CBIS
Concrete Block Insulating Systems

ENGINEERING REPORT

THE THERMAL EFFICIENCY
OF CONCRETE MASONRY UNITS
INSULATED WITH
KORFIL OR ICON INSULATION INSERTS

PREPARED BY

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ADDENDUM ADDED 5 MARCH 1997

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The original design of Icon Insulation Inserts covered an Insert with an average thickness of 2.5 inches. The original thermal calculations, as shown on page 8 of this report, used this 2.5 inches with a thermal R value of 3.9 per inch for a total R of 9.75.

Today Icon Inserts are produced with an average thickness of 2.25 inches at a tested R per inch of 4.35 for a total R of 9.79. Although this R value is slightly higher, it would have an insignificant impact on the presently published R values.

Also, the average thickness of each side of the U Shaped Korfil Insert is 1.125 inches. The combined thickness of both sides is 2.25 and it is the writer's opinion, the calculated values shown in this report would be equal for both Icon and Korfil Inserts.

Table of Contents

1.0 Introduction

In the past, several mathematical approaches have been used to determine the thermal efficiency of ordinary concrete blocks. In 1989, the American Society of Heating, Refrigeration and Air Conditioning Engineers(ASHRAE) published in their Fundamentals Handbook their accepted method of calculating the Overall R - Value of Masonry Walls. This method is also known as the Isothermal Planes method.

This report covers the thermal efficiency of masonry units factory insulated with ICON Universal Inserts using the Isothermal Planes method.

2.0 References

A. 1989 ASHRAE Fundamentals Handbook, pages 22.4 and 22.5 (Appendix - Exhibit A)

B. ASTM C90 Standard Specification for Hollow Load-Bearing Concrete Masonry as detailed in NCMA - TEK 141 (Appendix - Exhibit B)

C. Material R - Values as detailed in NCMA - TEK 101A (Appendix - Exhibit C)

D. Oak Ridge National Laboratory Report ORNL/Sub/86-22020/1 "Assessment of the Thermal and Physical Properties of Masonry Block Products", September 1988 for the U.S. Department of Energy, Paragraph 3.4.2 (Appendix - Exhibit D)

3.0 Description of Calculation Procedure

The equation to determine the isothermal plane method of calculating the total thermal resistance of an insulated concrete block wall is:

$$R_{T(Avg)} = R_i + \frac{R_f\ R_m}{a_m R_f + a_f R_m} + \frac{R_w\ R_c}{a_c R_w + a_w R_c} + R_o$$

This formula assumes heat flows laterally through block face shells so that transverse isothermal planes result and the average total resistance $R_{T(Avg)}$ is the sum of the resistance layers between the face shells.

Where:

$R_{T(Avg)}$ = Average Total Resistance

R_i = Thermal Resistance of inside air surface film(still air) and is a known value.

R_o = Thermal Resistance of outside air surface film(15 mph wind) and is a known value.

R_f = Thermal Resistance of block face shell. It is the product of the face shell thickness in inches times the resistance value per inch of the face shell material.

R_m = Thermal Resistance of mortar. It is the product of the face shell thickness in inches times the resistance value per inch of the mortar material.

R_w = Thermal Resistance of the block webs. It is the product of the web length in inches between the face shells times the resistance value.

R_c = Thermal Resistance of the block cores. In the case of cores insulated with ICON Universal Inserts, it is the product of the insert thickness in inches times the resistance value per inch of the insulation material plus the value of .97 which is the resistance value of the balance of the air space within the cores.

a_m = The fraction of the total area transverse to heat flow represented by the mortar.

3.0 Description of Calculation Procedure(cont.)

a_f = The fraction of the total area transverse to heat flow represented by the face shell of the block.

a_w = The fraction of the total area transverse to heat flow represented by the webs of the block.

a_c = The fraction of the total area transverse to heat flow represented by the cores of the block.

Table I represents the physical block dimensions used. These values are based upon the properties of hollow masonry units having the minimum dimensions as set forth in ASTM C90.

Table II represents the thermal resistivity of materials used. All masonry listings are based on an over dry condition.

Table I

Minimum Thickness of Face Shell and Webs

Reference - Appendix - Exhibit B

Nominal Width of Concrete Masonry Unit	Face Shell Thickness(in.)	Web Thickness(in.)
6	1	1
8	1 1/4	1
10	1 3/8	1 1/8
12	1 1/2	1 1/8

Table II

Material Resistivity Table

Reference - Appendix - Exhibit C

Material	Resistivity(hr·sf·°F/BTU·in)
Mortar	.20
Density of Concrete,pcf	
80	.404
95	.299
105	.245
115	.201
125	.164
135	.134
Expanded Polystyrene	4.00
Surface Films	
Inside	.68
Outside	.17
Airspace(3/4 in. to 4 in.)	.97

4.0 Example - Calculation of the Thermal Resistance of an 8 x 8 x 16 standard concrete masonry unit.

Known:

Density of Concrete - 105pcf(R = .245 per inch)

Mortar R = .20 per inch

Insulation - ICON Universal Insulation Inserts 2.5 inches thick(R = 3.9 per inch)

Face Shell Thickness - 1.25 inches

Web Thickness - 1 inch

$$R_{T(Avg)} = R_i + \frac{R_f R_m}{a_m R_f + a_f R_m} + \frac{R_w R_c}{a_c R_w + a_w R_c} + R_o$$

Where:

$R_i = .68$ R core air space = .97

$R_o = .17$

$R_f = 2^* \times 1.25 \times .245 = .613$

$R_m = 2^* \times 1.25 \times .20 = .50$

$R_w = 7.625 - (2 \times 1.25) \times .245 = 1.256$

$R_c = 2.5 \times 3.9 + .97 = 10.72$

$a_f = 7.625 \times 15.625/128 = .931$

$a_m = 1 - a_f = .069$

$a_w = 3 \times 1/15.625 = .192$

$a_c = 1 - a_w = .808$

* The terms R_f and R_m take into consideration both face shells of the block.

$$R_{T(Avg)} = .68 + \frac{.613 \text{ x } .5}{.069\text{x}.613 + .931\text{x}.5} + \frac{1.256 \text{ x } 10.72}{.808\text{x}1.256 + .192\text{x}10.72} + .17$$

$$= .68 + .604 + 4.381 + .17$$

$$R_{T(Avg)} = 5.835$$

$$U_{(Avg)} = \frac{1}{R_{T(Avg)}} = \frac{1}{5.835} = .171$$

5.0 Thermal Efficiency of Sixteen(16) Inch Long Concrete Masonry Units in 6, 8, 10 and 12 Inch Widths

Using the method as detailed in Section 4.0 of this report, the following values apply to masonry units insulated with ICON Universal Inserts. (Table III)

Table III

Density of Concrete Used in Block(pcf)	Type of Block(Width x Height x Length)							
	6 x 8 x 16		8 x 8 x 16		10 x 8 x 16		12 x 8 x 16	
	$R_{T(Avg)}$	U_{Avg}	$R_{T(Avg)}$	U_{Avg}	$R_{T(Avg)}$	U_{Avg}	$R_{T(Avg)}$	U_{Avg}
80	6.45	.16	7.74	.13	8.52	.12	9.38	.11
95	5.39	.19	6.55	.15	7.25	.14	8.09	.12
105	4.76	.21	5.83	.17	6.48	.15	7.27	.14
115	4.21	.24	5.17	.19	5.76	.17	6.51	.15
125	3.69	.27	4.56	.22	5.09	.20	5.78	.17
135	3.25	.31	4.01	.25	4.48	.22	5.11	.20

6.0 Example - Calculation of the Thermal Resistance of an 8 x 8 x 18 standard concrete masonry unit

Known:

Density of Concrete - 105pcf(R = .245 per inch)

Mortar R = .20 per inch

Insulation - ICON Universal Insulation Inserts
2.5 inches thick(R = 3.9 per inch)

Face Shell Thickness - 1.25 inches

Web Thickness - 1 inch

$$R_{T(Avg)} = R_i + \frac{R_f R_m}{a_m R_f + a_f R_m} + \frac{R_w R_c}{a_c R_w + a_w R_c} + R_o$$

Where:

$R_i = .68$ $R_{\text{core air space}} = .97$

$R_o = .17$

$R_f = 2^* \times 1.25 \times .245 = .613$

$R_m = 2^* \times 1.25 \times .20 = .50$

$R_w = 7.625 - (2 \times 1.25) \times .245 = 1.256$

$R_c = 2.5 \times 3.9 + .97 = 10.72$

$a_f = 7.625 \times 17.625/144 = .933$

$a_m = 1 - a_f = .067$

$a_w = 3 \times 1/17.625 = .170$

$a_c = 1 - a_w = .830$

6.0 Example(cont.)

* The terms R_f and R_m take into consideration both face shells of the block.

$$R_{T(Avg)} = .68 + \frac{.613 \text{ x } .5}{.067\text{x}.613 + .933\text{x}.5} + \frac{1.256 \text{ x } 10.72}{.830\text{x}1.256 + .170\text{x}10.72} + .17$$

$$= .68 + .604 + 4.700 + .17$$

$$R_{T(Avg)} = 6.154$$

$$U_{(Avg)} = \frac{1}{R_{T(Avg)}} = \frac{1}{6.154} = .162$$

7.0 Thermal Efficiency of Eighteen(18) Inch Long Concrete Masonry Units in 8 and 12 Inch Widths

Again using the method shown in Section 6 of this report, the values shown in Table IV apply to eighteen(18) inch long masonry units insulated with ICON Universal Inserts.

Table IV

Density of Concrete Used in Block(pcf)	Type of Block(Width x Height x Length)			
	8 x 8 x 18		12 x 8 x 18	
	$R_{T(Avg)}$	U_{Avg}	$R_{T(Avg)}$	U_{Avg}
80	8.06	.12	9.42	.11
95	6.88	.15	8.13	.12
105	6.15	.16	7.31	.14
115	5.48	.18	6.55	.15
125	4.84	.21	5.81	.17
135	4.27	.23	5.14	.19

8.0 Conclusions

The use of ICON Universal Insulation Inserts can reduce the heating or cooling loss thru standard concrete masonry units by upwards to 50%. This conclusion is based on results obtained by using the Isothermal Planes method detailed in the 1989 ASHRAE Handbook of Fundamentals.

In the absence of actual laboratory thermal test data on insulated wall systems, building designers can rely on the Isothermal Planes method to provide accurate heat flow measurements for conventional masonry construction. It should be obvious to the reader however, the real world conditions of workmanship along with environmental conditions such as moisture penetration are not taken into consideration by either laboratory tests or the calculation method. In todays energy conservation era with the adoption of strict energy codes it is essential that suppliers of energy related products to the construction industry provide qualified thermal data so that designers can make realistic comparisons between the many wall systems available today. The data submitted in this report fulfills that requirement.

Appendix

Exhibit A
Page 1 of 2

If the wood framing is included using the isothermal planes method, the U-factor of the wall is determined using Equations (2) and (3) from Chapter 20 as follows:

$$R_{T(av)} = 2.30 + 1/[(0.85/11.00) + (0.15/4.38)] + 1.13$$
$$= 12.44\ \mathrm{F \cdot ft^2 \cdot h/Btu}$$
$$U_{av} = 0.080\ \mathrm{Btu/h \cdot ft^2 \cdot {}^\circ F}$$

For a frame wall with a 24 in. OC stud space, the average overall R-value becomes 13.16°F·ft²·h/Btu. Similar calculation procedures can be used to evaluate other wall designs.

Masonry Walls

The average overall R-values of masonry walls can be estimated by assuming a combination of layers in series, one or more of which provides parallel paths. This method is used because heat flows laterally through block face shells so that transverse isothermal planes result. Average total resistance $R_{T(av)}$ is the sum of the resistances of the layers between such planes, each layer calculated as shown in Example 2.

Example 2. Calculate the overall thermal resistance and average U-factor of the 7-5/8-in. thick insulated concrete block wall shown in Figure 3. The two-core block has an average web thickness of 1-in. and a face shell thickness of 1-1/4-in. Overall block dimensions are 7-5/8 by 7-5/8 by 15-5/8 in. Thermal resistances of 112 lb/ft³ concrete and 5 lb/ft³ expanded perlite insulation are 0.10 and 2.90°F·ft²·h/Btu per in., respectively.

Solution: The equation used to determine the overall thermal resistance of the insulated concrete block wall is derived from Equations (2) and (5) from Chapter 20 and is given below:

$$R_{T(av)} = R_i + R_f + \frac{R_w R_c}{a_c R_w + a_w R_c} + R_o$$

where

$R_{T(av)}$ = overall thermal resistance based on the assumption of isothermal planes
R_i = thermal resistance of inside air surface film (still air)
R_o = thermal resistance of outside air surface film (15 mph wind)
R_f = total thermal resistance of face shells
R_c = thermal resistance of cores between face shells
R_w = thermal resistance of webs between face shells

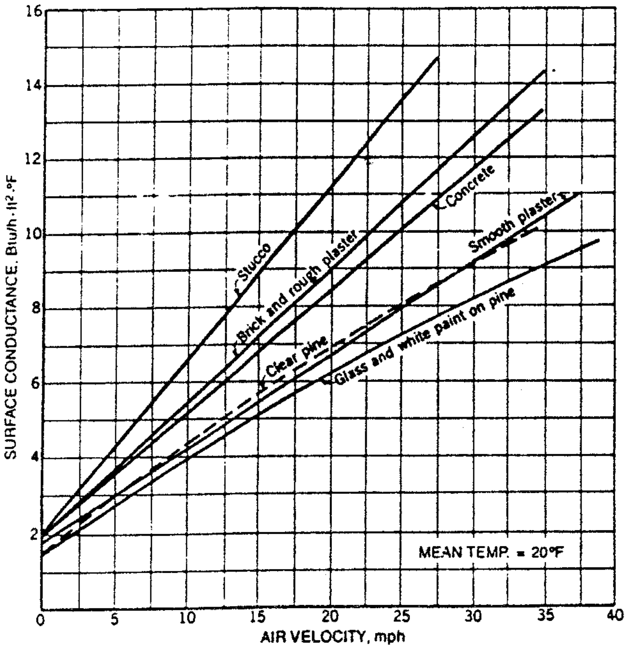


Fig. 1 Surface Conductance for Different 12-Inch-Square Surfaces as Affected by Air Movement

a_w = fraction of total area transverse to heat flow represented by webs of blocks
a_c = fraction of total area transverse to heat flow represented by cores of blocks

From the information given and the data in Table 1, determine the values needed to compute the overall thermal resistance.

$$R_i = 0.68$$
$$R_o = 0.17$$
$$R_f = (2)(1.25)(0.10) = 0.25$$
$$R_c = (5.125)(2.90) = 14.86$$
$$R_w = (5.125)(0.10) = 0.51$$
$$a_w = 3/15.625 = 0.192$$
$$a_c = 12.625/15.625 = 0.808$$

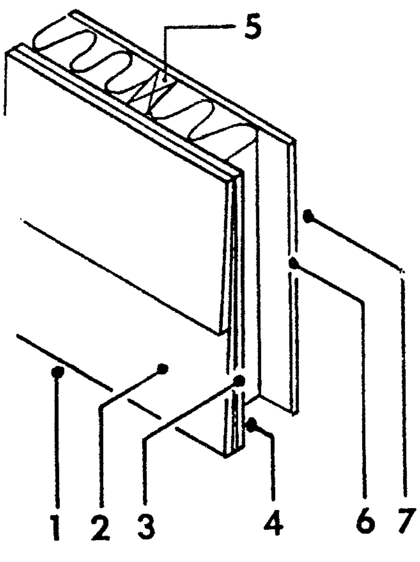
Using the equation given, the overall thermal resistance and average U-factor are calculated as follows:

$$R_{T(av)} = 0.68 + 0.25 + (0.51)(14.86)/[(0.808)(0.51) + (0.192)(14.86)] + 0.17$$
$$= 0.68 + 0.25 + 2.33 + 0.17 = 3.43\,{}^\circ\mathrm{F \cdot ft^2 \cdot h/Btu}$$
$$U_{av} = 1/3.43 = 0.292\ \mathrm{Btu/h \cdot ft^2 \cdot {}^\circ F}$$

Based on guarded hot box tests, Van Geem (1985) measured the average R-value for this insulated concrete block wall as 3.13°F·ft²·h/Btu.

Assuming parallel heat flow only, the calculated resistance is usually higher than that calculated on the assumption of isothermal planes. The actual resistance generally is some value between the two calculated values. In the absence of test values, examination of the construction usually reveals whether a value closer to the higher or lower calculated R-value should be used. Generally, if the construction contains a layer in which lateral conduction is high compared with transmittance through the construction, the calculation with isothermal planes should be used. If the construction has no layer of high lateral conductance, the parallel heat flow calculation should be used.

Hot box tests of insulated and uninsulated masonry walls constructed with block of conventional configuration show that thermal resistances calculated using the isothermal planes heat flow



1. Outside surface (15 mph wind)
2. Wood siding, 0.5 in. by 8 in. lapped
3. Sheating, 0.5 in. vegetable fiber board
4. Mineral fiber batt insulation, 3.5 in.
5. Nominal 2 by 4 wood stud
6. Gypsum wallboard, 0.5 in.
7. Inside surface (still air)

Fig. 2 Insulated Wood Frame Wall (Example 1)

Exhibit A
Page 2 of 2

method agree well with measured values (see Van Geem 1985, Valore 1980, Shu *et al.* 1979). Neglecting horizontal mortar joints can result in thermal transmittance values up to 16% lower than actual, depending on the density and thermal properties of the masonry, and 1 to 6% lower depending on the core insulation material (Van Geem 1985, McIntyre 1984). Horizontal mortar joints usually found in concrete block wall construction are neglected in Example 2.

Panels Containing Metal

Curtain wall constructions often include metallic and other thermal bridges. Thermal resistance of panels can be significantly reduced by metallic thermal bridges. However, the capacity of the adjacent facing materials to transmit heat transversely to the metal is limited, and some contact resistance between all materials in contact limits the reduction. Contact resistances in building structures are only 0.06 to 0.6 °F·ft²·h/Btu which are too small to be of concern in many cases. However, the contact resistances of steel framing members are important to consider. Also, in many cases (as illustrated in Example 3) the area of metal in contact with the facing greatly exceeds the thickness of the metal which mitigates the influence.

Thermal characteristics for panels of sandwich construction can be computed by combining the thermal resistances of the various layers. However, few panels are true sandwich constructions; many have ribs and stiffeners that create complicated heat flow paths. R-values for the assembled sections should be determined on a representative sample by using a hot box method. If the sample is a wall section with air cavities on both sides of fibrous insulation, the sample must be of representative height since convective airflow can contribute significantly to heat flow through the test section. Computer modeling can also be useful, but all heat transfer mechanisms must be considered.

In Example 3, the metal member is only 0.020 in. thick, but it is in contact with adjacent facings over a 1.25 in.-wide area. The steel member is 3.50 in. deep, has a thermal resistance of approximately 0.011 °F·ft²·h/Btu, and is virtually isothermal. The calculation involves careful selection of the appropriate thickness for the steel member. If the member is assumed to be 0.020 in. thick, the fact that the flange transmits heat to the adjacent facing is ignored. If the member is assumed to be 1.25 in. thick, the heat flow through the steel is overestimated. In Example 3, the steel member behaves in much the same way as a rectangular member 1.25 in. thick and 3.50 in. deep with a thermal resistance of 0.69 °F·ft²·h/Btu [(1.25/0.020) × 0.011] does. The Building Research Association of New Zealand (BRANZ) commonly uses this approximation.

Table 3 Emittance Values of Various Surfaces and Effective Emittances of Airspaces[a]

		Effective Emittance, *E* of Airspace	
Surface	Average Emittance ε	One surface emittance ε; the other 0.9	Both surfaces emittance ε
Aluminum foil, bright	0.05	0.05	0.03
Aluminum foil, with condensate just visible (> 0.7gr/ft²)	0.30[b]	0.29	—
Aluminum foil, with condensate clearly visible (> 2.9 gr/ft²)	0.70[b]	0.65	—
Aluminum sheet	0.12	0.12	0.06
Aluminum coated paper, polished	0.20	0.20	0.11
Steel, galvanized, bright	0.25	0.24	0.15
Aluminum paint	0.50	0.47	0.35
Building materials: wood, paper, masonry, nonmetallic paints	0.90	0.82	0.82
Regular glass	0.84	0.77	0.72

[a] These values apply in the 4 to 40 μm range of the electromagnetic spectrum.
[b] Values are based on data presented by Bassett and Trethowen (1984).

Example 3. Calculate the C-factor of the insulated steel frame wall shown in Figure 4. Assume that the steel member has an R-value of 0.69 °F·ft²·h/Btu and that the framing behaves as though it occupies approximately 8% of the transmission area.

Solution: Obtain the R-values of the various building elements from Table 4.

Element	R(Insulation)	R(Framing)
1. 0.5-in. gypsum wallboard	0.45	0.45
2. 3.5-in. mineral fiber batt insulation	11	—
3. Steel framing member	—	0.69
4. 0.5-in. gypsum wallboard	0.45	0.45
	R_1 = 11.90	R_2 = 1.59

Therefore, $C_1 = 0.084$; $C_2 = 0.629$ Btu/h·ft²·°F.

If the steel framing (*i.e.*, thermal bridging) is not considered, the C-factor of the wall is calculated using Equation (3) from Chapter 20 as follows:

$$C_{av} = C_1 = 1/R_1 = 0.084 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}$$

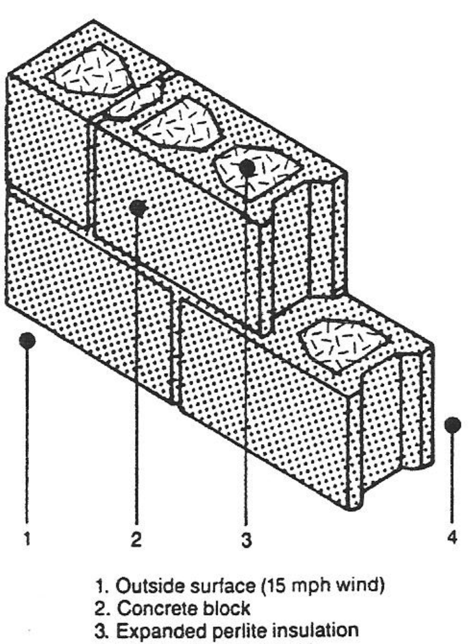
If the steel framing is accounted for using the parallel flow method, the C-factor of the wall is determined using Equation (5) from Chapter 20 as follows:

$$\begin{aligned} C_{av} &= (0.92 \times 0.084) + (0.08 \times 0.629) \\ &= 0.128 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F} \\ R_{T(av)} &= 7.81\,{}^\circ\text{F}\cdot\text{ft}^2\cdot\text{h/Btu} \end{aligned}$$

If the steel framing is included using the isothermal planes method, the C-factor of the wall is determined using Equations (2) and (3) from Chapter 20 as follows:

$$\begin{aligned} R_{T(av)} &= 0.45 + 1/[(0.92/11.00) + (0.08/0.69)] + 0.45 \\ &= 5.91\,{}^\circ\text{F}\cdot\text{ft}^2\cdot\text{h/Btu} \\ C_{av} &= 0.169 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F} \end{aligned}$$

Farouk and Larson (1983) measured an average R-value of 6.61 °F·ft²·h/Btu for this insulated steel frame wall.



1. Outside surface (15 mph wind)
2. Concrete block
3. Expanded perlite insulation
4. Inside surface (still air)

Fig. 3 Insulated Concrete Block Wall (Example 2)

Exhibit B
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An Information series from National Concrete Masonry Association 141

Concrete Masonry Section Properties for Design

Introduction

This publication is intended for use as a guide in the design of concrete masonry structures.

Section properties of concrete masonry units, required for the determination of stresses under design loads and as a check against the allowable stresses permitted by the applicable building codes, are presented in the tables which follow. These tables are based upon the properties of hollow units having the minimum dimensions as set forth in ASTM C 90, "Standard Specification for Hollow Load-Bearing Concrete Masonry Units." (Table 1) Concrete masonry units are available in many sizes and shapes having dimensions which do not necessarily correspond with those indicated. Use of the tables should produce results which are conservative since they are based on minimum allowable face shell and web thicknesses. When a specific manufacturer's block are specified, section properties of the actual units to be used may be obtained from the producer if more precise calculations are desired.

TABLE 1
Minimum Thickness of Face-Shell and Webs—ASTM C 90

Nominal Width (W) of Units, in. (mm)	Face-Shell Thickness (FST) min, in. (mm)[a]	Web Thickness (WT) Webs,[a] min, in. (mm)	Web Thickness (WT) Equivalent Web Thickness, min, in./linear ft[b] (mm/linear m)[b]
3 (76.2) and 4 (102)	¾ (19)	¾ (19)	1⅝ (136)
6 (152)	1 (25)	1 (25)	2¼ (188)
8 (203)	1¼ (32)	1 (25)	2¼ (188)
10 (254)	1⅜ (35) 1¼ (32)[c]	1⅛ (29)	2½ (209)
12 (305)	1½ (38) 1¼ (32)[c]	1⅛ (29)	2½ (209)

[a] Average of measurements on 3 units taken at the thinnest point, when measured as described in Methods C 140, Sections 15 and 17.2.

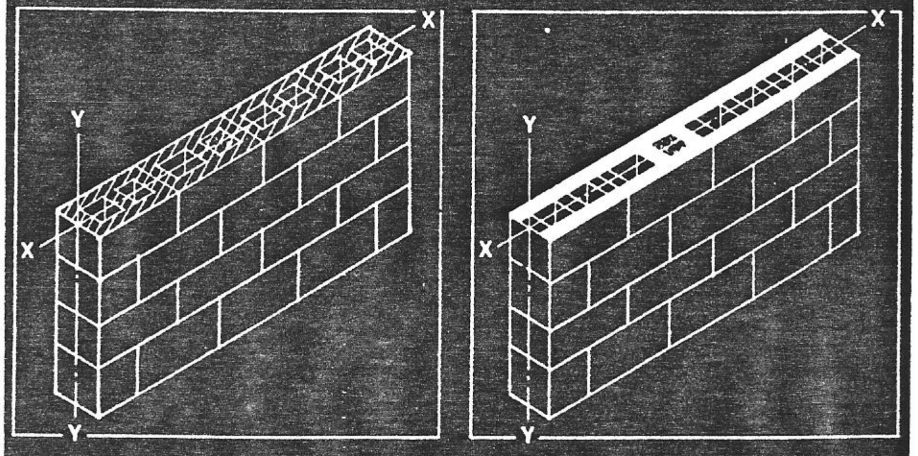
[b] Sum of the measured thickness of all webs in the unit, multiplied by 12, and divided by the length of the unit.

[c] This face-shell thickness (FST) is applicable where allowable design load is reduced in proportion to the reduction in thickness from basic face-shell thicknesses shown.

FIGURE 1.
Illustration of Net Cross Sectional Area and Net Section Properties Presented in Tables 4-8

NET CROSS-SECTIONAL AREA—The Average Net Area of the Masonry Unit Plus the Grouted Area.

NET SECTION—Mortar Bedded Areas Plus the Grouted Area



NET CROSS-SECTIONAL AREA IS THE EFFECTIVE AREA FOR AXIAL COMPRESSIVE STRESS CALCULATIONS.

NET SECTION IS THE EFFECTIVE AREA FOR SHEAR, TENSION, AND FLEXURE

Explanation of Tables

Figure 1 illustrates the net cross sectional area and net section values contained in Tables 4 through 8. The net cross sectional area is the average net area of the masonry unit plus the grouted area

Exhibit B
Page 2 of 2

TABLE 2
Average Weight of Concrete Masonry Units

Nominal Size	Density (pcf) 80	90	100	110	120	130	140
4x8x16	14.5	16.5	18.0	20.0	22.0	23.5	25.5
6x8x16	17.0	19.0	21.5	23.5	25.5	27.5	30.0
8x8x16	22.5	25.0	28.0	30.5	33.5	36.0	39.0
10x8x16	27.5	31.0	34.5	37.5	41.0	44.5	48.0
12x8x16	31.0	35.0	39.0	43.0	47.0	50.5	54.5

NOTE: The above Table gives the approximate average weights of standard 2 core hollow units in pounds for various concrete densities.

TABLE 3
Average Weight of Completed Walls

Wall Thickness	Unit Density (pcf) 80	90	100	110	120	130	140
4"	18.0	20.0	22.0	24.0	26.5	28.0	30.5
6"	21.0	23.5	26.0	28.5	30.5	33.0	36.0
8"	28.0	30.5	34.0	37.0	40.0	43.0	46.5
10"	33.5	37.5	41.5	45.0	48.5	52.5	56.5
12"	37.5	42.0	46.5	51.0	55.5	59.5	64.0

NOTE: The above Table gives the approximate average weights of completed walls of various thicknesses in pounds per square foot of wall face area. Units are assumed to be standard 2 core hollow units with face shell bedding. Mortar density = 140 pcf.

TABLE 4
Properties for Wall Design

Unit Designation: 4x8x16 Load Bearing Concrete Masonry Units
Unit Specification: ASTM C 90

Actual Dimensions:

Unit Thickness	3.625 Inches	Face Shell Thickness	0.750 Inch
Unit Height	7.625 Inches	Web Thickness	0.750 Inch

		An Net Cross$^{(1)}$ Sectional Area In^2/Ft.	Net$^{(2)}$ Section In^2/Ft.	$I_x^{(3)}$ In^4/Ft.	$I_y^{(4)}$ In^4/Ft.	$S_x^{(5)}$ In^3/Ft.	$S_y^{(6)}$ In^3/Ft.
Face Shell Mortar Bedding		21.6	18.0	38.0	38.0	21.0	21.0
Full Mortar Bedding (Face Shell & Web)		21.6	21.6	39.4	38.5	21.7	21.2
Grouted Walls	8	43.5	43.5	47.6	47.6	26.3	26.3
Spacing of	16	32.2	31.0	42.9	42.8	23.7	23.6
Vertically	24	28.7	26.7	41.3	41.2	22.8	22.8
Grouted cores	32	26.9	24.5	40.5	40.4	22.3	22.3
for x axis.	40	25.8	23.2	40.0	40.0	22.1	22.0
Spacing of	48	25.1	22.3	39.7	39.6	21.9	21.9
Horizontally	56	24.6	21.7	39.4	39.4	21.8	21.7
Grouted courses	64	24.3	21.3	39.3	39.2	21.7	21.6
for y axis.	72	24.0	20.9	39.1	39.1	21.6	21.6

TABLE 5
Properties for Wall Design

Unit Designation: 6x8x16 Load Bearing Concrete Masonry Units
Unit Specification: ASTM C 90

Actual Dimensions:

Unit Thickness	5.625 Inches	Face Shell Thickness	1.000 Inch
Unit Height	7.625 Inches	Web Thickness	1.000 Inch

		An Net Cross$^{(1)}$ Sectional Area In^2/Ft.	Net$^{(2)}$ Section In^2/Ft.	$I_x^{(3)}$ In^4/Ft.	$I_y^{(4)}$ In^4/Ft.	$S_x^{(5)}$ In^3/Ft.	$S_y^{(6)}$ In^3/Ft.
Face Shell Mortar Bedding		32.2	24.0	130.3	130.3	46.3	46.3
Full Mortar Bedding (Face Shell & Web)		32.2	32.2	139.3	132.6	49.5	47.1
Grouted Walls	8	67.5	67.5	178.0	178.0	63.3	63.3
Spacing of	16	49.3	46.6	155.1	154.2	55.1	54.8
Vertically	24	43.6	39.1	146.8	146.2	52.2	52.0
Grouted cores	32	40.7	35.3	142.7	142.3	50.7	50.6
for x axis.	40	39.0	33.0	140.2	129.9	49.9	49.7
Spacing of	48	37.9	31.5	138.6	138.3	49.3	49.2
Horizontally	56	37.1	30.5	137.1	137.1	48.9	48.8
Grouted courses	64	36.4	29.6	136.3	136.3	48.5	48.5
for y axis.	72	36.0	29.0	135.6	135.6	48.3	48.2

and is used in determining the compressive strength of masonry prisms (f'_m) as well as the compressive stress (f_a) due to axial compressive loading only.

The net section (mortar bedded area plus the grouted area) is used in calculating the flexural compressive stress (f_b), flexural tensile stress (f_t), and shear stress (f_v). The values given in the tables pertain to face shell bedding only.

The subscript "x" in the moment of inertia (I_x) and section modulus (S_x) columns indicates that the masonry is spanning vertically (bending about the x-x axis). The subscript "y" indicates that the walls are spanning horizontally (bending about the y-y axis).

Section modulus (S) is used to determine the flexural tensile stress (f_t) in masonry where the applied load is normal to the plane of the wall, as in the case of wind.

$$f_t = \frac{M}{S} - f_d$$

Where: f_t = Flexural tensile stress in masonry
M = Moment due to lateral load
S = Section modulus
f_d = Dead load compressive stress

The section modulus is also used to calculate the maximum flexural compressive stress (f_b) where reinforcing steel does not resist tension.

$$f_b = \frac{M}{S}$$

Where reinforcement acts to resist tension, the flexural compressive stress (f_b) may be determined by the following equation when the masonry is either solidly grouted or the neutral axis falls within the face shell of the unit.

$$f_b = \frac{2M}{jkbd^2}$$

Exhibit C
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NCMA-TEK

An Information series from National Concrete Masonry Association

"U" VALUES FOR CONCRETE MASONRY WALLS WITH LOOSE FILL and/or GROUT

TEK 101A

Introduction

Often concrete masonry walls are constructed of hollow block having the cores filled with loose fill and/or grout. Determining the thermal insulation values of such walls may be time consuming, especially where the wall is composed of several materials with different thermal conductivity properties. This TEK is intended to facilitate the calculation of the thermal resistance (R) or thermal transmittance (U) properties of such concrete masonry walls.

Included are tables of calculated "R" and "U" values for hollow block of 6", 8", 10" and 12" in thickness made with concrete having densities ranging from 80 to 135 lbs. per cubic foot. The concrete block used in the tables represent typical 2-core block used in masonry construction. Also included is a table which shows the approximate percentage of grouted and ungrouted wall volume for different spacings of vertical and horizontal grouted elements. R values of the different insulating materials used in compiling the tables are shown in Table 6.

When using these tables the first step in determining the R or U-value of the wall is to calculate the percentages of the grouted and ungrouted areas of the wall. Table 1 provides a rapid method for doing this. The U-value of the wall is equal to the decimal percentage of the grouted area times its U-value plus the decimal percentage of the ungrouted area times its U-value. This can be demonstrated by the following example:

Assume an 8" wall composed of hollow concrete masonry having a density of 105 lb. per cu. ft. grouted at 48" o. c. both vertically and horizontally with grout fill having a density of 130 lb. per cu. ft. Ungrouted cores contain perlite loose fill insulation.

From Table 1, 31% of the wall is grouted and 69% contains loose fill insulation. From Table 3, the U-value for a fully grouted concrete masonry wall (block density is 105 lb. per cu. ft. and grout density is 130 lb. per cu. ft.) is 0.44. From the same table, a wall containing perlite loose fill insulation has a U-value of 0.15. The U-value of the wall may then be calculated as follows:

$$U = (0.31 \times 0.44) + (0.69 \times 0.15)$$

$$U = 0.24 \text{ Btu/(hr}\cdot\text{ft}^2\cdot{}^\circ\text{F)}$$

Table 1. Percent Ungrouted Area/Percent grouted Area

Vertical Grout Spacing, Inches

Horizontal Grout Spacing, Inches	48"	40"	32"	24"	16"
48"	69/31	67/33	63/37	56/44	42/58
40"	67/33	64/36	60/40	53/47	40/60
32"	63/37	60/40	56/44	50/50	37/63
24"	56/44	53/47	50/50	44/56	33/67
16"	42/58	40/60	37/63	33/67	25/75

The ASHRAE Series-Parallel Method was used in calculating the base case values (i. e., Exposed Block, Both Sides - Cores Empty or containing Loose Fill Insulation or Grout) which appear in the following Tables.

In calculating the values for the remainder of the Tables, the assumption was made that the gypsum board was mounted on 1" furring strips in all cases, resulting in a framing factor of 19% (rounded to 20%)

For example, if 1" of polyisocyanurate plus 1/2" gypsum board was installed on the surface of the wall, the added value of the insulation would be:

$$R = \frac{1}{\frac{.20}{1.45} + \frac{.80}{7.65}} = 4.12 \qquad U = 1/R = 0.24$$

Where:

$$1.45 = R_{wood} + R_{gyp}$$

$$7.65 = R_{poly} + R_{gyp}$$

The total R-value for the wall system in the first example with 1" of polyisocyanurate plus 1/2" gypsum board added to the surface would be 4.12 + 4.12 = 8.24.

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Table 2. "R" and "U" Values of typical 6-Inch Hollow Concrete Masonry Walls

Construction	Cores Empty		Loose-Fill Insulation				Grout Fill 100 lb/ft³		Grout Fill 130 lb/ft³		Density of Block lb/ft³
			Perlite		Vermiculite						
	R	U	R	U	R	U	R	U	R	U	
Exposed Block, Both Sides	2.64	.38	6.75	.15	6.26	.16	2.65	.38	2.21	.45	80
	2.42	.41	5.64	.18	5.31	.19	2.43	.41	2.02	.50	95
	2.29	.44	4.99	.20	4.73	.21	2.30	.43	1.91	.52	105
	2.17	.46	4.40	.23	4.21	.24	2.18	.46	1.82	.55	115
	2.05	.49	3.86	.26	3.72	.27	2.06	.49	1.73	.58	125
	1.95	.51	3.40	.29	3.30	.30	1.96	.51	1.65	.61	135
1/2" Gypsum Board on Furring Strips	4.09	.24	8.20	.12	7.71	.13	4.10	.24	3.66	.27	80
	3.87	.26	7.09	.14	6.76	.15	3.88	.26	3.47	.29	95
	3.74	.27	6.44	.16	6.18	.16	3.75	.27	3.36	.30	105
	3.62	.28	5.85	.17	5.66	.18	3.63	.28	3.27	.31	115
	3.50	.29	5.31	.19	5.17	.19	3.51	.28	3.18	.31	125
	3.40	.29	4.85	.21	4.75	.21	3.41	.29	3.10	.32	135
1/2" Foil-backed Gypsum Board on Furring Strips	5.34	.19	9.45	.11	8.96	.11	5.35	.19	4.91	.20	80
	5.12	.20	8.34	.12	8.01	.12	5.13	.19	4.72	.21	95
	4.99	.20	7.69	.13	7.43	.13	5.00	.20	4.61	.22	105
	4.87	.21	7.10	.14	6.91	.14	4.88	.20	4.52	.22	115
	4.75	.21	6.56	.15	6.42	.16	4.76	.21	4.43	.23	125
	4.65	.22	6.10	.16	6.00	.17	4.66	.21	4.35	.23	135
1" Rigid Glass Fiber or 1" Polystyrene Plus 1/2" Gypsum Board	5.79	.17	9.90	.10	9.41	.11	5.80	.17	5.36	.19	80
	5.57	.18	8.79	.11	8.46	.12	5.58	.18	5.17	.19	95
	5.44	.18	8.14	.12	7.88	.13	5.45	.18	5.06	.20	105
	5.32	.19	7.55	.13	7.36	.14	5.33	.19	4.97	.20	115
	5.20	.19	7.01	.14	6.87	.15	5.21	.19	4.88	.20	125
	5.10	.20	6.55	.15	6.45	.16	5.11	.20	4.80	.21	135
1" Extruded Polystyrene plus 1/2" Gypsum Board	6.15	.16	10.26	.10	9.77	.10	6.16	.16	5.72	.17	80
	5.93	.17	9.15	.11	8.82	.11	5.94	.17	5.53	.18	95
	5.80	.17	8.50	.12	8.24	.12	5.81	.17	5.42	.18	105
	5.68	.18	7.91	.13	7.72	.13	5.69	.18	5.33	.19	115
	5.56	.18	7.73	.13	7.23	.14	5.57	.18	5.24	.19	125
	5.46	.18	6.91	.14	6.81	.15	5.47	.18	5.13	.19	135
1" Expanded Polyurethane plus 1/2" Gypsum Board	6.52	.15	10.63	.09	10.14	.10	6.53	.15	6.09	.16	80
	6.30	.16	9.52	.11	9.19	.11	6.31	.16	5.90	.17	95
	6.17	.16	8.87	.11	8.61	.12	6.18	.16	5.79	.17	105
	6.05	.17	8.28	.12	8.09	.12	6.06	.17	5.70	.18	115
	5.93	.17	7.74	.13	7.60	.13	5.94	.17	5.61	.18	125
	5.83	.17	7.28	.14	7.18	.14	5.84	.17	5.53	.18	135
1" Polyisocyanurate plus 1/2" Gypsum Board	6.76	.15	10.87	.09	10.38	.10	6.77	.15	6.33	.16	80
	6.54	.15	9.76	.10	9.43	.11	6.55	.15	6.14	.16	95
	6.41	.16	9.11	.11	8.85	.11	6.42	.16	6.03	.17	105
	6.29	.16	8.52	.12	8.33	.12	6.30	.16	5.94	.17	115
	6.17	.16	7.98	.13	7.84	.13	6.18	.16	5.85	.17	125
	6.07	.16	7.52	.13	7.42	.13	6.08	.16	5.77	.17	135

Table 3. "R" and "U" Values of typical 8-Inch Hollow Concrete Masonry Walls

Construction	Cores Empty		Loose-Fill Insulation				Grout Fill 100 lb/ft³		Grout Fill 130 lb/ft³		Density of Block lb/ft³
			Perlite		Vermiculite						
	R	U	R	U	R	U	R	U	R	U	
Exposed Block, Both Sides	2.86	.35	9.07	.11	8.37	.12	3.27	.31	2.65	.38	80
	2.61	.38	7.53	.13	7.06	.14	2.99	.33	2.41	.41	95
	2.46	.41	6.62	.15	6.26	.16	2.82	.35	2.27	.44	105
	2.33	.43	5.80	.17	5.53	.18	2.66	.38	2.15	.47	115
	2.21	.45	5.06	.20	4.86	.21	2.51	.40	2.04	.49	125
	2.10	.48	4.40	.23	4.26	.23	2.37	.42	1.94	.52	135
1/2" Gypsum Board on Furring Strips	4.31	.23	10.52	.10	9.82	.10	4.72	.21	4.10	.24	80
	4.06	.25	8.98	.11	8.51	.12	4.44	.23	3.86	.26	95
	3.91	.26	8.07	.12	7.71	.13	4.27	.23	3.72	.27	105
	3.78	.26	7.25	.14	6.98	.14	4.11	.24	3.60	.28	115
	3.66	.27	6.51	.15	6.31	.16	3.96	.25	3.49	.29	125
	3.55	.28	5.85	.17	5.71	.18	3.82	.26	3.39	.29	135
1/2" Foil-backed Gypsum Board on Furring Strips	5.56	.18	11.77	.08	11.07	.09	5.97	.17	5.35	.19	80
	5.31	.19	10.23	.10	9.76	.10	5.69	.18	5.11	.20	95
	5.16	.19	9.32	.11	8.96	.11	5.52	.18	4.97	.20	105
	5.03	.20	8.50	.12	8.23	.12	5.36	.19	4.85	.21	115
	4.91	.20	7.76	.13	7.56	.13	5.21	.19	4.74	.21	125
	4.80	.21	7.10	.14	6.96	.14	5.07	.20	4.64	.22	135
1" Rigid Glass Fiber or 1" Expanded Polystyrene Plus 1/2" Gypsum Board	6.01	.17	12.22	.08	11.52	.09	6.42	.16	5.80	.17	80
	5.76	.17	10.68	.09	10.21	.10	6.14	.16	5.56	.18	95
	5.61	.18	9.77	.10	9.41	.11	5.97	.17	5.42	.18	105
	5.48	.18	8.95	.11	8.68	.12	5.81	.17	5.30	.19	115
	5.36	.19	8.21	.12	8.01	.12	5.66	.18	5.19	.19	125
	5.25	.19	7.55	.13	7.41	.13	5.52	.18	5.09	.20	135
1" Extruded Polystyrene plus 1/2" Gypsum Board	6.37	.16	12.58	.08	11.88	.08	6.78	.15	6.16	.16	80
	6.12	.16	11.04	.09	10.57	.09	6.50	.15	5.92	.17	95
	5.97	.17	10.13	.10	9.77	.10	6.33	.16	5.78	.17	105
	5.84	.17	9.31	.11	9.04	.11	6.17	.16	5.66	.18	115
	5.72	.17	8.57	.12	8.37	.12	6.02	.17	5.55	.18	125
	5.61	.18	7.91	.13	7.77	.13	5.88	.17	5.45	.18	135
1" Expanded Polyurethane plus 1/2" Gypsum Board	6.74	.15	12.95	.08	12.25	.08	7.15	.14	6.53	.15	80
	6.49	.15	11.41	.09	10.94	.09	6.87	.15	6.29	.16	95
	6.34	.16	10.50	.10	10.14	.10	6.70	.15	6.15	.16	105
	6.21	.16	9.68	.10	9.41	.11	6.54	.15	6.03	.17	115
	6.09	.16	8.94	.11	8.74	.11	6.39	.16	5.92	.17	125
	5.98	.17	8.28	.12	8.14	.12	6.25	.16	5.82	.17	135
1" Polyisocyanurate plus 1/2" Gypsum Board	6.98	.14	13.19	.08	12.49	.08	7.39	.14	6.77	.15	80
	6.73	.15	11.65	.09	11.18	.09	7.11	.14	6.53	.15	95
	6.58	.15	10.74	.09	10.38	.10	6.94	.14	6.39	.16	105
	6.45	.16	9.92	.10	9.65	.10	6.78	.15	6.27	.16	115
	6.33	.16	9.18	.11	8.98	.11	6.63	.15	6.16	.16	125
	6.22	.16	8.52	.12	8.38	.12	6.49	.15	6.06	.17	135

Exhibit C
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Table 4. "R" and "U" Values of typical 10-Inch Hollow Concrete Masonry Walls

Construction	Cores Empty		Loose-Fill Insulation				Grout Fill 100 lb/ft^3		Grout Fill 130 lb/ft^3		Density of Block lb/ft^3
			Perlite		Vermiculite						
	R	U	R	U	R	U	R	U	R	U	
Exposed Block, Both Sides	3.00	.33	11.02	.09	10.22	.10	3.88	.26	3.06	.33	80
	2.73	.37	9.06	.11	8.52	.12	3.54	.28	2.78	.36	95
	2.57	.39	7.90	.13	7.50	.13	3.34	.30	2.63	.38	105
	2.43	.41	6.88	.15	6.58	.15	3.14	.32	2.48	.40	115
	2.31	.43	5.95	.17	5.73	.17	2.95	.34	2.35	.43	125
	2.19	.46	5.14	.19	4.99	.20	2.77	.36	2.22	.45	135
1/2" Gypsum Board on Furring Strips	4.45	.22	12.47	.08	11.67	.09	5.33	.19	4.51	.22	80
	4.18	.24	10.51	.10	9.97	.10	4.99	.20	4.23	.24	95
	4.02	.25	9.35	.11	8.95	.11	4.79	.21	4.08	.25	105
	3.88	.26	8.33	.12	8.03	.12	4.59	.22	3.93	.25	115
	3.76	.27	7.40	.14	7.18	.14	4.40	.23	3.80	.26	125
	3.64	.27	6.59	.15	6.44	.16	4.22	.24	3.67	.27	135
1/2" Foil-backed Gypsum Board on Furring Strips	5.70	.18	13.72	.07	12.92	.08	6.58	.15	5.76	.17	80
	5.43	.18	11.76	.09	11.22	.09	6.24	.16	5.48	.18	95
	5.27	.19	10.60	.09	10.20	.10	6.04	.17	5.33	.19	105
	5.13	.19	9.58	.10	9.28	.11	5.84	.17	5.18	.19	115
	5.01	.20	8.65	.12	8.43	.12	5.65	.18	5.05	.20	125
	4.89	.20	7.84	.13	7.69	.13	5.47	.18	4.92	.20	135
1" Rigid Glass Fiber or 1" Expanded Polystyrene Plus 1/2" Gypsum Board	6.15	.16	14.17	.07	13.37	.07	7.03	.14	6.21	.16	80
	5.88	.17	12.21	.08	11.67	.09	6.69	.15	5.93	.17	95
	5.72	.17	11.05	.09	10.65	.09	6.49	.15	5.78	.17	105
	5.58	.18	10.03	.10	9.73	.10	6.29	.16	5.63	.18	115
	5.46	.18	9.10	.11	8.88	.11	6.10	.16	5.50	.18	125
	5.34	.19	8.29	.12	8.14	.12	5.92	.17	5.37	.19	135
1" Extruded Polystyrene plus 1/2" Gypsum Board	6.51	.15	14.53	.07	13.73	.07	7.39	.14	6.57	.15	80
	6.24	.15	12.57	.08	12.03	.08	7.05	.14	6.29	.16	95
	6.08	.16	11.41	.09	11.01	.09	6.85	.15	6.14	.16	105
	5.94	.16	10.39	.10	10.09	.10	6.65	.15	5.99	.17	115
	5.82	.16	9.46	.11	9.24	.11	6.46	.15	5.86	.17	125
	5.70	.16	8.65	.12	8.50	.12	6.28	.16	5.73	.17	135
1" Expanded Polyurethane plus 1/2" Gypsum Board	6.88	.15	14.90	.07	14.10	.07	7.76	.13	6.94	.14	80
	6.61	.15	12.94	.08	12.40	.08	7.42	.13	6.66	.15	95
	6.45	.16	11.78	.08	11.38	.09	7.22	.14	6.51	.15	105
	6.31	.16	10.76	.09	10.46	.10	7.02	.14	6.36	.16	115
	6.19	.16	9.83	.10	9.61	.10	6.83	.15	6.23	.16	125
	6.07	.16	9.02	.11	8.87	.11	6.65	.15	6.10	.16	135
1" Polyisocyanurate plus 1/2" Gypsum Board	7.12	.14	15.14	.07	14.34	.07	8.00	.13	7.18	.14	80
	6.85	.15	13.18	.08	12.64	.08	7.66	.13	6.90	.14	95
	6.69	.15	12.02	.08	11.62	.09	7.46	.13	6.75	.15	105
	6.55	.15	11.00	.09	10.70	.09	7.26	.14	6.60	.15	115
	6.43	.16	10.07	.10	9.85	.10	7.07	.14	6.47	.15	125
	6.31	.16	9.26	.11	9.11	.11	6.89	.15	6.34	.16	135

Table 5. "R" and "U" Values of typical 12-Inch Hollow Concrete Masonry Walls

Construction	Cores Empty		Loose-Fill Insulation				Grout Fill 100 lb/ft^3		Grout Fill 130 lb/ft^3		Density of Block lb/ft^3
			Perlite		Vermiculite						
	R	U	R	U	R	U	R	U	R	U	
Exposed Block, Both Sides	3.12	.32	13.44	.07	12.44	.08	4.49	.22	3.45	.29	80
	2.83	.35	11.02	.09	10.34	.10	4.10	.24	3.15	.32	95
	2.66	.38	9.59	.10	9.09	.11	3.86	.26	2.97	.34	105
	2.52	.40	8.32	.12	7.95	.13	3.63	.28	2.81	.36	115
	2.38	.42	7.17	.14	6.90	.14	3.42	.29	2.86	.38	125
	2.26	.44	6.18	.16	5.98	.17	3.20	.31	2.52	.40	135
1/2" Gypsum Board on Furring Strips	4.57	.22	14.89	.07	13.89	.07	5.94	.17	4.90	.20	80
	4.28	.23	12.47	.08	11.79	.08	5.55	.18	4.60	.22	95
	4.11	.24	11.04	.09	10.54	.09	5.31	.19	4.42	.23	105
	3.97	.25	9.77	.10	9.40	.11	5.08	.20	4.26	.23	115
	3.83	.26	8.62	.12	8.35	.12	4.87	.21	4.11	.24	125
	3.71	.27	7.63	.13	7.43	.13	4.65	.22	3.97	.25	135
1/2" Foil-backed Gypsum Board on Furring Strips	5.82	.17	16.14	.06	15.14	.07	7.19	.14	6.15	.16	80
	5.53	.18	13.72	.07	13.04	.08	6.80	.15	5.85	.17	95
	5.36	.19	12.29	.08	11.79	.08	6.56	.15	5.67	.18	105
	5.22	.19	11.02	.09	10.65	.09	6.33	.16	5.51	.18	115
	5.08	.20	9.87	.10	9.60	.10	6.12	.16	5.36	.19	125
	4.96	.20	8.88	.11	8.68	.12	5.90	.17	5.22	.19	135
1" Rigid Glass Fiber or 1" Expanded Polystyrene Plus 1/2" Gypsum Board	6.27	.16	16.59	.06	15.59	.06	7.64	.13	6.60	.15	80
	5.98	.17	14.17	.07	13.49	.07	7.25	.14	6.30	.16	95
	5.81	.17	12.74	.08	12.24	.08	7.01	.14	6.12	.16	105
	5.67	.18	11.47	.09	11.10	.09	6.78	.15	5.96	.17	115
	5.53	.18	10.32	.10	10.05	.10	6.57	.15	5.81	.17	125
	5.41	.18	9.33	.11	9.13	.11	6.35	.16	5.67	.18	135
1" Extruded Polystyrene plus 1/2" Gypsum Board	6.63	.15	16.95	.06	15.95	.06	8.00	.13	6.96	.14	80
	6.34	.16	14.53	.07	13.85	.07	7.61	.13	6.66	.15	95
	6.17	.16	13.10	.08	12.60	.08	7.37	.14	6.48	.15	105
	6.03	.17	11.83	.08	11.46	.09	7.14	.14	6.32	.16	115
	5.89	.17	10.68	.09	10.41	.10	6.93	.14	6.17	.16	125
	5.77	.17	9.69	.10	9.49	.11	6.71	.15	6.03	.17	135
1" Expanded Polyurethane plus 1/2" Gypsum Board	7.00	.14	17.32	.06	16.32	.06	8.37	.12	7.33	.14	80
	6.71	.15	14.90	.07	14.22	.07	7.98	.13	7.03	.14	95
	6.54	.15	13.47	.07	12.97	.08	7.74	.13	6.85	.15	105
	6.40	.16	12.20	.08	11.83	.08	7.51	.13	6.69	.15	115
	6.26	.16	11.05	.09	10.78	.09	7.30	.14	6.54	.15	125
	6.14	.16	10.06	.10	9.86	.10	7.08	.14	6.40	.16	135
1" Polyisocyanurate plus 1/2" Gypsum Board	7.24	.14	17.56	.06	16.56	.06	8.61	.12	7.57	.13	80
	6.95	.14	15.14	.07	14.46	.07	8.22	.12	7.27	.14	95
	6.78	.15	13.71	.07	13.21	.08	7.98	.13	7.09	.14	105
	6.64	.15	12.44	.08	12.07	.08	7.75	.13	6.93	.14	115
	6.50	.15	11.29	.09	11.02	.09	7.54	.13	6.78	.15	125
	6.38	.16	10.30	.10	10.10	.10	7.32	.14	6.64	.15	135

Table 6. Values Used For Compiling Tables

Material	R-Value Per Inch
Mortar	0.200
Grout 100 pcf	0.271
Grout 130 pcf	0.149
Concrete 80 pcf	0.404
Concrete 95 pcf	0.299
Concrete 105 pcf	0.245
Concrete 115 pcf	0.201
Concrete 125 pcf	0.164
Concrete 135 pcf	0.134
Insulation:	
Gypsum Board	0.90
Wood Furring	1.00
Vermiculite	2.44
Perlite	3.13
Rigid Glass Fiber	4.00
Expanded Polystyrene	4.00
Extruded Polystyrene	5.00
Polyisocyanurate	7.20
Surface Conductance:	
Outside (15 mph wind)	0.17
Inside	0.68
Air Space Conductance:	
3/4" - 4"	0.97
3/4" - 4" w/bright foil lining	3.00

Exhibit D
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MARTIN MARIETTA

Assessment of the Thermal and Physical Properties of Masonry Block Products

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Part of
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and Materials

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Office of Buildings and Community Systems
Building Systems Division

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

R_{fc} = 1.88 + 0.85 = 2.73; U_{fc} = 0.366

Average thermal transmittance:

U = (0.07 x 0.424) + (0.205 x 0.328) + (0.725 x 0.366)

U = 0.362 Btu/h-ft^2-F (2.06 W/m^2-K).

For cores filled with insulation [Conductivity = 0.35 Btu/h-ft^2-(F/in) (0.05 W/m^2-K)]:

U = 0.126 Btu/h-ft^2-F (0.716 W/m^2-K).

The parallel method based on calculation of air-to-air thermal transmittances for each slice (i.e. the sum of fractional U-values proportioned according to wall face area fractions of individual slices) yielded an average U-value virtually identical to that based on the calculation of surface-to-surface thermal conductances for each slice for the wall cores empty. For the wall with cores insulated, calculation by proportionate conductances yielded a U-value about six percent higher than that provided by proportionate U-value calculations.

The calculation by the parallel (U) method assumes that there is no lateral heat flow in any layer of material perpendicular to heat flow in a wall. Calculation by the parallel (U) method always provides the lowest U-value for the masonry unit.

The calculation by the parallel (C) method assumes that there is no lateral heat flow except at outer surface-air boundaries. The assumption that these surfaces are isothermal planes is correct, and has been demonstrated in reports of tests of masonry walls in which surface temperatures were listed (e.g. Pennsylvania State University tests).

3.4.2 The Isothermal Planes Method

The isothermal planes calculation method (series-parallel method) yields the highest U-values. This method assumes that heat can flow laterally in layers perpendicular to heat flow that are bounded by isothermal planes. The hollow block previously considered is divided into three layers: two are formed by parallel combinations of face shells and mortar and the middle layer is a parallel combination of webs and cores or webs and insulation. Thermal resistance is calculated for each layer by the equation:

$$R = \frac{R_1 R_2}{a_1 R_2 + a_2 R_1}$$

where a_1 and a_2 are face area fractions of parallel segments in a layer and R_1 and R_2 are respective resistances of these segments. For the hollow block wall of Fig 3.21, the thermal resistance of the face shell mortar layers is:

$$R_{f,m} = \frac{R_f R_m}{a_f R_m + a_m R_f}$$

in which a_f is the face shell area fraction, equal to 0.93, and a_m is the mortar area fraction, 0.07:

$$a_f = (7.62 \times 15.63)/128 = 0.93$$

$$a_m = 1 - a_f = 0.07$$

Since the thickness of the face shell and mortar layers is 1.52 x 2 inches, then:

$$R_f = 3.04/3.47 = 0.876 \ \text{h-ft}^2\text{-F/Btu}$$
$$R_m = 3.04/6 = 0.507 \ \text{h-ft}^2\text{-F/Btu}$$

The thermal resistance of two face shell and mortar layers is:

$$R_{f,m} = \frac{0.876 \times 0.507}{(0.93 \times 0.507) + (0.07 \times 0.876)}$$

$$R_{f,m} = 0.834 \ \text{h-ft}^2\text{-F/Btu} \ (0.147 \ \text{m}^2\text{-K/W}).$$

Thickness of the web and core layer is 4.58 in.; the thermal resistances of parallel segments in this layer are:

$$R_w = 4.58/3.47 = 1.320 \ \text{h-ft}^2\text{-F/Btu}$$

$$R_c = 4.58/4.58 = 1.0 \ \text{h-ft}^2\text{-F/Btu}$$

$$(\text{or } R_{ins} = 4.58/0.35 = 13.09 \ \text{h-ft}^2\text{-F/Btu})$$

Face area fractions are 0.205 for webs and 1 - 0.205 = 0.795 for cores. The thermal resistance of the web and core layer is:

$$R_{w,c} = \frac{1.32 \times 1.0}{(0.205 \times 1.0) + (0.795 \times 1.32)}$$

$$R_{w,c} = 1.052 \ \text{h-ft}^2\text{-F/Btu} \ (0.185 \ \text{m}^2\text{-K/W}).$$

The total thermal resistance of the block is obtained by adding the thermal resistances of the various layers to the surface thermal resistance of the two air films, 0.85:

$$R_T = 0.834 + 1.052 + 0.85 = 2.737$$
$$\text{h-ft}^2\text{-F/Btu} \ (0.482 \ \text{m}^2\text{-K/W})$$

$$U = 1/R_T = 1/2.737 = 0.365 \ \text{Btu/h-ft}^2\text{-F}, \ (2.07 \ \text{W/m}^2\text{-K}).$$

The thermal resistance of the middle layer for cores filled with granular insulation [conductivity = 0.35 Btu/h-ft^2-(F/in) (0.05 W/m^2-K), is recalculated. The thermal resistance of the insulated cores is 4.58/0.35 = 13.69. The thermal resistance of the web and insulated core layer, $R_{w,ins}$, is:

$$R_{w,ins} = \frac{1.32 \times 13.09}{(0.205 \times 13.09) + (0.795 \times 1.32)}$$

$$= 4.629 \text{ h-ft}^2\text{-F/Btu } (0.815 \text{ m}^2\text{-K/W})$$

$$R_T = 0.834 + 4.629 + 0.85 = 6.313 \text{ h-ft}^2\text{-F/Btu}$$

$$(1.111 \text{ m}^2\text{-K/W})$$

$$U = 1/R_T = 1/6.313 = 0.158 \text{ Btu/h-ft}^2\text{-F}$$

$$(0.90 \text{ W/m}^2\text{-K}).$$

3.4.3 Comparison of the Three Calculation Methods

Calculation methods are compared in Table 3.16 for walls of regular 8 in. thick hollow-core blocks, with moisture adjusted thermal conductivity of concrete of 3.47 Btu/h-ft^2-(F/in) (0.5 W/m-K). U-values for CMU_s made of materials with different thermal conductivities will vary from those shown here.

TABLE 3.16 CALCULATED U-VALUE OF CONCRETE MASONRY BLOCKS

CALCULATION METHOD	Cores Empty	Cores Insulated
	Btu/h-ft^2-F	(W/m^2-K)
PARALLEL (C)	0.363 (0.206)	0.133 (0.758)
PARALLEL (U)	0.362 (0.206)	0.126 (0.716)
SERIES-PARALLEL	0.365 (0.207)	0.158 (0.900)

Both versions of the parallel method underestimate U-values and are considered unacceptable for walls of hollow blocks with in situ applied insulation, premolded insulating inserts, or for walls of multicore units.

The British CIBS Guide (1980) recommends calculation of resistance of <u>hollow blocks</u> by both parallel (conductance) and series-