THE BRICK INDUSTRY ASSOCIATION
TECHNICAL NOTES on Brick Construction
1850 Centennial Park Drive, Reston, Virginia 20191 | www.gobrick.com | 703-620-0010
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January 2016

Introduction to Energy Performance of Brick Masonry

Abstract: Thermal performance of the building envelope is a significant factor in the energy efficiency of a building. Thermal performance depends upon many factors, including the amount of insulation, the extent of glass/glazing used, mass and thickness of the walls, and the thermal resistance of wall materials. This *Technical Note* provides a foundation for understanding building thermal energy performance. Material properties for common building materials are given including thermal resistance (R-values) and transmittance (U-factors) based on steady-state conditions. The impacts of thermal mass and thermal bridges, which are often excluded from R-value and U-factor calculations, are also explained. The relative accuracy of various methods for estimating thermal performance are presented, including computer analyses that account for both thermal mass and thermal bridging effects. Other *Technical Notes* in this series provide further information on energy code requirements and thermal performance of specific brick masonry wall assemblies for residential and commercial construction.

Key Words: building envelope, energy, heat loss, overall thermal transmittance, R-value, thermal bridge, thermal mass, thermal resistance, U-factor

SUMMARY OF RECOMMENDATIONS:

Thermal Mass
- Use mass wall systems and exposed masonry on the interior of the building to help moderate indoor air temperatures and achieve the optimum benefit of thermal mass
- Consider climate and outside temperature swing in evaluating the potential benefit of thermal mass

Heat Transfer
- Use dynamic energy analysis (computer modeling) to more accurately determine the impact of the thermal mass on building performance
- Employ recommended construction practices to minimize the effect of workmanship on heat transfer performance

Thermal Bridging
- Use details that minimize the extent of highly conductive materials (e.g., metals) that pass through insulation layers or layers with lower thermal conductivity
- Minimize the number and size of thermal bridges by considering material conductances and other characteristics

INTRODUCTION

The energy performance of a building is dependent upon a number of factors, including climate, building orientation, massing, building occupancy, window-to-wall ratio and building envelope composition, as well as the energy used by HVAC equipment, lighting and controls. Since the building envelope is a permanent part of a building, its design should include energy-efficient measures that make sense from a life cycle standpoint. As the opaque portion of the building envelope becomes increasingly efficient, the impact of curtain walls, windows, equipment and plug loads (energy used by products drawing power through electrical receptacles) on the total energy used becomes even greater. As a result, a holistic design including all of these factors should be considered rather than relying on simple prescriptive insulation requirements.

This *Technical Note* introduces the basic principles of heat transfer through the building envelope in general and through exterior wall assemblies specifically. General information is provided on building thermal design, terminology associated with energy analysis and calculation of thermal transmittance coefficients, commonly referred to as R-values and U-factors. For specific energy code requirements and examples, refer to *Technical Note* 4A for residential buildings and *Technical Note* 4B for commercial buildings. See *Technical Note* Series 43 for further information on incorporating passive design strategies, such as passive solar heating and cooling.

BUILDING ENVELOPE THERMAL DESIGN – CONCEPTS

There are many factors that influence the energy efficiency of a building, although the building envelope is often the starting point. Building envelope performance depends upon many factors including the amount of insulation, the glass/glazing area, mass and thickness of the walls, and the thermal resistance of wall materials. Individual assembly components such as air barriers and vapor barriers also play an important role. It is important to have a thorough understanding of basic heat transfer principles and the thermal resistance of materials.

Heat Transfer Through Materials and Assemblies

In a building, heat is transferred in three ways: by convection (heat flow through air currents), by radiation (heat flow from materials) and by conduction (heat flow through materials). While all three are important, this *Technical Note* focuses on heat transfer *through* materials and assemblies (conduction).

In order to determine heat transfer through an assembly, the heat transmission characteristics of individual materials must be known. Direct measurement with laboratory equipment such as the guarded hot-box (ASTM C1363 [Ref. 2]) is the most accurate method of determining the overall thermal resistance for building materials combined as a building envelope assembly, particularly for more complex assemblies or for those with higher heat capacities. However, testing all assemblies is not a practical approach.

For many simple constructions, calculated R-values result in values similar to those determined in hot-box measurements. Thermal resistance and conductance coefficients of various elements are listed in Table 1. Using the methods described in this *Technical Note*, and more fully in the 2013 ASHRAE *Handbook – Fundamentals* [Ref. 1], these values can be used to calculate steady-state thermal resistance (R-values) of building wall assemblies. Alternately, heat flow through an assembly can be measured directly.

The definitions of the properties found in Table 1 are as follows:

- **k = Thermal Conductivity.** The rate of heat flow through a homogeneous material, 1 in. thick, per unit of temperature difference between its two surfaces; expressed in Btu · in./(h · ft² · °F)
- **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 inch of thickness; expressed in Btu/(h · ft² · °F)
- **R = Thermal Resistance or R-Value.** The thermal resistance of a material, and the reciprocal of the thermal conductance; expressed in (h · ft² · °F)/Btu
- **U = Overall Coefficient of Heat Transmission or U-Factor.** 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; expressed in Btu/(h · ft² · °F)

Table 1
Heat Transmission Coefficients of Common Building Materials[a]

Material Description	Density lb/ft³	Conductivity (k) per Inch	U-Factor for Listed Thickness	Resistance (R)	
				Per-Inch Thickness (1/k)	For Thickness Listed (1/U)
Masonry Units					
Face brick	130[c] 120[c]	6.4–7.8 5.6–6.8		0.15[b]	
Hollow brick[d,e]					
4 in. (62.9% solid)	81.0		1.36		0.74
6 in. (67.3% solid)	86.0		1.07		0.93
8 in. (61.2% solid)	78.0		0.94		1.06
10 in. (60.9% solid)	78.0		0.83		1.20
Hollow brick with vermiculite fill[d,f]					
4 in. (62.9% solid)	83.0		0.91		1.10
6 in. (67.3% solid)	88.0		0.66		1.52
8 in. (61.2% solid)	80.0		0.52		1.92
10 in. (60.9% solid)	80.0		0.42		2.38

Table 1 (continued)

Heat Transmission Coefficients of Common Building Materials[a]

Material Description	Density lb/ft³	Conductivity (k) per Inch	U-Factor for Listed Thickness	Resistance (R)	
				Per-Inch Thickness (1/k)	For Thickness Listed (1/U)
Medium weight concrete block, 105 lb./ft³ density concrete[d,g]					
4 in.			0.518		1.93
6 in.			0.465		2.15
8 in.			0.433		2.31
10 in.			0.423		2.37
12 in.			0.417		2.40
Lightweight concrete block, 85 lb./ft³ density concrete[d,g]					
4 in.			0.467		2.14
6 in.			0.421		2.37
8 in.			0.391		2.56
10 in.			0.383		2.61
12 in.			0.380		2.63
Insulating Materials					
Glass fiber batts, 3.5 in.					11.0
Glass fiber batts, 5.5 in.					19.0
Extruded polystyrene, smooth skin (aged)	1.4–3.6	0.18–0.20			
Expanded polystyrene, molded beads	1.0–1.8	0.23–0.26			
Polyisocyanurate, unfaced (aged)	1.6–2.3	0.16–0.17			
Polyisocyanurate, foil faced (aged)		0.15–0.16			
Spray-applied polyurethane foam, low-density (½ lb), open cell	0.45–0.65	0.26–0.29			
Spray-applied polyurethane foam, medium-density (2 lb), closed cell (aged)	1.9–3.2	0.14–0.20			
Loose Fill					
Vermiculite, exfoliated	7.0–8.2 4.0–6.0	0.47 0.44			
Perlite, expanded	2–4 4.0–7.5 7.5–11	0.27–0.31 0.31–0.36 0.36–0.42		2.86	
Rock wool board	4.0–8.0	0.27–0.29			
Siding Materials					
0.5 in. OSB sheathing	41				0.68
Gypsum board	40	1.1			
0.5 in. plywood (Douglas fir)	29				0.79
0.625 in. plywood (Douglas fir)	34				0.85
Woods					
Softwoods	22–41	0.80			
Air Space					
1.5 in., winter					0.90–1.23
1.5 in., summer					0.87–1.02

Table 1 (continued)
Heat Transmission Coefficients of Common Building Materials[a]

Material Description	Density lb/ft³	Conductivity (k) per Inch	U-Factor for Listed Thickness	Resistance (R)	
				Per-Inch Thickness (1/k)	For Thickness Listed (1/U)
Air Surfaces					
Inside, still air			1.46		0.68
Outside, 15 mph wind, winter			6.00		0.17
Outside, 7.5 mph wind, summer			4.00		0.25

a. From 2013 ASHRAE *Handbook – Fundamentals* [Ref. 1], except as noted.
b. Calculated from median conductivity value. The 2013 ASHRAE *Handbook – Fundamentals* lists k values for a range of brick densities from 70 to 150 lb/ft³. When the density of brick is unknown, a resistance value of 0.15 is suggested, based on an assumed density for most fired clay brick between 120 and 130 lb/ft³.
c. 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.
d. Nominal thickness.
e. Calculated data based on hollow brick (25 to 40 percent cored) from one manufacturer. Values based upon coring and density given by supplier using parallel path method.
f. Vermiculite fill in all cores/cells.
g. From NCMA TEK 6-2C (2013). Values based on units with three full-height webs.

Heat Transfer

Steady-state heat transfer or flow through materials, known as conduction, is the simplest form or basis for energy analysis. R-value, measured in units of (h · ft² · °F)/Btu, is a common method used to evaluate the thermal performance of a material. It is a measure of resistance to heat flow, or *thermal resistance*, when “steady-state” conditions exist (the heat flow is no longer variable). This means that all ambient conditions are assumed to be constant, 24 hours a day, 365 days a year. The reciprocal of the R-value is the U-factor where U=1/R for single materials and $U=1/(R_1 + R_2 + \ldots)$ for assemblies.

Steady-state R-value and U-factor calculations are used in energy conservation studies and comparisons for predicting thermal performance of building components and buildings; however, the actual rate of heat flow through a building envelope is not constant, and steady-state calculations do not take into account dynamic, time-dependent conditions such as the thermal storage capacity of materials, fluctuating outdoor temperatures, wind and other variables.

For many mid- to lightweight materials such as vinyl and wood sidings and wood and steel studs, steady-state heat transfer calculations (R-values) provide an adequate estimation of their actual performance; however, for denser materials like masonry and concrete, which have a higher thermal mass, R-values do not accurately reflect their actual performance under the varying conditions found in the real world [Ref. 3].

Thermal Mass

Thermal mass, or thermal inertia as it is sometimes known, describes a material’s ability to absorb and store heat. Materials with high thermal mass, such as masonry, react more slowly to temperature by absorbing solar radiation, slowing its transfer through the wall and thereby reducing peak energy loads in buildings. This thermal lag, along with a damping effect that reduces the amount of heat transferred, is why historic multi-wythe brick masonry buildings are often comfortable even without insulation in the walls. Economical, energy-efficient designs may be achieved by recognizing this inherent aspect of masonry and incorporating it in the design of the building envelope. Thermal mass is most beneficial where there is a big difference between daytime and nighttime outdoor temperatures, especially in hot, dry climates. The benefit of thermal lag is realized when maximum heating or cooling loads are shifted to off-peak hours, when the demand for power and utility rates are lower.

Thermal mass is quantified by heat capacity, the measure of the energy needed to raise the temperature of 1 ft² of wall by 1 °F. Brick masonry walls have higher heat capacities than lightweight walls. Heat capacities of lightweight walls range from 1 to 2, while most brick masonry walls have heat capacities ranging from 5 to 15.

Currently, prescriptive requirements within energy codes and standards are specified as a function of thermal resistance and climate zone. Adjustments are made for masonry and other mass walls. In the case of masonry, the thermal mass effect is expressed through prescriptive insulation (R-value) requirements that are less stringent for mass walls than for lightweight walls. It is important to note that current codes do not consider the thermal mass of brick veneer. Thermal mass is most effective when it is placed on the interior side of the insulation, such as in a brick and concrete masonry cavity wall. *Technical Notes* 4A and 4B include further discussion of energy-related code requirements.

BUILDING ENVELOPE THERMAL DESIGN – CALCULATIONS

A simple method of energy code compliance is meeting the prescriptive U-factor or R-value of insulation requirements for building assemblies such as walls, roofs and floors. Therefore, determination of the thermal resistance of wall materials is the starting point for most building envelope thermal design calculations.

The energy efficiency of a wall is calculated from the rate of heat flow through all the materials in the wall, per unit of temperature difference between the outside and inside air. This overall coefficient of heat transmission is the U-factor, expressed in Btu/(hr · °F · ft²). In the simplest case, the U-factor is calculated by adding the thermal resistances (R-value) of each component of the wall assembly and taking their reciprocal: $U = 1/(R_1 + R_2 + R_3 \ldots)$. The U-factor, like the R-value, is a steady-state measure of heat flow. U-factors also are used to measure the thermal performance of non-homogeneous materials.

For many typical masonry, wood-framed and steel-framed walls, U-factors have been precalculated and can be found within Appendix A of ASHRAE 90.1. These should be used when the interior construction of the wall is the same as the listed assembly and the surface materials (excluding insulation) do not change the R-value by more than 2 Btu/(hr · °F · ft²).

One-Dimensional Assembly U-Factor Calculation

One-dimensional heat flow through materials is the basis for building envelope calculations and in turn whole-building energy calculations. One-dimensional assemblies are uniform, or thermally homogeneous, in the direction of heat flow. For thermally homogeneous materials, there is a directly proportional relationship between the resistance and conductance coefficients, R-values and C-factors as shown in Figure 1. For homogeneous materials, doubling the thickness doubles the R-value and halves the C-factor.

$C_x = k/x$
$R_x = x/k$
$C_x = 1/R_x$

Where:
x = thickness of material in inches
k = conductivity

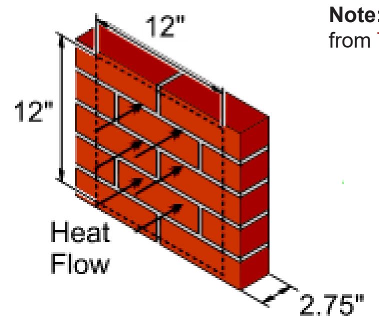
To determine the conductivity of brick, consider an assumed fired clay brick density of between 120 to 130 lb/ft³ and use the values in Table 1 as follows:

$k_{brick} = (5.6 + 7.8)/2 = 6.7$

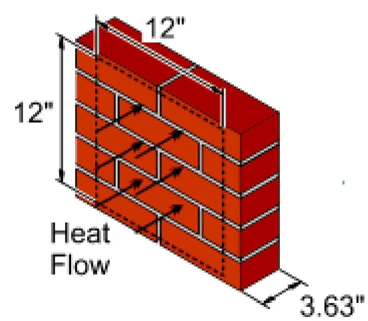
For a 3 in. nominal brick, (2.75 in. actual dimension):

Resistance, R = 0.15 (h · ft² · °F/Btu · in.)
R = (0.15 (h · ft² · °F/Btu · in) · (2.75 in.) = 0.41 (h · ft² · °F)/Btu

Note: Values taken from Table 1



$R_3 = \frac{2.75}{6.70} = 0.41 \quad C_3 = \frac{6.70}{2.75} = 2.44$



$R_4 = \frac{3.63}{6.70} = 0.54 \quad C_4 = \frac{6.70}{3.63} = 1.85$

Figure 1
Calculation of Heat Transmission for Homogeneous Materials (Brick)

4 in. nominal brick, (3.63 in. actual dimension):

Resistance, R = 0.15 (h · ft² · °F/Btu · in.)
R = (0.15 (h · ft² · °F/Btu · in) (3.63 in.) = 0.54 (h · ft² · °F)/Btu

Or alternately:

If the conductivity of a brick, k, is equal to 6.70 Btu · in./(h · ft² · °F)
$R_{3\ \text{in. nom}}$ = x/k = 2.75 in./6.70 Btu · in./(h · ft² · °F) = 0.41 (h · ft² · °F)/Btu
$R_{4\ \text{in. nom}}$ = x/k = 3.63 in./6.70 Btu · in./(h · ft² · °F) = 0.54 (h · ft² · °F)/Btu

For layered construction, where the path of the heat flow is in series, the total thermal resistance of the wall is obtained by adding the thermal resistance of the individual layers: $R_t = R_1 + R_2 + ...$; and the overall coefficient of heat transmission is the reciprocal of the overall thermal resistance: $U=1/R_t$. The word “series” implies that in cross-section, each layer of building assembly is one continuous material.

A simple example of layered construction is a multi-wythe brick masonry wall, as found in historic construction. The overall thermal resistance of a three-wythe brick wall is given below. Whenever an opaque wall is to be analyzed, the wall assembly should include both the outside and inside air surfaces and all other layers of materials.

Material	**R, (h · ft² · °F)/Btu**
Outside air surface	0.17
4 in. nominal face brick	0.54
4 in. nominal face brick	0.54
4 in. nominal face brick	0.54
Inside air surface	0.68
Total	**R_t = 2.47**

Two-Dimensional Assembly U-Factor Calculation

In many cases, the calculation of heat flow is more complex than simple, homogenous layers of materials. These may occur in thermally heterogeneous materials or when assemblies contain layers of dissimilar materials. For the thermally heterogeneous material, there is no directly proportional relationship between the material thickness and the R-value or C-factor. As shown for the hollow bricks in Figure 2, a 50 percent increase in thickness does not result in a 50 percent increase in resistance or reduction in conductance. This is because the void area of hollow brick is significant enough to act as a separate path for heat flow, and resistance to heat flow across the cells is different than the resistance through the webs of the brick.

For a 4 in. nominal hollow brick, (3.63 in actual dimension, 62.9 percent solid):
Conductance, C = 1.36 Btu/(h · ft² · °F)
R = 1/C = 1/1.36 = 0.74 (h · ft² · °F)/Btu

For a 6 in. nominal hollow brick, (5.63 in actual dimension, 67.3 percent solid):
Conductance, C = 1.07 Btu/(h · ft² · °F)
R = 1/C = 1/1.07 = 0.93 (h · ft² · °F)/Btu

In computing the heat transmission coefficients of layered construction, the paths of heat flow must first be determined. The 2013 ASHRAE *Handbook – Fundamentals* provides three methods

Note: Values taken from Table 1

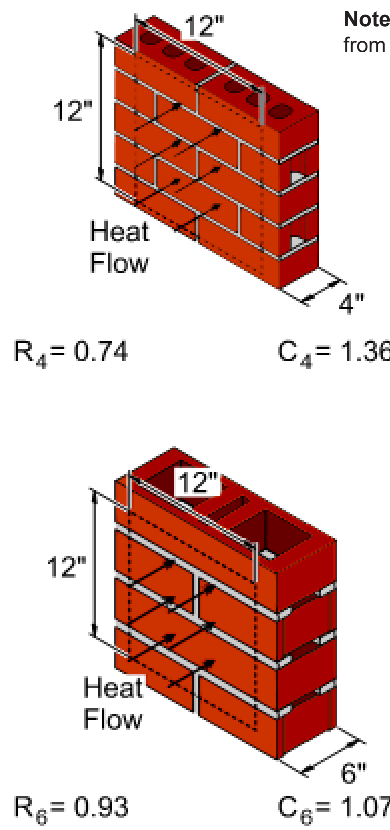


Figure 2
Calculation of Heat Transmission for Heterogeneous Materials (Hollow Brick)

of two-dimensional steady-state heat transfer analysis through wall assemblies that contain layers of dissimilar materials: “The *parallel-path method* is used when the thermal conductivity of the dissimilar materials in the layer are rather close in value (within the same order of magnitude), as with wood-framed walls. The *isothermal-planes method* is appropriate for materials with conductivities moderately different from those of adjacent materials (e.g., masonry). The *zone method* and the *modified zone method* are appropriate for materials with a very high difference in conductivity (two orders of magnitude or more), such as with assemblies containing metal” [Ref. 1]. None of these methods consider thermal mass, or heat storage capacities of the materials.

Two-dimensional analysis is important for wall assemblies having parallel paths of heat flow, particularly when one path acts as a thermal bridge. In addition to studs that interrupt the insulation layer, common thermal bridges in masonry wall assemblies include slab edges, shelf angles, parapets and metal anchors (wall ties). The extent that each of these elements impacts heat transfer may vary considerably and depends not only on the type of element involved but also on the material, configuration and installation of the element and the materials and components in the wall assembly. As a result, each should be considered and assessed individually. Examples of heat transmission calculations showing each step of the calculation process are given in *Technical Note* 4A for residential construction and *Technical Note* 4B for commercial construction.

Parallel Path Method. Building assemblies often include layers that are composed of more than one material. For instance, in an assembly with a layer composed of insulation placed between wood studs, parallel paths of heat flow with different conductances exist as shown in Figure 3. In this case, a weighted average of the thermal transmittances can be taken. For brick veneer over wood stud walls with batt insulation using the parallel path method, the heat transmission (U_{avg}) is about 13 percent higher than without consideration of the thermal bridging that occurs at the studs. See *Technical Note* 4A for an example calculation.

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

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

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 ft²

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 being considered ($A_A + A_B + ...$), in ft²

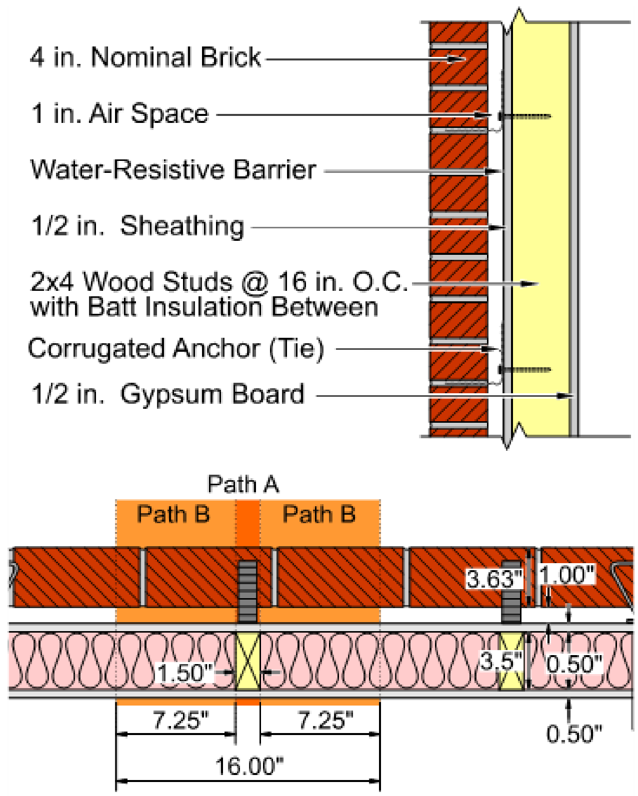


Figure 3
Parallel Path Method – Brick Veneer/Wood Stud

The Zone Method. Heat transfer calculations for assemblies having metallic thermal bridges can be calculated using a slightly modified parallel path method known as the zone method. This method assumes that an area larger than the area of the metal is affected by the metallic bridge and considers that the location of the metal in the wall also affects the thermal performance. The farther the metal is located from the exterior face of the wall, the larger the area of the zone affected by the metal.

The width of the zone around the metal is determined from the following formula:

$W = m + 2d$

Where:

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

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

This can be demonstrated with brick veneer/steel stud wall systems. Consider the brick veneer/steel stud wall assembly shown in Figure 4. The backing system consists of 6 in., 0.068 in. (14 gage) steel studs at 24 in. o.c., with 2 in. of continuous insulation on the exterior of the sheathing and batt insulation between the studs. 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 15.88 in.

Without consideration of sills, jambs, heads, and toe and top channels, the heat transferred through the zone including the steel stud is almost 50 percent more than the value calculated through the insulated zone, using the procedures in the 2013 ASHRAE *Handbook – Fundamentals*. Hot-box tests of metal stud walls indicate that the modified zone method is the most accurate simplified method for metal frame walls with insulated cavities.

The Modified Zone Method. For metal stud walls with insulated cavities, this method provides the best results by further defining the width of the zone affected by the studs. In addition to the stud size and distance from the surface, this method considers the thermal properties of materials adjacent to the studs.

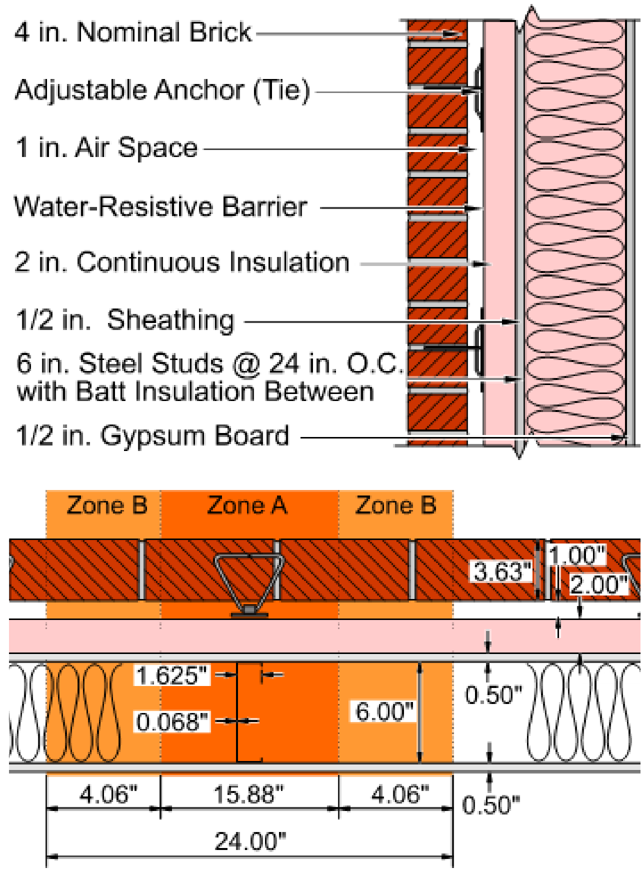


Figure 4
Brick Veneer/Steel Stud Wall

The intent of these examples is simply to show that the thermal performance of a brick veneer/metal stud wall system is not the same as a brick veneer/wood stud system. The designer should be aware of this discrepancy and the accuracy or inaccuracy of the approximation of thermal performance given by simplified calculation procedures. This information can also be found in energy codes such as ASHRAE 90.1. Such simplified procedures also neglect the thermal mass effects of brick veneer wall systems. The performance of masonry buildings is most accurately evaluated using dynamic modeling (software).

Thermal Bridging

At the opposite end of the thermal spectrum from thermal mass materials are those materials that are good thermal conductors. Thermal conductance (C), also known as the coefficient of heat transmission, is the reciprocal of thermal resistance (R-value) and is measured in Btu/(h · ft² · °F). Materials such as steel and other metals are the most common conductors in building envelopes. Materials with high thermal conductance have a greater rate of heat flow and can be thought of as pathways for heat to flow to colder areas. As a result, these materials often form thermal bridges or areas of high heat transfer. Building scientists have found that elements such as cantilevered slabs and shelf angles can act as thermal bridges between the building interior and exterior. While thermal bridging is generally small as compared with overall heat transfer, the thermal performance of the building envelope can be improved by using alternative materials and details for such elements. For example shelf angles that incorporate a thermal break to reduce heat transfer and allow insulation to pass behind them are a recent innovation.

Masonry anchors or wall ties are small but numerous thermal bridges whose impacts on assembly R-values vary based primarily on material conductance, spacing and type (configuration). As the R-value of the material penetrated by the metal tie increases (such as insulation in the cavity), the percent of heat loss due to the metal tie also increases. Where possible, reductions in thermal performance due to masonry ties can be minimized by selecting the tie material with the lowest conductivity, such as stainless steel, with the least amount of material penetrating the insulation and using the maximum allowable spacing [Ref. 5].

These thermal bridges impact the thermal performance of the building envelope in ways that cannot be accurately accounted for using assembly U-factors because they have different thermal conductivities from the rest of the assembly. Heat transfer in these areas is more difficult to calculate and requires computer analysis rather than simplified hand calculations. Although some alternative methods have been developed that attempt to quantify the heat lost through these details [Ref. 4], there is not yet consensus on the extent or the methods to account for it, and these methods have not yet been incorporated into energy codes and standards.

Total Heat Loss

Once the overall coefficient of heat transmission (U-factor) of the various building elements is known, the total heat loss for the building can be estimated. Since the overall coefficient of heat transmission (U-factor) is a rate of heat flow per area and per unit of temperature difference, the heat loss, H, measured in Btu/hr for a given assembly can be calculated by multiplying the U-factor of the assembly by the given area and the difference between the indoor and outdoor design temperatures.

$$H = U_A(t_i - t_o)$$

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 ft²
U = overall coefficient of heat transmission of the walls or other elements, in Btu/(h · ft² · °F)
t_i = indoor design temperature, in °F
t_o = outdoor design temperature, in °F

The outdoor design temperatures required for this calculation can be found in the 2013 ASHRAE *Handbook – Fundamentals*. Typically, the indoor design temperature for cooling should be 75 °F or as prescribed by governing codes. For heating, 68 °F is a common design value. Depending upon the relative temperatures, the heat loss may be to the interior or the exterior. The overall heat transmission for the building is in turn based on the heat transfer through the various assemblies and components. Computer software can simplify these calculations.

Computer Analysis

As building complexity increases, so too does the complexity of the building thermal design. A prescriptive approach is still the norm in most residential and many simple commercial designs. Designers desiring more flexibility and accuracy in the design of the building envelope (walls as well as roofs) often utilize software programs to assist in the energy analysis, and more complex buildings often require it. Many green building rating systems require the annual energy performance of the whole building to be simulated with software to meet the requirements of the energy performance compliance path. More sophisticated energy simulation software considers not only building material properties, but also includes hourly variations in occupancy, lighting power, equipment power, and thermal mass effects associated with materials such as masonry and concrete, among others. See *Technical Notes* 4A and 4B for further discussion.

PERFORMANCE – INSTALLATION AND WORKMANSHIP QUALITY

Actual thermal performance of building assemblies may vary from what is expected. Optimal performance depends upon a number of factors, the most important being installation and environmental conditions. As Chapter 26 of the 2013 ASHRAE *Handbook – Fundamentals* states: "In practice, overall thermal performance can be reduced significantly by factors such as improper installation, quality of workmanship and shrinkage, settling, or compression of the insulation. Good workmanship becomes increasingly important as the insulation requirement becomes greater." For example, air barriers with unsealed joints and water absorption of certain types of insulation can lead to significantly lower performance. To ensure a weather-resistant covering, codes and standards require the joints of air barriers and exterior insulation to be sealed. Verifying the performance and construction of the building envelope through commissioning is one way to help ensure that the construction meets the design intent.

SUMMARY

Building envelope energy performance is one aspect of total building energy performance and is founded on basic principles of heat transfer. At the most basic level, thermal performance of a wall assembly is the sum of the thermal resistances of each layer of material. Many wall assemblies incorporate dissimilar materials in the same layer of the wall, resulting in parallel paths of heat transfer. When dissimilar materials have very different thermal conductances, they are known as thermal bridges and require use of the zone method or modified zone method of analysis. These methods assume steady-state heat transfer, which may estimate the performance of non-masonry wall systems. However, for masonry and other materials with high thermal mass, dynamic energy analysis (computer modeling) is required to accurately estimate overall thermal energy performance.

The information and suggestions contained in this Technical Note *are based on the available data and the experience of the engineering staff of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this* Technical Note *are not within the purview of the Brick Industry Association and must rest with the project architect, engineer and owner.*

REFERENCES

1. 2013 ASHRAE *Handbook – Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), Atlanta, GA, 2013.
2. ASTM C1363-11, "Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus," *Annual Book of Standards*, Vol. 4.06, ASTM International, West Conshohocken, PA, 2011.
3. Marceau, Medgar, "Understanding Thermal Mass," *Eco-Structure*, January 2009.
4. "Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (1365-RP)," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), Atlanta, GA, 2011.
5. "Thermal Performance of Facades," 2012 AIA Upjohn Grant Research Initiative, Payette, Boston, MA, 2014.