TECHNICAL DATA SHEET/No. 2-6 1982

# THERMAL PERFORMANCE OF MASONRY WALLS INSULATED WITH PERLITE

The continuing need to conserve energy has resulted in mandated requirements for the thermal performance of construction. Since it is impractical to measure all buildings or building components and systems for thermal properties, simple and accurate methods to reliably predict thermal performance are necessary. Design professionals must estimate the energy requirements associated with all types of building systems, including masonry, to select appropriate systems and to provide for economical heating and cooling design.

Much of the thermal data available for concrete block construction use the block density as a guide to thermal conductivity. However, actual thermal testing shows it is not possible to accurately predict the conductivity of masonry block from the density of the concrete, because of the diversity of materials used in concrete for block manufacture (aggregates, etc.).[1] Thermal conductivity tests of similar density concretes produce considerable variation.[2]

In the interest of presenting realistic information, Perlite Institute sponsored research to develop an accurate calculation method useful in predicting the thermal performance of concrete block walls insulated with perlite loose fill.

Two calculation techniques, the series-parallel (isothermal planes) and the parallel analyses methods, are given in the ASHRAE Handbook of Fundamentals to determine the thermal performance of building assemblies from the properties of the individual components. The series-parallel method has been regarded as more accurate in representing actual installations.[3,4] However, the effects of moisture, mass, air infiltration, orientation, construction techniques and other factors influencing total performance, including dynamic effects are not included in this analysis. The thermal resistive components generally dominates in determining thermal performance, and for comparison purposes, is used to provide realistic design information.

## PERLITE INSTITUTE SPONSORED TEST PROGRAM TO DEVELOP MODEL OF CONCRETE BLOCK WALL THERMAL PERFORMANCE

The program provided a data base to assist in developing a mathamatical model of the thermal performance of typical perlite insulated two-core concrete block wall constructions.

The measured wall thermal transmittance (U value), in comparison with the calculated data based on the concrete block and perlite insulation components, established the validity of generating thermal transmittance design values based on series-parallel calculations. This model and the verification are presented in following sections. The following information discusses a part of the test program.

Four walls were constructed using four block types of known thermal conductivity from measurements conducted in accordance with ASTM C 177 "Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate." The blocks were standard 8-inch two-core concrete blocks. The walls were constructed four blocks long and eight courses high using a dry stack assembly. Two tests were conducted on each wall, one with the cores empty and one with the cores filled with perlite. The thermal transmittance of each wall was tested in accordance with ASTM C 236 "Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box."

TABLE A THE MEASURED THERMAL PERFORMANCE OF FOUR 8-INCH TWO-CORE CONCRETE BLOCK WALLS UNFILLED AND FILLED WITH PERLITE

| Concrete Block Discription | | Thermal Transmittance (U value) at 75F and 15 mph Btu/h·ft$^2$·°F | | |
|---|---|---|---|---|
| Designation | Block Density lbs/ft$^3$ | Cores Unfilled | Cores Filled with 7 lbs/ft$^3$ Perlite | Reduction % |
| #20 | 73 | 0.35 | 0.15 | 57 |
| #28 | 108 | 0.45 | 0.29 | 36 |
| #32 | 112 | 0.47 | 0.32 | 32 |
| #38 | 129 | 0.54 | 0.35 | 33 |

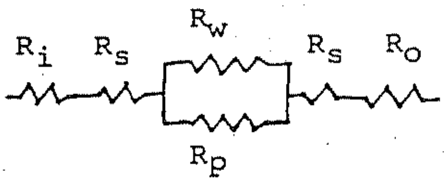
The last column in Table A shows the percent reduction in U value which is achieved by filling the cores with perlite loose fill insulation. The greater effect of the perlite fill occurs at lower concrete thermal conductivity. This is because at low concrete thermal conductivities a greater percentage of energy is passing through the core section. As the thermal conductivity of the concrete increases, a greater percentage of energy passes through the webs and the effect of filling the cores is lessened.

## SERIES-PARALLEL (ISOTHERMAL PLANES) ANALYSIS FOR MASONRY THERMAL PERFORMANCE CALCULATIONS

Providing the thermal conductivities of the system components are known, the thermal transmittance of a two-core concrete block wall system can be modelled using the simple technique of adding the thermal resistances in series and parallel by contributing percent areas.

For a two-core block, a schematic of thermal resistance:

Series-parallel
(Isothermal Planes)
Model



$R_i$ = inside air film resistance

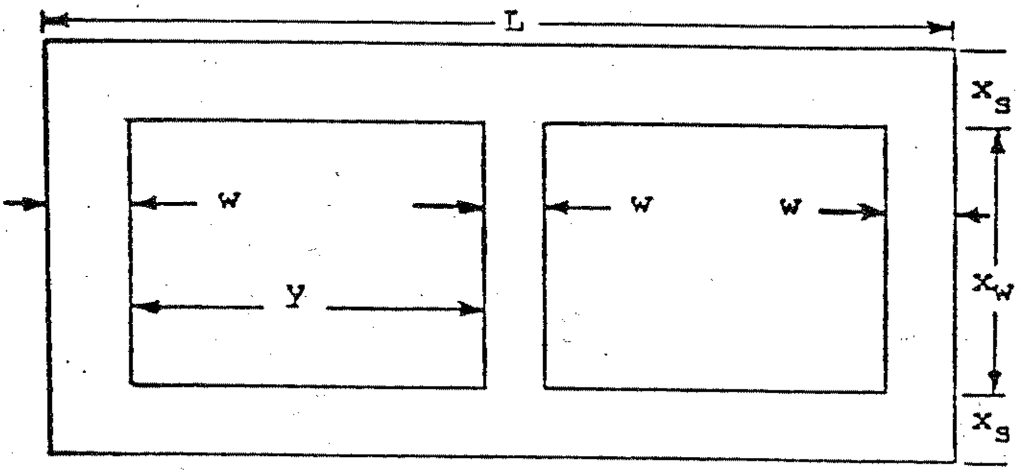
$R_s$ = face shell resistance

$R_p$ = resistance of perlite insulation

$R_w$ = web resistance

$R_o$ = outside air film resistance

A schematic of a typical two-core concrete block filled with perlite is shown below together with a mathematical analog. For simplication, the block is assumed to have square corners, no radii, and no ears.



For the series-parallel model, the equation for calculating the overall thermal resistance of the block, $R_b$, can be written as:

$$R_b = R_i + R_s + \left[\frac{A_c}{R_p} + \frac{A_w}{R_w}\right]^{-1} + R_s + R_o$$

where $A_c$ = percentage of cross sectional area not taken by webs expressed as a decimal number $2y/L$

$A_w$ = percentage of web cross sectional area expressed as a decimal number $1 - (2y/L)$

The thermal resistance terms are obtained or calculated as follows:

$R_i$ and $R_o$ are literature values

$$R_s = \frac{X_s}{\lambda_c}$$

where $X_s$ = thickness of face shell

$\lambda_c$ = apparent thermal conductivity of concrete

$$R_p = \frac{X_w}{\lambda_p}$$

where $X_w$ = thickness of core-web

$\lambda_p$ = apparent thermal conductivity of perlite

$$R_w = \frac{X_w}{\lambda_c}$$

This technique was employed for the four current walls measured in the guarded hot box using the measured values of thermal conductivity of the block concrete and perlite insulation.

## TESTED AND CALCULATED RESULTS/VERIFICATION OF MODEL

Comparison of values resulting from the calculation procedure against perlite insulated and uninsulated wall sections tested in accordance with ASTM C 236 shows the viability of the calculation procedure. The analytical technique will produce calculated values within 15% of actual measurements in most cases. Such values, providing that the concrete thermal conductivity is known, will be very good estimates of the actual resistive thermal transmittance and are considered to be more valid and rigorous than most previous literature values based only on concrete density or the parallel analyses method.

Thus for a standard two core 8-inch block where:

$X_s$ = 1-1/4 inch

$X_w$ = 5-1/8 inch

$W = 1$ inch

$L = 15\text{-}5/8$ inch

and for perlite loose-fill at 7 lb/ft$^3$ having an apparent thermal conductivity of 0.34 btu in/h·ft$^2$·°F, the series-parallel (isothermal planes analysis) can calculate the thermal transmittances for various thermal conductivities of the concrete block material.

Table B compares the measured and calculated thermal transmittance for the test walls. The percent deviation was calculated as being $\frac{(U_c - U_m)100}{U_m}$ where $U_c$ and $U_m$ are the calculated and measured thermal transmittance deviation respectively.

TABLE B

THE MEASURED AND CALCULATED THERMAL TRANSMITTANCE OF FOUR 8-INCH TWO-CORE CONCRETE BLOCK WALLS, EMPTY AND FILLED WITH 7 lbs/ft$^3$ PERLITE LOOSE FILL INSULATION

| Concrete Density lbs/ft$^3$ | Concrete Thermal Conductivity Btu·in/h·ft$^2$·°F | Thermal Transmittance Btu/h·ft$^2$·°F | | | | Percent Deviation of Calculated Values | |
|---|---|---|---|---|---|---|---|
| | | Empty | | Perlite Filled | | | |
| | | Calculated | Measured | Calculated | Measured | Empty | Filled |
| 73 | 2.6 | 0.345 | 0.35 | 0.12 | 0.15 | -1 | -20 |
| 108 | 7.3 | 0.475 | 0.45 | 0.235 | 0.29 | +6 | -19 |
| 112 | 10.1 | 0.52 | 0.47 | 0.295 | 0.32 | +11 | -8 |
| 129 | 14.7 | 0.575 | 0.53 | 0.375 | 0.35 | +8 | +7 |

Table C shows the results for a seven-fold increase in concrete block conductivity from 2 to 14 Btu·in/h·ft$^2$·°F. This range covers that of all concretes currently in use for block constructions. The results confirm the considerable improvement obtained by using loose-fill insulation.

Table D exhibits thermal values of perlite insulated block based on concrete thermal conductivity values published by the National Concrete Masonry Association (NCMA)[6] and the series-parallel (isothermal planes) model.

## TABLE C CALCULATED THERMAL TRANSMITTANCE OF CONCRETE BLOCK WALL SYSTEMS

| Concrete Thermal Conductivity | Thermal Transmittance of 8-inch Two-Core Block Btu/h·ft$^2$·°F | | Percent Reduction for Filled System |
|---|---|---|---|
| Btu·in/h·ft$^2$·°F | Unfilled | Filled 7 pcf Perlite | |
| 2 | 0.312 | 0.101 | 67.6 |
| 4 | 0.401 | 0.157 | 60.9 |
| 6 | 0.452 | 0.206 | 54.4 |
| 8 | 0.489 | 0.251 | 48.7 |
| 10 | 0.519 | 0.291 | 43.9 |
| 12 | 0.[illegible]44 | 0.329 | 39.5 |
| 14 | 0.[illegible]56 | 0.363 | 35.9 |

## TABLE D THERMAL RESISTANCE (R) VALUES[1] AND THERMAL TRANSMITTANCE (U) VALUES[3] OF CONCRETE BLOCK WALLS UNINSULATED AND INSULATED WITH PERLITE LOOSE FILL▲

| Block | 6 in. Block | | | | 8 in. Block | | | | 12 in. Block | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Density (PCF) | Uninsulated | | Insulated with Perlite | | Uninsulated | | Insulated with Perlite | | Uninsulated | | Insulated with Perlite | |
| | R[2] | U[4] | R[2] | U[4] | R[2] | U[4] | R[2] | U[4] | R[2] | U[4] | R[2] | U[4] |
| 80 | 1.80 | 0.38 | 5.93 | 0.15 | 2.03 | 0.35 | 8.25 | 0.11 | 2.30 | 0.32 | 11.93 | 0.08 |
| 95 | 1.57 | 0.41 | 4.86 | 0.18 | 1.77 | 0.38 | 6.76 | 0.13 | 2.00 | 0.35 | 9.64 | 0.10 |
| 105 | 1.45 | 0.44 | 4.25 | 0.20 | 1.63 | 0.40 | 5.91 | 0.15 | 1.84 | 0.37 | 8.36 | 0.11 |
| 115 | 1.34 | 0.46 | 3.69 | 0.22 | 1.51 | 0.42 | 5.14 | 0.17 | 1.70 | 0.39 | 7.21 | 0.12 |
| 125 | 1.20 | 0.49 | 3.04 | 0.26 | 1.36 | 0.45 | 4.23 | 0.20 | 1.54 | 0.42 | 5.88 | 0.15 |
| 135 | 1.06 | 0.52 | 2.42 | 0.31 | 1.21 | 0.49 | 3.37 | 0.24 | 1.33 | 0.45 | 4.64 | 0.18 |

1. The values in this table represent typical R values of concrete block. The actual R of a concrete block is influenced by the concrete constituents and by moisture content. More accurate estimates of thermal performance can be made if the actual thermal conductivity k or thermal resistance R of the specific block has been determined by tests. Pro-

2. R values expressed in °F • ft$^2$ • h/Btu do not include inside and outside air film resistances. To determine total resistance (Rt) of single wythe block walls add .85 to R values shown above.

factors:

3. U values expressed in Btu/h • ft$^2$ • °F were calculated using thermal conductivity k factor of 0.32 Btu • in/h • ft$^2$ • °F. Different densities of perlite in the core spaces of concrete block has only a slight effect on the overall U value.

4. U values shown include the effect of inside and outside air film resistances (15 mph wind).

5. These U values are based on steady state heat flow and must be considered conservative. Some designers may choose to use a mass correction factor which will result in lower U values.

▲Metric: To determine R and U values in S (metric) units use the following conversion factors:

Thermal resistance, R: °F • ft$^2$ • h/Btu x 1.761 102 E−01 = K • m$^2$/W
Thermal transmittance, U: Btu/h • ft$^2$ • °F x 5.687 263 E + 00 = W/m$^2$ • K

## THE EFFECT OF DIFFERING PERLITE THICKNESS AND DENSITIES OF INSULATED BLOCK THERMAL PERFORMANCE

The apparent thermal conductivity of perlite is related to density. Tests of the same density perlite at varying thicknesses were conducted in accordance with ASTM C 518 "Steady State Thermal Transmission Properties by Means of the Heat Flow Meter" to determine if a "thickness effect" was present. For the range of density typically used as masonry insulation there is little or no thickness effect.[7] Results of measurements at test thickness of 1 to 2" are representative of the material in use and can be used for deriving R values at greater thicknesses.

Table E exhibits this consistency of measured conductivity in several samples of perlite at varying thicknesses.

TABLE E

THE APPARENT THERMAL CONDUCTIVITY OF PERLITE

| Test Density lb/ft$^3$ | Test Thickness in. | Apparent Thermal Conductivity at °75F Btu·in/h·ft$^2$·°F |
|---|---|---|
| 4.55 | 2 | 0.298 |
| 4.55 | 6 | 0.296 |
| 6.35 | 3.7 | 0.34 |
| 6.35 | 6.0 | 0.33 |
| 7.0 | 2.0 | 0.34 |
| | 6.0 | 0.34 |
| 7.4 | 2.0 | 0.35 |
| | 6.0 | 0.35 |

Any change in the resistance of an insulated block as a function of perlite differing densities is small, generally less than 5%. For instance, the change in R value on a 12" block manufactured with 80 pcf concrete from insulating the cores with 5 pcf perlite in comparison with 7 pcf is less than 2%. This is because a large proportion of the energy passing through a block is conducted through the webs of the blocks. The isothermal planes model accommodates different perlite conductivities in the insulated cores of the block. For design purposes, the Perlite Institute thermal values published in Sweet's Catalog 7.14d/Pe can be considered representative of the masonry insulation material. More specific information regarding the thermal conductivity of perlite insulation is contained in other P.I. literature.[8]

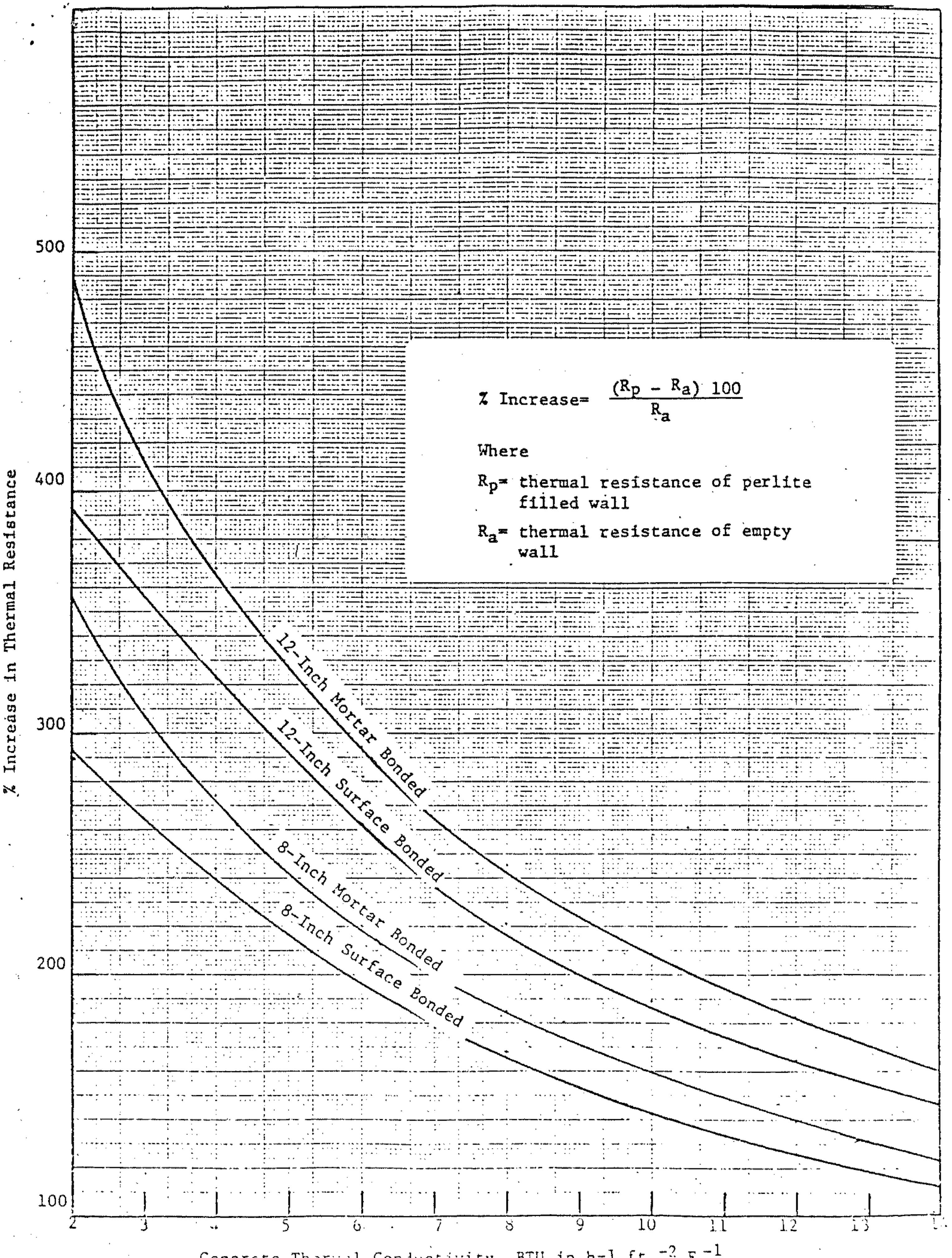
Figures F, G and H exhibit thermal values of perlite insulated single wythe concrete block walls using the series-parallel (isothermal planes) model. Figure F exhibits the percentage increase in thermal resistance, R value, of concrete block walls as a result of using perlite loose fill insulation in the block cores. The curve in Figure F is based on a multiplicity of block samples at varying densities.[9]

Once the thermal conductivity of the concrete used in block manufacture has been determined, the thermal transmittance (U value) of the completed, perlite insulated wall is shown in Figures G and H. Figure G is for conventional face shell mortar bonded block wall construction. Figure H pertains to dry stacked, surface bonded block wall construction.

## PERFORMANCE OF PERLITE LOOSE FILL INSULATION AFTER INSTALLATION IN MASONRY WALLS

Once insulation is placed within a structure, its performance is largely dependent on its in-place dimensional stability. In response to this legitimate concern, Perlite Institute sponsored measurements of insulated masonry to record any "settlement" or volume change which may take place over a period of time in a functioning installation. The building selected was a 12-inch concrete block structure in Dundee Industrial Park, Andover, Massachusetts. The walls are 20 feet in height, with strategically placed plexiglas blocks to observe any change in the perlite insulation. The building was constructed by the dry stack-surface bond method and core holes were aligned to form unobstructed 20 foot vertical columns for the insulation. An independent inspection and testing laboratory was engaged to witness and record settlement data at 90 day intervals. The results indicate minimal settlement. The inspection report dated 235 days after installation measured net settlement in the 20 foot column of perlite to be 0.41%. Additional measurements show the insulation has ceased to "settle" and no further dimensional changes have occurred.[10]

Figure E Empty Concrete Block Wall with Perlite



$$\% \text{ Increase} = \frac{(R_p - R_a)\,100}{R_a}$$

Where

$R_p$ = thermal resistance of perlite filled wall

$R_a$ = thermal resistance of empty wall

Figure F

Thermal Transmittance (U Value), BTU $h^{-1}$ $ft.^{-2}$ $F^{-1}$, of Perlite Insulated Two Core Concrete Block, Face Shell Mortar Bonded

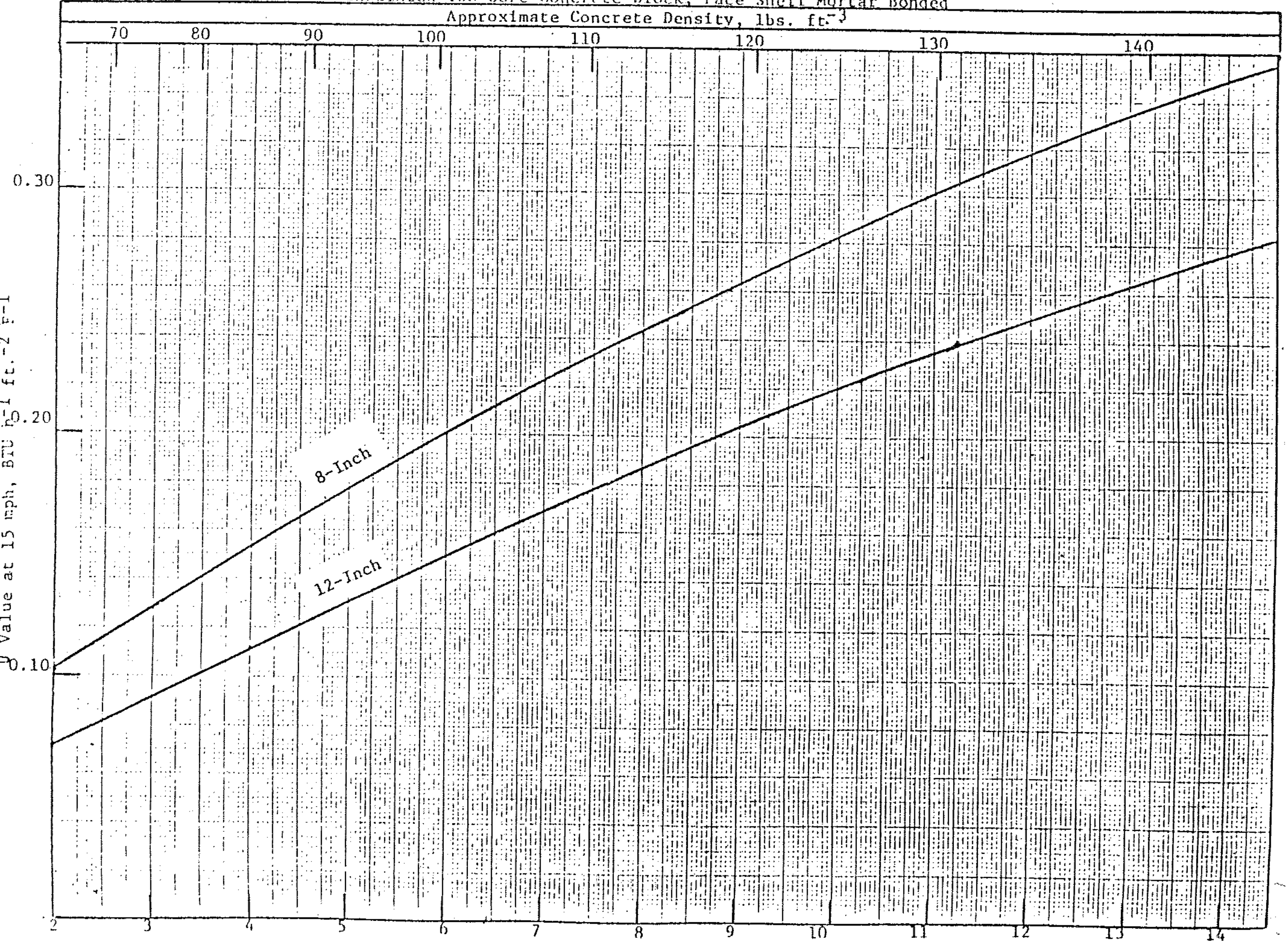
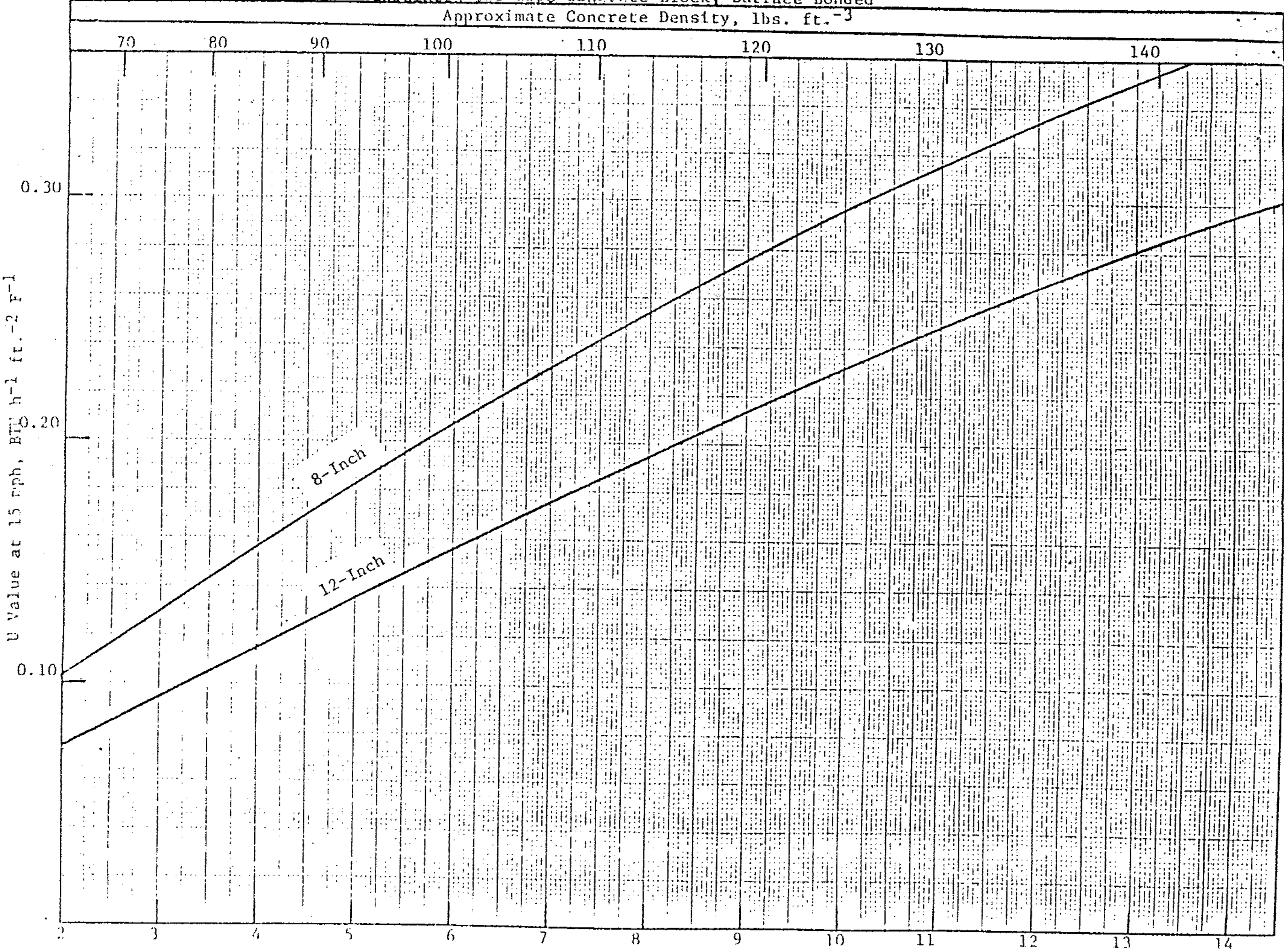


Figure G

Thermal Transmittance (U Value), BTU $h^{-1}$ ft.$^{-2}$ $F^{-1}$, of Perlite Insulated Two Core Concrete Block, Surface Bonded



# FOOTNOTES

1. Spinney and Tye, "A Study of Various Factors Affecting the Thermal Performance of Perlite Insulated Masonry Construction". Dynatech R/D Co.

2. ibid

3. R. C. Valore, "Calculation of U Values of Hollow Concrete Masonry".

4. Shu, Fiorato and Howanski, "Heat Transmission Coefficients of Concrete Block Walls and Core Insulation". ASHRAE/DOE Sumposium

5. ASHRAE Handbook of Fundamentals

6. National Concrete Masonry Association publication: NCMA - TEK 101

7. Dynatech R/D Co. report referenced in footnotes 1, 2

8. Perlite Institute publication: Technical Data Sheet No. 2-4

9. Spinney and Tye, "Thermal Conductivity of Concrete: Measurement Problems and Effect of Moisture". Dynatech R/D Co.

10. The Thompson & Lichtner Co., Inc. report "Inspection of Perlite Wall Fill Settlement, Dundee Park, Andover, Massachusetts".

# GLOSSARY

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASTM: American Society for Testing and Materials.

insulation, thermal: a material or assembly of materials used primarily to provide resistance to heat flow.

isothermal plane: a surface or plane of uniform temperature.

parallel-path analysis: an approximate method of calculation for determining the thermal performance of building structures where the components of the structures are arranged so that parallel heat flow paths of different thermal resistances result. No lateral heat flow between paths is assumed.

perlite: a naturally occurring volcanic mineral which is expanded under high temperature to product granular loose fill insulation. The expanded particles consist of sealed air cells within a mineral matrix.

series-parallel or isothermal planes analysis: an approximate method of calculation for determining the thermal performance of building structures where components are arranged in layers and the thermal resistance of the structure is the sum of the thermal resistances of the layers. It is assumed that heat can flow laterally in any layer so that transverse isothermal planes result.

settlement: the consolidation of an insulation material over time due to gravity, thermal cycling, vibration or the presence of moisture.

silicone treated perlite: expanded perlite particles coated with a silicone material to produce a highly water repellent loose fill insulation material. The material is inert, odorless, does not promote fungal or rodent attack, is light in weight and has superior fire resistance properties.

thermal conductivity, k: a property of a homogeneous body measured by the ratio of steady state heat flux (time rate of heat flow per unit area) to the temperature gradient (temperature difference per unit length of heat flow path) in the direction perpendicular to the area. Typically measured in units of $\mathrm{Btu \cdot in/hr \cdot ft^2 \cdot {}^\circ F}$.

thermal resistance, R: a property of a particular body or assembly measured by the ratio of the difference between the average temperatures of two surfaces to the steady state heat flux in common through them (time rate of heat flow per unit area of one surface which must be identified). Typically measured in units of hr·ft$^2$·°F/Btu·in.

thermal transmittance, U (over-all coefficient of heat transfer): the ratio of the steady state heat flux from the surroundings on one side of a body, through the body, to the surroundings on its opposite side (time rate of heat flow per unit area of a surface which must be identified) to the temperature difference between the two surroundings. Typically measured in units of Btu/hr·ft$^2$·°F.

thickness effect: the recognized phenomenon of reduced thermal performance of an insulation material due to increased thickness. For instance, the effectiveness of 6 inches of many insulations is less than 6 times the measured effectiveness of 1 inch.

SRS:gem