HEAT TRANSMISSION COEFFICIENTS OF CONCRETE BLOCK WALLS WITH CORE INSULATION

By

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ABSTRACT

An investigation of heat transmission coefficients of 8-in. concrete block walls with and without core insulation is described. Measured average thermal conductance (C) and transmittance (U) values were obtained from Guarded Hot Box Tests (ASTM Designation: C236). They were compared with values calculated in accordance with current design practice. Test results differed considerably from design values. This was attributed to the following factors: (1) The thermal conductivity of a core insulation material is not the sole factor in the overall thermal performance of a masonry wall. The ability of the core insulation to fill all voids in the wall is also important. (2) Design thermal conductivities do not represent in situ material properties. (3) Design calculations of heat transmission coefficients do not reflect multi-dimensional heat flow conditions.

Closer estimates of transmittance were calculated using measured rather than design conductivity values. However, it is recommended that measured U-values be used as a primary basis for the design of wall assemblies.

INTRODUCTION

Thermal insulation characteristics of building envelopes have come under increased scrutiny with growing national concern over energy and resource conservation. Current design approaches require determination of steady-state overall thermal transmittance (U). Since U-values are an essential part of building codes they should be determined realistically.

This paper provides guidance for consideration of core insulation in the selection of heat transmission coefficients for hollow concrete masonry walls. Heat transmission coefficients of 8-in. concrete block walls with and without core insulation were evaluated. Calculated and measured coefficients are compared, and reasons for differences are indicated.

OBJECTIVES & SCOPE

The objective of this investigation was to evaluate heat transmission coefficients of concrete masonry walls with different types of core insulation. Primary emphasis was given to comparison of measured coefficients with current design values.

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Four types of insulations were considered*:

1. Vermiculite
2. Expanded Polystyrene (EPS) Beads
3. Urea Formaldehyde (UF) Foam
4. Expanded Polystyrene (EPS) Inserts

For comparison, uninsulated walls were also evaluated.

Walls were constructed using 8-in. hollow core blocks made with lightweight aggregate concrete.

MEASUREMENT OF HEAT TRANSMISSION COEFFICIENTS

The masonry wall panels were tested in a guarded hot box in accordance with ASTM C-236-66.** (Standard Test Method for Thermal Conductance and Transmittance of Built-Up sections by Means of the Guarded Hot Box)

TEST SPECIMENS

Wall panel specimens were constructed of 8-in. lightweight concrete masonry units. Lightweight concrete for the units was made with Haydite aggregate. Block properties are summarized in Table 2.

Panels, 64-in. (1.63 m) wide by 72-in. (1.83 m) high, were constructed using common building practices. Mortar consisted of one part masonry cement and three parts masonry sand by volume. Blocks were laid in a running bond pattern with face shell mortar bedding. Standard 3/8-in. (10 mm) tooled mortar joints were used. Panel surfaces were not coated or finished prior to testing. A wall panel being prepared for test is shown in Fig. 1. Panels were air dried in the laboratory at $65^{o}F$ ($18^{o}C$) for at least two months prior to testing. Laboratory humidity was not controlled.

Panels were tested with four different types of core insulation. Properties of insulation materials are given in Table 1.

Except for the specimen with EPS inserts, panels were tested before and after addition of insulation. This could not be done for the panel with EPS inserts because these inserts must be installed in the blocks before they are laid.

After testing the uninsulated walls, loose fill type insulation (vermiculite or EPS beads) was poured into cores, and specimens were immediately retested. The specimen with EPS beads was also used for the test with UF foam. Beads were vacuumed from cores and foam was added by a licensed applicator. Ten days later the panel was tested. It was retested again after six months to investigate effects of drying.

TEST PROCEDURE

Tests were conducted in accordance with ASTM Designation: C236 "Standard Test Method for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box."(1)*** Using a Guarded Hot Box, as illustrated in Fig. 2, the test panel is placed between a cold box and a guard box. A metering box inside the guard box defines the test area. A predetermined temperature differential is maintained across the test panel until

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*See Table 1 for manufacturers.

**Guarded Hot Box tests (ASTM-C-236-66) were conducted by Dynatherm Engineering, Lino Lakes, Minnesota.

***References are listed at the end of the paper.

constant heat flow conditions are established. The metering box and the guard box are held at the same temperature. Thus, heat input to the metering box after equilibrium conditions are established is a measure of heat flow through the test panel. Measured heat flow, air temperatures, surface temperatures, and test area are used to determine steady-state heat transmission coefficients.

The facility used for tests described in this investigation had a metered area 48-in. (1.22 m) wide and 60-in. (1.52 m) high. Twenty thermocouples were mounted on each side of the panels to measure surface temperatures at the locations shown in Fig. 3. Locations of thermocouples were selected to provide measurements at core, web, and joint sections. Nominal test conditions were:

Warm Air Temperature = 105°F (41°C)
Cold Air Temperature = 45°F (7°C)
Mean Temperature of Panel = 75°F (24°C)
Air Velocity - Warm Side = 60 ft./min. (0.3 m/s)
- Cold Side = 40 ft./min. (0.2 m/s)
Metered Area = 20 ft.^{2} (1.9 m^2)

Panels were tested in a vertical position.

TEST RESULTS

Results of Guarded Hot Box tests are summarized in Table 3. Measured conductance and transmittance values are presented for walls with empty and filled cores. Transmittance values were obtained by correcting conductance values for standard air film coefficients. Results for the wall with EPS inserts are compared with average results from uninsulated walls tested prior to filling with other insulation materials. Since results for uninsulated wall tests were nearly identical, this comparison is valid.

Measured thermal coefficients for panels insulated with vermiculite, EPS beads, UF foam and EPS inserts are shown in Table 3.

Vermiculite, EPS beads, and UF foam were similar in overall thermal performance. The wall insulated with vermiculite had a 6% lower U-value than the walls insulated with UF foam or EPS beads. The wall insulated with the EPS inserts had a measured U-value approximately 30% higher than the walls with the other three insulations.

It is apparent that effectiveness of insulation cannot be evaluated solely on the basis of conductivity of the fill material. As can be seen by comparing results in Tables 2 and 3 for the insulation materials tested, there is a considerable difference in the relationship between thermal conductivities of insulation materials and their effectiveness at reducing overall conductance of wall panels. Evaluation must be based on performance of the entire assembly of wall and insulating material.

Test results were compared with heat transmission coefficients calculated using "design" and "measured" conductivities.

CALCULATION OF HEAT TRANSMISSION COEFFICIENTS

Two methods of calculation were used to obtain thermal transmittance (U) and conductance (C) values. These are described in the ASHRAE Handbook.[2] Their application to masonry units has been discussed in detail by Valore.[3] For convenience, they are denoted as the "Parallel Path" and the "Isothermal Planes" methods.

Parallel Path Method

Overall coefficients were calculated assuming parallel paths in the direction of heat flow as illustrated in Fig. 4(a) for a masonry unit*. First, U-values for each path are calculated. In general, overall coefficients are obtained as follows:

*See Appendix A for a sample calculation.

$$U = a_w \frac{1}{R_w + R_o + R_i} + a_c \frac{1}{R_C + R_o + R_i} \quad (1)$$

where U = overall thermal transmittance based on parallel heat flow paths, Btu/hr.·ft.^{2} ·F (W/m^2 ·K).

a_w = fraction of total area transverse to heat flow represented by webs of block; Paths 1, 3, and 5 in Fig. 4(a). See Fig. 5 for block dimensions.

R_w = total thermal resistance of webs and face shell, hr.· ft.^{2}· F/Btu (m^2 · K/W).

a_c = fraction of total area transverse to heat flow represented by cores of block; Paths 2 and 4 in Fig. 4(a). See Fig. 5 for block dimensions.

R_c = total thermal resistance of cores and face shells, hr.· ft.^{2}·F/Btu (m^2 · K/W).

R_o = thermal resistance of outside air surface film. Usually taken as 0.17 hr.· ft^2 ·F/ Btu (0.03 K · m^2/W) for 15 mph (24 km/hr) wind.

R_i = thermal resistance of inside air surface film. Usually taken as 0.68 hr.· ft.^{2} ·F/ Btu (0.12 K · m^2/W)

To calculate overall thermal conductance (C), surface air film resistance coefficients, R_o and R_i, are taken as zero in Eq. (1).

Isothermal Planes Method

For assemblies in which heat can flow laterally in any continuous layer, the "Isothermal Planes" method of calculation is applicable. Lateral heat flow in continuous layers is assumed to result in isothermal planes*. These planes are assumed to occur along the face shells of concrete masonry as illustrated in Fig. 4(b). In addition, parallel combinations of webs and cores are assumed to act in series with face shells. In general, overall coefficients are calculated as follows:

$$U = \frac{1}{R_i + R_s + \dfrac{R_w\, R_c}{a_c\, R_w + a_w\, R_c} + R_o} \quad (2)$$

where U = overall thermal transmittance based on series-parallel heat flow paths, Btu/hr. · ft.^{2} · F (W/m^2 . K)

R_i = thermal resistance of inside air surface film. Usually taken as 0.68 hr. · ft^2 . F/Btu (0.12 K . m^2/W) for still air.

R_o = thermal resistance of outside air surface film. Usually taken as 0.17 hr. · ft^2 . F/Btu (0.03K . m^2/W) for 15 mph (24 km/hr) wind.

R_s = total thermal resistance of face shells, hr. · ft.^{2} · F/Btu (K · m^2/W).

R_w = thermal resistance of webs between face shells, hr. · ft.^{2} · F/But (K · m^2/W)

R_c = thermal resistance of cores between face shells, hr. · ft.^{2} ·F/Btu (K · m^2/W)

a_w = fraction of total area transverse to heat flow represented by webs of blocks; Paths 1, 3, and 5 in Fig. 2(b).

a_c = fraction of total area transverse to heat flow represented by cores of block Paths 2 and 4 in Fig. 1(b).

*See Appendix B for a sample calculation

Overall thermal conductance (C) is calculated from Eq. 2 with $R_o = R_i = 0$.

COMPARISON WITH DESIGN COEFFICIENTS

Measured transmittance values are compared with design values in Table 4. Design values were calculated by the "Parallel Path" and "Isothermal Planes" methods described earlier. Conductivities of block and insulation materials were taken from the ASHRAE Handbook[2] or from manufacturers' literature when ASHRAE values were not available. Thermal resistance of air spaces was based on the ASHRAE Handbook.[2]

As given in Table 4, results indicate that, for insulated walls, design coefficients do not agree well with measured coefficients. Design by the "Isothermal Planes" method gave values closer to those measured than design by the "Parallel Path" method.

Discrepancies between design and measured coefficients can be attributed to a number of factors that include:

1. Design coefficients were determined on the assumption of completely filled cores. Insulation materials vary in effectiveness with regard to obtaining complete filling.

2. Design conductivities are "typical" values. They do not necessarily represent materials used. This is particularly true for a material such as concrete that can be made at the same density with a variety of aggregates.[3]

3. Design calculations are based on one dimensional heat flow through wall panel thickness. This may not be realized due to the non-homogeneity of the insulated blocks.

COMPARISON WITH CALCULATED COEFFICIENTS

To further evaluate test results, calculations were repeated using measured conductivities for concrete and insulation materials. Results are given in Table 5 in terms of calculated and measured conductances.

Conductivity of the concrete was determined in accordance with ASTM Designation: C177 "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate."[1] A value of 3.50 Btu-in./hr. · ft.^{2} · F (0.50 W/m · K) was obtained.

Vermiculite and EPS beads were tested in accordance with ASTM Designation: C518 "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter." Values obtained were 0.39 Btu-in./ hr. · ft.^{2} · F (0.06 W/m · K) for vermiculite and 0.29 Btu-in./hr. · ft.^{2} · F (0.04 W/m · K) for EPS beads.

Tests were not made on UF foam and EPS inserts. Manufacturers' values were used for calculations.

Comparison of measured and calculated results in Table 5 indicates that closer agreement was obtained using measured conductivity values in the calculations. Once again, better agreement between measured and calculated coefficients was obtained using the "Isothermal Planes" method of calculation. This conclusion was also reached by Valore[3] who compared results for 71 hollow concrete masonry walls with and without core insulation.

Wall panels with EPS beads and UF foam showed a significant difference between measured and calculated conductances. This may be a result of voids in cores that would have reduced effectiveness of the insulation.

CONCLUSIONS

The following conclusions are based on results obtained in this program:

1. The thermal conductivity of core insulation materials is not the sole measure of their ability to reduce overall thermal transmittance of a masonry wall. The free-flowing characteristics necessary to fill all voids in cores is also important.

2. Design calculations of heat transmission coefficients do not consistently predict steady-state performance of insulated block walls. Assumptions with regard to complete filling of core space, material conductivities, in-place shrinkage, and uni-dimensional heat flow are believed to be the major cause of the discrepancy between measured and design values. Calculation by the "Isothermal Planes" method provided a better correlation with test results than calculation by the "Parallel Path" method.

3. Beacuse of uncertanties involved in design calculations of heat transfer coefficients of block walls with core insulation, it is reccommended that test values be a primary basis of evaluating overall thermal performance. Tests should be conducted on full size panels representative of field conditions.

ACKNOWLEDGEMENTS

Guarded Hot Box tests on wall panels were performed at Dynatherm Engineering under the direction of J. B. Funkhouser. Guarded Hot Plate tests on the concrete were conducted at Dynatech R/D Company under the direction of S. Spinney.

Heat Flow Meter Tests were conducted by Greg Derderian of W. R. Grace & Co.

REFERENCES

1. Annual Book of ASTM Standards, Part 18, Thermal and Cryogenic Insulating Materials; Building Seals and Sealants; Fire Standards; Building Construction; Environmental Acoustics, American Society for Testing and Materials, Philadelphia, PA, 1978.

2. ASHRAE Handbook and Product Directory - 1977 Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1977.

3. Valore, R. C., "Calculation of U-Values of Hollow Concrete Masonry," Journal of the American Concrete Institute (to be published).

APPENDIX A.

PARALLEL PATH METHOD FOR CALCULATING THE OVERALL U VALUE FOR THE WALL INSULATED WITH VERMICULITE

Shown below is the parallel path method for calculating the overall U-value of the block wall insulated with vermiculite. There are two distinct paths for heat to transfer through the wall. One path being through the webs and the other through the core, ears and mortar joints. These three areas are sufficiently similar that they are lumped together and will be referred to as the core. Figure 5. shows three views of the block along with the dimensions necessary to perform the following calculations. Equation (1) can be written as follows:

$$U = \frac{a_w}{\frac{W_B}{k_c} + R_{AF}} + \frac{a_c}{\frac{W_{FS}}{k_c} + \frac{W_c}{k_v} + R_{AF}}$$

Where:

a_w = .21

a_c = .79

W_B = Width of Block = 7.625"

W_{FS} = Width of Face Shells = 2.6"

W_c = Width of Core = 5.025"

k_c = Thermal Conductivity of the Concrete = $3.5 \frac{\text{Btu-in.}}{\text{hr.}^\circ\text{F ft.}^2}$

k_v = Thermal Conductivity of the Vermiculite = $.39 \frac{\text{Btu-in.}}{\text{hr.}^\circ\text{F ft.}^2}$

R_{AF} = Thermal Resistance of the Inside and Outside Air Films = $.85 \frac{^\circ\text{F hr. ft.}^2}{\text{Btu}}$

Therefore:

$$\text{Overall } U = \frac{.21}{\frac{7.625}{3.5} + .85} + \frac{.79}{\frac{2.6}{3.5} + \frac{5.025}{.39} + .85} = 0.12 \frac{\text{Btu}}{\text{hr.}^\circ\text{F ft.}^2}$$

APPENDIX B.

ISOTHERMAL PLANES METHOD FOR CALCULATING THE OVERALL U VALUE FOR THE WALL INSULATED WITH VERMICULITE

Shown below is the Isothermal Planes Method for calculating the overall U value of the block wall insulated with vermiculite. Using this technique, an isothermal plane is formed where the cores and face shells meet (see Figure 4). Using the dimensions in Figure 5 and the thermal properties of the material, the overall U value can be calculated as follows. Equation (2) can be written as follows:

$$U = \cfrac{1}{\cfrac{W_{fs}}{k_c} + \cfrac{(W_c/k_c) \cdot (W_c/k_v)}{(a_w)\ (W_c/k_v) + (a_c)\ (W_c/k_c)} + R_{AF}}$$

Where:

a_w	=	0.21		
a_c	=	0.79		
W_B	=	Width of Block	=	7.625"
W_{FS}	=	Width of Face Shells	=	2.6"
W_c	=	Width of Core	=	5.025"
k_c	=	Thermal Conductivity of the Concrete	=	$3.5\ \frac{\text{Btu-in.}}{\text{hr.}\,^\circ\text{F ft.}^2}$
k_v	=	Thermal Conductivity of the Vermiculite	=	$.39\ \frac{\text{Btu-in.}}{\text{hr.}\,^\circ\text{F ft.}^2}$
R_{AF}	=	Thermal Resistance of the Inside and Outside Air Films	=	$.85\ \frac{^\circ\text{F hr. ft.}^2}{\text{Btu}}$

Therefore:

$$\text{overall } U = \cfrac{1}{\cfrac{2.6}{3.5} + \cfrac{(5.025/3.5)\ (5.025/.39)}{(.21)\ (5.025/.39) + (.79)\ (5.025/3.5)} + 0.85}$$

$$= 0.16$$

TABLE 1 - PROPERTIES OF INSULATION MATERIALS[4]

	Density pcf (kg/m^3)	Thermal Conductivity Btu-in./hr. · $ft.^2$ · F (W/m · K)
Vermiculite	5.9[1] (94.5)	0.39[3] (0.06)
EPS Beads	0.7[1] (11.2)	0.29[3] (0.04)
UF Foam	0.7[2] (11.2)	0.23[2] (0.03)
EPS Inserts	1.0[2] (16.0)	0.26[2] (0.04)

(1) Measured in accordance with ASTM Designation: C520.

(2) Obtained from manufacturer's literature.

(3) Measured in accordance with ASTM Designation: C518.

(4) Manufacturers of the materials are as follows:
Vermiculite - Zonolite® Masonry Insulation, Construction Products Division, W. R. Grace & Co., Cambridge, MA
EPS Beads - Styro Pour-Pak, Minnesota Diversified Products, St. Paul, MN
UF Foam - Rapco® Foam, Rapperswill Corporation, New York, NY
EPS Inserts - Korfil I, Korfil, Inc., Chicopee, MA

TABLE 2 - PROPERTIES OF MASONRY UNITS

Property	8-inch. Hollow Core Concrete Block
Applicable Specifications	ASTM Designation: C90
Standard Dimensions, in. (mm)	7-5/8 x 7-5/8 x 15-5/8 (194 x 194 x 397)
Average Web Thickness, in. (mm)	1.13 (29)
Average Face Shell Thickness, in. (mm)	1.30 (33)
Aggregate	Haydite
Number of Cores	2
Percent Solid Volume	46
Nominal Block Weight lbs. (kg)	24.0 (10.9)
Nominal Density, pcf (kg/m^3)	85.0 (1363)
Oven Dry Density* pcf (kg/m^3)	86.2 (1382)
Thermal Conductivity** Btu-in./hr. · $ft.^2$ · F (W/m · K)	3.50 (0.50)

*Measured in accordance with ASTM Designation: C140.

**Measured in accordance with ASTM Designation: C177.

TABLE 3 - SUMMARY OF TEST RESULTS [4]

Insulation Type	Measured C-Value[1]		C_{Filled}/C_{Empty}	Measured U-Value[2]		U_{Filled}/U_{Empty}
	Empty	Filled		Empty	Filled	
Vermiculite	0.53 (3.01)	0.19 (1.08)	0.36	0.36 (2.04)	0.17 (0.97)	0.47
EPS Beads	0.52 (2.95)	0.21 (1.19)	0.40	0.36 (2.04)	0.18 (1.02)	0.50
UF Foam (10 days old)	0.52 (2.95)	0.22 (1.25)	0.42	0.36 (2.04)	0.18 (1.02)	0.50
UF Foam (6 months old)	0.52 (2.95)	0.22 (1.25)	0.42	0.36 (2.04)	0.19 (1.08)	0.53
EPS Inserts	0.53[3] (3.01)	0.29 (1.65)	0.55	0.36[3] (2.04)	0.23 (1.31)	0.64

(1) Thermal conductance (C) values, Btu/hr. · ft.^{2} · F (W/m^2 · K).

(2) Thermal transmittance (U) values, Btu/hr. · ft.^{2} · F (W/m^2 · K). Standard surface resistances (inside - 0.68 and outside = 0.17) are assumed.

(3) Average of tests of uninsulated walls.

(4) The tolerance for the Guarded Hot Box Test device was reported to be 4.0%, so that 4.0% may be added to the measured C value to obtain a maximum C value for the construction measured.

TABLE 4 - COMPARISON OF DESIGN AND MEASURED TRANSMITTANCE VALUES

Insulation Type	Design Conductivity(1)		Design U-Value(2)		Measured U-Value(2)	$U_{Meas.}/U_{Parallel\ Path}$	$U_{Meas.}/U_{Isothermal\ Planes}$
	Concrete	Fill	Parallel Path	Isothermal Planes			
None	2.78 (0.40)	- (-)	0.35 (1.99)	0.35 (1.99)	0.36 (2.04)	1.03	1.03
Vermiculite	2.78 (0.40)	0.44 (0.06)	0.12 (0.68)	0.14 (0.79)	0.17 (0.97)	1.42	1.21
EPS Beads	2.78 (0.40)	0.28 (0.04)	0.10 (0.57)	0.12 (0.68)	0.18 (1.02)	1.80	1.50
UF Foam	2.78 (0.40)	0.23 (0.03)	0.09 (0.51)	0.12 (0.68)	0.18 (1.02)	2.00	1.50
EPS Inserts	2.78 (0.40)	0.26 (0.04)	0.18(3) (1.02)	0.21(4) (1.19)	0.23 (1.31)	1.28	1.10

(1) Conductivity values from ASHRAE 1977 Fundamentals and manufacturer's literature, Btu-in./hr. · ft.^{2} · F (W/m · K).

(2) Thermal transmittance (U) values, Btu/hr. · ft.^{2} · F (W/m^2 · K). Standard surface resistances (inside = 0.68 and outside = 0.17) are assumed.

(3) If a more refined model is used in the calculations U = 0.19 (1.08).

(4) If a more refined model is used in the calculations U = 0.24 (1.37).

TABLE 5 - COMPARISON OF CALCULATED AND MEASURED TRANSMITTANCE VALUES

Insulation Type	Measured Conductivity		Calculated U-Value[4]		Measured U-Value[4]	Meas. / Parallel Path	Meas. / Isothermal Planes
	Concrete[1]	Fill	Parallel Path	Isothermal Planes			
None	3.50 (0.50)	- (-)	0.38 (2.16)	0.38 (2.16)	0.36 (2.04)	0.95	0.95
Vermiculite	3.50 (0.50)	0.39[2] (0.06)	0.12 (0.68)	0.16 (0.91)	0.17 (0.97)	1.42	1.06
EPS Beads	3.50 (0.50)	0.29[2] (0.04)	0.11 (0.62)	0.15 (0.85)	0.18 (1.02)	1.64	1.20
UF Foam	3.50 (0.50)	0.23[3] (0.03)	0.10 (0.57)	0.14 (0.80)	0.18 (1.02)	1.80	1.29
EPS Inserts	3.50 (0.50)	0.26[3] (0.04)	0.20[5] (1.14)	0.23[6] (1.31)	0.23 (1.31)	1.15	1.00

(1) Obtained from test in accordance with ASTM Designation: C177, Btu-in./hr. · ft.^{2} · F (W/m · K).

(2) Obtained from test in accordance with ASTM Designation: C518, Btu-in./hr. · ft.^{2} · F (W/m · K).

(3) Test value not available. Design value used for calculations, Btu-in./hr. · ft.^{2} · F (W/m · K).

(4) Thermal conductance (U) values, Btu/hr. · ft.^{2} · F (W/m^2 · K).

(5) If a more refined model is used in the calculations U = 0.21 (1.19).

(6) If a more refined model is used in the calculations U - 0.26 (1.48).

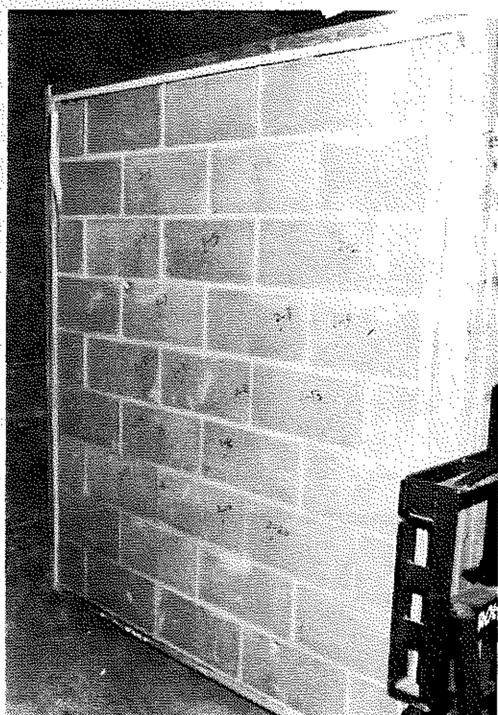

Fig. 1 Masonry wall panel prior to testing

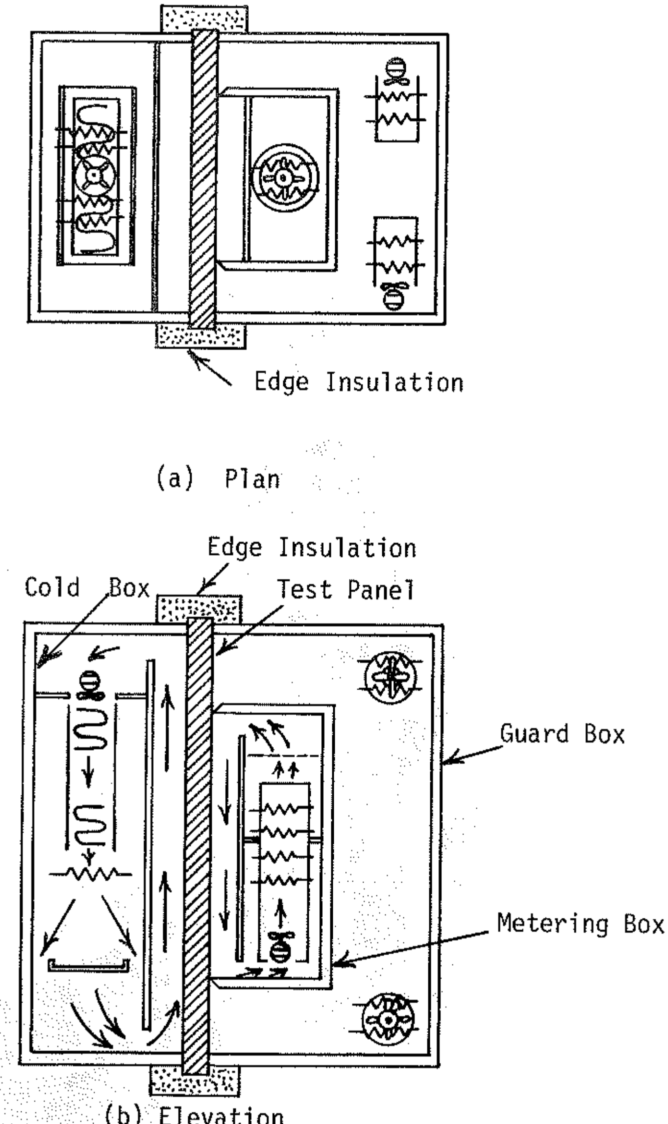

Fig. 2 Schematic of guarded hot box (Ref 1)

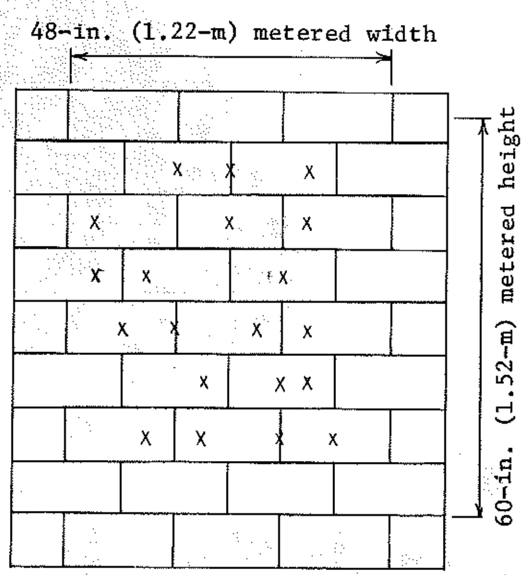

Fig. 3 Location of surface thermocouples

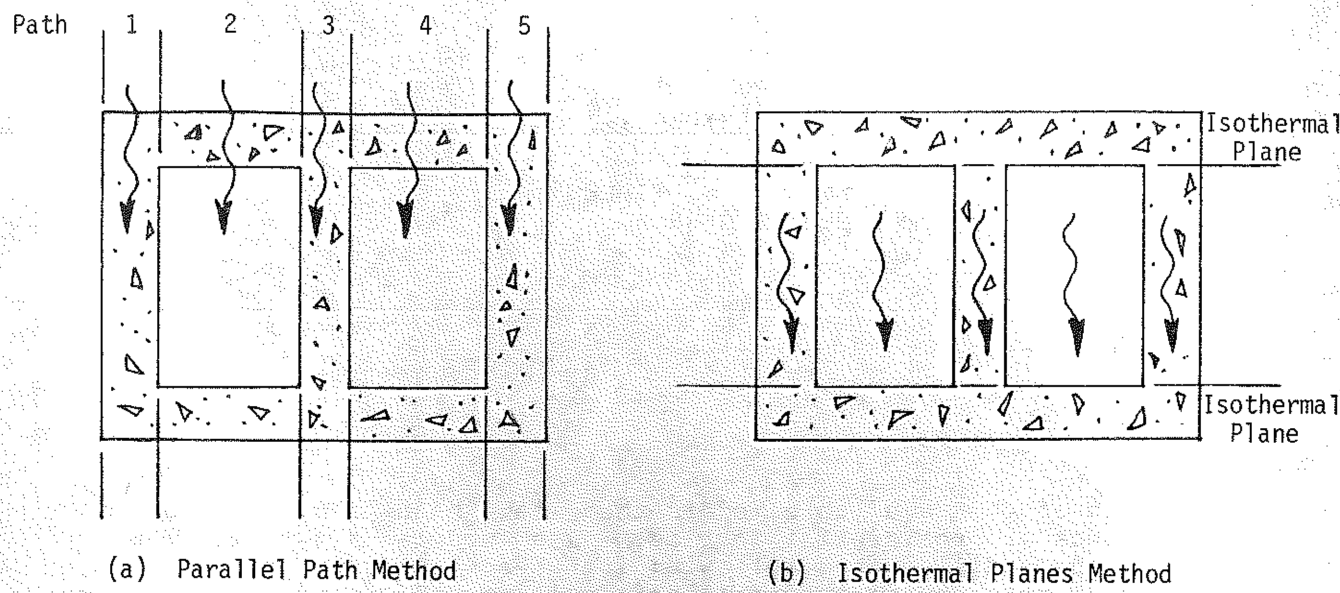

Fig. 4 Schematics of heat flow paths assumed in calculations

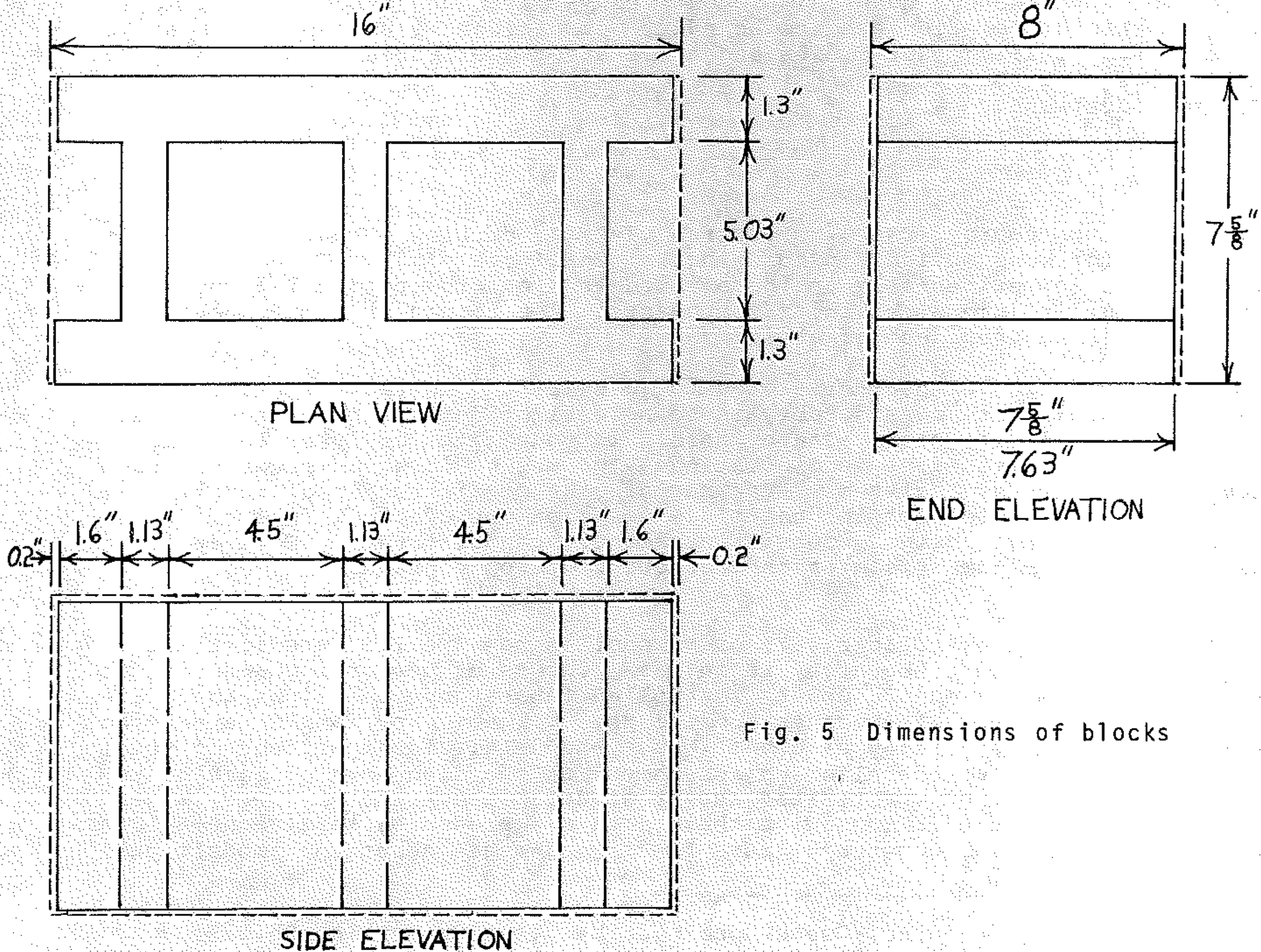

Fig. 5 Dimensions of blocks