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Thermal Transmittance of Concrete Block Walls with Core Insulation

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ABSTRACT

Thermal transmittance values (U-values) of concrete block walls, with and without core insulation, tested at three laboratories are summarized. Insulations were perlite, vermiculite, expanded polystyrene (EPS) beads, and EPS inserts.

Measured U-values are compared to values calculated using the isothermal planes method. For empty core concrete block walls with known concrete thermal conductivity, measured U-values were within 10% of calculated values. However, for walls with core insulation, measured U-values differed by 0% to 40% from calculated values.

Sensitivity of wall thermal transmittance to changes in block configuration, concrete thermal conductivity, and fill thermal conductivity is discussed.

INTRODUCTION

Rising fuel prices have resulted in greater public awareness of building envelope thermal losses. Thermal performance of exterior walls contributes to the overall energy efficiency of the building envelope. Determination of an optimal wall system is based on thermal performance, as well as construction costs, structural requirements, and aesthetics.

Concrete block walls with different types of core insulation are frequently compared by the relative ranking of their individual thermal transmittances (U-values). Concrete block wall systems are also compared to other wall systems, such as wood frame walls, using U-values. However, published values vary depending on the method used to determine thermal transmittance, and on the concrete block wall system actually used.

Also, in some cases effectiveness of fill insulation is judged by ranking thermal conductivities of the fill materials. However, wall transmittance is not directly proportional to fill thermal conductivity, but also depends on block geometry, concrete conductivity, and uniformity of fill material within the cores.

This paper summarizes values of thermal transmittance of concrete block walls, with and without core insulation, tested at three different laboratories. Perlite, vermiculite, expanded polystyrene (EPS) beads, and EPS inserts were used as core insulation. Calculated values are determined using the isothermal planes method, and are then compared with measured values.

Sensitivity of thermal transmittance to changes in block configuration and constituent material properties is also shown. The sensitivity analysis defines the range of U-values possible for the same type of wall assembly. For example, the thermal transmittance of an 8 in (200 mm) concrete block with perlite fill will vary depending on block geometry, thermal conductivity of the block, and thermal conductivity of the perlite.

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BACKGROUND

Measured values of thermal transmittance may be determined using ASTM Designation: C236 "Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box"(1) or ASTM Designation: C976 "Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box."(1) These methods are particularly suitable for measuring thermal performance of nonhomogeneous building construction assemblies.

Calculated U-values are generally determined using the isothermal planes (designated series parallel method by ASHRAE) or parallel path methods. The isothermal planes method is used to calculate thermal transmittances for this paper. Actual wall thermal transmittance generally falls between values calculated using the two methods, with the isothermal planes method yielding an upper bound and the parallel path method yielding a lower bound.

The ASHRAE Handbook - 1981 Fundamentals (p. 23.3) states, "Generally, if the construction contains any highly conducting layer in which lateral conductance is very high compared to transmittance through the wall, a value closer to the series parallel calculation should be used."(2) For insulated concrete block walls, the large difference between the conductivity of the concrete in the web and the insulation in the core warrants the use of the isothermal planes method.

In a paper comparing test results of concrete block walls containing core insulation, Shu, et al.(3) concluded that better agreement between measured and calculated U-values was obtained using the isothermal planes method. Valore(4) also recommends the use of the isothermal planes method for concrete block calculations. Either of these papers should be consulted for a more detailed comparison of the two methods.

MEASUREMENT OF THERMAL TRANSMITTANCE

Concrete block walls with and without core insulation were tested at three laboratories, designated Laboratories A,(5-10) B,(11) and C.(12) Brief descriptions of specimens and procedures are given in the following sections. More detailed information may be found in the individual test reports.(5-12)

Test Specimens

Lightweight and normal weight concrete masonry units were used to construct test walls. Block properties are summarized in Table 1.

Walls tested at Laboratories A and C were constructed using a running bond pattern and nominal 3/8 in (10 mm) wide mortar joints. Type M masonry mortar was used and joints were tooled. Walls tested at Laboratory C had face shell mortar bedding and measured 102 1/4 in (2650 mm) square. Walls tested at Laboratory A were nine courses high and four blocks long.

Walls constructed at Laboratory B were built using a dry stack assembly. Vertical and horizontal joints on both sides of wall assemblies were taped to reduce air infiltration. Finished walls were eight courses high and four blocks long.

Eliminating conventional vertical and horizontal mortar joints increases web area in walls by 7%. Dry stacked walls will have higher thermal transmittances than walls with conventional mortar joints due to the greater area of webs acting as thermal bridges.

Test Methods

Tests at Laboratories A and B were conducted in accordance with ASTM Designation: C236 "Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box."(1) Wall tests at Laboratory C were conducted in general accordance with ASTM Designation: C976 "Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box."(1)

Using a guarded hot box, the test specimen is placed between a cold box and guard box. A metering box inside the guard box defines the test area. A predetermined temperature differential is maintained across the test specimen until constant heat flow conditions are established. The metering box and guard box are held at the same temperature. Thus, heat input to the metering box is a measure of heat flow through the test specimen. After equilibrium conditions are established, measured heat input, air temperatures, surface temperatures, and test area are used to calculate thermal transmittance.(13) Measurement techniques and procedures for guarded hot box tests are described in References 5 through 11.

A calibrated hot box is similar to a guarded hot box. However, the calibrated hot box apparatus has no guard box. In effect, the laboratory space in which the apparatus is located serves as the guard. The test specimen is placed between the outdoor and indoor chambers. The amount of energy required to maintain a constant temperature in the indoor chamber, as well as measured air temperatures, surface temperatures, and test area are used to calculate thermal transmittance of the test specimen.(13) Measurement techniques and calibration procedures for calibrated hot box tests are described in References 12 and 13.

Nominal test conditions for walls tested at Laboratories A and B are listed in Table 2.

At Laboratory C, walls with and without core insulation were tested at selected temperature differentials to determine steady-state properties.(12) Outdoor chamber air temperatures ranged from -5 to 125F (-21 to 52°C) for tests on the two walls. Calibrated hot box indoor chamber air temperatures were maintained at approximately 72F (22°C). Steady-state test results for a mean specimen temperature of 75F (24°C) were determined by interpolation between test results for the selected temperature conditions. Air velocities for the calibrated hot box tests were less than approximately 60 ft/min (0.30 m/s). Metered area was 72.6 ft^2 (6.74 m^2), the area of the masonry walls.

Test Results

Measured values of thermal transmittance for concrete block walls with and without core insulation are summarized in Table 3. Values are corrected for standard inside and outside air film resistances of 0.68 and 0.17 $h \cdot ft^2 \cdot F/Btu$ (0.12 and 0.03 $m^2 \cdot K/W$), respectively. These values are commonly used in design and are considered to represent still air on the inside and an air flow of 15 mph (6.7 m/s) on the outside.(2)

Tests demonstrate that empty core concrete block walls with lower U-values benefit more from core insulation than walls with higher U-values. Data in Table 3 show that thermal transmittance is reduced 49% or more for the test with core insulation added to a 12 in (300 mm) concrete block wall, and for tests on walls with block densities less than 100 pcf (1600 kg/m^3).

CALCULATION OF THERMAL TRANSMITTANCE

As discussed in the introduction, the isothermal planes method is used to calculate thermal transmittances in this paper.

Isothermal Planes Method

As shown in Figure 1, the isothermal planes method assumes lateral heat flow along the face shells of concrete masonry. In addition, parallel combinations of webs and cores are assumed to act in series with face shells. Thermal transmittance of concrete block is calculated using the following equation:(3)

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

where

U = overall thermal transmittance based on isothermal planes (series parallel heat flow paths), $Btu/h \cdot ft^2 \cdot F$ ($W/m^2 \cdot K$).

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

R_o = thermal resistance of outside air surface film, usually assumed to be 0.17 h•ft^2•F/Btu (0.03 m^2•K/W) for 15 mph (6.7 m/s) wind.

R_s = total thermal resistance of face shells, h•ft^2•F/Btu (m^2•K/W).

R_w = thermal resistance of webs between face shells, h•ft^2•F/Btu (m^2•K/W).

R_c = thermal resistance of cores between face shells, h•ft^2•F/Btu (m^2•K/W).

a_w = fraction of total area transverse to heat flow represented by webs of blocks; paths 1, 3, and 5 in Figure 1.

a_c = fraction of total area transverse to heat flow represented by cores of block: paths 2 and 4 in Figure 1.

A sample calculation using this method is given in Appendix A.

Horizontal mortar joints were neglected for calculations in this paper. This assumption was valid for walls tested at Laboratory B since these test walls were dry stacked and had no mortar joints. The assumption results in higher than actual U-Values for walls tested at Laboratories A and C because within the horizontal joint no mortar connects the face shells to cause thermal bridging. Usual construction practice calls for mortar to be applied on the face shells only. Therefore, within a horizontal joint, the volume between the face shells is occupied by either air or core insulation.

The percent error in U-values introduced by neglecting horizontal joints of Laboratories A and C walls depends on whether core insulation is present. For walls without core insulation material, neglecting horizontal mortar joints results in a change in calculated U-values of less than 1%. For walls with core insulation, neglecting horizontal joints increases calculated U-values a maximum of 6%. For the 6% difference to be realized, insulation material must fill the entire volume between face shells in the region of horizontal joints. Since it is unlikely that insulation material fills the space between webs of adjacent blocks along horizontal joints, calculated U-values are affected by less than 6% when horizontal mortar joints are neglected.

Vertical mortar joints, when present in test walls, were considered in the analysis. It was assumed that mortar thermal conductivity was the same as the adjacent block conductivity, and that mortar was applied to face shells only.

Material Properties of Concrete Block and Core Insulation

In addition to wall geometry, thermal conductivities of concrete and core insulation must be known to calculate block wall thermal transmittance.

Concrete Block. Laboratories A(15) and B(11) measured thermal conductivity of concrete block material in accordance with ASTM Designation: C177 "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate."(1) At the two laboratories, thermal conductivity was measured for each density block used in wall tests. Test specimens were oven dried prior to testing. Results are listed in Table 1.

Lightweight and normal weight concrete blocks contain 1 to 4% moisture, by volume.(16) Because of the difference in moisture contents, an oven-dried test specimen will have a conductivity that is approximately 5% less than that of an actual block.(16) This difference between oven-dried and actual conductivities will be neglected in this paper.

Laboratory B test specimens measured 7.63 in (195 mm) in diameter and were 1 in (25 mm) thick.(11) Laboratory A 85 and 103 pcf (1360 and 1650 kg/m^3) block specimens were 1.164 in (29.6 mm) and 1.179 in (29.9 mm) thick, respectively.(15) Test procedures are described in References 11 and 15.

Laboratory B used thermocouples embedded in the concrete test specimens to minimize contact resistance measurement error. The error is due to the influence of any thin air gap between the thermocouple wire and the concrete at the point of contact. This additional thermal resistance can be introduced when thermocouples are not embedded in the test material. Contact resistance can be a large portion of the total resistance for materials with large thermal conductivities. For normal weight concrete, contact resistance may be of the same order of magnitude as the resistance of the concrete.(17,18)

Since measured U-values in this paper are for walls with mean temperatures of 75F (24°C), concrete thermal conductivity used in calculations should be for a mean specimen temperature of 75F (24°C). Mean temperatures of Laboratory B thermal conductivity specimens varied from 92 to 108F (33 to 42°C). The change in concrete thermal conductivity from 75 to 110F (24 to 43°C) is less than 5%. Therefore, the thermal conductivity measured by Laboratory B is not significantly different than it would have been had specimens been tested at 75F (24°C).

Thermal conductivity of Laboratory C concrete block was estimated to be 11.2 Btu•in/h•ft^2•F (1.62 W/m•K). This value was determined from measured concrete density and Laboratory B test results.

Based on recommendations from the ASHRAE Handbook,(2) thermal resistance of all air spaces was assumed to be 0.97 h•ft^2•F/Btu (0.17 m^2•K/W). Air space dimensions parallel to heat flow ranged from 4 5/8 to 8 1/8 in (117 to 206 mm).

Perlite Insulation. Thermal conductivity of perlite insulation used in cores is summarized in Table 4. The estimated density of perlite in each wall was used to determine thermal conductivity. Laboratory B measured conductivity of perlite insulations with densities ranging from 2.1 to 7.4 pcf (34 to 120 kg/m^3). Tests were conducted in accordance with ASTM Designation: C518, "Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter."(1) Other density-conductivity relationships are provided in References 2 and 19. Perlite thermal conductivity is relatively constant within the range of densities used in the test walls.

Estimated perlite densities in cores for Laboratory A tests are based on estimated wall core volumes and the amount of perlite poured into the walls. Wall core volumes were calculated as the volume between face shells, minus the total web volume. Total wall dimensions, including horizontal and vertical mortar joints, were used.

Laboratory B reported an approximate density of perlite in cores of 7 pcf (110 kg/m^3). Estimated density in the wall tested by Laboratory C is not available.

A perlite thermal conductivity of 0.34 Btu•in/h•ft^2•F (0.049 W/m•K) was used in isothermal planes calculations. This is consistent with Laboratory B test results. Variations in perlite density between test specimens were small enough to result in a negligible effect on conductivity.

Vermiculite Insulation. Measured loose density of vermiculite was 6.6 pcf (106 kg/m^3).(8) Based on wall core volume of 10.0 ft^3 (0.28 m^3), estimated density of vermiculite in the Laboratory A wall was 5.8 pcf (93 kg/m^3). Thermal conductivity of vermiculite in the density range from 5.8 to 6.6 pcf (93 to 106 kg/m^3) may vary from 0.39 to 0.46 Btu•in/h•ft^2•F (0.056 to 0.066 W/m•K).(2,3,20)

Vermiculite conductivity was assumed to be 0.44 Btu•in/h•ft^2•F (0.063 W/m•K). This is an average determined from values published by ASHRAE(2) and the Naval Civil Engineering Laboratory.(20)

EPS Beads. Measured loose density of EPS beads was 0.68 pcf (11 kg/m^3).(9) Based on wall core volume of 10.0 ft^3 (0.28 m^3), estimated density of EPS beads in the Laboratory A wall was 0.52 pcf (8.3 kg/m^3). The significant difference between the measured loose density and the estimated "in place" density of the EPS beads may be indicative of voids or air pockets within the fill. Thermal conductivity of EPS beads is assumed to be 0.29 Btu•in/h•ft^2•F (0.042 W/m•K).(3)

EPS Inserts. U-shaped EPS inserts placed in each block core extended the height of the block and were 1 in (25 mm) thick. The insert base was 4.875 in (125 mm) wide and legs were 2.5 in (65 mm) long. Measured density of EPS inserts was 1.1 pcf (18 kg/m^3).(10) Thermal conductivity of the inserts is assumed to be 0.26 Btu•in/h•ft^2•F (0.037 W/m•K).(21)

Comparison of Measured and Calculated Values

In Table 5, thermal transmittance values calculated using the isothermal planes method are compared to measured values.

The discrepancy between calculated and measured U-values for Wall 11 is probably due to the uncertainty in estimating concrete conductivity. As discussed previously, concrete block thermal conductivities for Walls 1 through 10 were measured. Conductivity of concrete in blocks used for Wall 11 was interpolated from Laboratory B test results on similar density block. Even though the block tested at Laboratory B was made from concretes with similar densities to block tested at Laboratory C, aggregates were not from the same source. Since blocks with the same density constructed with different aggregates may have different conductivities, the estimate of conductivity for Laboratory C blocks may not be accurate.

For Walls 1 through 10, with no insulation in cores, measured U-values were within 10% of calculated values. Except for the wall with EPS beads, walls with core insulation tested by Laboratories A and B had measured values within 26% of calculated values.

Effectiveness of the different insulation types may be evaluated from results of tests on Walls 3 through 6, all constructed of 8 in (200 mm) 103 pcf (1650 kg/m^3) concrete block. Calculated U-values for blocks filled with perlite, vermiculite, and EPS beads were relatively constant at 0.19, 0.20, and 0.18 Btu/h•ft^2•F (1.08, 1.14, and 1.02 W/m^2•K), respectively. Measured U-values of walls were 0.22 Btu/h•ft^2•F (1.25 W/m^2•K) for perlite, 0.24 Btu/h•ft^2•F (1.36 W/m^2•K) for vermiculite, and 0.25 Btu/h•ft^2•F (1.42 W/m^2•K) for EPS beads. Of the three types of loose-fill insulation, perlite had the smallest measured U-value and had measured thermal transmittance closest to the calculated value.

The wall with expanded polystyrene inserts had the highest thermal transmittance of the four 103 pcf (1650 kg/m^3) walls with insulation tested by Laboratory A. However, calculated U-value of the wall with inserts was within 10% of the measured value.

The largest difference between measured and calculated values was for Wall 5 with EPS beads. This difference may be due to voids or air pockets within fill. A possibility that defects were present was previously discussed as a reason for the difference between loose and "in place" densities of EPS beads.

Calculations based on the isothermal planes method assume uniform distribution of fill material within cores. Since the thermal resistance of air pockets is less than that of EPS beads, calculated U-values neglecting air pockets would be unconservatively low if voids exist. Results shown in Table 5 may reflect this effect.

Discrepancies between calculated and measured thermal transmittances can be attributed to a number of factors including the following:(3)

1. Insulation thermal conductivities were determined assuming completely filled cores. Insulation materials vary in effectiveness with regard to obtaining complete filling.
2. Calculations are based on one dimensional heat flow through the wall panel thickness. This may not be realized due to the nonhomogeneity of the insulated blocks.
3. Properties of constituent materials may vary from measured values due to material variability, construction procedures, or accuracy of test methods. Because of these variations, predictions of wall thermal transmittance should be supplemented by guarded or calibrated hot box test results.

SENSITIVITY ANALYSIS

Thermal transmittance of a concrete block wall increases as thermal conductivities of the constituent materials increase. Thermal transmittance also increases if the volume of high conductivity materials in the wall increases relative to the volume of low conductivity materials. Sensitivity of thermal transmittance to thermal conductivity of concrete, thermal conductivity of insulation, and block configuration is discussed in the following sections.

Effect of Concrete Conductivity

Figure 2 shows measured thermal transmittance of concrete block walls as a function of measured thermal conductivity of concrete in the block. Results are for 8 in (200 mm) block walls with and without perlite insulation in the cores. Wall thermal transmittance increases as concrete thermal conductivity increases for both types of walls.

Generally, concrete thermal conductivity increases with concrete density. However, concretes with the same density may have different thermal conductivities due to differences in aggregates. Therefore, thermal conductivity of all 103 pcf (1650 kg/m^3) density block is not necessarily 4.3 Btu•in/h•ft^2•F (0.62 W/m•K).

Effect of Fill Conductivity

Figure 3 shows calculated thermal transmittance values as a function of thermal conductivity of concrete. Values in Figure 3 were calculated using dimensions of the 8 in (200 mm) Laboratory A block. In addition to showing the effect of concrete conductivity on wall thermal transmittance, Figure 3 illustrates the effects of different fill thermal conductivities. The conductivities considered cover the range used in normal construction practice and represent perlite densities of 2 to 11 pcf (32 to 180 kg/m^3).(19) Over a range of fill conductivity from 0.26 to 0.44 Btu•in/h•ft^2•F (0.037 to 0.063 W/m•K), the maximum change in magnitude of thermal transmittance is 0.02 Btu/h•ft^2•F (0.11 W/m^2•K) for any given concrete block conductivity.

Figure 4 illustrates the effect of concrete and fill conductivity on thermal transmittance of a 12 in (300 mm) concrete block wall. Values in Figure 4 were calculated using dimensions of the 12 in (300 mm) block measured at Laboratory A. The change in fill conductivity has a smaller effect for 12 in (300 mm) than 8 in (200 mm) block because the 12 in (300 mm) block has thicker webs. The relative contribution of fill on thermal transmittance, when compared to the contribution of the webs, is reduced, because thicker webs allow less volume for fill material. Over a range of fill conductivities from 0.26 to 0.44 Btu•in/h•ft^2•F (0.037 to 0.063 W/m•K), the maximum change in magnitude of thermal transmittance is 0.01 Btu/h•ft^2•F (0.06 W/m^2•K) for 12 in (300 mm) block with any given concrete conductivity.

Effect of Block Dimensions

Block dimensions also influence thermal transmittance of insulated walls. In the United States, variations in dimensions of commonly used concrete block are small. Table 6 lists minimum and maximum dimensions normally found in construction and the corresponding U-values calculated for five nominal block widths. Cores were assumed to be filled with perlite. As indicated by Column E, and for the conditions noted in Table 6, thermal transmittance of 103 pcf (1650 kg/m^3) blocks may vary 19 to 36%, depending on face shell and web thicknesses assumed.

The sensitivity of block dimensions shown in Table 6 is based on two-core blocks. Two-core blocks have lower U-values than three-core blocks, because minimum web thickness requirements (ASTM Designation: C90(1)) entail larger total web areas for three-core blocks. All insulated block walls summarized in this report were constructed from two-core block.

Generally, one-third of all two-core 8 in (200 mm) block shipments consist of splittable jam units. These blocks are similar to standard blocks with the exception that the center web is actually two webs, as illustrated in Figure 5. Since these blocks have a larger percent solid volume, less volume is available for fill material. Therefore, splittable jam units have larger U-values, as shown in Column C of Table 6. Column D of Table 6 lists the U-value of a wall constructed with splittable jam and regular 8 in (200 mm) units in a 1 to 2 ratio.

Column F shows that using one splittable block for every two regular 8 in (200 mm) blocks will increase wall thermal transmittance 5%. This result is based on perlite and concrete properties listed in Table 6. The regular unit is assumed to have the U-value listed in Column B.

OTHER PUBLISHED RESULTS

Figure 6 shows test results from Laboratories A, B and C as well as data from Shu, et al.(3) The vertical axis represents the ratio of the U-value for a block with core insulation to the U-value of the same block without fill. The lower the value of this ratio, the greater the effectiveness of the core insulation. Dashed lines in Figure 6 connect points for walls filled with the same type of insulation.

Figure 6 confirms two results previously discussed in this report. First, measured data in Figure 6, represented by individual points, show that perlite insulation was the most effective core insulation of those tested. Vermiculite and EPS beads was next in effectiveness, and EPS inserts were least effective. Data from Reference 3 were determined from guarded hot box tests of walls constructed from two-core 8 in (200 mm) blocks with a unit weight of 85 pcf (1360 kg/m^3) and a measured concrete conductivity of 3.5 Btu•in/h•ft^2•F (0.50 W/m•K).

Secondly, the curves illustrate that blocks with lower concrete thermal conductivity benefit more from the addition of core insulation. The curves are derived from calculated U-values assuming 8 and 12 in (200 and 300 mm) two-core concrete block, Laboratory A block dimensions, and conductivity of fill material equal to 0.34 Btu•in/h•ft^2•F (0.049 W/m•K).

SUMMARY AND CONCLUSIONS

Thermal transmittances of concrete block walls, with and without core insulation, tested at three laboratories, were evaluated. Measured U-values were compared to values calculated using the isothermal planes method. The effects of concrete block thermal conductivity, core insulation thermal conductivity, and concrete block dimensions on wall thermal transmittance were determined. The following conclusions are based on evaluation of measured and calculated data:

1. Empty core concrete block walls with lower U-values benefit more from core insulation than walls with higher U-values. Thermal transmittance of a concrete block wall is reduced as much as 57% when core insulation is added.

2. Test results from one laboratory show that for 8 in (200 mm) concrete block with a unit weight of 103 pcf (1650 kg/m^3), perlite insulation provided lower U-values than vermiculite, EPS beads, or EPS inserts.

3. For empty core concrete block walls with known concrete thermal conductivity, measured U-values were within 10% of calculated values.

4. For walls with core insulation, measured U-values differed by 0% to 40% from calculated values. Reasons for differences are listed in the "Comparison of Measured and Calculated Values" portion of the "Calculation of Thermal Transmittance" section.

5. Because of differences between calculated and measured values, predictions of wall U-values should be supplemented by guarded or calibrated hot box test results.

6. Thermal conductivity of concrete has a significant effect on wall thermal transmittance. Thermal transmittance increases as concrete thermal conductivity increases for all concrete block walls.

7. For commonly used block densities and configurations, variations in core insulation conductivity have a relatively small effect on wall thermal transmittance. Over a range of fill conductivities from 0.26 to 0.44 Btu•in/h•ft^2•F (0.037 to 0.063 W/m•K), the maximum change in U-value is 0.01 and 0.02 Btu/h•ft^2•F (0.06 and 0.11 W/m^2•K), respectively, for 12 in (300 mm) and 8 in (200 mm) block of any given conventional concrete conductivity.

8. Depending on the face shell and web thicknesses assumed, U-values may vary 19% to 36% for 103 pcf (1650 kg/m^3) blocks with nominal widths of 4 to 12 in (100 to 300 mm).

9. The use of one splittable jam unit for every two regular units will increase thermal transmittance of a 103 pcf (1650 kg/m^3) density, perlite filled, 8 in (200 mm) concrete block wall by 5%.

REFERENCES

1. 1983 Annual Book of ASTM Standards (Philadelphia: American Society for Testing and Materials, 1983).

2. ASHRAE Handbook - 1981 Fundamentals (Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1981).

3. Shu, L. S.; Fiorato, A. E.; and Howanski, J. W., "Heat Transmission Coefficients of Concrete Block Walls with Core Insulation," Proceedings of the ASHRAE/DOE-ORNL Conference on Thermal Performance of the Exterior Envelopes of Buildings, Orlando, Florida, December 1979, ASHRAE SP28, New York, pp. 401-436.

4. Valore, R. V. C., Jr., "Calculation of U-Values of Hollow Concrete Masonry," Concrete International, Vol. 2, No. 2, February 1980, pp. 40-63.

5. Funkhouser, J. B., "Thermal Transmittance Testing of 8 in. Lightweight (85 pcf) Concrete Blocks With and Without Perlite," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

6. Funkhouser, J. B., "Thermal Transmittance Testing of 12 in. Lightweight Concrete Blocks With and Without Perlite," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

7. Funkhouser, J. B., "Thermal Transmittance Testing of 8 in. Lightweight (103 pcf) Concrete Blocks Empty and with Perlite Insulation," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

8. Funkhouser, J. B., "Thermal Transmittance Testing of 8 in. Lightweight (103 pcf) Concrete Blocks Empty and With Vermiculite," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

9. Funkhouser, J. B., "Thermal Transmittance Testing of 8 in. Lightweight (103 pcf) Concrete Blocks Empty and with EPS Beads," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

10. Funkhouser, J. B., "Thermal Transmittance Testing of 8 in. Lightweight (103 pcf) Concrete Blocks Empty and With Korfil Inserts," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 6 pages.

11. Spinney, S. V. C. and Tye, R. P., "A Study of Various Factors Affecting the Thermal Performance of Perlite Insulated Masonry Construction," Dynatech Report No. PII-2, Dynatech R/D Company, Cambridge, February 1980, 28 pages.

12. Fiorato, A. E. and Cruz, C. R., "Thermal Performance of Masonry Walls," Research and Development Bulletin RD071, Portland Cement Association, Skokie, Illinois, 1980, 17 pages.

13. Fiorato, A. E., "Laboratory Tests of Thermal Performance of Exterior Walls," Proceedings of the ASHRAE/DOE-ORNL Conference on Thermal Performance of the Exterior Envelopes of Buildings, Orlando, Florida, December 1979, ASHRAE SP28, New York, 1981, pp. 221-236.

14. Telephone conversation with Mr. James Funkhouser, Dynatherm Engineering, Lino Lakes, Minn.

15. Funkhouser, J.B., "Product Evaluation, Concrete Thermal Conductivity," Report to Perlite Institute, Inc., Dynatherm Engineering, Lino Lakes, Minn., 1982, 2 pages.

16. Van Geem, M. G. and Fiorato, A. E., "Thermal Properties of Masonry Materials for Passive Solar Design - A State-of-the-Art Review," Construction Technology Laboratories, Portland Cement Association, Skokie, 1983, 86 pages.

17. Tye, R. P. and Spinney, S. C., "Thermal Conductivity of Concrete: Measurement Problems and Effect of Moisture," Presented at Meeting of Commission of BI of Institute International Du Froid, Washington, D.C., September 14-15, 1976, Dynatech R/D Company, Cambridge, 17 pages.

18. Van Geem, M. G.; Fiorato, A. E.; and Julien, J. T., "Heat Transfer Characteristics of a Normal-Weight Concrete Wall, Construction Technology Laboratories, Portland Cement Association, Skokie, 1983, 89 pages.

19. "Perlite Loose Fill Insulation," Bulletin 7.14d/Pe, Perlite Institute, Inc., New York.

20. Buildings Insulation Materials Compilation, Bulletin CR80.001, Civil Engineering Laboratory, Port Hueneme, California, 1980, 134 pages.

21. "Korfil Block Insulation," Bulletin 7, Korfil Incorporated, Chicopee, Mass., 12 pages.

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APPENDIX A - ISOTHERMAL PLANES METHOD FOR CALCULATING THE OVERALL U-VALUE FOR THE 8 in (200 mm) WALL INSULATED WITH PERLITE

The isothermal planes method for calculating the overall U-value of an 8 in (200 mm) block wall insulated with perlite is shown below. Using this technique, an isothermal plane is formed where the cores and face shells meet as shown in Figure 1. Using dimensions in Figure A1 and thermal properties of the material, the overall U-value can be calculated. Equation 1 can be rewritten as follows:(3)

$$U = \cfrac{1}{\cfrac{W_{fs}}{k_c} + \cfrac{(W_c/k_c) \cdot (W_c/k_f)}{(a_w)\,(W_c/k_f) + (a_c)\,(W_c/k_c)} + R_{AF}} \qquad \text{(A1)}$$

where

a_w = (3)(32)/406 = 0.23

a_c = 1 - a_w = 0.77

W_{FS} = width of face shells = 0.070 m

W_c = width of core = 0.124 m

k_c = thermal conductivity of the concrete = 0.541 W/m•K

k_f = thermal conductivity of the perlite = 0.049 W/m•K

R_{AF} = thermal resistance of the inside and outside air films = 0.15 $\frac{m^2 \cdot K}{W}$

Therefore:

$$U = \cfrac{1}{\cfrac{0.070}{0.541} + \cfrac{(0.124/0.541)(0.124/0.049)}{(0.23)(0.124/0.049) + (0.77)(0.124/0.541)} + 0.15}$$

$$= 0.96 \ W/m^2 \cdot K$$

TABLE 1

Properties of Hollow Core Concrete Block

Property	Laboratory A			Laboratory B				Laboratory C
Block Description	8 in 103 pcf (200 mm, 1650 kg/m^3)	8 in 85 pcf (200 mm, 1360 kg/m^3)	12 in 85 pcf (300 mm, 1360 kg/m^3)	8 in 73 pcf (200 mm, 1170 kg/m^3)	8 in 108 pcf (200 mm, 1730 kg/m^3)	8 in 112 pcf (200 mm, 1790 kg/m^3)	8 in 129 pcf (200 mm, 2070 kg/m^3)	8 in 116 pcf (200 mm, 1860 kg/m^3)
Standard Dimensions, in (mm)	7-5/8x7-5/8 x15-5/8 (194x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)	11-5/8x7-5/8 x15-5/8 (295x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)	7-5/8x7-5/8 x15-5/8 (194x194x397)
Average Web Thickness, in (mm)	1-1/4 (32)	1-1/4* (32)	1-3/4 (44)	1 (25)	1 (25)	1 (25)	1 (25)	1-1/8 (29)
Average Face Shell Thickness, in (mm)	1-3/8 (35)	1-3/8* (35)	1-3/4 (44)	1-1/4 (32)	1-1/4 (32)	1-1/4 (32)	1-1/4 (32)	1-1/2 (38)
Aggregate	-	-	-	-	-	-	-	Expanded Shale, Carbonate Rock
Number of Cores	2	2	2	2	2	2	2	2
Percent Solid Volume	-	-	-	-	-	-	-	49
Nominal Block Weight, lbs (kg)	32 (145)	24-3/4 (112)	36-3/4 (167)	-	-	-	-	31 (141)
Nominal Concrete Density, pcf (kg/m^3)	-	-	-	73 (1170)	108 (1730)	112 (1790)	129 (2070)	116 (1860)
Ovendry Concrete Density, pcf (kg/m^3)	103 (1650)	85 (1360)	85 (1360)	-	-	-	-	115 (1840)
Thermal Conductivity, Btu•in/h•ft^2•F (W/m•K)	4.3** @ 75F (0.62 @ 24°C)	3.75** @ 75F (0.54 @ 24°C)	3.75** @ 75F (0.54 @ 24°C)	2.6*** @ 108F (0.37 @ 42°C)	7.3*** @ 106F (1.05 @ 41°C)	10.1*** @ 104F (1.46 @ 40°C)	14.7*** @ 92F (2.12 @ 33°C)	- -
Moisture Content, % ovendry weight	-	-	-	-	-	-	-	0.8
Absorption, % ovendry weight	-	-	-	-	-	-	-	10.1

*Measured block dimensions were not given; dimensions are assumed to be the same as for the 8 in. (200 mm), 103 pcf (1650 kg/m^3) block.

**Measured by Laboratory A using a guarded hot plate (ASTM Designation: C177); test specimens were oven dried.

***Measured by Laboratory B using a guarded hot plate (ASTM Designation: C177); with thermocouples embedded in test specimen; test specimens were oven dried.

TABLE 2

Nominal Guarded Hot Box Test Conditions

Test Condition	Laboratory A	Laboratory B
Mean Temperature of Test Specimen, F (°C)	75 (24)	75 (24)
Warm Air Temperature, F (°C)	100 (38)	95 (35)
Cold Air Temperature, F (°C)	50 (10)	13 (55)
Air Velocity, Warm Side, ft/min (m/s)	60 (0.30)	-
Air Velocity, Cold Side, ft/min (m/s)	40 (0.20)	-
Metered Area, ft^2 (m^2)	20.0 (1.9)	11.4 (1.1)

TABLE 3

Measured Thermal Transmittance (U) of Concrete Block Walls With and Without Core Insulation

Wall No.	Core Insulation	Testing Laboratory	Nominal Block Width, in (mm)	Block Density, pcf (kg/m^3)	Measured U* Btu/h•ft^2•F (W/m^2•K)		$\frac{U_{filled}}{U_{empty}}$
					Empty	Filled	
1	Perlite	A	12 (300)	85 (1360)	0.32 (1.82)	0.14 (0.79)	0.43
2	Perlite	A	8 (200)	85 (1360)	0.37 (2.10)	0.19 (1.08)	0.51
3	Perlite	A	8 (200)	103 (1650)	0.41** (2.33)	0.22 (1.25)	0.54
4	Vermiculite	A	8 (200)	103 (1650)	0.41** (2.33)	0.24 (1.36)	0.58
5	EPS Beads	A	8 (200)	103 (1650)	0.41** (2.33)	0.25 (1.42)	0.61
6	EPS Inserts	A	8 (200)	103 (1650)	0.41** (2.33)	0.28 (1.59)	0.70
7	Perlite	B	8 (200)	73 1170)	0.35 (1.99)	0.15 (0.85)	0.43
8	Perlite	B	8 (200)	108 (1730)	0.45 (2.56)	0.29 (1.65)	0.64
9	Perlite	B	8 (200)	112 (1790)	0.47 (2.67)	0.32 (1.82)	0.68
10	Perlite	B	8 (200)	129 (2070)	0.54 (3.07)	0.35 (1.99)	0.65
11	Perlite	C	8 (200)	116 (1860)	0.36 (2.04)	0.22 (1.25)	0.61

*Values are corrected to standard inside and outside air film resistances of 0.68 and 0.17 h•ft^2•F/Btu (0.12 and 0.03 m^2• K/W), respectively.

**These walls were tested with core insulation only. Laboratory A tested a similar wall without core insulation.(14)

TABLE 4

Thermal Conductivity of Perlite Insulation in Test Walls

Wall No.	Testing Laboratory	Nominal Block Width, in (mm)	Block Density, pcf (kg/m^3)	Measured Loose Density of Perlite, pcf (kg/m^3)	Estimated Density of Perlite in Wall, pcf (kg/m^3)	Thermal Conductivity of Perlite, Btu•in/h•ft^2•F (W/m•K)			
						Ref. 19	Ref. 11*	Ref. 2	Assumed
1	A	12 (300)	85 (1360)	6.1 (98)	6.9** (111)	0.36 (0.052)	0.34 (0.049)	0.35 (0.050)	0.34 (0.049)
2	A	8 (200)	85 (1360)	6.1 (98)	5.7*** (91)	0.34 (0.049)	0.34 (0.049)	0.33 (0.048)	0.34 (0.049)
3	A	8 (200)	103 (1650)	6.1 (98)	5.3*** (85)	0.33 (0.048)	0.34 (0.049)	0.33 (0.048)	0.34 (0.049)
7	B	8 (200)	73 (1170)	-	7 (112)	0.36 (0.052)	0.34 (0.049)	0.35 (0.050)	0.34 (0.049)
8	B	8 (200)	108 (1730)	-	7 (112)	0.36 (0.052)	0.34 (0.049)	0.35 (0.050)	0.34 (0.049)
9	B	8 (200)	112 (1790)	-	7 (112)	0.36 (0.052)	0.34 (0.049)	0.35 (0.050)	0.34 (0.049)
10	B	8 (200)	129 (2070)	-	7 (112)	0.36 (0.052)	0.34 (0.049)	0.35 (0.050)	0.34 (0.049)
11	C	8 (200)	116 (1860)	6.1 (98)	-	0.34 (0.049)	0.34 (0.049)	0.34 (0.049)	0.34 (0.049)

*Laboratory B measured conductivity of perlite insulations with densities ranging from 2.1 to 7.4 pcf (34 to 120 kg/m^3) estimated densities of perlite in the wall are used to determine values in this column from Laboratory B test results.

**Estimated assuming total core volume in wall is 14.6 ft^3 (0.41 m^3)

***Estimated assuming total core volume in wall is 10.0 ft^3 (0.28 m^3)

TABLE 5

Comparison of Calculated and Measured Thermal Transmittance Values

Wall No.	Core Insulation	Nominal Block Width, in (mm)	Block Density, pcf (kg/m^3)	Thermal Conductivity*		Empty Cores			Cores with Insulation		
				Concrete	Core Insulation	Calculated U**	Measured U**	Meas. U / Calc. U	Calc. U**	Meas. U**	Meas. U / Calc. U
1	Perlite	12 (300)	85 (1360)	3.75 (0.54)	0.34 (0.049)	0.34 (1.93)	0.32 (1.82)	0.96	0.14 (0.79)	0.14 (0.79)	1.00
2	Perlite	8 (200)	85 (1360)	3.75 (0.54)	0.34 (0.049)	0.38 (2.16)	0.37 (2.10)	0.95	0.17 (0.97)	0.19 (1.08)	1.08
3	Perlite	8 (200)	103 (1650)	4.3 (0.62)	0.34 (0.049)	0.40 (2.27)	0.41 (2.33)	1.02	0.19 (1.08)	0.22 (1.25)	1.18
4	Vermiculite	8 (200)	103 (1650)	4.3 (0.62)	0.44 (0.063)	0.40 (2.27)	0.41 (2.33)	1.02	0.20 (1.14)	0.24 (1.36)	1.20
5	EPS Beads	8 (200)	103 (1650)	4.3 (0.62)	0.29 (0.042)	0.40 (2.27)	0.41 (2.33)	1.02	0.18 (1.02)	0.25 (1.42)	1.39
6	EPS Inserts	8 (200)	103 (1650)	4.3 (0.62)	0.29 (0.037)	0.40 (2.27)	0.41 (2.33)	1.02	0.26 (1.48)	0.28 (1.59)	1.09
7	Perlite	8 (200)	73 (1170)	2.6 (0.37)	0.34 (0.049)	0.35 (1.99)	0.35 (1.99)	1.00	0.12 (0.68)	0.15 (0.85)	1.26
8	Perlite	8 (200)	108 (1730)	7.3 (1.05)	0.34 (0.049)	0.48 (2.73)	0.45 (2.56)	0.94	0.24 (1.36)	0.29 (1.65)	1.23
9	Perlite	8 (200)	112 (1790)	10.1) (1.46)	0.34 (0.049)	0.52 (2.95)	0.47 (2.67)	0.90	0.29 (1.65)	0.32 (1.82)	1.09
10	Perlite	8 (200)	129 (2070)	14.7 (2.12)	0.34 (0.049)	0.57 (3.24)	0.54 (3.07)	0.94	0.38 (2.16)	0.35 (1.99)	0.93
11	Perlite	8 (200)	116 (1860)	11.2*** (1.62)	0.34 (0.049)	0.53 (3.01)	0.36 (2.04)	0.67	0.35 (1.99)	0.22 (1.25)	0.63

*Units are Btu•in/h•ft^2•F (W/m•K)

**Units are Btu/h•ft^2•F (W/m^2•K)

***Estimated

TABLE 6

Effect of Block Dimensions on Wall Thermal Transmittance - Walls with Insulated Cores*

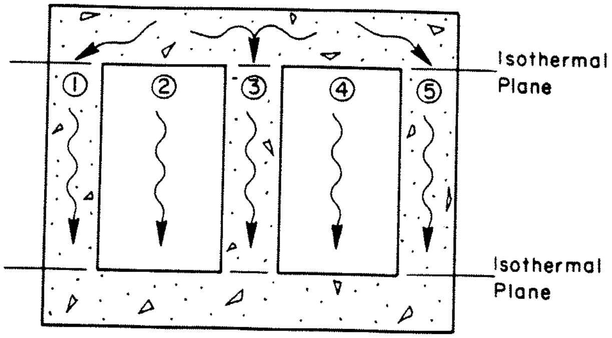
Nominal Width in (mm)	Face Shell Thickness, in (mm)		Web Thickness, in (mm)		Calculated Thermal Transmittance Btu/h•ft^2•F (W/m^2•K)				E	F
	Min.	Max.	Min.	Max.	A Min. for Regular Wall	B Max. for Regular Wall	C Splittable Jam Unit Only	D Wall with 1/3 Splittable Jam Units	B (Max.) / A (Min.)	D / B
4 (100)	3/4 (19)	1 (25)	3/4 (19)	1 (25)	0.28 (1.59)	0.36 (2.04)	0.39 (2.21)	-	1.29	-
6 (150)	1 (25)	1-3/8 (35)	1 (25)	1-1/8 (29)	0.21 (1.19)	0.25 (1.42)	0.29 (1.65)	-	1.19	-
8 (200)	1-1/4 (32)	1-1/2 (38)	1 (25)	1-1/4 (32)	0.16 (0.91)	0.19 (1.08)	0.22 (1.25)	0.20	1.19	1.05
10 (250)	1-1/4 (32)	1-1/2 (38)	1-1/8 (29)	1-1/2 (38)	0.13 (0.74)	0.16 (0.91)	0.19 (1.08)	-	1.23	-
12 (300)	1-1/4 (32)	1-3/4 (44)	1-1/8 (29)	1-3/4 (44)	0.11 (0.62)	0.15 (0.85)	0.18 (1.02)	-	1.36	-

*Assumptions:

(1) Cores filled with perlite insulation

(2) Thermal Conductivity of perlite fill = 0.34 Btu•in/h•ft^2•F (0.049 W/m•K)

(3) Thermal conductivity of concrete with a unit weight of 103 pcf (1650 kg/m^3) = 4.3 Btu•in/h•ft^2•F (0.62 W/m•K)



Cross Section of Concrete Block

Figure 1. Schematic of heat flow paths assumed in isothermal planes calculation method

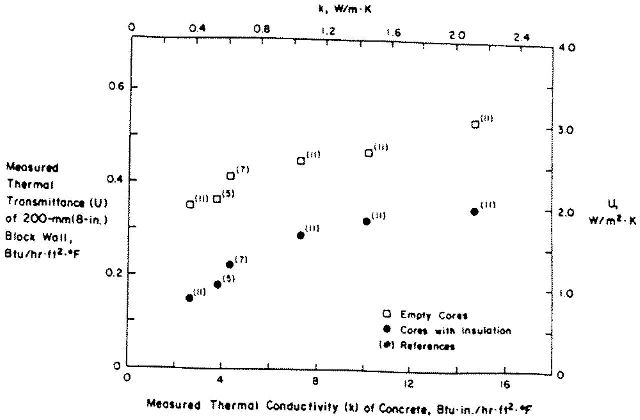


Figure 2. Measured thermal transmittance of 200 mm (8 in). Concrete block wall versus measured thermal conductivity of concrete in block

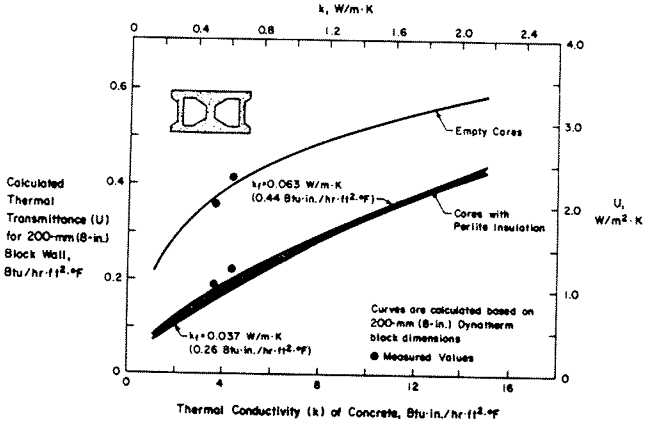


Figure 3. Calculated thermal transmittance of 200 mm (8 in). Concrete block wall as a function of thermal conductivity of concrete in block - walls with and without Perlite insulation

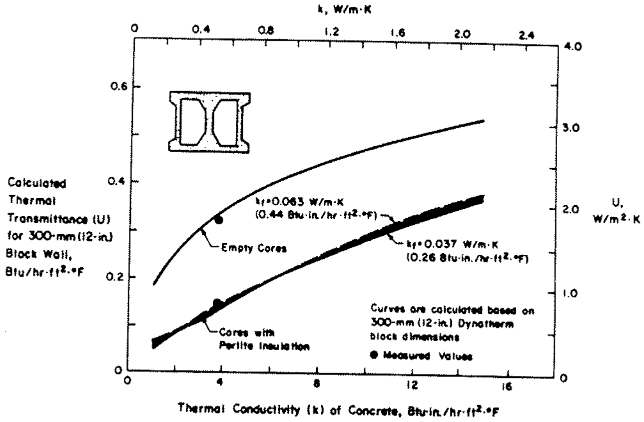


Figure 4. Calculated thermal transmittance of 300 mm (12 in). Concrete block wall as a function of thermal conductivity of concrete in block - walls with and without Perlite insulation

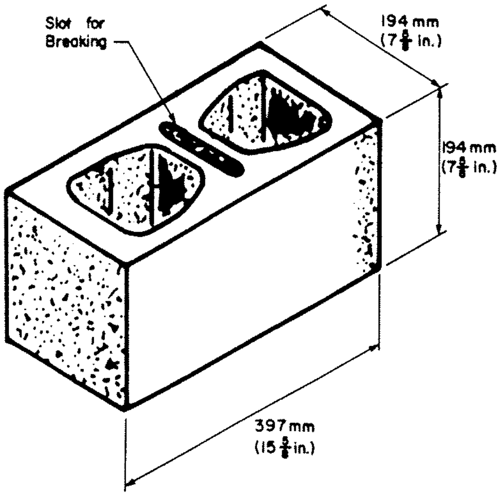


Figure 5. Splittable jam unit

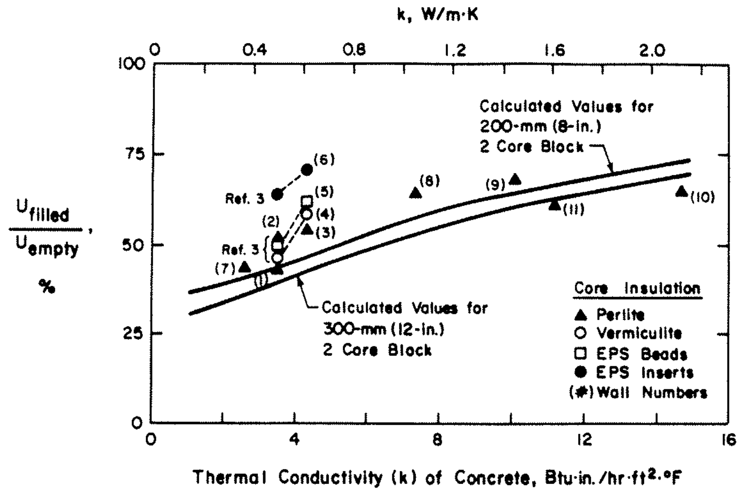
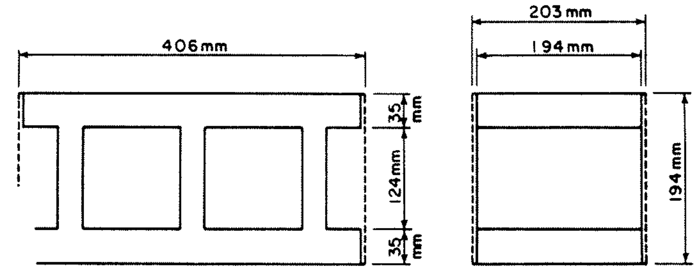
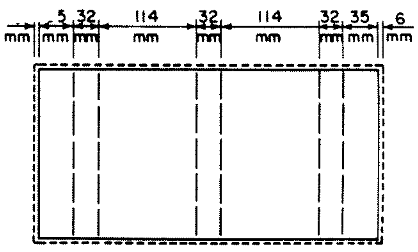


Figure 6. Effect of core insulation as a function of thermal conductivity of concrete in block



a) Plan View

b) End Elevation



c) Side Elevation

Figure A1. Dimensions of 200 mm (8 in). Block used in sample calculations