3	-1.3	0.0	67.2	69.2	71.3
58	-5.4	-1.2	0.0	67.3	69.2	71.3
60	-5.3	-1.2	0.0	67.3	69.2	71.3
62	-5.4	-1.2	0.0	67.3	69.2	71.3
64	-5.4	-1.2	0.0	67.3	69.2	71.3
66	-5.3	-1.2	0.0	67.3	69.2	71.4
68	-5.3	-1.3	0.0	67.3	69.1	71.4
70	-5.3	-1.3	0.0	67.3	69.2	71.3
72	-5.3	-1.3	0.0	67.3	69.2	71.3

TABLE D3(b) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P2, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t3 Internal Outdoor	t4 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	22.7	23.1	22.6	22.8	22.5	22.3
1	5.4	15.7	21.8	22.8	22.5	22.3
2	-8.3	7.2	17.4	22.7	22.5	22.3
3	-13.2	1.9	11.9	22.6	22.5	22.3
4	-15.2	-1.9	6.7	22.4	22.4	22.3
5	-16.3	-4.8	2.4	22.2	22.3	22.3
6	-17.2	-7.2	-1.2	21.9	22.1	22.2
7	-17.9	-9.1	-4.2	21.7	22.0	22.2
8	-18.4	-10.7	-6.4	21.5	21.9	22.2
9	-18.8	-11.9	-8.3	21.3	21.8	22.1
10	-19.2	-13.0	-9.9	21.1	21.7	22.1
11	-19.5	-13.9	-11.2	21.0	21.6	22.1
12	-19.7	-14.6	-12.2	20.8	21.5	22.1
13	-19.9	-15.2	-13.1	20.7	21.4	22.0
14	-20.0	-15.7	-13.9	20.6	21.3	22.0
15	-20.1	-16.2	-14.5	20.4	21.2	22.0
16	-20.2	-16.5	-15.0	20.3	21.1	21.9
17	-20.3	-16.8	-15.4	20.2	21.1	22.0
18	-20.4	-17.1	-15.8	20.1	21.0	21.9
19	-20.4	-17.3	-16.1	20.1	21.0	21.9
20	-20.5	-17.5	-16.3	20.0	20.9	21.9
21	-20.5	-17.6	-16.6	20.0	20.9	21.9
22	-20.6	-17.8	-16.8	19.9	20.8	21.9
23	-20.6	-17.9	-16.9	19.9	20.8	21.9
24	-20.6	-18.0	-17.0	19.8	20.8	21.9
26	-20.6	-18.1	-17.2	19.8	20.8	21.9
28	-20.7	-18.2	-17.4	19.7	20.7	21.8
30	-20.7	-18.3	-17.5	19.7	20.8	21.9
32	-20.7	-18.3	-17.6	19.7	20.7	21.8
34	-20.7	-18.4	-17.6	19.7	20.7	21.8
36	-20.7	-18.4	-17.7	19.7	20.7	21.8
38	-20.7	-18.4	-17.7	19.7	20.7	21.8
40	-20.7	-18.4	-17.7	19.7	20.7	21.8
42	-20.7	-18.4	-17.7	19.6	20.7	21.8
44	-20.7	-18.4	-17.7	19.7	20.7	21.8
46	-20.8	-18.5	-17.8	19.6	20.7	21.8
48	-20.8	-18.5	-17.8	19.7	20.7	21.8
50	-20.8	-18.5	-17.8	19.6	20.7	21.8
52	-20.8	-18.5	-17.8	19.6	20.7	21.8
54	-20.8	-18.5	-17.8	19.6	20.7	21.8
56	-20.7	-18.5	-17.8	19.6	20.7	21.8
58	-20.8	-18.5	-17.8	19.6	20.7	21.8
60	-20.7	-18.5	-17.8	19.6	20.7	21.8
62	-20.8	-18.5	-17.8	19.6	20.7	21.9
64	-20.8	-18.4	-17.8	19.6	20.7	21.8
66	-20.7	-18.5	-17.8	19.6	20.7	21.9
68	-20.7	-18.5	-17.8	19.6	20.6	21.9
70	-20.7	-18.5	-17.8	19.6	20.7	21.9
72	-20.7	-18.5	-17.8	19.6	20.7	21.9

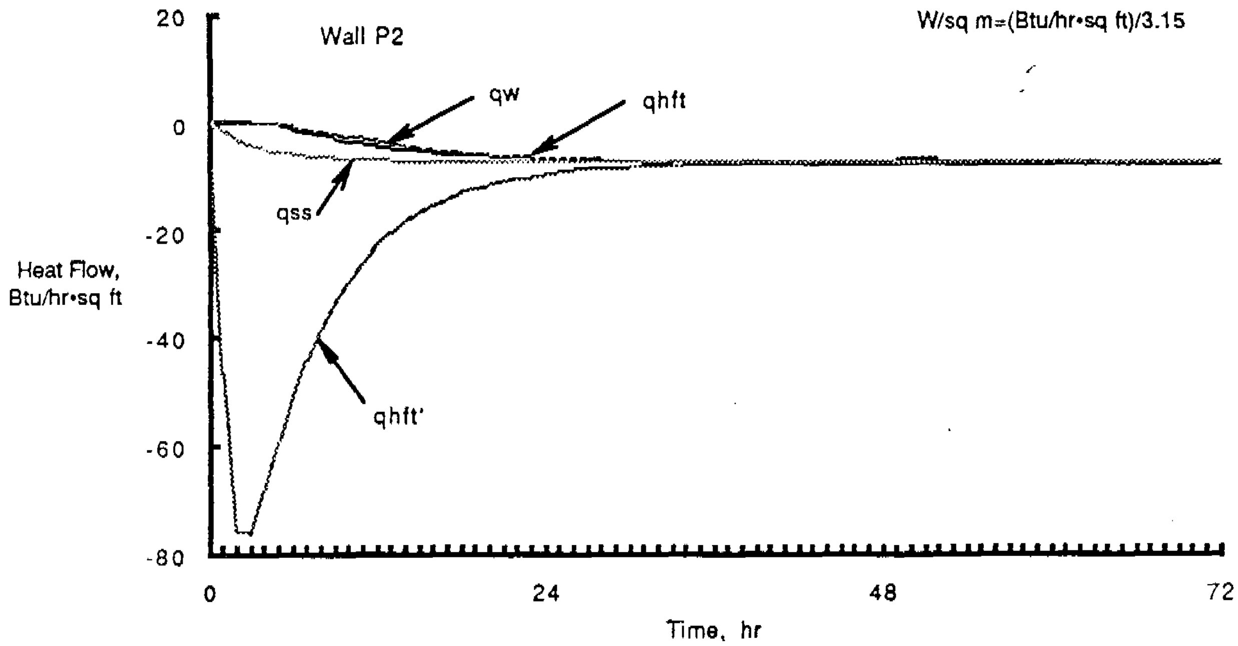

Fig. D6 Heat Flow for Transient Test on Wall P2

TABLE D4(a) - HEAT FLOW FOR TRANSIENT TEST ON WALL P2, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	0.10	0.34	0.25	0.13
1	0.22	0.33	-46.62	-1.48
2	0.38	0.30	-75.76	-3.21
3	0.28	0.20	-76.13	-4.24
4	-0.07	0.02	-67.50	-4.92
5	-0.51	-0.34	-59.00	-5.43
6	-1.14	-0.77	-51.19	-5.83
7	-1.78	-1.28	-44.06	-6.14
8	-2.37	-1.77	-38.36	-6.38
9	-3.06	-2.27	-33.55	-6.58
10	-3.72	-2.80	-29.46	-6.73
11	-4.13	-3.27	-26.12	-6.86
12	-4.52	-3.70	-22.88	-6.96
13	-4.84	-4.13	-20.52	-7.04
14	-4.99	-4.49	-18.32	-7.10
15	-5.19	-4.84	-16.58	-7.15
16	-5.65	-5.17	-15.21	-7.20
17	-5.62	-5.42	-13.94	-7.23
18	-5.89	-5.72	-12.85	-7.26
19	-5.86	-5.96	-12.17	-7.28
20	-6.08	-6.13	-11.28	-7.31
21	-6.08	-6.30	-10.73	-7.33
22	-6.15	-6.43	-10.22	-7.32
23	-6.52	-6.59	-9.82	-7.34
24	-6.66	-6.74	-9.38	-7.36
26	-6.92	-6.98	-8.78	-7.37
28	-7.04	-7.09	-8.47	-7.38
30	-7.43	-7.29	-8.08	-7.40
32	-7.53	-7.36	-8.01	-7.40
34	-7.26	-7.39	-7.85	-7.40
36	-7.09	-7.46	-7.76	-7.40
38	-7.05	-7.48	-7.67	-7.40
40	-7.36	-7.55	-7.54	-7.40
42	-7.45	-7.63	-7.59	-7.40
44	-7.29	-7.61	-7.59	-7.40
46	-7.14	-7.58	-7.55	-7.41
48	-7.11	-7.59	-7.51	-7.41
50	-6.67	-7.50	-7.53	-7.41
52	-7.25	-7.57	-7.50	-7.40
54	-7.31	-7.59	-7.50	-7.41
56	-7.36	-7.64	-7.45	-7.41
58	-7.19	-7.62	-7.39	-7.41
60	-7.32	-7.63	-7.41	-7.41
62	-7.15	-7.62	-7.44	-7.41
64	-7.45	-7.66	-7.43	-7.41
66	-7.36	-7.68	-7.42	-7.41
68	-7.47	-7.69	-7.42	-7.40
70	-7.28	-7.67	-7.44	-7.41
72	-7.08	-7.60	-7.38	-7.41

TABLE D4(b) - HEAT FLOW FOR TRANSIENT TEST ON WALL P2, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	0.31	1.07	0.78	0.40
1	0.70	1.04	-147.08	-4.66
2	1.19	0.95	-239.01	-10.12
3	0.88	0.64	-240.20	-13.37
4	-0.21	0.05	-212.95	-15.53
5	-1.61	-1.07	-186.16	-17.14
6	-3.61	-2.43	-161.50	-18.39
7	-5.62	-4.03	-138.99	-19.36
8	-7.48	-5.59	-121.02	-20.14
9	-9.66	-7.15	-105.86	-20.75
10	-11.74	-8.84	-92.93	-21.23
11	-13.03	-10.31	-82.42	-21.63
12	-14.26	-11.68	-72.18	-21.94
13	-15.26	-13.04	-64.74	-22.20
14	-15.74	-14.18	-57.80	-22.40
15	-16.39	-15.28	-52.32	-22.57
16	-17.81	-16.31	-47.98	-22.71
17	-17.74	-17.10	-43.97	-22.82
18	-18.59	-18.05	-40.55	-22.91
19	-18.47	-18.79	-38.38	-22.98
20	-19.18	-19.35	-35.57	-23.05
21	-19.19	-19.88	-33.86	-23.11
22	-19.40	-20.29	-32.23	-23.10
23	-20.56	-20.78	-30.98	-23.17
24	-21.01	-21.25	-29.60	-23.21
26	-21.84	-22.02	-27.69	-23.25
28	-22.20	-22.38	-26.74	-23.28
30	-23.44	-23.01	-25.48	-23.34
32	-23.76	-23.22	-25.26	-23.34
34	-22.90	-23.32	-24.77	-23.35
36	-22.37	-23.52	-24.48	-23.36
38	-22.25	-23.61	-24.19	-23.36
40	-23.23	-23.82	-23.78	-23.36
42	-23.49	-24.08	-23.95	-23.36
44	-22.99	-24.00	-23.96	-23.36
46	-22.54	-23.91	-23.83	-23.37
48	-22.44	-23.96	-23.68	-23.38
50	-21.03	-23.66	-23.76	-23.37
52	-22.88	-23.90	-23.65	-23.36
54	-23.06	-23.95	-23.65	-23.38
56	-23.21	-24.12	-23.50	-23.37
58	-22.68	-24.03	-23.31	-23.37
60	-23.09	-24.08	-23.37	-23.36
62	-22.57	-24.04	-23.46	-23.37
64	-23.51	-24.18	-23.45	-23.37
66	-23.24	-24.24	-23.42	-23.37
68	-23.56	-24.26	-23.39	-23.34
70	-22.98	-24.19	-23.47	-23.37
72	-22.34	-23.97	-23.29	-23.37

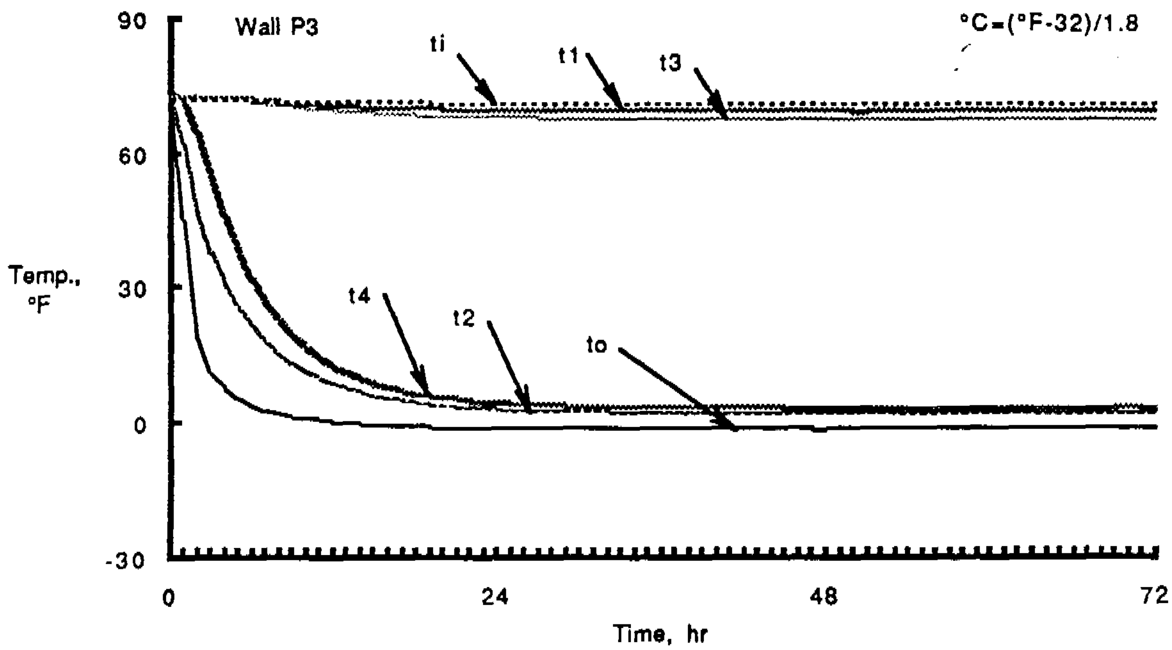

Fig. D7 Measured Temperatures for Transient Test on Wall P3

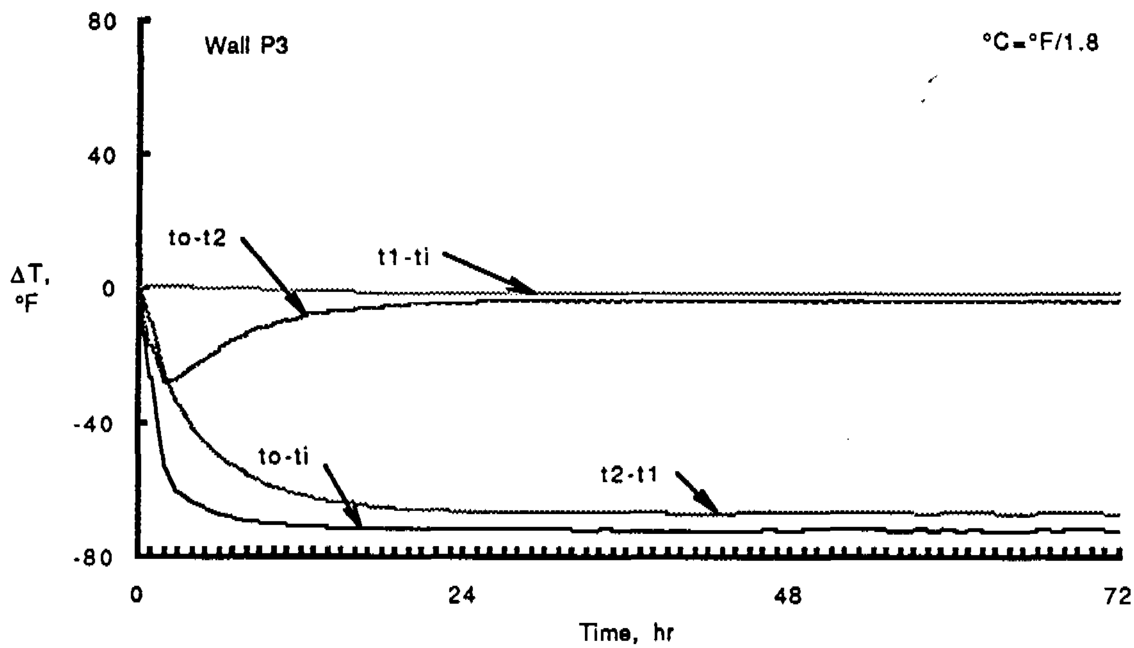

Fig. D8 Temperature Differentials for Transient Test on Wall P3

TABLE D5(a) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P3, US UNITS

Time, hr	Measured Temperatures, °F					
	to Outdoor Air	t2 Outdoor Surface	t4 Internal Outdoor	t3 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	73.0	69.3	72.8	72.5	72.0	71.5
1	44.9	58.1	71.6	72.5	72.0	71.5
2	19.0	43.9	64.4	72.4	72.0	71.6
3	10.9	35.1	54.7	72.1	71.9	71.6
4	7.7	29.0	45.6	71.9	71.8	71.5
5	5.5	24.2	38.0	71.5	71.6	71.4
6	3.8	20.2	31.8	71.1	71.4	71.3
7	2.7	17.0	26.7	70.7	71.2	71.3
8	1.8	14.4	22.6	70.3	71.0	71.3
9	1.2	12.2	19.2	70.0	70.7	71.2
10	0.7	10.5	16.5	69.7	70.5	71.1
11	0.3	9.0	14.2	69.4	70.3	71.1
12	-0.1	8.0	12.4	69.1	70.2	71.0
13	-0.3	7.6	10.9	68.9	70.0	71.0
14	-0.5	6.7	9.6	68.6	69.9	70.9
15	-0.6	5.9	8.5	68.4	69.8	70.9
16	-0.8	5.3	7.6	68.2	69.6	70.8
17	-0.9	4.8	6.9	68.1	69.6	70.8
18	-1.0	4.4	6.3	68.0	69.5	70.8
19	-1.1	4.0	5.8	67.9	69.4	70.8
20	-1.2	3.6	5.4	67.8	69.3	70.7
21	-1.2	3.2	5.0	67.7	69.3	70.7
22	-1.3	2.9	4.7	67.7	69.2	70.7
23	-1.3	2.8	4.4	67.6	69.2	70.7
24	-1.3	2.7	4.2	67.6	69.2	70.7
26	-1.3	2.5	3.9	67.5	69.1	70.7
28	-1.3	2.3	3.7	67.4	69.1	70.7
30	-1.4	2.2	3.5	67.4	69.0	70.7
32	-1.4	2.3	3.4	67.3	69.0	70.7
34	-1.4	2.3	3.3	67.2	69.0	70.7
36	-1.4	2.2	3.2	67.3	69.0	70.7
38	-1.4	2.2	3.2	67.2	68.9	70.7
40	-1.4	2.1	3.2	67.3	69.0	70.7
42	-1.4	2.2	3.1	67.2	69.0	70.7
44	-1.4	2.0	3.1	67.2	69.0	70.7
46	-1.5	1.9	3.0	67.2	68.9	70.5
48	-1.6	1.8	2.9	67.1	68.8	70.5
50	-1.5	1.8	3.0	67.1	68.8	70.5
52	-1.4	1.9	3.1	67.1	68.9	70.6
54	-1.4	1.9	3.0	67.1	68.9	70.6
56	-1.5	1.9	3.0	67.1	68.9	70.6
58	-1.5	1.9	3.0	67.1	68.9	70.6
60	-1.4	1.9	3.1	67.1	68.9	70.6
62	-1.4	1.9	3.1	67.2	68.9	70.7
64	-1.4	1.9	3.0	67.2	69.0	70.7
66	-1.4	1.9	3.1	67.2	68.9	70.7
68	-1.4	1.9	3.1	67.2	69.0	70.6
70	-1.3	2.0	3.1	67.2	68.9	70.6
72	-1.4	2.0	3.1	67.2	68.9	70.6

TABLE D5(b) - MEASURED TEMPERATURES FOR TRANSIENT TEST ON WALL P3, SI UNITS

Time, hr	Measured Temperatures, °C					
	to Outdoor Air	t2 Outdoor Surface	t3 Internal Outdoor	t4 Internal Indoor	t1 Indoor Surface	ti Indoor Air
0	22.8	20.7	22.6	22.5	22.2	-17.8
1	7.2	14.5	22.0	22.5	22.2	-17.8
2	-7.2	6.6	18.0	22.4	22.2	-17.8
3	-11.7	1.7	12.6	22.3	22.2	-17.8
4	-13.5	-1.7	7.6	22.2	22.1	-17.8
5	-14.7	-4.3	3.4	21.9	22.0	-17.8
6	-15.7	-6.5	-0.1	21.7	21.9	-17.8
7	-16.3	-8.3	-2.9	21.5	21.8	-17.8
8	-16.8	-9.8	-5.2	21.3	21.6	-17.8
9	-17.1	-11.0	-7.1	21.1	21.5	-17.8
10	-17.4	-12.0	-8.6	20.9	21.4	-17.8
11	-17.6	-12.8	-9.9	20.8	21.3	-17.8
12	-17.8	-13.4	-10.9	20.6	21.2	-17.8
13	-17.9	-13.6	-11.8	20.5	21.1	-17.8
14	-18.1	-14.1	-12.5	20.4	21.0	-17.8
15	-18.1	-14.5	-13.1	20.2	21.0	-17.8
16	-18.2	-14.8	-13.5	20.1	20.9	-17.8
17	-18.3	-15.1	-13.9	20.1	20.9	-17.8
18	-18.3	-15.3	-14.3	20.0	20.8	-17.8
19	-18.4	-15.6	-14.6	20.0	20.8	-17.8
20	-18.4	-15.8	-14.8	19.9	20.7	-17.8
21	-18.4	-16.0	-15.0	19.8	20.7	-17.8
22	-18.5	-16.1	-15.2	19.8	20.7	-17.8
23	-18.5	-16.2	-15.3	19.8	20.7	-17.8
24	-18.5	-16.3	-15.4	19.8	20.7	-17.8
26	-18.5	-16.4	-15.6	19.7	20.6	-17.8
28	-18.5	-16.5	-15.7	19.7	20.6	-17.8
30	-18.5	-16.6	-15.8	19.6	20.6	-17.8
32	-18.6	-16.5	-15.9	19.6	20.6	-17.8
34	-18.6	-16.5	-16.0	19.6	20.6	-17.8
36	-18.6	-16.6	-16.0	19.6	20.6	-17.8
38	-18.6	-16.6	-16.0	19.6	20.5	-17.8
40	-18.6	-16.6	-16.0	19.6	20.6	-17.8
42	-18.6	-16.6	-16.1	19.6	20.6	-17.8
44	-18.6	-16.7	-16.0	19.6	20.5	-17.8
46	-18.6	-16.7	-16.1	19.5	20.5	-17.8
48	-18.6	-16.8	-16.1	19.5	20.5	-17.8
50	-18.6	-16.8	-16.1	19.5	20.4	-17.8
52	-18.6	-16.7	-16.1	19.5	20.5	-17.8
54	-18.6	-16.7	-16.1	19.5	20.5	-17.8
56	-18.6	-16.7	-16.1	19.5	20.5	-17.8
58	-18.6	-16.7	-16.1	19.5	20.5	-17.8
60	-18.6	-16.7	-16.1	19.5	20.5	-17.8
62	-18.6	-16.7	-16.1	19.6	20.5	-17.8
64	-18.6	-16.7	-16.1	19.6	20.5	-17.8
66	-18.5	-16.7	-16.1	19.6	20.5	-17.8
68	-18.5	-16.7	-16.1	19.5	20.5	-17.8
70	-18.5	-16.7	-16.1	19.5	20.5	-17.8
72	-18.6	-16.7	-16.1	19.5	20.5	-17.8

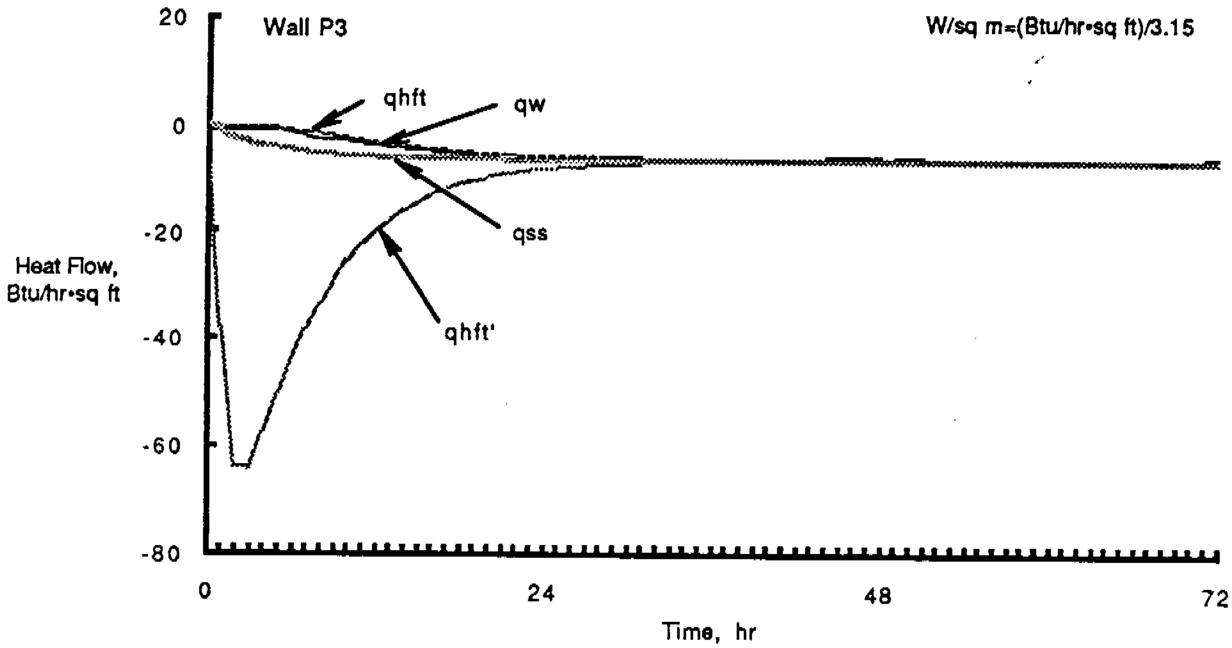

Fig. D9 Heat Flow for Transient Test on Wall P3

TABLE D6(a) - HEAT FLOW FOR TRANSIENT TEST ON WALL P3, US UNITS

Time, hr	Measured Heat Flow, Btu/hr•sq ft			Calculated Heat Flow, Btu/hr•sq ft
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	-0.74	-0.18	-0.35	-0.27
1	-0.70	-0.19	-37.91	-1.37
2	-0.64	-0.22	-64.03	-2.76
3	-0.65	-0.30	-64.26	-3.60
4	-0.83	-0.48	-57.29	-4.17
5	-0.95	-0.71	-50.31	-4.60
6	-1.49	-1.07	-43.83	-4.96
7	-2.02	-1.47	-38.18	-5.24
8	-2.49	-1.89	-33.56	-5.46
9	-2.87	-2.30	-29.29	-5.65
10	-3.03	-2.70	-25.64	-5.78
11	-3.41	-3.06	-22.42	-5.90
12	-3.76	-3.48	-20.04	-5.98
13	-4.25	-3.80	-17.77	-6.00
14	-4.44	-4.12	-15.95	-6.07
15	-4.59	-4.41	-14.37	-6.13
16	-4.87	-4.64	-12.90	-6.17
17	-5.12	-4.89	-11.99	-6.21
18	-5.33	-5.14	-11.02	-6.24
19	-5.42	-5.30	-10.36	-6.27
20	-5.58	-5.47	-9.71	-6.30
21	-5.53	-5.58	-9.17	-6.33
22	-5.70	-5.70	-8.77	-6.35
23	-5.83	-5.84	-8.34	-6.36
24	-5.94	-5.91	-8.02	-6.37
26	-6.04	-6.11	-7.47	-6.39
28	-5.94	-6.11	-7.17	-6.39
30	-6.00	-6.26	-6.99	-6.40
32	-6.32	-6.36	-6.77	-6.38
34	-6.27	-6.36	-6.71	-6.39
36	-6.37	-6.46	-6.63	-6.39
38	-6.52	-6.48	-6.46	-6.38
40	-6.53	-6.54	-6.46	-6.40
42	-6.49	-6.49	-6.39	-6.40
44	-5.99	-6.45	-6.42	-6.41
46	-6.01	-6.38	-6.43	-6.42
48	-6.18	-6.46	-6.41	-6.41
50	-5.83	-6.37	-6.41	-6.41
52	-6.22	-6.46	-6.33	-6.41
54	-6.41	-6.57	-6.32	-6.41
56	-6.50	-6.58	-6.42	-6.41
58	-6.36	-6.55	-6.39	-6.42
60	-6.32	-6.52	-6.31	-6.41
62	-6.74	-6.59	-6.34	-6.41
64	-6.40	-6.57	-6.36	-6.42
66	-6.20	-6.54	-6.32	-6.41
68	-6.10	-6.46	-6.30	-6.41
70	-6.30	-6.49	-6.38	-6.41
72	-6.08	-6.53	-6.36	-6.41

TABLE D6(b) - HEAT FLOW FOR TRANSIENT TEST ON WALL P3, SI UNITS

Time, hr	Measured Heat Flow, W/sq m			Calculated Heat Flow, W/sq m
	qw Calib. Hot Box	qhft HFT @ In. Surf.	qhft' HFT @ Out. Surf.	qss Steady-State
0	-2.35	-0.58	-1.11	-0.84
1	-2.20	-0.60	-119.61	-4.33
2	-2.01	-0.69	-202.02	-8.70
3	-2.06	-0.95	-202.73	-11.36
4	-2.62	-1.50	-180.74	-13.15
5	-3.00	-2.26	-158.74	-14.51
6	-4.70	-3.36	-138.30	-15.63
7	-6.36	-4.64	-120.47	-16.52
8	-7.84	-5.96	-105.87	-17.23
9	-9.06	-7.25	-92.41	-17.81
10	-9.57	-8.50	-80.89	-18.24
11	-10.76	-9.67	-70.73	-18.61
12	-11.88	-10.97	-63.23	-18.87
13	-13.42	-11.98	-56.06	-18.94
14	-14.01	-12.99	-50.32	-19.15
15	-14.48	-13.90	-45.33	-19.33
16	-15.38	-14.63	-40.69	-19.48
17	-16.14	-15.43	-37.82	-19.60
18	-16.81	-16.23	-34.77	-19.70
19	-17.11	-16.71	-32.68	-19.78
20	-17.60	-17.27	-30.63	-19.88
21	-17.46	-17.60	-28.92	-19.98
22	-17.98	-18.00	-27.67	-20.04
23	-18.38	-18.44	-26.32	-20.07
24	-18.74	-18.65	-25.32	-20.10
26	-19.06	-19.28	-23.56	-20.15
28	-18.75	-19.29	-22.63	-20.16
30	-18.92	-19.76	-22.06	-20.19
32	-19.93	-20.07	-21.36	-20.14
34	-19.77	-20.07	-21.16	-20.16
36	-20.09	-20.39	-20.92	-20.17
38	-20.56	-20.44	-20.39	-20.14
40	-20.61	-20.64	-20.39	-20.20
42	-20.47	-20.46	-20.16	-20.20
44	-18.90	-20.34	-20.25	-20.22
46	-18.95	-20.12	-20.30	-20.24
48	-19.51	-20.38	-20.21	-20.24
50	-18.39	-20.09	-20.24	-20.23
52	-19.62	-20.38	-19.97	-20.22
54	-20.22	-20.73	-19.93	-20.22
56	-20.50	-20.76	-20.25	-20.23
58	-20.07	-20.65	-20.16	-20.25
60	-19.94	-20.57	-19.91	-20.24
62	-21.25	-20.79	-20.01	-20.24
64	-20.19	-20.73	-20.07	-20.25
66	-19.57	-20.62	-19.94	-20.24
68	-19.26	-20.38	-19.88	-20.24
70	-19.88	-20.46	-20.14	-20.21
72	-19.19	-20.60	-20.08	-20.22