THE BRICK INDUSTRY ASSOCIATION
TECHNICAL NOTES on Brick Construction
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Technical Notes 4 - Heat Transmission Coefficients of Brick Masonry Walls

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Abstract: A procedure to analyze the heat flow through the opaque walls of a building envelope is provided. The design coefficients of heat transmission are provided for commonly used construction materials. Methods of calculating heat transmission coefficients and examples of heat loss calculations under steady-state conditions are provided for opaque wall assemblies.

Key Words: **brick,** conductance, conductivity, **energy,** heat loss, rate of heat flow, resistance, resistivity, steady-state conditions, series and parallel path, thermal transmission.

INTRODUCTION

Because of the finite supply of fossil fuels and the high cost of energy, the need to design energy-efficient buildings that are also economical becomes important. Various industry groups are continually updating and refining energy conservation standards and guidelines for use in the design of new buildings. These standards and guidelines may be used to assist the building designers. The designer is confronted with the fact that no two buildings are exactly identical, nor are the methods or modes of operation similar. Thus, the energy performance of each building, as a whole, must be evaluated relative to the real performance of its materials, systems and equipment.

This *Technical Notes* provides information and methods of calculating transmission coefficients and heat transfer values of brick masonry walls under static conditions. These may be used in energy conservation studies and comparisons for predicting thermal performance of building components. However, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) cautions the designer that heat flow through a building envelope is actually not static, and although steady-state calculations provide an estimate of energy consumption, they do not take into account dynamic conditions such as the thermal storage capacity of materials, direct solar radiation, wind and other variables. The term "steady-state" means that all ambient conditions are assumed to be constant, which in the real world is virtually never the case.

BUILDING THERMAL DESIGN

The ASHRAE *Handbook of Fundamentals* states the following concerning heat transfer calculations:

"Current methods for estimating the heat transferred through floors, walls and roofs of buildings are largely based on a steady-state or steady-periodic heat flow concept (Equivalent Temperature Difference Concept). The engineering application of these concepts is not complicated and has served well for many years in the process of design and selection of heating and cooling equipment for buildings. However, competitive practices of the building industry sometimes require more than the selection or design of a single heating or cooling system. Consultants are requested to present a detailed comparison of alternative heating and cooling systems for a given building, including initial costs as well as short- and long-term operating and maintenance costs. The degree of sophistication required for costs may make it necessary to calculate the heating and cooling load for estimating energy requirements in hourly increments for a year's time for given buildings at known geographic locations. Because of the number of calculations involved, computer processing becomes necessary. The hour-by-hour heating and cooling load calculations, when based upon a steady heat flow or steady-periodic heat flow concept, do not account for the heat storage effects of the building structure, especially with regard to net heat gain to the air-conditioned spaces."

The Handbook of Fundamentals also suggests that the designer consider the following factors when performing heating load calculations: 1) building construction-heavy, medium or light; 2) presence of insulation; 3) infiltration and ventilation loads; 4) glass area-normal or greater than normal; 5) occupancy nature and schedule; 6) presence of auxiliary heating devices; and 7) expected cost of energy.

Actual heat flow through a wall under normal weather conditions will involve daily cycles of solar radiation and air temperature, changing wind speeds and directions, and radiation to the night sky. In studies ("Effective *U*-Values", New Mexico Energy Institute, 1978) of dynamic heat transmission through a building envelope, it was found that consideration of solar heat gain and material thermal storage effects provided results significantly different from steady-state heat flow calculations. These studies also showed that the optimum economic insulation level varies with wall orientations, and that changing the color of East, West and South walls was more cost-effective in some instances than insulating. For a detailed description of the thermal storage effects of brick masonry walls, see *Technical Notes* 43 and 43D.

The actual rate of heat flow through typical masonry building walls may be up to 20% less than the calculated rate based on published U-values. This is indicated by past research (Structural Clay Products Research Foundation, *Studies of Heat Transfer*.), which points out that the rate of heat transfer can be 20% to 60% greater than the calculated rate for wood frame walls and metal panel walls, respectively.

Masonry walls have a more favorable rate of heat transfer because of their greater heat storage capacity, which is sometimes referred to as *thermal mass, or capacity insulation.* The heat flows calculated by steady-state methods are 29% to 60% greater than those measured under dynamic conditions for masonry walls. (*Dynamic Thermal Performance of an Experimental Masonry Building*, Building Science Series 45, National Bureau of Standards.) This means that massive masonry walls may be up to 60% better at retarding heat flow than steady-state U-values indicate. A method to modify the steady-state calculations, in order to account for the effect of mass, is provided in *Technical Notes* 4B.

The overall coefficient of heat transmission (U-value) of various walls discussed in this *Technical Notes* is used in steady-state heat transfer and steady-periodic heat gain calculations.

Computer programs, such as those used by the National Bureau of Standards, (National Bureau of Standards Loads Determination (NBSLD) Computer Program, T. Kasuda, "NBSLD-National Bureau of Standards Heating and Cooling Load Determination Program", Journal, Automated Procedures for Engineering Consultants (APEC), Winter 1973-1974.) give values much closer to the actual performance of walls than is possible under the steady-state concept of heat transfer. Government agencies and industry groups are continuing to examine simplified methods to calculate dynamic heat flow without the use of computers.

TERMINOLOGY

Commonly used terms relative to heat transmission are defined below in accordance with ASHRAE Standard 12-75, *Refrigeration Terms and Definitions.* All of these terms describe the same phenomenon, however, some are described as determined by material dimensions and boundaries.

U = Overall Coefficient of Heat Transmission.

The rate of heat flow through a unit area of building envelope material or assembly, including its boundary films, per unit of temperature difference between the inside and outside air. The term is commonly called the "U-value". The Overall Coefficient of Heat Transmission is expressed in Btu/(hr ^{0}F ft^2). Note that in computing U-values, the component heat transmissions are not additive, but the overall U-value is actually less (i.e., better) than any of its component layers. Normally, the U-value is calculated by determining the resistance (R, defined below) of each component, and then taking the reciprocal of the total resistance.

k = Thermal Conductivity.

The rate of heat flow through a homogeneous material, 1-in. thick, per unit of temperature difference between its two surfaces. A material is considered homogeneous when the value of its thermal conductivity does not depend on its dimensions (within the range normally used in construction). Thermal Conductivity is expressed in (Btu in)/(hr ^{0}F ft^2)

C = Thermal Conductance.

The rate of heat flow through a unit area of material per unit of temperature difference between its two surfaces for the thickness of construction given, not per in. of thickness. Note that the conductance of an air space is dependent on height, depth, position, character and temperature of the boundary surfaces. Therefore, the air space must be fully described if the values are to be meaningful. For a description of other than vertical air spaces, see the 1981 ASHRAE *Handbook of Fundamentals,* Chapter 23. Thermal Conductance is expressed in Btu/(hr °F ft^2)

h = Film or Surface Conductance.

The rate of heat exchange between a unit or surface area and the air it is in contact with. Subscripts i and o are used to denote inside and outside conductances, respectively. Film or surface conductance is expressed in Btu/(hr °F ft^2).

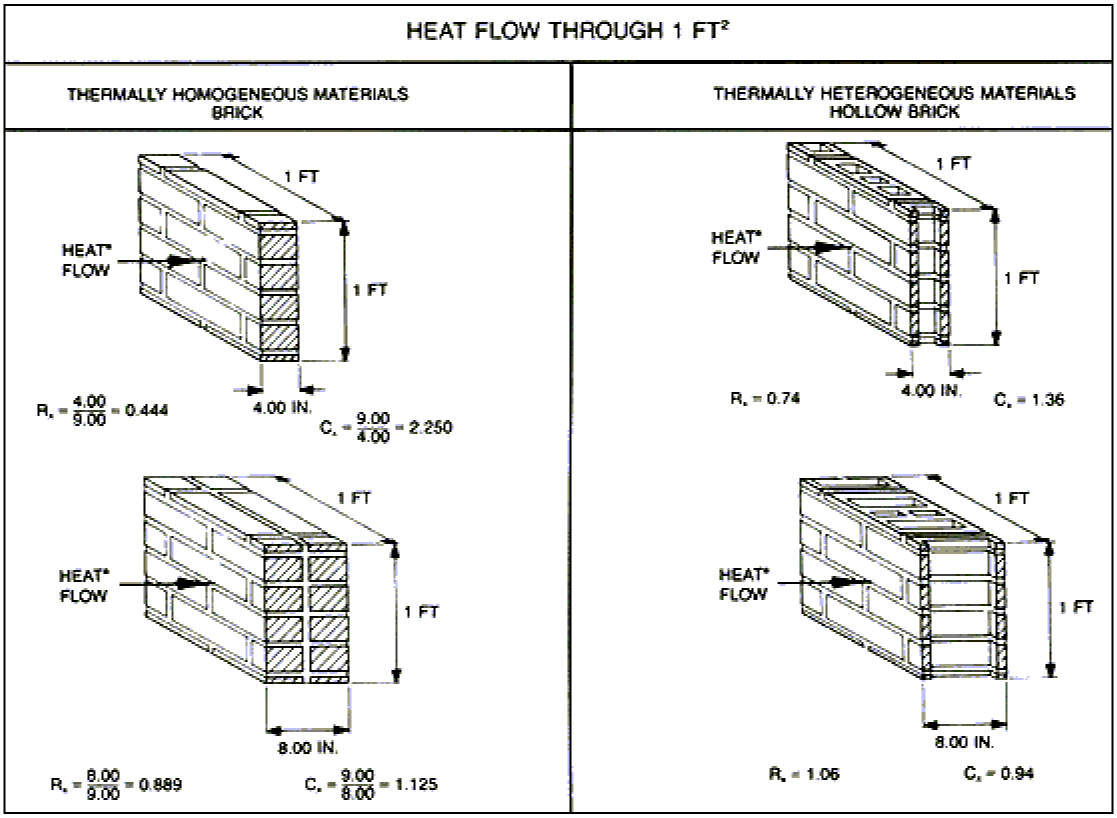
R = Thermal Resistance.

The reciprocal of a heat transfer coefficient, as expressed by U, C, or h. R is in (hr °F ft^2)/Btu. For example, a wall with a U-value of 0.25 would have a resistance value of R = I/U = 1/0.25=4.0. The value of R is also used to represent Thermal Resistivity, the reciprocal of the thermal conductivity. Thermal Resistivity is expressed in (hr °F ft^2)/(Btu in)

Btu **=** British Thermal Unit.

It is the approximate heat required to raise 1 lb. of water 1 deg Fahrenheit, from 59°F to 60°F.

The difference of thermally homogeneous materials and thermally heterogeneous materials is shown in Figure 1. There is a directly proportional relationship between the R and C of the thermally homogeneous material, at twice the thickness the R is twice as great and the C is halved. For the thermally heterogeneous material, there is no directly proportional relationship to the R or C and the material thickness. Fig. 1 also shows the horizontal path of heat flow through a 1 ft^2 surface area of the wall component.



Thermal Transmittance Through Materials[a]

FIG. 1

[a] It is important to note that not all materials are isotropic with respect to heat transmission. In such thermally heterogeneous materials, the specific thermal property under consideration could vary with temperature and material orientation. For this reason, care must be taken that the direction of heat flow through a material is suitable for the material's intended use. Materials in which heat flow is identical in all directions are considered thermally homogeneous.

CALCULATION OF OVERALL COEFFICIENTS

General

Conductance and resistance coefficients of various wall elements are listed in Table 1. These coefficients were taken from the 1981 ASHRAE *Handbook of Fundamentals,* Chapter 23, which states:

"The most exact method of determining heat transmission coefficients for a given combination of building materials assembled as a building section is to test a representative section in a guarded hot box. However, it is not practicable to test all the combinations of interest. Experience has indicated that U-values for many constructions, when calculated by the methods given in this chapter using accurate values for component materials, and with corrections with framing member heat loss, are in good agreement with the values determined by guarded hot box measurements, when there are no free air cavities within the construction. "Remember, the values shown for materials in calculating overall heat transmission are representative of laboratory specimens tested under idealized conditions. In actual practice, if insulation is improperly installed (for example), shrinkage, settling, insulation compression, and similar factors may have a significant effect on the overall U-value numbers. Materials that are field fabricated and consequently especially sensitive to the skills of the mechanic, are especially prone to variations resulting in performance less than the idealized number."

Calculation Methods

Conductances and resistances of homogeneous material of any thickness can be obtained from the following formula:
C_x=k/x, and R_x=x/k

where:
x=thickness of material in inches.

This calculation for a homogeneous material is shown in Fig. 1. The calculation only considers the brick component of the wall assembly. Whenever an opaque wall is to be analyzed, the wall assembly should include both the outside and inside air surfaces. The inclusion of these air surfaces makes all opaque wall assemblies layered construction.

In computing the heat transmission coefficients of layered construction, the paths of heat flow should first be determined. If these are in series, the resistances are additive, but if the paths of heat flow are in parallel, then the thermal transmittances are averaged. The word "series" implies that in cross-section, each layer of building material is one continuous material. However, that is not always the case. For instance, in a longitudinal wall section, one layer could be composed of more than one material, such as wood studs and insulation, hence having parallel paths of heat flow within that layer. In this case, a weighted average of the thermal transmittances should be taken.

For layered construction, with paths of heat flow in series, the total thermal resistance of the wall is obtained by:

$$R_1=R_1+R_2+...$$

and the overall coefficient of heat transmission is:

$$U=1/R_1$$

A solid 8-in. face brick wall would be a layered construction assembly in regard to thermal analysis:

R
(hr * ^{0}F * ft^2)

BTU

Outside Air Surface 0.17
8-in. Face Brick 0.88
Inside Air Surface 0.68
Total: R_1=1.73

$U = 1/R_1 = 0.578$ Btu/(hr * ^{0}F * ft^2

Average transmittances for parallel paths of heat flow may be obtained from the formula:

$$u_{avg}[A_A(U_A) + A_B(U_B) + ...] / A_t$$

or

$$U_{avg} = [1/ (R_A/A_A) + 1/(R_B/A_B)...]/A_T$$

where:

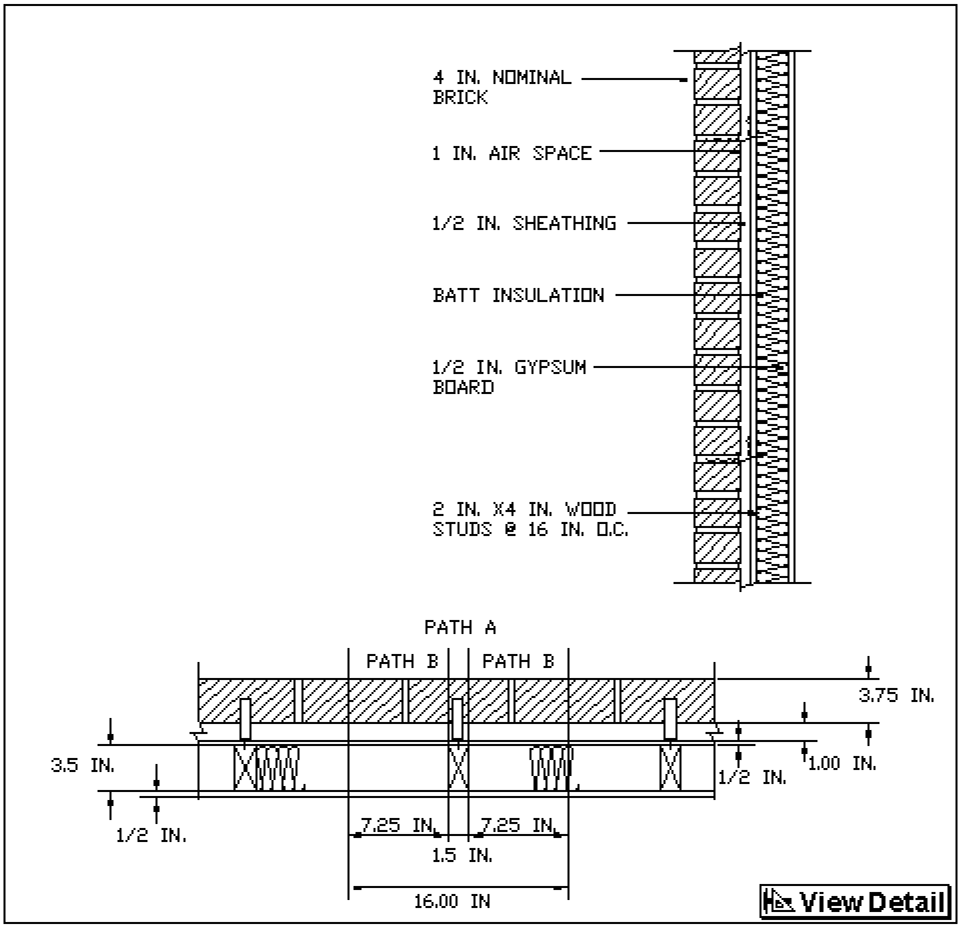
A_A, A_B, etc. = area of heat flow path, in Ft^2,
U_A,U_B, etc.= transmission coefficients of the respective paths,
R_A, R_B, etc.=thermal resistance of the respective paths.
A_t= total area beign considered (A_A+A_B+...), in Ft^2

A_t = total area being considered (A_A+A_B+...), in ft^2

Such an analysis is important for wall construction with parallel paths of heat flow when one path has a high heat transfer and the other a low heat transfer, or the paths involve large percentages of the total wall with small variations in the transfer coefficients for the paths.

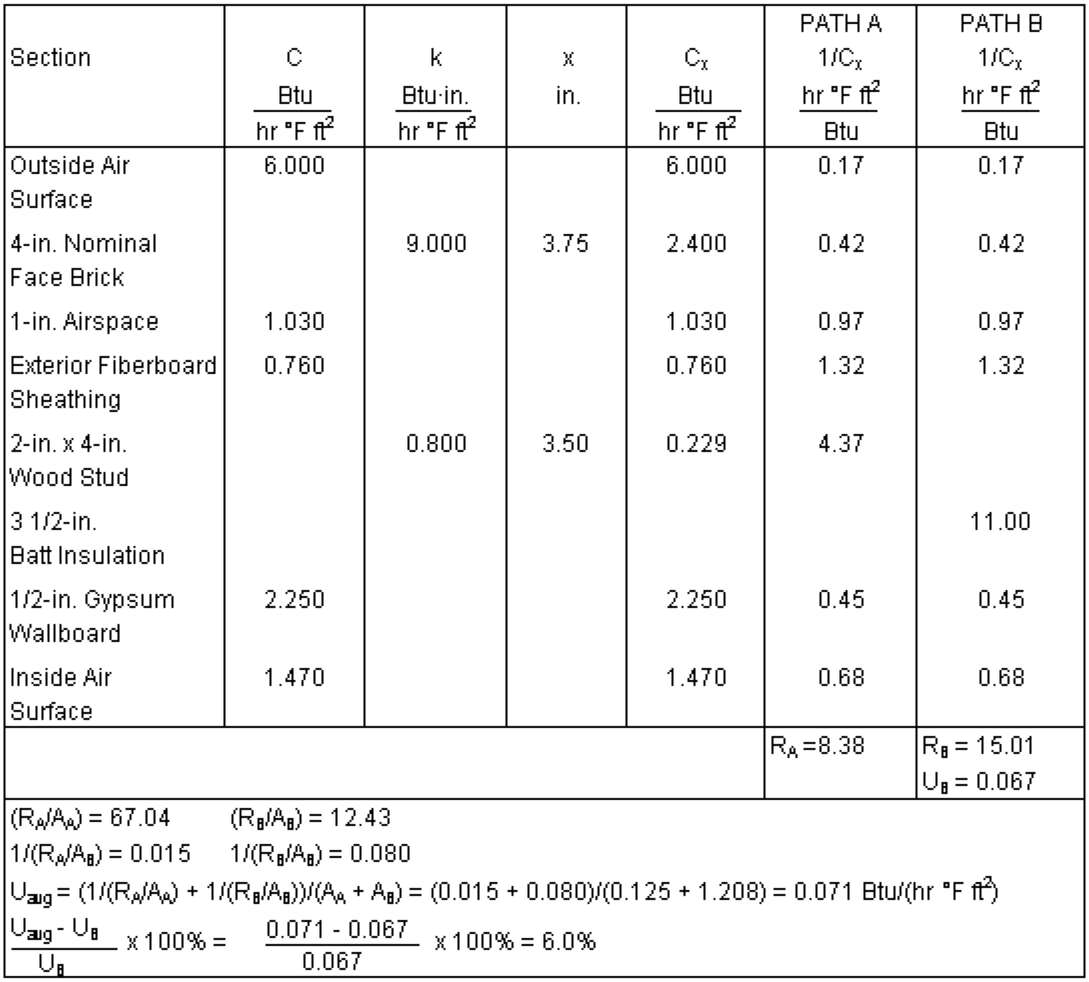
Thermal bridges built into a wall may increase heat transfer substantially above the calculated amount if the bridge is ignored. Thermal bridges occur in several types of walls. Three examples of these are shown. Different methods are used in calculating the U_{avg} for metallic and non-metallic bridges. Examples of both are shown.

The brick veneer-frame wall shown in Fig. 2 has thermal bridges which occur at the wood studs. The parallel path method allows the average U-value of the wall to be calculated by first calculating the U-values in series of the two paths involved. Using the heat transmission coefficients for the various materials found in Table 1, the calculation is shown in Fig. 2. The path at the wood stud is Path A and the path at the insulation is Path B.



Brick Veneer/Wood Stud

FIG. 2a



Section	C $\frac{\text{Btu}}{\text{hr °F ft}^2}$	k $\frac{\text{Btu·in.}}{\text{hr °F ft}^2}$	x in.	C_x $\frac{\text{Btu}}{\text{hr °F ft}^2}$	PATH A $1/C_x$ $\frac{\text{hr °F ft}^2}{\text{Btu}}$	PATH B $1/C_x$ $\frac{\text{hr °F ft}^2}{\text{Btu}}$
Outside Air Surface	6.000			6.000	0.17	0.17
4-in. Nominal Face Brick		9.000	3.75	2.400	0.42	0.42
1-in. Airspace	1.030			1.030	0.97	0.97
Exterior Fiberboard Sheathing	0.760			0.760	1.32	1.32
2-in. x 4-in. Wood Stud		0.800	3.50	0.229	4.37	
3 1/2-in. Batt Insulation						11.00
1/2-in. Gypsum Wallboard	2.250			2.250	0.45	0.45
Inside Air Surface	1.470			1.470	0.68	0.68
					R_A =8.38	R_B = 15.01 U_B = 0.067

$(R_A/A_A) = 67.04$ $(R_B/A_B) = 12.43$

$1/(R_A/A_B) = 0.015$ $1/(R_B/A_B) = 0.080$

$U_{avg} = (1/(R_A/A_A) + 1/(R_B/A_B))/(A_A + A_B) = (0.015 + 0.080)/(0.125 + 1.208) = 0.071$ Btu/(hr °F ft^2)

$$\frac{U_{avg} - U_B}{U_B} \times 100\% = \frac{0.071 - 0.067}{0.067} \times 100\% = 6.0\%$$

Brick Veneer/Wood Stud

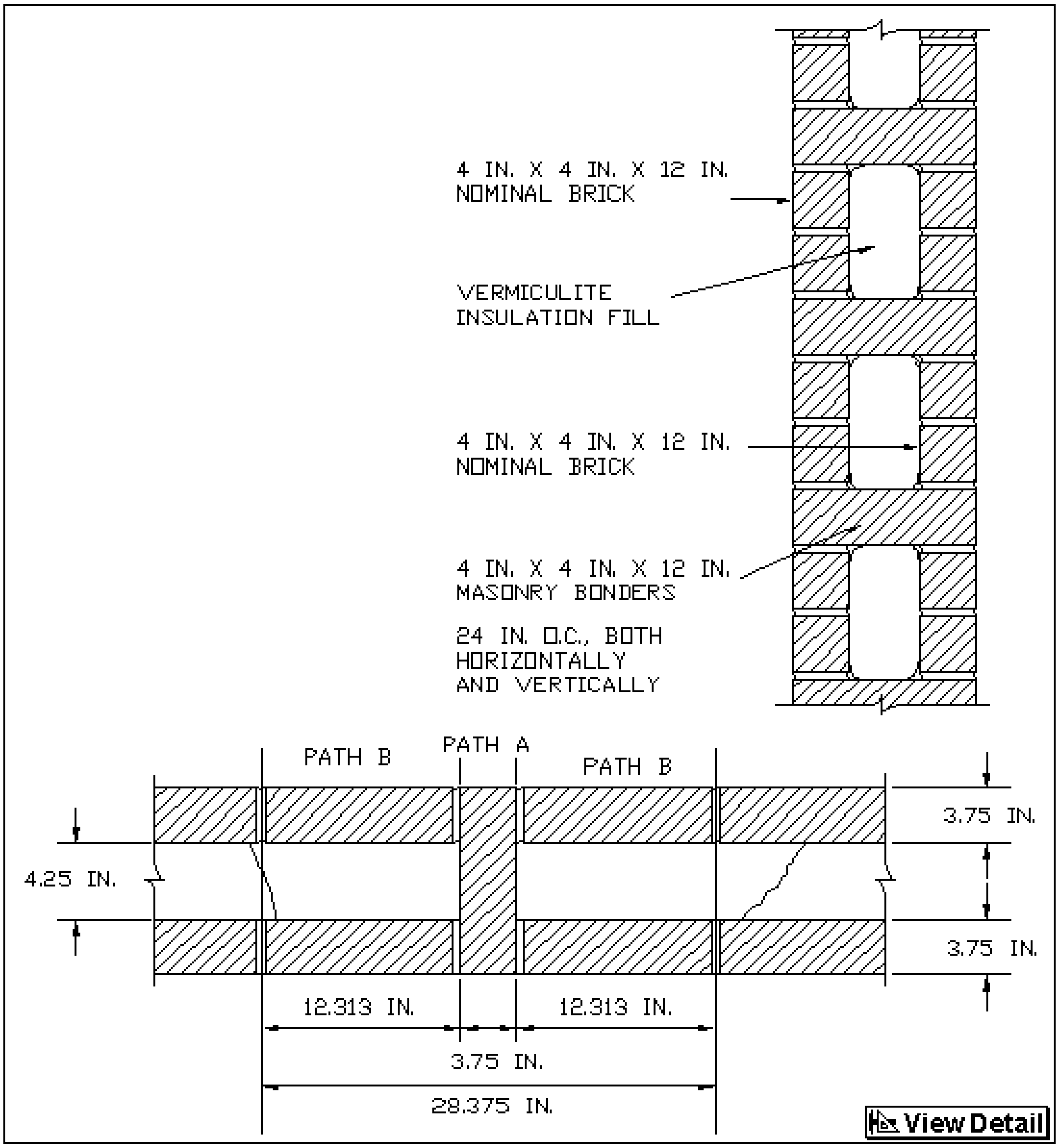
FIG. 2b

This calculation reveals that, if the thermal bridge formed by the stud is considered, the U_{avg} exceeds the U of the wall having the insulation (Path B) by approximately 6 per cent. It is common practice to calculate the U-values for the insulation path by the series method and then multiply this value by 1.08 to obtain the U_{avg} for the wood frame walls.

This method of correcting for wood framing in the walls is still used in many energy calculation guidelines procedures, although it is no longer provided in the ASHRAE *Handbook of Fundamentals.* It should be noted that the correction factor should be higher because this value properly predicts the U_{avg} for the studs, but does not appropriately adjust the U-value for jambs, heads, sills, and top and toe plates. Also, if 2 in. x 6 in. wood studs are used, the correction factor may no longer be appropriate.

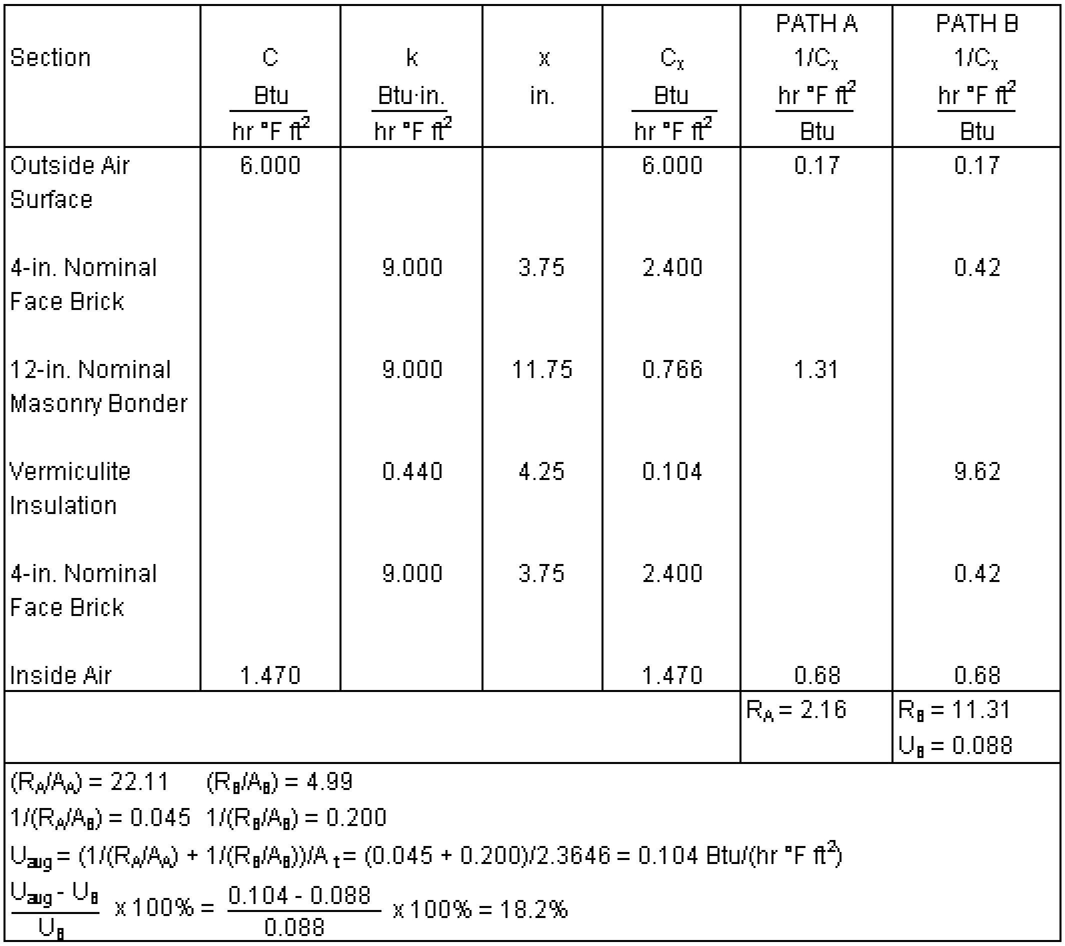
Most masonry walls have parallel paths of heat flow which result from bonding the separate wythes together. This may be by masonry bonders or metal ties. However, for conventional constructions, the effect of the bonders is not significant, because of the relatively small area of the metal ties per sq ft of wall, and the slight differences in conductivity or conductance of masonry units.

However, if masonry bonded cavity walls with insulation in the cavity of walls with a large amount of headers are being considered, the parallel path method of calculation should be used. This is illustrated by the calculated U-values of the brick cavity wall, shown in Fig. 3.



Brick Masonry Cavity Wall(Masonry Bonded)

FIG. 3a



Section	C $\frac{\text{Btu}}{\text{hr °F ft}^2}$	k $\frac{\text{Btu·in.}}{\text{hr °F ft}^2}$	x in.	C_x $\frac{\text{Btu}}{\text{hr °F ft}^2}$	PATH A $1/C_x$ $\frac{\text{hr °F ft}^2}{\text{Btu}}$	PATH B $1/C_x$ $\frac{\text{hr °F ft}^2}{\text{Btu}}$
Outside Air Surface	6.000			6.000	0.17	0.17
4-in. Nominal Face Brick		9.000	3.75	2.400		0.42
12-in. Nominal Masonry Bonder		9.000	11.75	0.766	1.31	
Vermiculite Insulation		0.440	4.25	0.104		9.62
4-in. Nominal Face Brick		9.000	3.75	2.400		0.42
Inside Air	1.470			1.470	0.68	0.68
					$R_A = 2.16$	$R_B = 11.31$ $U_B = 0.088$

$(R_A/A_A) = 22.11 \quad (R_B/A_B) = 4.99$

$1/(R_A/A_B) = 0.045 \quad 1/(R_B/A_B) = 0.200$

$U_{avg} = (1/(R_A/A_A) + 1/(R_B/A_B))/A_t = (0.045 + 0.200)/2.3646 = 0.104$ Btu/(hr °F ft^2)

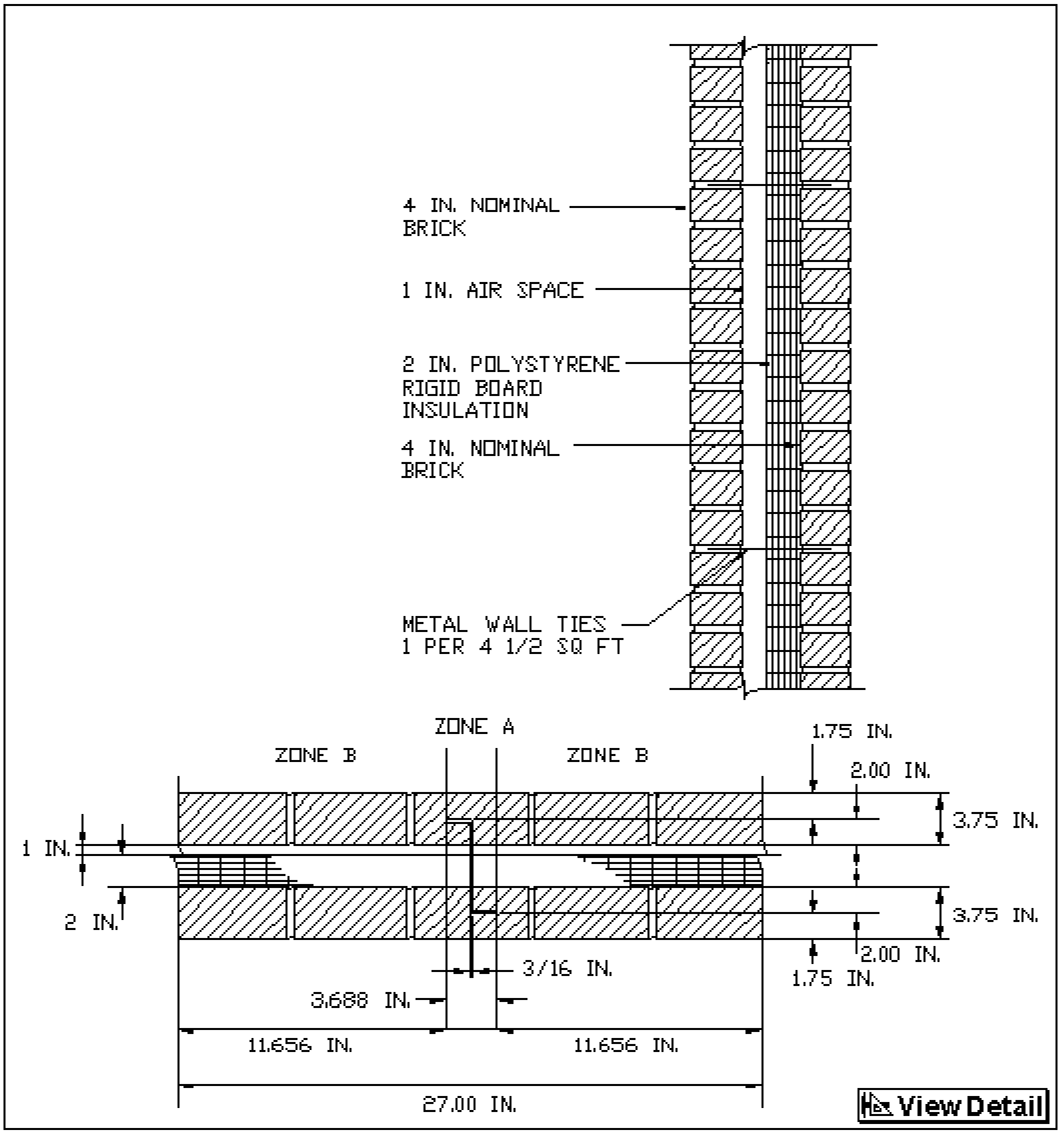
$$\frac{U_{avg} - U_B}{U_B} \times 100\% = \frac{0.104 - 0.088}{0.088} \times 100\% = 18.2\%$$

Brick Masonry Cavity Wall(Masonry Bonded)

FIG. 3b

If the thermal bridge at the bonder were ignored, the U-value would be the same as U_B, which is 0.088. This is approximately an 18 per cent differential between the series and parallel path calculated transmission coefficients.

The metal-tied cavity wall shown in Fig. 4 requires the parallel path method of calculation. However, a slightly modified parallel path method should be used because the ASHRAE *Handbook of Fundamentals* requires that calculations for metallic thermal bridges be done by the *Zone Method.* Under this method a slightly larger area is assumed to be affected by the metallic bridge than just the area of the metal. The wall is divided into two zones, Zone A, containing the metal; and Zone B, the remaining portion of the wall.



Brick Masonry Insulated Cavity Wall

FIG. 4a

Section	C	k	x	C_x	Zone A			Zone B		
					A	$C_x \cdot A$	$\frac{1}{C_x \cdot A}=\frac{R}{A}$	A	$C_x \cdot A$	$\frac{1}{C_x \cdot A}=\frac{R}{A}$
	$\frac{\text{Btu}}{\text{hr °F ft}^2}$	$\frac{\text{Btu} \cdot \text{in.}}{\text{hr °F ft}^2}$	in.	$\frac{\text{Btu}}{\text{hr °F ft}^2}$	ft^2	$\frac{\text{Btu}}{\text{hr °F}}$	$\frac{\text{hr °F}}{\text{Btu}}$	ft^2	$\frac{\text{Btu}}{\text{hr °F}}$	$\frac{\text{hr °F}}{\text{Btu}}$
Outside Air Surface	6.000			6.000	0.07416	0.445	2.25	4.42584	26.555	0.04
4-in. Nominal Face Brick		9.000	3.75	2.400				4.42584	10.622	0.09
Brick		9.000	1.75	5.143	0.07416	0.381	2.62			
Brick		9.000	2.00	4.500	0.07397	0.333				
Steel		314.000	2.00	157.000	0.00019	0.030				
					Sub-Total	0.363	2.75			
2-in. Airspace	1.030			1.030	0.07397	0.076		4.42584	4.559	0.22
Steel		314.000	1.00	314.000	0.00019	0.060				
					Sub-Total	0.136	7.35			
2-in. Polystyrene Rigid Board		0.250	2.00	0.125	0.07397	0.009		4.42584	0.553	1.81
Insulation		314.000	2.00	157.000	0.00019	0.030				
					Sub-Total	0.039	25.64			
Brick		9.000	2.00	4.500	0.07397	0.333				
Steel		314.000	2.00	157.000	0.00019	0.030				
					Sub-Total	0.363	2.75			
Brick		9.000	1.75	5.143	0.07416	0.381	2.62			
4-in. Nominal Face Brick		9.000	3.75	2.400				4.42584	10.622	0.09
Inside Air Surface	1.470			1.470	0.07416	0.109	9.17	4.42584	6.506	0.15
					$R_A/A_A = 55.15$ $1/(R_A/A_A) = 0.018$			$R_B/A_B = 2.40$ $1/(R_B/A_B) = 0.417$		

$U_{avg} = (1/(R_A/A_A) + 1/(R_B/A_B))/(A_A + A_B) = (0.018 + 0.417)/(0.07416 + 4.42584) = 0.097 \text{ Btu/(hr °F ft}^2)$

$U_B\ (1/(R_B/A_B))/A_B = 0.417/4.42584 = 0.094 \text{ Btu/(hr °F ft}^2)$

$\frac{U_{avg} - U_B}{U_B} \times 100\% = \frac{0.097-0.094}{0.094} \times 100\% \cong 3.2\%$

Brick Masonry Insulated Cavity Wall

FIG. 4b

The *Handbook of Fundamentals* also prescribes a method for determining the size and shape of Zone A. The surface shape of Zone A in the case of a metal beam would be a strip of width, W, centered on the beam. In the wall shown in Fig. 4, the shape of Zone A, due to the circular tie, would be a circle of diameter W. W is calculated from the following formula:

$$W = m + 2d$$

where:

W = width or diameter of the zone, in in.,

m = width or diameter of the metal heat path, in in.,

d = distance from the panel surface to the metal, in in. The value of d should not be taken as less than 0.5 in.

Calculations for W should be run for both surfaces and the larger of the two values used.

For the insulated cavity wall with one metal tie provided for each 4 1/2 sq ft of wall surface, the calculations in Fig. 4 show that there is about 3.2 per cent increase in the heat loss through the wall when the ties are considered as compared to the heat loss through the wall without consideration of the ties.

For a cavity wall which does not contain any insulation, the effect of the metal ties is much less. By subtracting out the effects of the insulation and the metal ties through the insulation shown in Fig. 4, the effect of the wall tie through a 1-in. air space may be determined:

$$R_A / A_A = 55.17 - 25.64 = 29.53$$

$$1 / (R_A / A_A) = 0.034$$

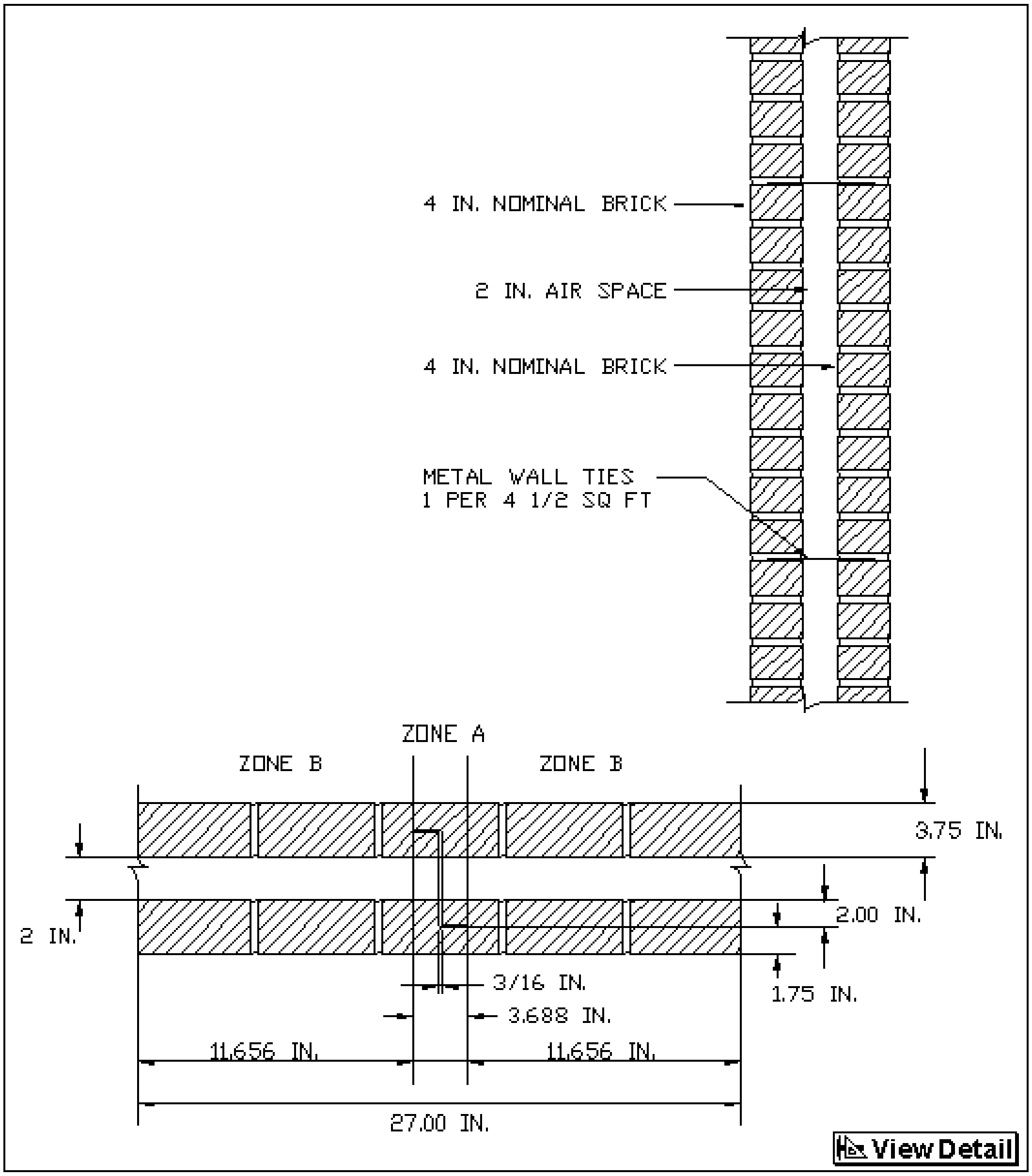
$$R_B / A_A = 2.40 - 1.81 = 0.59$$

$$1 / (R_A / A_A) = 1.695$$

$$U_{avg} = (0.034 + 1.695) / 4.50 = 0.384 \text{ Btu} / (\text{hr } ^\circ\text{F ft}^2)$$

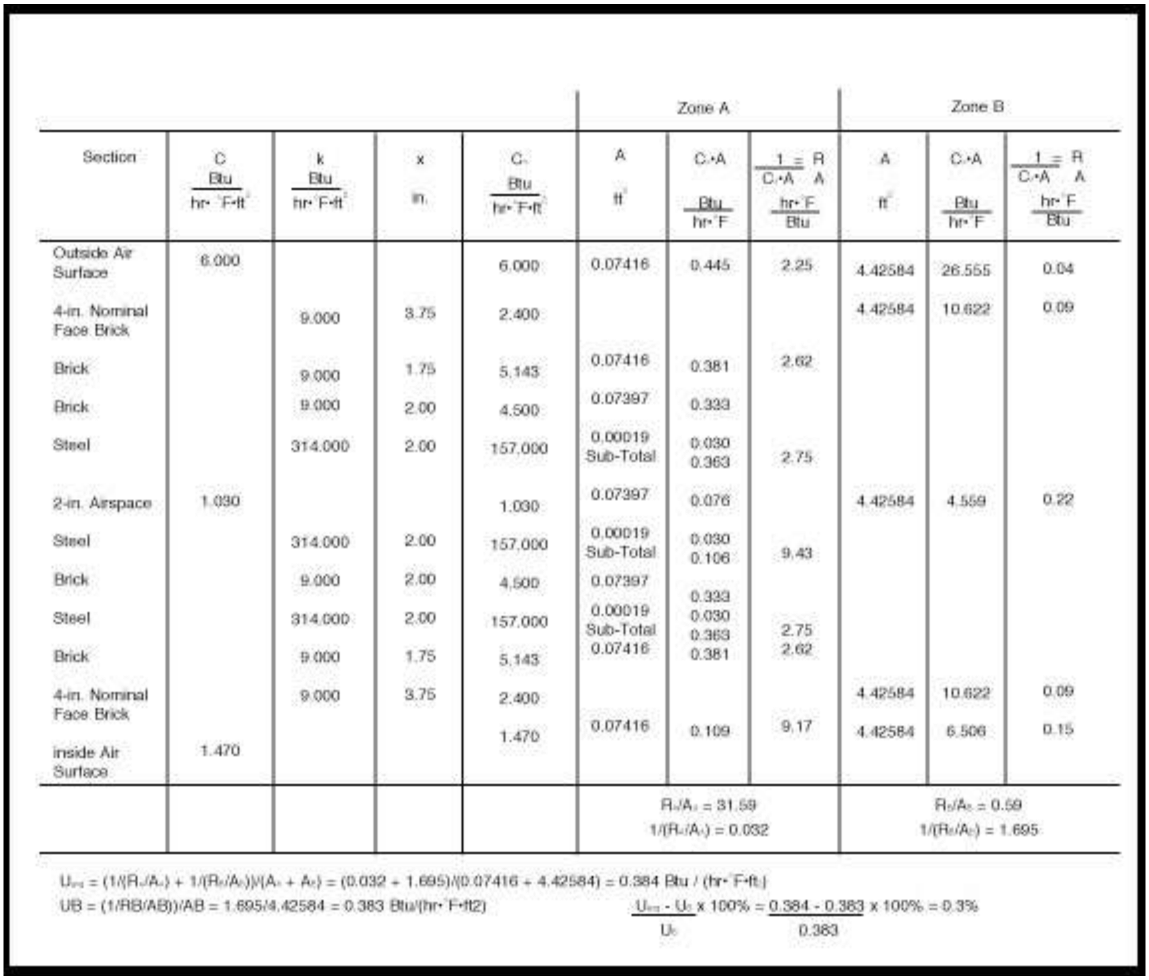
$$U_B = 1.695 / 4.42584 = 0.383 \text{ Btu} / (\text{hr } ^\circ\text{F ft}^2)$$

This calculation procedure shows that the effect of a metal tie across a 1-in. air space is negligible. Fig. 5 shows the calculations for an uninsulated cavity wall and again the effect is negligible. These calculations demonstrate that the effect of a metal tie would be negligible in the 1-in. air space in brick veneer construction and also in uninsulated cavity walls. There will be minor variations, depending on the type, size and spacing of metal ties, but the effect may usually be ignored. However, as demonstrated in the calculations in Fig. 4, if the metal tie passes through insulation, the effect of the metal tie on the thermal performance of the wall may become more significant. It should be noted that as the R-value of the material the metal tie penetrates in creases, the per cent of heat loss due to the metal tie also increases.



Brick Masonry Cavity Wall

FIG. 5a



Section	C $\frac{\text{Btu}}{\text{hr}\cdot{}^\circ\text{F}\cdot\text{ft}^2}$	k $\frac{\text{Btu}}{\text{hr}\cdot{}^\circ\text{F}\cdot\text{ft}^2}$	x in.	C_T $\frac{\text{Btu}}{\text{hr}\cdot{}^\circ\text{F}\cdot\text{ft}^2}$	Zone A A ft²	 $C_T\cdot A$ $\frac{\text{Btu}}{\text{hr}\cdot{}^\circ\text{F}}$	 $\frac{1}{C_T\cdot A} = \frac{R}{A}$ $\frac{\text{hr}\cdot{}^\circ\text{F}}{\text{Btu}}$	Zone B A ft²	 $C_T\cdot A$ $\frac{\text{Btu}}{\text{hr}\cdot{}^\circ\text{F}}$	 $\frac{1}{C_T\cdot A} = \frac{R}{A}$ $\frac{\text{hr}\cdot{}^\circ\text{F}}{\text{Btu}}$
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Steel		314.000	2.00	157,000	0.00019 Sub-Total	0.030 0.363	2.75			
2-in. Airspace	1.030			1.030	0.07397	0.076		4.42584	4.559	0.22
Steel		314.000	2.00	157,000	0.00019 Sub-Total	0.030 0.106	9.43			
Brick		9.000	2.00	4,500	0.07397	0.333				
Steel		314.000	2.00	157,000	0.00019 Sub-Total	0.030 0.363	2.75			
Brick		9.000	1.75	5.143	0.07416	0.381	2.62			
4-in. Nominal Face Brick		9.000	3.75	2.400				4.42584	10.622	0.09
inside Air Surface	1.470			1.470	0.07416	0.109	9.17	4.42584	6.506	0.15
					$R_A/A_A = 31.59$ $1/(R_A/A_A) = 0.032$			$R_B/A_B = 0.59$ $1/(R_B/A_B) = 1.695$		

$U_{eq} = (1/(R_A/A_A) + 1/(R_B/A_B))/(A_A + A_B) = (0.032 + 1.695)/(0.07416 + 4.42584) = 0.384$ Btu / (hr·°F·ft²)

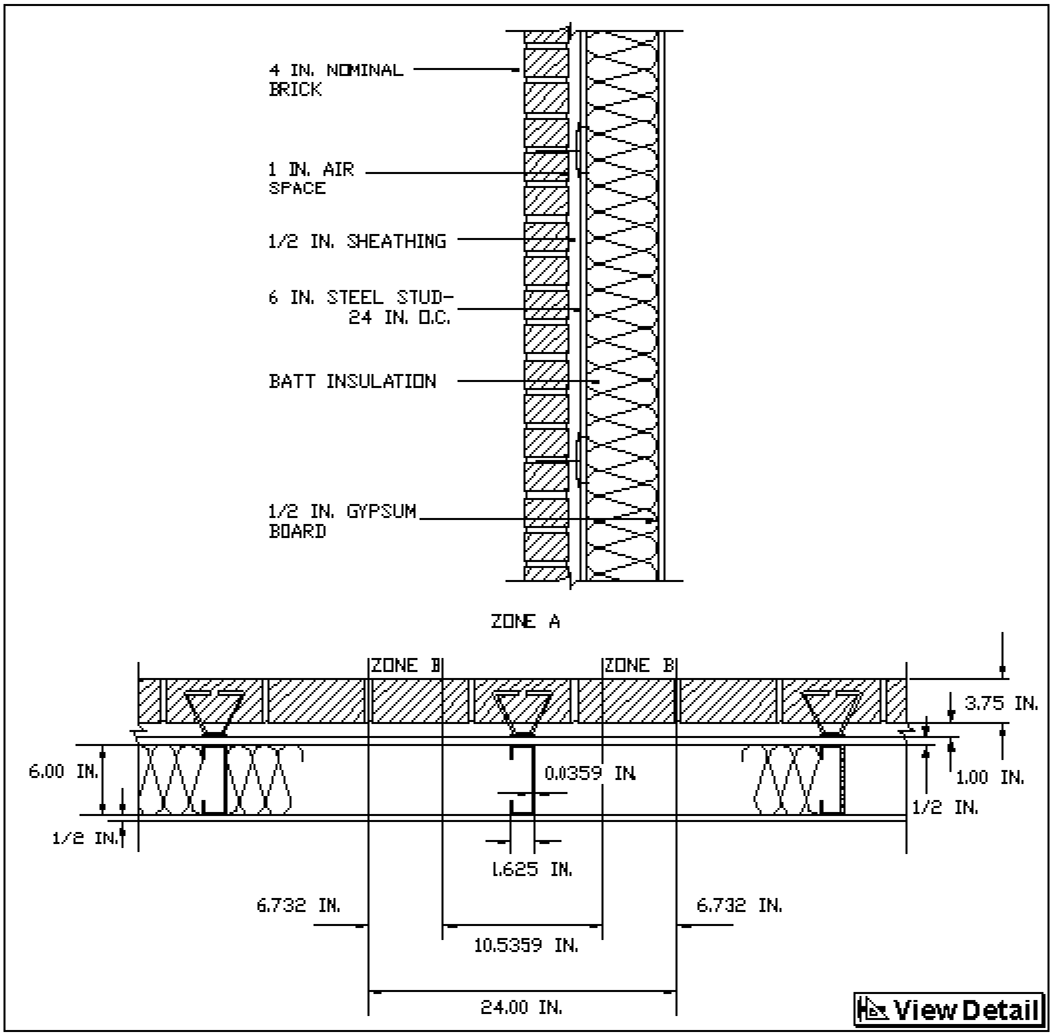
UB = (1/RB/AB))/AB = 1.695/4.42584 = 0.383 Btu/(hr·°F·ft2)

$$\frac{U_{eq} - U_B}{U_B} \times 100\% = \frac{0.384 - 0.383}{0.383} \times 100\% = 0.3\%$$

Brick Masonry Cavity Wall

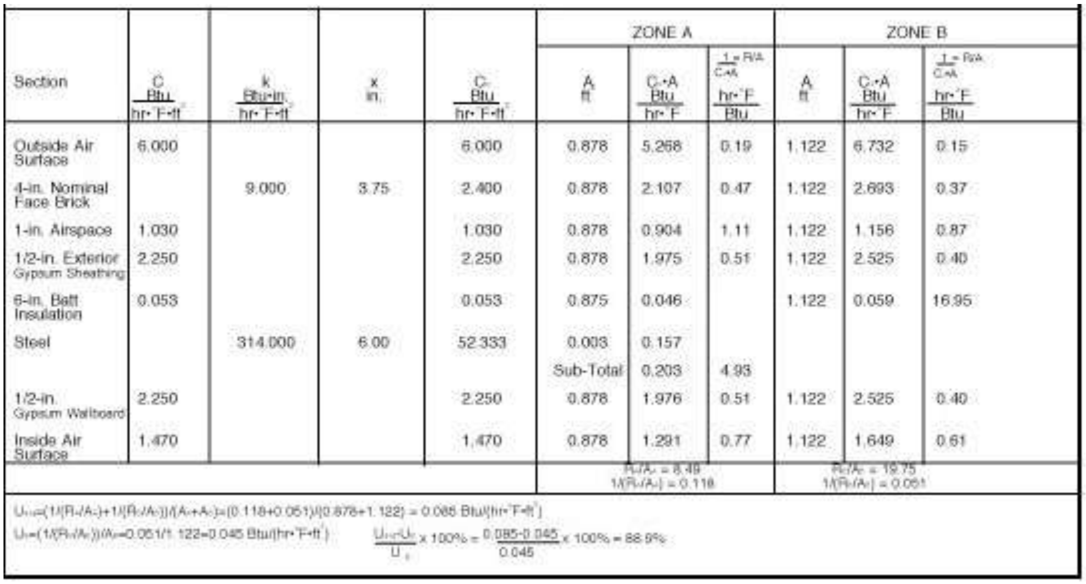
FIG. 5b

Another factor which affects the thermal performance of walls containing metal is the location of the metal in the wall. The farther the metal is located from the face of the wall, the larger the area of the zone affected by the metal tie. This may be demonstrated with brick veneer/steel stud systems. Consider the brick veneer/steel stud system shown in Fig. 6. The steel stud backup system consists of 6-in., 20 gage steel studs at 24 in. o.c., with 6-in. batt insulation between the steel studs. The width of Zone A is determined from the exterior flange of the steel stud to the exterior face of the brick veneer, as shown in Fig. 6. The zone, including the metal, is quite wide for this type of construction. In accordance with steady-state analysis, assuming that the 1-in. air space is a material of the system, the width of the zone becomes 10.5359 in. The 1 5/8-in. wide flange of the metal studs, being relatively thin as compared to the wall section, is not considered in the analysis because it will not significantly affect the average thermal performance of the system.



Brick Veneer/Steel Stud

FIG. 6a



Section	C $\frac{Btu}{hr \cdot °F \cdot ft^2}$	k $\frac{Btu \cdot in.}{hr \cdot °F \cdot ft^2}$	x in.	C_T $\frac{Btu}{hr \cdot °F \cdot ft^2}$	ZONE A			ZONE B		
					A ft²	$C_T \cdot A$ $\frac{Btu}{hr \cdot °F}$	$\frac{1}{C_T \cdot A} = R/A$ $\frac{hr \cdot °F}{Btu}$	A ft²	$C_T \cdot A$ $\frac{Btu}{hr \cdot °F}$	$\frac{1}{C_T \cdot A} = R/A$ $\frac{hr \cdot °F}{Btu}$
Outside Air Surface	6.000			6.000	0.878	5.268	0.19	1.122	6.732	0.15
4-in. Nominal Face Brick		9.000	3.75	2.400	0.878	2.107	0.47	1.122	2.693	0.37
1-in. Airspace	1.030			1.030	0.878	0.904	1.11	1.122	1.156	0.87
1/2-in. Exterior Gypsum Sheathing	2.250			2.250	0.878	1.975	0.51	1.122	2.525	0.40
6-in. Batt Insulation	0.053			0.053	0.875	0.046		1.122	0.059	16.95
Steel		314.000	6.00	52.333	0.003	0.157				
					Sub-Total	0.203	4.93			
1/2-in. Gypsum Wallboard	2.250			2.250	0.878	1.976	0.51	1.122	2.525	0.40
Inside Air Surface	1.470			1.470	0.878	1.291	0.77	1.122	1.649	0.61
					$R_A/A_A = 8.49$ $1/(R_A/A_A) = 0.118$			$R_B/A_B = 19.75$ $1/(R_B/A_B) = 0.051$		

$U_{ave}=(1/(R_A/A_A)+1/(R_B/A_B))/(A_A+A_B)=(0.118+0.051)/(0.878+1.122)=0.085$ Btu/(hr·°F·ft²)

$U_B=(1/(R_B/A_B))/A_B=0.051/1.122=0.045$ Btu/(hr·°F·ft²)

$\frac{U_{ave}-U_B}{U_B}\times 100\% = \frac{0.085-0.045}{0.045}\times 100\% = 88.9\%$

Brick Veneer/Steel Stud

FIG. 6b

Without consideration of sills, jambs, heads, and toe and top channels, the performance of the brick veneer/ steel stud system analyzed is almost 50 per cent less than the value calculated through the insulation. This performance is calculated using the procedures in the 1981 ASHRAE *Handbook and Product Directory*. However, actual tests of the heat transmission and more precise calculation procedures will probably demonstrate that the calculated heat loss is considerably higher than the actual heat loss.

The intent of this example is simply to show that the thermal performance of brick veneer/metal stud systems is not the same as brick veneer over wood frame. The designer should be aware of this discrepancy and the accuracy, or inaccuracy of the approximation of thermal performance by simplified calculation procedures. The thermal performance of the brick veneer/metal stud system would require a correction factor for the framing which greatly exceeds the 8 per cent or the 1.08 U adjustment factor allowable for wood frame given in the previous brick veneer example. Even for the wood frame, because of the presence of fire stops, heads, jambs, sills and top and toe plates, it is recommended that the 1.08 factor for wood frame be increased to about 1.20, and that an even larger factor be used for metal studs.

HEAT LOSS AND HEAT GAIN

Building envelope heat losses and heat gains are calculated using the overall heat transmission coefficients and other known data.

Even though heat losses and heat gains are calculated using U-values in the steady-state and steady-periodic formulae in lieu of the more accurate methods available, other factors greatly affect the performance of the building envelope in conserving energy. It should be remembered that the values obtained from the steady-state and steady-periodic calculations are merely an estimate of the thermal performance of the envelope.

The designer should be aware that several factors, other than U-values, determine the actual performance of the envelope in conserving energy. Some of these factors are: 1) building orientation and aspect ratio (The aspect ratio is the proportion of length to width. As the ratio approaches 1, the surface area to volume ratio decreases, and generally there will be less loss of thermal energy from interior spaces through the building envelope); 2) exterior surface color of envelope materials; 3) color of inside walls and ceilings; 4) mass and specific heat of envelope materials; 5) wind velocities; 6) infiltration through the envelope; and 7) orientation, area and external shading of glazing.

These factors are not considered in the steady-state calculations. However, if their effects on heat transmission are kept foremost in the designer's mind, he can utilize the energy-conserving characteristics of each of these factors. The resulting structure will be more thermally efficient than is shown by the steady-state calculations. Note that some of these factors are accounted for by the CLTD values in heat gain calculations.

The steady-state method of calculation for heat loss is straightforward and simple to perform. The outdoor design temperatures required can be found in the 1981 ASHRAE *Handbook of Fundamentals.* The inside design temperature should be 72^{o}F, or as prescribed by governing codes. The formula for calculating heat loss is as follows:

where:

H = heat loss transmitted through the walls or other elements of the building envelope, in Btu/hr,

A = area of the walls or other elements, in ft^{2},

U = overall coefficient of heat transmission of the walls or other elements, in Btu/(hr^{o}F ft^{2}),

t_i = indoor design temperature, in ^{o}F,

t_o = outdoor design temperature, in ^{o}F.

TABLE 1[a]
Heat Transmission Coefficients of Building Materials

Materials Description	Density $\frac{lb}{ft^3}$	Conductivity or Conductance		Resistance (R) Per Inch Thickness	Resistance (R) For Thickness Listed
		(k)	(C)	(l/k)	(l/C)
Masonry Units					
Face brick	130[b]	9.00		0.11	
Common brick	120[b]	5.00		0.20	
Hollow brick[c]					
4 in. (62.9% solid)	81.00		1.36		0.74
6 in. (67.3% solid)	86.00		1.07		0.93
8 in. (61.2% solid)	78.00		0.94		1.06
10 in. (60.9% solid)	78.00		0.83		1.20
Hollow brick vermiculite fill[c]					
4 in. (62.9% solid)	83.00		0.91		1.10
6 in. (67.3% solid)	88.00		0.66		1.52
8 in. (61.2% solid)	80.00		0.52		1.92
10 in. (60.9% solid)	80.00		0.42		2.38
Lightweight concrete blocks[d]					
---100-lb density concrete					
4 in.	78.00		0.71		1.40
6 in.	66.00		0.65		1.53
8 in.	60.00		0.57		1.75
10 in.	58.00		0.51		1.97
12 in.	55.00		0.47		2.14
Lightweight concrete block, vermiculite fill - 100 - lb density concrete[d]					
4 in.	79.00		0.43		2.33
6 in.	68.00		0.27		3.72
8 in.	62.00		0.21		4.85
10 in.	61.00		0.17		5.92
12 in.	58.00		0.15		6.80
Building Board					
3/8 - in. Drywall (gypsum)	50.00		3.10		0.32
1/2 - in. Drywall (gypsum)	50.00		2.25		0.45
Plywood	34.00	0.80		1.25	
1/2 - in. Fiberboard sheathing	18.00		0.76		1.32

TABLE 1[a] Continued
Heat Transmission Coefficients of Building Materials

Materials Description	Density $\frac{lb}{ft^3}$	Conductivity or Conductance		Resistance (R)	
				Per Inch Thickness	For Thickness Listed
		(k)	(C)	(1/k)	(1/C)
Siding					
7/16 - in. Hardboard	40.00		1.49		0.67
1/2 - in. by 8- in. Wood bevel	32.00		1.23		0.81
Aluminum or steel over sheathing[d]	-		1.61		0.61
Insulating Materials					
Batt or blanket[f]					
2 to 2 3/4 in.					7.00
3 to 3 1/2 in.	1.20				11.00
5 1/2 to 6 1/2 in.	1.20				19.00
Boards					
Expanded polystyrene[g]					
Cut Cell Suface	1.80	0.25		4.00	
Smooth Skin	1.80	0.20		5.00	
Expanded polyurethane[g]	1.50	0.16		6.25	
Polyisocyanurate[h]	2.00	0.14		7.14	
Loose fill					
Vermiculite	4--6	0.44		2.27	
Perlite	5--8	0.37		2.70	
Woods					
Hard woods	45.00	1.10		0.91	
Soft woods	32.00	0.80		1.25	
Metals					
Steel	---	312.0		0.003	
Aluminum	---	1416.0		0.0007	
Copper	---	2640.0		0.0004	
Air Space					
3/4 in. to 4 in., winter			1.03		0.97
3/4 in. to 4 in., summer			1.16		0.86
			(h)		(1/h)
Air Surfaces					
Inside --- still air			1.47		0.68
Outside --- 15 mph wind, winter			6.00		0.17
7.5 mph wind, summer			4.00		0.25

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[a] From ASHRAE *Handbook of Fundamentals*, except as noted.

[b] Face brick and common brick do not always have these specific densities. When the density is different from that shown, there will be a change in the thermal conductivity.

[c] Calculated data based upon hollow brick (25% to 40% cored) of one manufacturer. Based upon coring and density given. R figures based upon coring and density of supplier using parallel path method. Vermiculite fill in cores.

[d] From NCMA TEK 38

[e] Values for metal siding applied over flat surfaces vary widely depending upon the amount of ventilation of air space beneath the siding, whether the air space is reflective or non-reflective, and on the thickness, type. and application of insulating backing-board used. Values given are averages intended for use as design guide values and were obtained from several guarded hot-box tests (ASTM C 236) on hollow-backed types and on types made using backer-board of wood-fiber, foamed plastic, and glass fiber. Departures of +/- 50%. or more, from the values given may occur.

[f] Thicknesses can vary. R values must be stamped on batt.

[g] Based upon values as commercially produced. For calculations use specific manufacturer's specified values.

[h] Time-aged values for board stock with gas-barrier quality (0.001 in thickness or greater) aluminum foil facers on two major surfaces.

CONCLUSION

Present-day technology for heat transmission (steady-state and steady-periodic) does not permit the designer to take full advantage of the thermal mass of the element. While these design methods are relatively easy to understand and calculate, they are *not* a true measure of the performance of massive elements. These methods do give the designer an approximate solution which is on the conservative side in relation to the actual performance of massive walls.

The designer should take into account the higher performance of massive construction which in many cases, may provide savings in operational costs, efficiency of operation and energy. To provide a more accurate prediction of these savings, a detailed computer study of the thermal performance of the structure is usually warranted.

Other *Technical Notes* in this series discuss heat gain through opaque walls, thermal transmission corrections for dynamic conditions, balance point temperatures and energy conservation including worksheets, examples and data tables.

METRIC CONVERSION

Because of the possible confusion inherent in showing dual unit systems in calculations, the metric (Sl) units are not given in the data, equations or examples. Table 2 provides metric (Sl) conversion for the more commonly used heat transmission units. This table is provided so that the user may use the data and procedures with Sl units.

REFERENCES

1. 1997 ASHRAE *Handbook and Product Directory*, Fundamentals Volume.

2. 1981 ASHRAE *Handbook and Product Directory*, Fundamentals Volume.