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R-VALUES OF MULTI-WYTHE CONCRETE MASONRY WALLS

INTRODUCTION

Multi-wythe concrete masonry construction lends itself to placing insulation between two wythes of masonry when the wythes are separated to form a cavity. Placing insulation between two wythes of masonry offers maximum protection for the insulation while allowing a vast amount of the thermal mass to be exposed to the conditioned interior to help moderate temperatures. Masonry cavity walls can easily meet or exceed energy code requirements, because the cavity installation allows a continuous layer of insulation to envelop the masonry. When properly sealed, this continuous insulation layer can also increase energy efficiency by mitigating air infiltration/exfiltration.

Cavity wall construction provides hard, durable surfaces on both sides of the assembly, efficiently utilizing the inherent impact resistance and low maintenance needs of concrete masonry. While these needs are most commonly associated with multi-family dwellings, hospitals, schools and detention centers, the benefits of resistance to damage from hail, shopping and loading carts, gurneys, motorized chairs, and even sports make cavity construction ideal for any application.

This TEK lists thermal resistance (R) values of multi-wythe walls. Single wythe R-values are listed in TEK 06-02C,, *R-Values and U-Factors of Single Wythe Concrete Masonry Walls* (ref. 1).

The R-values listed in this TEK were determined by calculation using the code-recognized series-parallel (also called isothermal planes) calculation method (refs. 2, 3, 4). The method accounts for the thermal bridging (energy loss) that occurs through the webs of concrete masonry units. The method is fully described on page 4 of this TEK. Alternate code-approved means of determining R-values of concrete masonry walls include two-dimensional calculations and testing (ref. 2).

CAVITY WALLS

The term cavity insulation, which in some codes refers to the insulation between studs in lightweight framing systems, should not be confused with the long established term "masonry cavity wall." Cavity walls are comprised of at least two wythes of masonry separated by a continuous airspace (cavity).

Under current building code requirements a 1 in. (25-mm) clear airspace between the insulation and the outer wythe is required (2 in. (51 mm) is preferred) to help ensure free water drainage (ref. 5).

Cavity walls are typically designed and detailed using actual out-to-out dimensions. Thus, a 14-in. (356-mm) cavity wall with a nominal 4-in. (102-mm) exterior wythe and 8-in. (203-mm) backup wythe has an actual cavity width of 2$^3/_4$ in. (68 mm), allowing for 1$^1/_2$ in. (38 mm) of rigid board insulation.

Typical cavity walls are constructed with a 4, 6, 8, 10 or 12 in. (102, 152, 203, 254 or 305 mm) concrete masonry backup wythe, a 2 to 4$^1/_2$ in. (51 to 114 mm) wide cavity, and a 4-in. (102-mm) masonry veneer. By reference to *Specification for Masonry Structures* (ref. 6), the *International Building Code* (ref. 7) allows cavity widths up to 4$^1/_2$ in. (114 mm), beyond which a detailed wall tie analysis must be performed. More detailed information on cavity walls can be found in References 8 through 11

Changing the interior finish materials of a multi-wythe assembly does not typically change the overall assembly R-value significantly, unless the finish material itself is insulative. For cavity assemblies with interior-side finish materials installed on furring, such as wood paneling, the R-values for $^1/_2$ in. (13 mm) gypsum wallboard on furring in Table 4 can be used as a very close approximation.

CONCRETE MASONRY ENERGY PERFORMANCE

Although this TEK presents concrete masonry assembly R-values, it is important to note that R-values or U-factors alone do not fully describe the thermal performance of a concrete masonry assembly.

Concrete masonry's thermal performance depends on both its steady-state thermal characteristics (described by R-value or U-factor) as well as its thermal mass (heat capacity) characteristics. The steady state and mass performance are influenced by the size, type, and configuration of masonry unit, type and location of insulation, finish materials, density of masonry, climate, and building orientation and exposure conditions.

Thermal mass describes the ability of materials to store energy. Because of its comparatively high density and specific heat, masonry provides very effective thermal storage. Masonry walls retain their temperature long after the heat or air-conditioning has shut off. This, in turn, effectively reduces heating and cooling loads, moderates indoor temperature swings, and shifts heating and cooling loads to off-peak hours.

Due to the significant benefits of concrete masonry's inherent thermal mass, concrete masonry buildings can provide similar energy performance to more heavily insulated light frame buildings.

These thermal mass effects have been incorporated into energy code requirements as well as sophisticated computer models. Due to the thermal mass, energy codes and standards such as the *International Energy Conservation Code* (IECC) (ref. 12) and *Energy Efficient Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE Standard 90.1 (ref. 2), require less insulation in concrete masonry assemblies than equivalent light-frame systems. Although applicable to all climates, the greater benefits of thermal mass tend to be found in warmer climates (lower-numbered Climate Zones).

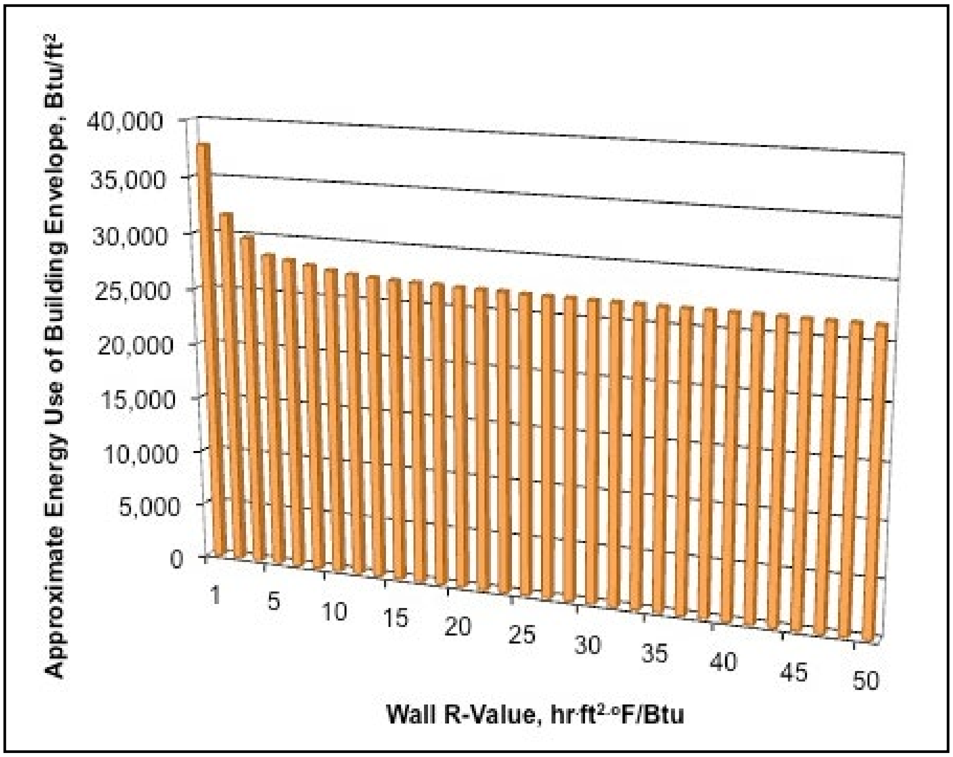

Figure 1—Diminishing Returns of Added Wall Insulation

Although the thermal mass and inherent R-value/U-factor of concrete masonry may be enough to meet energy code requirements (particularly in warmer climates), concrete masonry assemblies may require additional insulation, particularly when designed under more contemporary building code requirements or to achieve above-code thermal performance. For such conditions, there are many options available for insulating concrete masonry construction.

Although in general higher R-values reduce energy flow through a building element, R-values have a diminishing impact on the overall building envelope energy use. In other words, it's important not to automatically equate higher R-value with improved energy efficiency. As an example, consider a two-story elementary school in Bowling Green, Kentucky. If this school is built using single wythe concrete masonry walls with cell insulation only and a resulting wall R-value of 7 hr·ft$^{2}\cdot{}^{\circ}$F/Btu (1.23 m$^{2}\cdot$K/W), an estimate of the building envelope energy use for this structure is approximately 27,800 Btu/ft^2 (87.7 kW·h/m^2), as shown in Figure 1. If we increase the R-value of the wall to R14 by adding additional insulation while holding the other envelope variables constant, the building envelope energy use drops by only 2.5%, which is not in proportion to doubling the wall R-value. Figure 1 illustrates this trend: as wall R-value increases, it has less and less impact on the building envelope thermal performance.

In this example, a wall R-value larger than about R12 no longer has a significant impact on the envelope energy use. At this point, it makes more sense to invest in energy efficiency measures other than wall insulation. The effect of adding insulation to a multi-wythe wall is virtually the same.

When required, concrete masonry can provide assemblies with R-values that exceed code minimums. For overall project economy, however, the industry recommends balancing needs and performance expectations with reasonable insulation levels.

ENERGY CODE COMPLIANCE

Compliance with prescriptive energy code requirements can be demonstrated by:

- the concrete masonry wall by itself or the concrete masonry wall plus a prescribed R-value of added insulation, or
- the overall U-factor of the wall.

The IECC prescriptive R-value table calls for "continuous insulation" on concrete masonry and other mass walls. This refers to insulation uninterrupted by furring or by the webs of concrete masonry units. Examples of continuous insulation include rigid insulation adhered to the interior of the wall with furring and drywall applied over the insulation, continuous insulation in the cavity of a masonry cavity wall, and exterior insulation and finish systems. These and other insulation options for concrete masonry assemblies are discussed in TEK 06-11A, *Insulating Concrete Masonry Walls* (ref. 13).

If the concrete masonry assembly will not include continuous insulation, there are several other options to comply with the IECC requirements—concrete masonry assemblies are not required to have continuous insulation in order to meet the IECC, regardless of climate zone.

Other compliance methods include prescriptive U-factor tables and computer programs which may require U-factors and heat capacity (a property used to indicate the amount of thermal mass) to be input for concrete masonry walls. See TEK 06-04B, *Energy Code Compliance Using COMcheck*, (ref. 14) for more detailed information. Another compliance method, the energy cost budget method, incorporates sophisticated modeling to estimate a building's annual energy cost.

A more complete discussion of concrete masonry IECC compliance can be found in TEK 06-12E (for the 2012 IECC) (ref. 15).

CONCRETE MASONRY UNIT CONFIGURATIONS

Revisions in 2011 to ASTM C90¸ *Standard Specification for Loadbearing Concrete Masonry Unit*s (ref. 16) have significantly reduced the minimum amount of web material required for CMU. Values in this TEK are based on concrete masonry units with three webs, with each web being the full height of the unit, and having a minimum thickness as provided in historical versions of ASTM C90 (see Table 1).

The changes in C90, however, allow a much wider range of web configurations, with corresponding changes in R-values and U-factors (because the webs of a CMU act as thermal bridges, reducing the CMU web area increases the R-value of the corresponding concrete masonry assembly). More discussion on the impact of web configuration and thermal performance can be found in CMU-TEC-001-23, *Concrete Masonry Unit Shapes, Sizes, Properties, and Specifications* (Ref. 17).

The *Thermal Catalog of Concrete Masonry Assemblies* (ref. 18) lists R-values and U-factors based on traditional units, as included here, as well as units with smaller web areas, as now allowed by ASTM C90. The additional wall assemblies are based on:

- CMU having two full-height $^3/_4$ in. (19 mm) thick webs, and
- a 'hybrid' system of CMU, intended to maximize thermal efficiency. The hybrid system uses the two-web units described above for areas requiring a grouted cell, and a one-web unit where grout confinement is not required.

Table 1—**Unit Dimensions**[A]

Nominal unit width, in. (mm)	Face shell thickness, in. (mm)	Web thickness, in. (mm)
4 (102)	0.75 (25.4)	0.75 (25.4)
6 (152)	1.00 (31.8)	1.00 (25.4)
8 (203)	1.25 (31.8)	1.00 (28.6)
10 (254)	1.25 (31.8)	1.125 (28.6)
12 (305)	1.25 (31.8)	1.125 (28.6)

[A] Table lists unit configurations used to calculate values in Table 2. Units have three full-height webs. Web and face shell thicknesses meet the minimum requirements historically required by ASTM C90 prior to the 2011b version of the standard.

R-VALUE TABLES—TRADITIONAL THREE-WEB UNITS

Table 2 presents R-values of uninsulated concrete masonry cavity walls with 4, 6, 8, 10 and 12 in. (102, 152, 203, 254 and 305 mm) backup wythes and a 4 in. (102 mm) hollow unit concrete masonry veneer. These R-values should be added to the applicable R-values in Tables 3 and 4 to account for cavity insulation and/or interior furring with insulation, respectively. Table 5 contains the thermal data used to develop the tables.

To convert the R-value to U-factor (as may be needed for code compliance), simply invert the R-value, i.e.: $U = 1/R$. Note that U-factors of various wall components cannot be directly added together. To determine the overall cavity wall U-factor, first add the component R-values together, then determine overall U-factor by inverting the total R-value.

As an example, to determine the R-value of a concrete masonry cavity wall with 8 in. (152 mm) 105 pcf (1,682 kg/m^3) backup insulated with 2 in. (51 mm) of extruded polystyrene insulation in the cavity, first determine the R-value of the uninsulated wall from Table 2 (4.22 ft^2·hr·°F/Btu, 0.74 m^2·K/W), then add the cavity insulation R-value from Table 3 (10 ft^2·hr·°F/Btu, 1.8 m^2·K/W), to obtain the total R-value of 14.2 ft^2·hr·°F/Btu (2.5 m^2·K/W). The corresponding U-factor for this wall is:

$U = 1/R = 1/14.2 = 0.070$ Btu/ hr·°F/Btu (0.4 W/ m^2·K)

Note that tables of precalculated R-values and U-factors, including the various insulation and finish systems, are available in *Thermal Catalog of Concrete Masonry Assemblies*.

The values in Table 2 are based on an ungrouted backup wythe. However, the addition of grout to a hollow concrete masonry backup wythe does not significantly affect the overall R-value of an insulated cavity wall. For example, the R-value of a cavity wall with 8 in. (203 mm) ungrouted 105 pcf (1,682 kg/m^3) backup and insulated cavity decreases only about 5% when the backup wythe is solidly grouted. With a partially-grouted backup, the difference in R-value is smaller than 5%.

SERIES-PARALLEL R-VALUE CALCULATION

The series-parallel calculation method is recommended (refs. 1, 5) for estimating R-values of concrete masonry walls. This calculation treats the block as a series of thermal layers, as illustrated in Figure 2. The face shells form continuous outer layers, which are in series with the layer containing webs and cores. The total R-value, R_T, of the block is the sum of the R-values of each layer, as outlined below. An example illustrating use of the equation is provided in Appendix C of *Thermal Catalog of Concrete Masonry Assemblies.* Note: When the core is partially filled (i.e. when using insulation inserts), the core is divided into multiple layers.

$$R_T = R_i + \frac{R_f R_m}{a_f R_m + a_m R_f} + \frac{R_w R_c}{a_c R_w + a_w R_c} + R_a + R_v + R_o$$

where:

a_c = fractional core area, see Section A-A
a_f = fractional face shell area, see elevation
a_m = fractional mortar joint area, see elevation
a_w = fractional web area, see Section A-A
R_a = thermal resistance of cavity
R_c = thermal resistance of cores
R_f = thermal resistance of both face shells, r_c x ($2t_{fs}$)
R_i = thermal resistance of inside air surface film
R_m = thermal resistance of mortar joint, r_m x ($2t_{fs}$)
R_o = thermal resistance of outside air surface film
R_T = total thermal resistance of wall
R_v = thermal resistance of veneer
R_w = thermal resistance of concrete webs, r_c x t_w
r_c = thermal resistivity of concrete
r_m = thermal resistivity of mortar
t_{fs} = face shell thickness
t_w = length of concrete webs

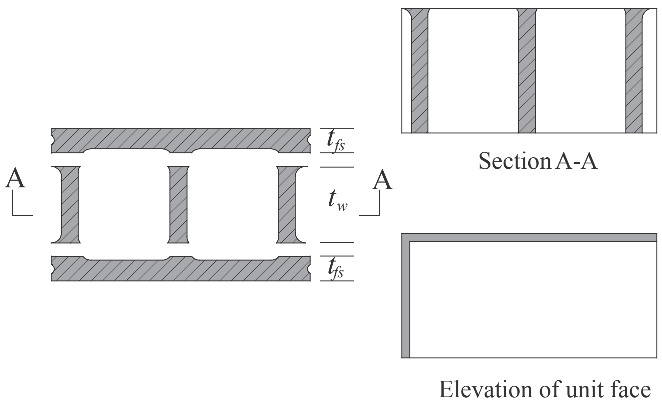

Figure 2—Concrete Masonry Unit Thermal Model

Calculations are performed using the series-parallel (also called isothermal planes) calculation method (refs. 2, 3, 4). The method accounts for the thermal bridging that occurs through the webs of concrete masonry units. The method is briefly described below, and its use is demonstrated in Appendix C of *Thermal Catalog of Concrete Masonry Assemblies*.

Table 2—R-Values of Uninsulated Cavity Walls With 4-in. Concrete Masonry Veneer (hrft^{2}·°F/Btu) [A]

Nominal thickness of backup, in.	Density of concrete used in concrete masonry backup unit, pcf					
	85	95	105	115	125	135
4	4.17	4.01	3.86	3.73	3.60	3.49
6	4.40	4.26	4.13	4.00	3.89	3.78
8	4.47	4.34	4.22	4.11	4.00	3.90
10	4.50	4.38	4.27	4.16	4.07	3.97
12	4.53	4.41	4.30	4.20	4.10	4.02

Table 3—R-Values of Cavity Insulation[A]

Insulation type:	Insulation thickness, in.:	R-value, hrft^{2}·°F/Btu
Cellular polyisocyanurate, gas-impermeable facer[B]	1	8.5
	1.5	12.3
	2	16.2
	2.5	19.6
	3	23.0
	3.5	26.4
Closed-cell spray polyurethane foamed insulation (SPF)[C]	1	6.8
	2	13.0
	3	19.0
	3.5	22.0
Expanded polystyrene (EPS) [C]	1	4.0
	1.5	6.0
	2	8.0
	2.5	10.0
	3	12.0
	3.5	14.0
Extruded polystyrene (XPS) [C]	1	5.0
	1.5	7.5
	2	10.0
	2.5	12.5
	3	15.0
	3.5	17.5

[A] Values should be added to the values presented in Table 2 to achieve the total R-value of an insulated cavity wall.
[B] Values adjusted to include the effect of a reflective air space.
[C] A nonreflective air space is included in the values in Table 2, so this value is not included here.

Table 4—R-Values of Finish Systems[A]

System:	R-value, hr·ft^2·°F/Btu
$^1/_2$ in. gypsum board on furring [B]	1.1
$^1/_2$ in. foil-faced gypsum board on furring [C]	2.9
Continuous rigid insulation, $^3/_4$-in. min. furring (for electrical rough-in) and $^1/_2$-in. gypsum wallboard:	
$^3/_4$ in. extruded polystyrene[B]	4.9
$^3/_4$ in. polyisocyanurate[C]	7.4
1 in. extruded polystyrene	6.1
1 in. polyisocyanurate[C]	9.0
1$^1/_2$ in. extruded polystyrene[B]	8.6
1$^1/_2$ in. polyisocyanurate[C]	12.8
2 in. extruded polystyrene[B]	11.1
2 in. polyisocyanurate[C]	16.7
2$^1/_2$ in. extruded polystyrene[B]	13.6
2$^1/_2$ in. polyisocyanurate[C]	20.1
3 in. extruded polystyrene[B]	16.1
3 in. polyisocyanurate[C]	23.5
Continuous polyisocyanurate, heavy duty (HD) (joints taped or butt caulked) attached directly to masonry:	
2 in.	13.0
2$^1/_2$ in.	15.8
3 in.	19.0
3$^1/_2$ in.	22.0
Metal furring at 24 in. o.c., insulation (between furring), and $^1/_2$ in. gypsum wallboard[D]:	
R-11 batt [E]	6.6
R-13 batt [E]	7.2
R-15 batt [E]	7.8
R-19 batt [E]	8.6
R-21 batt [E]	9.0
Wood furring at 24 in. o.c., insulation (between furring) and $^1/_2$ in. gypsum wallboard:	
$^3/_4$ in. extruded polystyrene	4.0
$^3/_4$ in. polyisocyanurate	5.2
1$^1/_2$ in. extruded polystyrene	7.6
1$^1/_2$ in. polyisocyanurate	10.4
R-11 batt [E]	10.6
R-13 batt [E]	11.6
R-15 batt [E]	12.5
R-19 batt [E]	15.4
R-21 batt [E]	16.7

[A] Add values to the appropriate R-values in Tables 2 and 3. After adding the R-values, determine the U-factor using $U = 1/R$.

[B] Values include a nonreflective air space.

[C] Values include a reflective air space.

[D] Values from Reference 2, Appendix A.

[E] Due to the susceptibility of batt insulation to moisture, its use is not recommended.

Table 5—Thermal Data Used to Develop Tables[A]

Material:	Thermal resistivity (R-value/in.), hr·ft^2·°F/Btu·in (m^2·K/W)
Cellular polyisocyanurate, gas-impermeable facer	6.7- 7.2 (1.2 - 1.3) [B]
Closed-cell spray polyurethane foamed insulation (SPF)	6.3 - 6.8 (1.1 - 1.2)[C]
Expanded polystyrene (EPS)	4.0 (0.70)
Extruded polystyrene (XPS)	5.0 (0.88)
Wood	1.0 (0.18)
Concrete	
85 pcf	0.30 (0.053)
95 pcf	0.25 (0.044)
105 pcf	0.20 (0.035)
115 pcf	0.17 (0.029)
125 pcf	0.14 (0.025)
135 pcf	0.11 (0.019)
Grout	0.10 (0.018)
Mortar	0.10 (0.018)
Material:	**R-value, hr·ft^2·°F/Btu (m^2·K/W)**
1/2 in. (13 mm) gypsum wallboard	0.45 (0.08)
Surface air films:	
Inside surface air film	0.68 (0.12)
Outside surface air film	0.17 (0.03)
Air spaces:	
3/4 in. (19 mm) minimum[E] nonreflective air space	0.97 (0.17)
3/4 in. (19 mm) minimum[E] reflective air space	2.8 (0.49)
5/8 in. (16 mm) cement stucco	0.13 (0.02)
5/16 in. (7.9 mm) synthetic stucco	0.2 (0.04)
4 x 8 x 16 in. hollow concrete masonry veneer (135 pcf)	0.94[D] (0.17)
4 in. solid concrete masonry veneer (135 pcf)	0.41[D] (0.07)
4 in. clay brick exterior wythe	0.44 (0.08)

[A] Thermal resistivity data may vary from one insulation manufacturer to another. Users of this TEK should verify the thermal properties of the specific insulation product they are using with the insulation manufacturer.

[B] The R-value of polyisocyanurate insulation does not vary linearly with thickness. R-values by thickness are 1 in. = R6.7; 1.5 in. = R10.5; 2 in. = R14.4; 2.5 in. = R17.8; 3 in. = R21.2; 3.5 in. = R24.6.

[C] The R-value of SPF insulation does not vary linearly with thickness. R-values by thickness are 1 in. = R6.8; 2 in.= R13; 3 in. = R19; 3.5 in. = R22.

[D] Applies to both full- and half-high units.

[E] Note that *Building Code Requirements for Masonry Structures* (ref. 5) requires a minimum 1 in. (25 mm) air space between wythes. This is considered appropriate if special precautions are taken to keep the air space clean (such as beveling the mortar bed away from the cavity or placing a board in the cavity to catch and remove mortar droppings and fins while they are still plastic. Otherwise, a 2 in. (51 mm) air space is preferred.

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ABOUT CMHA

The Concrete Masonry & Hardscapes Association (CMHA) represents a unification of the Interlocking Concrete Pavement Institute (ICPI) and National Concrete Masonry Association (NCMA). CMHA is a trade association representing US and Canadian producers and suppliers in the concrete masonry and hardscape industry, as well as contractors of interlocking concrete pavement and segmental retaining walls. CMHA is the authority for segmental concrete products and systems, which are the best value and preferred choice for resilient pavement, structures, and living spaces. CMHA is dedicated to the advancement of these building systems through research, promotion, education, and the development of manufacturing guides, design codes and resources, testing standards, and construction practices.