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R-VALUES OF MULTI-WYTHE CONCRETE MASONRY WALLS

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INTRODUCTION

Thermal resistance values (R-values) are numerical estimates of a building material's or element's ability to resist heat flow under steady-state conditions. Historically, R-values alone have been used in simple hand calculations to estimate building energy consumption. Today, the R-value, and more commonly U-factor (coefficient of thermal transmission) are used with other factors such as building orientation, thermal mass, and climate to more accurately represent the building envelope's thermal performance for a given building occupancy.

R-values of building materials are determined in the laboratory by applying a constant temperature difference across a material or building element, then measuring the steady state heat flow through the test specimen. For design, calculation methods have been developed to aid in determining R-values of various building materials (ref. 1).

The thermal mass of concrete masonry walls significantly influences heat transmission. For most applications, the effectiveness of thermal mass is determined by construction material properties, climate, building type, and the position of the insulation within the wall (relative to the masonry). Due to the significant benefits of concrete masonry's inherent thermal mass, concrete masonry buildings can provide similar performance to buildings constructed of lightweight framing materials while using less added insulation. The benefits of thermal mass have been incorporated into sophisticated programs for modeling building performance. Prescriptive energy code compliance methods currently account for the benefits of thermal mass. While the thermal mass benefits in the prescriptive tables tend to be overly simplified and thus conservative, energy codes and standards such as the *International Energy Conservation Code* (ref. 2) and ASHRAE Standard 90.1 (ref. 3) permit concrete masonry walls to have less insulation than frame wall systems to meet the code requirements.

When a concrete masonry wall requires additional thermal resistance, concrete masonry lends itself to many strategies that allow the design to provide the necessary thermal envelope without jeopardizing the other performance criteria for the project. Foam inserts, foamed-in-place or granular fill insulation may be inserted in the cores of the concrete masonry units. Rigid board insulation may be adhered to the interior or exterior of the masonry, or the interior can be furred or studded and rigid board, foamed-in-place, or batt insulation placed between studs or furrings. In addition, multi-wythe 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. The means to meet or exceed model building code requirements are easily obtainable, since the cavity installation allows a continuous layer of insulation to envelop the masonry. Thus, this continuous insulation layer can also reduce heat loss due to air infiltration. Cavity walls are also sometimes built with interior insulation only, leaving the entire cavity open for drainage.

Cavity walls, as well as single wythe masonry with core insulation, also provide hard, durable surfaces on both sides of the wall, 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 wall construction ideal for many other applications.

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 two wythes of masonry separated by a continuous airspace (cavity). 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 or $2^3/_4$ in. (68 mm) of granular fill insulation.

Loose fill insulations can occupy the entire cavity space since these materials allow water to drain freely through them. For this reason, these insulation materials are typically treated for water repellency. When using granular fill, screens or other methods must be employed at weepholes to contain the granular fill.

With closed-cell rigid board cavity insulation, 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. 7).

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. 4), the *International Building Code* (ref. 6) 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.

R-VALUE TABLES

Table 1 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) concrete masonry veneer. These R-values should be added to the applicable R-values in Tables 2 and 3 to account for cavity insulation and/or interior furring with insulation, respectively. Table 4 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 1 (4.0 ft^2·hr°F/Btu, 0.70 m^2·K/W), then add the cavity insulation R-value from Table 2 (10 ft^2·hr°F/Btu, 1.8 m^2·K/W), to obtain the total R-value of 14.0 ft^2·hr°F/Btu (2.5 m^2·K/W). The corresponding U-factor for this wall is:

$U = 1/R = 1/14.0 = 0.071$ Btu/ hr°F/Btu (0.4 W/ m^2·K)

Calculations are performed using the series-parallel (also called isothermal planes) calculation method (refs. 1, 5). The method accounts for the thermal bridging that occurs through the webs of concrete masonry units. The method is briefly described on the following page, and its use is demonstrated on page 4 of this TEK.

Thermal values for concrete masonry walls are correlated to density, since the thermal conductivity of concrete increases with increasing concrete density. For each density, Table 1 lists a range of R-values as well as a single value, which represents the middle of the range. A range of thermal values is appropriate for concrete products because the thermal conductivity of concrete cannot always be accurately estimated from density alone. The thermal conductivity of concrete may vary with aggregate type(s), the mix design, moisture content, etc.

These published values reflect a compendium of historical data on thermal conductivity of concrete (refs. 1, 5). Locally available products and local conditions may result in thermal values which fall outside of this range. The middle-of-the-range values are presented for use in cases where more accurate values are not available from local manufacturers.

The values in Table 1 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 2 in. (51 mm) of perlite in the cavity is 9.3 hr·ft^2·°F/Btu (1.72 m^2·K/W). When the backup wythe is grouted solid, the R-value becomes 8.8 hr·ft^2·°F/Btu (1.67 m^2·K/W), a decrease of about 5 percent. With a partially-grouted backup, the difference in R-value is smaller than 5%.

Table 1—R-Values of Uninsulated Cavity Walls With 4 in. Concrete Masonry Veneer (ft^2·hr°F/Btu)[A]

Nominal thickness of backup, in.	Density of concrete used in concrete masonry backup unit (pcf): 85		95		105		115		125		135	
	range	mid	range	mid	range	mid	range	mid	range	mid	range	mid
4	3.8-4.0	3.9	3.7-3.9	3.8	3.6-3.8	3.7	3.5-3.7	3.6	3.4-3.6	3.5	3.3-3.6	3.4
6	4.0-4.3	4.1	3.8-4.1	4.0	3.8-4.0	3.9	3.6-3.9	3.8	3.5-3.8	3.6	3.4-3.7	3.5
8	4.2-4.4	4.3	4.0-4.3	4.2	3.9-4.2	4.0	3.8-4.1	3.9	3.7-4.0	3.8	3.6-3.9	3.7
10	4.2-4.5	4.3	4.1-4.4	4.2	4.0-4.2	4.1	3.8-4.1	4.0	3.7-4.0	3.8	3.6-4.0	3.7
12	4.3-4.5	4.4	4.1-4.4	4.2	4.0-4.3	4.1	3.9-4.2	4.0	3.8-4.1	3.9	3.7-4.0	3.8

[A] (ft^2·hr°F/Btu)(0.176) = m^2·K/W. Includes a minimum 1 in. (25 mm) nonreflective air space, and inside and outside surface air films ($R \cong 0.85$). Mortar joints are assumed to be $^3/_8$ in. (9.5 mm) thick. For 4-in. solid concrete masonry veneer, subtract 0.45 from the R-values above; for clay brick veneer, subtract 0.40.

Table 2—R-Values of Cavity Insulation[A]

Insulation type	Insulation thickness, in.	R-value (hr·ft^2·°F/Btu)	Insulation type	Insulation thickness, in.	R-value (hr·ft^2·°F/Btu)
Vermiculite loose fill	1	1.3	Extruded polystyrene[B]	1	5.0
	2	3.6		$1^1/_2$	7.5
	3	5.8		2	10.0
	$4^1/_2$	9.3		$2^1/_2$	12.5
Perlite loose fill	1	2.2		3	15.0
	2	5.3		$3^1/_2$	17.5
	3	8.4	Polyisocyanurate[C]	1	8.3
	$4^1/_2$	13.1		$1^1/_2$	11.6
				2	14.8
				$2^1/_2$	17.6
				3	20.8
				$3^1/_2$	23.9

[A] Values should be added to the values presented in Table 1 to achieve the total R-value of an insulated cavity wall.
[B] A minimum 1 in. (25 mm) nonreflective air space is included in the values in Table 1.
[C] Values adjusted to include a 1 in. (25 mm) reflective air space.

Table 3—R-Values of Finish Systems[A]

System:	R-value (hr·ft^2·°F/Btu)
$^1/_2$ in. gypsum board on furring	1.4
$^1/_2$ in. foil-faced gypsum board on furring	2.9
Continuous rigid insulation, 1$^1/_2$-in. metal furring (for electrical rough-in) and $^1/_2$-in. gypsum wallboard:	
$^3/_4$ in. extruded polystyrene[B]	5.2
$^3/_4$ in. polyisocyanurate[C]	8.1
1$^1/_2$ in. extruded polystyrene[B]	8.9
1$^1/_2$ in. polyisocyanurate[C]	13.0
2 in. extruded polystyrene[B]	11.4
2 in. polyisocyanurate[C]	16.2
2$^1/_2$ in. extruded polystyrene[B]	13.9
2$^1/_2$ in. polyisocyanurate[C]	19.0
3 in. extruded polystyrene[B]	16.4
3 in. polyisocyanurate[C]	22.2

Wood furring, insulation (between furring) and $^1/_2$ in. gypsum wallboard:	Furring strip spacing: 16 in. o.c.	24 in. o.c.
$^3/_4$ in. extruded polystyrene[B]	5.2	5.2
$^3/_4$ in. polyisocyanurate[C]	8.0	8.1
1$^1/_2$ in. extruded polystyrene[B]	8.9	8.9
1$^1/_2$ in. polyisocyanurate[C]	13.2	13.4
R-11 batt	9.6	10.2
R-13 batt	10.8	11.6
R-15 batt	11.9	12.9
R-19 batt	15.9	16.9
R-21 batt	17.1	18.3
Metal furring, insulation, and $^1/_2$ in. gypsum wallboard[D]:		
R-11 batt	6.0	7.1
R-13 batt	6.5	7.7
R-15 batt	6.9	8.3
R-19 batt	7.6	9.1
R-21 batt	7.9	9.5

[A] Add values to those in Table 1 as appropriate.
[B] Values include a $^3/_4$ in. (19 mm) nonreflective air space.
[C] Values include a $^3/_4$ in. (19 mm) reflective air space.
[D] Values from ref. 3, Appendix A.

Table 4—Thermal Data Used to Develop Tables

Material:	Thermal resistivity (hr·ft^2·°F/Btu·in)
Vermiculite	2.27
Perlite	3.12
Extruded polystyrene (XPS)	5.00
Cellular polyisocyanurate, gas-impermeable facer (refs. 12, 13)	6.5
Concrete:	
85 pcf	0.23-0.34
95 pcf	0.18-0.28
105 pcf	0.14-0.23
115 pcf	0.11-0.19
125 pcf	0.08-0.15
135 pcf	0.07-0.12
Mortar	0.10

Material:	R-value (hr·ft^2·°F/Btu)
$^1/_2$ in. gypsum wallboard	0.45
Surface air films:	
inside	0.68
outside	0.17
Air spaces:	
$^3/_4$ - 1 in. nonreflective	0.97
$^3/_4$ - 1 in. reflective	2.80
4 in. hollow concrete masonry exterior wythe[A]	0.84
4 in. solid concrete masonry exterior wythe[A]	0.39
4 in. clay brick exterior wythe	0.44

[A] Applies to both full- and half-height units.

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 1. 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 on the following page 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, seeSection 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

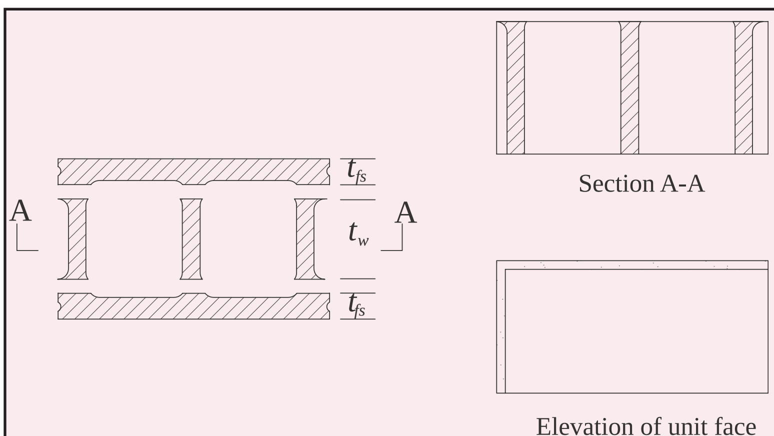
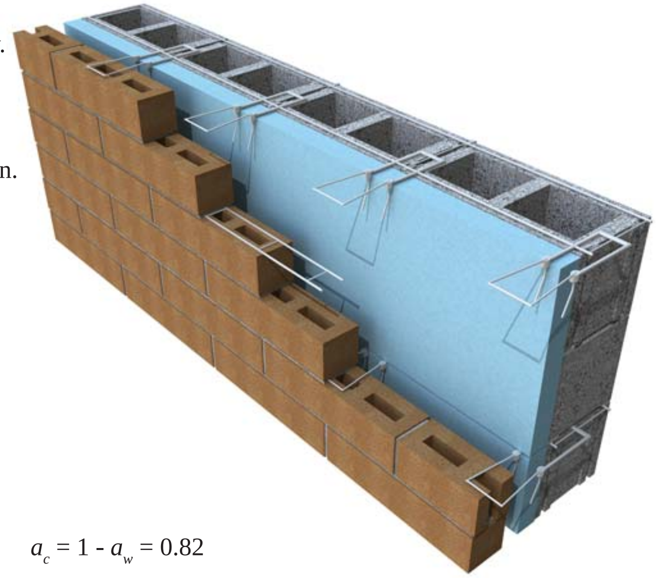


Figure 1— Concrete Masonry Unit Thermal Model

EXAMPLE R-VALUE/U-FACTOR CALCULATION



Determine the total R-value and U-factor of the masonry cavity wall shown below.

Calculate R-value of 8-in backup (series parallel calculation):

Given: r_c = 0.085 hr·ft^2·°F/Btu·in t_{fs} = 1$^1/_4$ in.

unit length = 15$^5/_8$ in. unit thickness = 7$^5/_8$ in.

unit height = 7$^5/_8$ in. mortar joint thickness = $^3/_8$ in.

r_m = 0.1 hr·ft^2·°F/Btu·in t_{web} = 1 in.

R_i = 0.68 hr·ft^2·°F/Btu R_o = 0.17 hr·ft^2·°F/Btu

R_a = 0.97 hr·ft^2·°F/Btu R_v = 0.84 hr·ft^2·°F/Btu

R-value of cavity insulation (XPS) = 10.0 hr·ft^2·°F/Btu

t_w = width of unit - 2t_{fs} = 7$^5/_8$ in. - 2(1$^1/_4$ in.) = 5$^1/_8$ in.

Determine fractional areas:

Total face area of one unit and mortar joints (see Figure 1 elevation),

A_{tot} = 8 in. x 16 in. = 128 in.^{2}

Face shell area = 7$^5/_8$ in. x 15$^5/_8$ = 119.14 in.^{2} a_f = 119.14/128 = 0.93

Mortar joint area = $^3/_8$ in.(16 + 7$^5/_8$) = 8.86 in.^{2} a_m = 8.86/128 = 0.07

Web area = 3 x 1 in. x 7$^5/_8$ in. = 22.87 a_w = 22.87/128 = 0.18 a_c = 1 - a_w = 0.82

Determine thermal resistances:

$R_f = r_c$ x (2t_{fs}) = 0.085 x (2 x 1$^1/_4$ in.) = 0.213 $R_m = r_m$ x (2t_{fs}) = 0.1 x (2 x 1$^1/_4$ in.) = 0.250

$R_w = r_c$ x t_w = 0.085 x 5$^1/_8$ in. = 0.436 R_c = 0.97 (nonreflective air space within masonry cores)

Calculate R-value of 8-in. concrete masonry unit:

$$R_{CMU} = \frac{R_f R_m}{a_f R_m + a_m R_f} + \frac{R_w R_c}{a_c R_w + a_w R_c} = \frac{(0.213)(0.250)}{0.93(0.250)+0.07(0.213)} + \frac{(0.436)(0.97)}{0.82(0.436)+0.18(0.97)} = 1.01$$

Calculate R-value of insulated cavity wall:

$R_T = R_i + R_{CMU} + R_{insulation} + R_a + R_v + R_o$ = 0.68 + 1.01 + 10.0 + 0.97 + 0.84 + 0.17 = 13.7 hr·ft^2·°F/Btu

Calculate the U-factor of the insulated cavity wall:

$U = 1/R$ = 1/13.7 = 0.073 Btu/hr·ft^2·°F

Note that with 2 in. of polyisocyanurate insulation and a reflective cavity air space, the calculations become:

$R_T = R_i + R_{CMU} + R_{insulation} + R_a + R_v + R_o$ = 0.68 + 1.01 + 13.0 + 2.67 + 0.84 + 0.17 = 18.4 hr·ft^2·°F/Btu

$U = 1/R$ = 1/18.4 = 0.054 Btu/hr·ft^2·°F

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