NATIONAL CONCRETE MASONRY ASSOCIATION
Sustainable Concrete Products for Structures and Hardscapes

R-VALUES AND U-FACTORS OF SINGLE WYTHE CONCRETE MASONRY WALLS

TEK 6-2B
Energy & IAQ (2009)

INTRODUCTION

Single wythe concrete masonry walls are often constructed of hollow units with cores filled with insulation and/or grout. This construction method allows insulation and reinforcement to be used to increase thermal and structural performance, respectively, without increasing the wall thickness.

The thermal performance of concrete masonry is heavily influenced by its thermal mass. Thermal mass (thermal inertia) is the ability of materials such as concrete masonry to store heat—they heat up and cool down slowly, which can help mitigate heat loss. Due to the significant benefits of concrete masonry's inherent thermal mass, concrete masonry buildings can provide similar performance to frame buildings while using less insulation.

The benefits of thermal mass have been incorporated into prescriptive energy code compliance methods as well as sophisticated computer models. Energy codes and standards such as the *International Energy Conservation Code* (IECC) (ref. 1) and ASHRAE Standard 90.1 (ref. 2) permit concrete masonry walls to have less insulation than frame wall systems to meet the energy code requirements. Although applicable to all climates according to the building envelope requirements of these energy codes and standards, the greater benefits of thermal mass tend to be found in the lower-numbered Climate Zones (warmer climates).

U-factors and R-values are used to estimate heat flow under steady-state conditions (neglecting the effects of thermal mass). These steady-state values can be used in conjunction with factors such as thermal mass, climate, and building orientation to estimate a building envelope's thermal performance, typically using software.

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, as in the IECC, or
- the overall U-factor of the wall, as in ASHRAE Standard 90.1.

Other compliance methods include 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. Another compliance method, the energy cost budget method, incorporates sophisticated modeling to estimate a building's annual energy cost.

This TEK lists thermal resistance (R) and thermal transmittance (U) values of single wythe walls. Cavity wall R-values are listed in TEK 6-1B, *R-Values of Multi-Wythe Concrete Masonry Walls* (ref. 3).

Related TEK:
6-1B, 6-11, 6-12C

Keywords: energy codes, insulation, reinforced concrete masonry, R-values, thermal insulation, thermal properties, U-factors

Note that the values presented in this TEK are based on the series-parallel (also called isothermal planes) calculation method. Alternate means of determining R-values of concrete masonry walls include two-dimensional calculations and testing (ref. 2).

As an alternative to the values published here, R-values and U-factors of concrete masonry walls are also published in ASHRAE Standard 90.1, Table A3.1C, which may offer slightly higher R-values (lower U-factors). As an example, for an 8-in. (203-mm) 115 pcf wall with perlite insulation in the cores, the R-value in Table A3.1C is 4.78, whereas the value determined by the series-parallel method (and shown in Table 1) is 4.4. Be aware that when using Table A3.1C, R-values listed for "Partially Grouted" are based on a reinforcement schedule of 32 in. (813 mm) o.c. vertically and 48 in. (1,219 mm) o.c. horizontally. Walls with less grout will have higher R-values than those shown in Table A3.1C.

U-FACTOR AND R-VALUE TABLES

Table 1 lists calculated U-factors and R-values of various thicknesses of concrete masonry walls, for concrete densities of 85 to 135 lb/ft^3 (1,362 to 2,163 kg/m^3), with various core fills. Table 2 shows the approximate percentage of grouted and ungrouted wall area for different vertical and horizontal grout spacings, which can be used to determine R-values of partially grouted walls (see following section).

R-values of various interior and exterior insulation and finish systems are listed in Table 3. (Note that the use of batt insulation is not recommended, due to its susceptibility moisture.) These R-values can be added to the wall R-values in Table 1. After adding the R-values, the wall U-factor can be found by inverting the total R-value (i.e., $U = 1/R$) (see also Table 3 footnote A). Note that tables of precalculated R-values and U-factors, including the various insulation and finish systems, are available on the NCMA website, at www.ncma.org.

Thermal properties used to compile the tables are listed in Table 4.

In addition to the core insulations listed across the top of Table 1, polystyrene inserts are available which fit in the cores of concrete masonry units. Inserts are available in many shapes and sizes to provide a range of insulating values and accommodate various construction conditions. Specially designed concrete masonry units may incorporate reduced-height webs to accommodate inserts. Such webs also reduce thermal bridging through masonry, since the reduced web area provides a smaller cross-sectional area for heat flow. To further reduce thermal bridging, some manufacturers have developed units with two webs rather than three. In addition, some inserts have building code approval to be left in the grouted cores, thus improving the thermal performance of fully or partially grouted masonry walls.

The ASHRAE series-parallel method (also called isothermal planes) (ref. 4) was used to calculate the values in Table 1. This method accounts for the thermal bridging through the webs of concrete masonry units. This calculation method is detailed in TEK 6-1B, *R-Values of Multi-Wythe Concrete Masonry Walls* (ref. 3).

R-values of any interior or exterior insulation or finish systems are added to the R-value of the concrete masonry wall from Table 1 (or, in the case of partially grouted walls, to the R-value of the partially grouted wall as determined using the procedure in the following section). After the R-values have been added, the U-factor may be determined as the inverse of the total R-value (see also the examples in the following section and in Table 3).

U-factors and R-values of concrete masonry walls are correlated to concrete density, because the thermal conductivity of concrete increases with increasing density. In addition to density, the thermal conductivity of concrete may also vary with factors such as aggregate type(s) used in the concrete mix, mix design and moisture content. These variations lead to a range of thermal values, as presented in TEK 6-1B (ref. 3). The range of thermal conductivities corresponds to a variation in R-value on the order of 5% to 10% for uninsulated concrete masonry units. For simplicity, only the middle-of-the-range values are presented in this TEK. The

Table 1—U-Factors (Btu/ $hr \cdot ft^{2} \cdot {}^{\circ}F$) and R-Values ($hr \cdot ft^{2} \cdot {}^{\circ}F$/Btu) of Concrete Masonry Walls [A]

Nominal wythe thickness, in. (mm)	Density of concrete, pcf	Cores empty		Cores filled with[B]: Loose-fill insulation: Perlite		Vermiculite		Polyurethane foamed-in-place		100% solid units	
		U	R	U	R	U	R	U	R	U	R
4 in. (102 mm)[C]	85	0.475	2.1	0.251	4.0	0.274	3.6	0.220	4.5	0.577	1.7
	95	0.501	2.0	0.284	3.5	0.306	3.3	0.255	3.9	0.635	1.6
	105	0.530	1.9	0.323	3.1	0.342	2.9	0.296	3.4	0.694	1.4
	115	0.560	1.8	0.366	2.7	0.384	2.6	0.342	2.9	0.752	1.3
	125	0.593	1.7	0.416	2.4	0.432	2.3	0.394	2.5	0.808	1.2
	135	0.628	1.6	0.470	2.1	0.484	2.1	0.451	2.2	0.860	1.2

Nominal wythe thickness, in. (mm)	Density of concrete, pcf	Cores empty		Cores filled with[B]: Loose-fill insulation: Perlite		Vermiculite		Polyurethane foamed-in-place		Solid grouted	
		U	R	U	R	U	R	U	R	U	R
6 in. (152 mm)	85	0.433	2.3	0.189	5.3	0.204	4.9	0.170	5.9	0.605	1.7
	95	0.459	2.2	0.219	4.6	0.233	4.3	0.200	5.0	0.640	1.6
	105	0.486	2.1	0.253	4.0	0.266	3.8	0.236	4.2	0.675	1.5
	115	0.515	1.9	0.293	3.4	0.305	3.3	0.277	3.6	0.707	1.4
	125	0.546	1.8	0.339	2.9	0.350	2.9	0.325	3.1	0.738	1.4
	135	0.580	1.7	0.391	2.6	0.400	2.5	0.378	2.6	0.767	1.3
8 in. (203 mm)	85	0.402	2.5	0.142	7.0	0.154	6.5	0.126	7.9	0.525	1.9
	95	0.427	2.3	0.165	6.1	0.177	5.6	0.150	6.7	0.559	1.8
	105	0.452	2.2	0.193	5.2	0.204	4.9	0.179	5.6	0.592	1.7
	115	0.479	2.1	0.226	4.4	0.236	4.2	0.213	4.7	0.623	1.6
	125	0.507	2.0	0.264	3.8	0.274	3.6	0.252	4.0	0.654	1.5
	135	0.537	1.9	0.309	3.2	0.317	3.2	0.298	3.4	0.684	1.5
10 in. (254 mm)	85	0.394	2.5	0.116	8.6	0.125	8.0	0.104	9.6	0.478	2.1
	95	0.417	2.4	0.136	7.4	0.145	6.9	0.124	8.1	0.507	2.0
	105	0.441	2.3	0.160	6.3	0.169	5.9	0.149	6.7	0.535	1.9
	115	0.465	2.2	0.189	5.3	0.197	5.1	0.179	5.6	0.563	1.8
	125	0.491	2.0	0.224	4.5	0.231	4.3	0.214	4.7	0.591	1.7
	135	0.518	1.9	0.264	3.8	0.271	3.7	0.225	4.4	0.618	1.6
12 in. (305 mm)	85	0.390	2.6	0.094	10.6	0.102	9.8	0.084	11.9	0.441	2.3
	95	0.411	2.4	0.111	9.0	0.118	8.5	0.101	9.9	0.466	2.1
	105	0.433	2.3	0.131	7.6	0.138	7.2	0.122	8.2	0.490	2.0
	115	0.455	2.2	0.155	6.5	0.162	6.2	0.146	6.8	0.515	1.9
	125	0.478	2.1	0.185	5.4	0.191	5.2	0.176	5.7	0.539	1.9
	135	0.503	2.0	0.219	4.6	0.226	4.4	0.212	4.7	0.564	1.8
14 in. (356 mm)	85	0.387	2.6	0.079	12.7	0.086	11.6	0.070	14.3	0.409	2.4
	95	0.408	2.5	0.093	10.8	0.100	10.0	0.085	11.8	0.431	2.3
	105	0.428	2.3	0.111	9.0	0.117	8.5	0.103	9.7	0.452	2.2
	115	0.449	2.2	0.132	7.6	0.138	7.2	0.124	8.1	0.474	2.1
	125	0.470	2.1	0.157	6.4	0.163	6.1	0.150	6.7	0.496	2.0
	135	0.492	2.0	0.188	5.3	0.193	5.2	0.181	5.5	0.518	1.9
16 in. (406 mm)	85	0.385	2.6	0.068	14.7	0.074	13.5	0.061	16.4	0.381	2.6
	95	0.405	2.5	0.081	12.3	0.086	11.6	0.073	13.7	0.400	2.5
	105	0.425	2.4	0.096	10.4	0.101	9.9	0.089	11.2	0.420	2.4
	115	0.445	2.2	0.114	8.8	0.120	8.3	0.108	9.3	0.439	2.3
	125	0.465	2.2	0.137	7.3	0.142	7.0	0.130	7.7	0.459	2.2
	135	0.485	2.1	0.164	6.1	0.169	5.9	0.158	6.3	0.480	2.1

[A] ($hr \cdot ft^{2} \cdot {}^{\circ}F$/Btu) (0.176) = $m^{2} \cdot K/W$. Mortar joints are $^{3}/_{8}$ in. (9.5 mm) thick, with face shell mortar bedding (except 4-in. (102-mm) solid units, which are assumed to have full mortar bedding). Unit dimensions based on *Standard Specification for Loadbearing Concrete Masonry Units*, ASTM C 90 (ref. 6). Surface air films are included.

[B] Values apply when all masonry cores are filled completely. Grout density is 140 pcf (2,243 kg/m^{3}). Lightweight grouts, which will provide higher R-values, may also be available in some areas.

[C] Because of the small core size and resulting difficulty consolidating grout, 4-in. (102-mm) units are rarely grouted. Note that filling the cores of these units may also be difficult. Full mortar bedding is assumed.

range and middle-of-the-range values reflect a compendium of historical data on the thermal conductivity of concrete (refs. 4, 5). Locally available products and local conditions may result in thermal values which fall outside of the range.

The values for insulated and grouted cores in Table 1 are based on the assumption that all masonry cores are insulated or grouted, respectively. In other words, for ungrouted walls and fully grouted, the values in Table 1 can be used directly. For partially grouted walls, refer to the following section.

Table 2—Ungrouted Area : Grouted Area For Partially Grouted Walls[A]

Horizontal grout spacing, in. (mm)	Vertical grout spacing, in. (mm)					
	no vert. grout	48 (1,219)	40 (1,016)	32 (813)	24 (610)	16 406)
no horiz. grout	100:0	83:17	80:20	75:25	67:33	50:50
48 (1,219)	83:17	69 :31	67:33	63:37	56:44	42:58
40 (1,016)	80:20	67:33	64:36	60:40	53:47	40:60
32 (813)	75:25	63:37	60:40	56:44	50:50	37:63
24 (610)	67:33	56:44	53:47	50:50	44:56	33:67
16 (406)	50:50	42:58	40:60	37:63	33:67	25:75

[A] Expressed as a percentage. Example: a wall grouted at 32-in. (813-mm) on center vertically, with no horizontal grout, has approximately 75% of the wall ungrouted, and 25% grouted.

R-VALUES AND U-FACTORS OF PARTIALLY GROUTED MASONRY

For partially grouted walls, the values in Table 1 must be modified to account for the grouted cores. The first step is to determine how much of the wall area is grouted, using Table 2. The U-factor of the wall is calculated from the area-weighted average of the U-factor of the grouted area and the U-factor of the ungrouted area as follows:

$U = (a_{gr} \times U_{gr}) + (a_{ungr} \times U_{ungr})$ and

$R = 1/U$

where:

a_{gr} = fractional grouted area of wall

a_{ungr} = fractional ungrouted area of wall

R = total thermal resistance of wall, $hr \cdot ft^2 \cdot {}^\circ F/Btu$ ($m^2 \cdot K/W$)

U = thermal transmittance of partially grouted wall, $Btu/hr \cdot ft^2 \cdot {}^\circ F$ ($W/m^2 \cdot K$)

U_{gr} = thermal transmittance of fully grouted wall, $Btu/hr \cdot ft^2 \cdot {}^\circ F$ ($W/m^2 \cdot K$)

U_{ungr} = thermal transmittance of ungrouted wall, $Btu/hr \cdot ft^2 \cdot {}^\circ F$ ($W/m^2 \cdot K$)

For example, consider an 8 in. (203 mm) wall composed of hollow 105 lb/ft^3 (1682 kg/m^3) concrete masonry, and grouted at 48 in. (1,219 mm) o.c. both vertically and horizontally. The ungrouted cores contain polyurethane foamed-in-place insulation, and the wall is finished on the interior with gypsum wallboard.

From Table 2, 31% of the wall is grouted and 69% contains insulation. From Table 1, the U-factor for this wall, if solidly grouted, is 0.592 $Btu/ hr \cdot ft^2 \cdot {}^\circ F$ (3.3 $W/m^2 \cdot K$). Again from Table 1, the same wall with foamed-in-place insulation in every core has a U-factor of 0.179 $Btu/ hr \cdot ft^2 \cdot {}^\circ F$ (1.0 $W/m^2 \cdot K$). Using this data, the U-factor and R-value of the wall (without the wallboard finish) are calculated as follows:

$U = a_{gr} \times U_{gr} + a_{ungr} \times U_{ungr}$

$= (0.31 \times 0.592) + (0.69 \times 0.179)$

$= 0.307$ $Btu/hr \cdot ft^2 \cdot {}^\circ F$ (1.72 $W/m^2 \cdot K$)

$R = 1/U = 1/0.307$

$= 3.3$ $hr \cdot ft^2 \cdot {}^\circ F/Btu$ (0.57 $m^2 \cdot K/W$)

The R-value of any finishes can now be added to this resulting R-value. From Table 3, the additional R-value due to the gypsum wallboard finish on furring is 1.4. So, the total R-value and U-factor of the wall is:

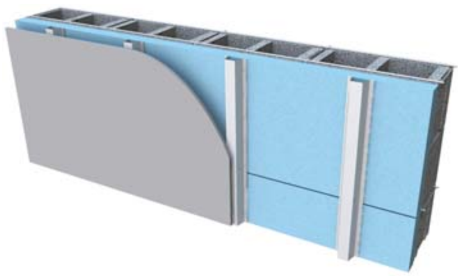
$R = 3.3 + 1.4 = 4.7$ $hr \cdot ft^2 \cdot {}^\circ F/Btu$ (0.81 $m^2 \cdot K/W$)

$U = 1/R = 1/4.7$

$= 0.213$ $Btu/hr \cdot ft^2 \cdot {}^\circ F$ (1.19 $W/m^2 \cdot K$)

Table 3—R-Values of Finish Systems[A]

System:	R-value (hr·ft²·°F/Btu)
$^1/_2$ in. gypsum board on furring [B]	1.4
$^1/_2$ in. foil-faced gypsum board on furring [C]	2.9

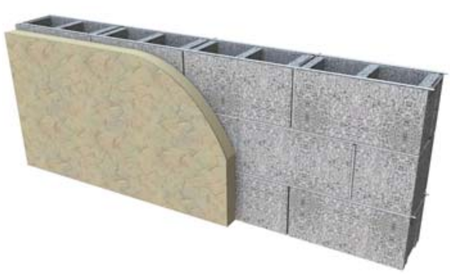


Continuous rigid insulation, $1^1/_2$-in. metal furring (for electrical rough-in) and $^1/_2$-in. gypsum wallboard:

$^3/_4$ in. extruded polystyrene[B]	5.2
$^3/_4$ in. polyisocyanurate[C]	8.1
1 in. extruded polystyrene[B]	6.4
1 in. polyisocyanurate[C]	9.8
$1^1/_2$ 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

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



Exterior insulation and finish system (rigid insulation and $^5/_{16}$ in. (7.9 mm) synthetic stucco):

1 in. polyisocyanurate (glass fiber faced)	6.8
$1^1/_2$ in. expanded polystyrene	6.3
2 in. expanded polystyrene	8.3
2 in. extruded polystyrene	10.3
2 in. polyisocyanurate (glass fiber faced)	13.3
$2^1/_2$ in. extruded polystyrene	12.8
3 in. expanded polystyrene	12.3
3 in. polyisocyanurate (glass fiber faced)	19.3

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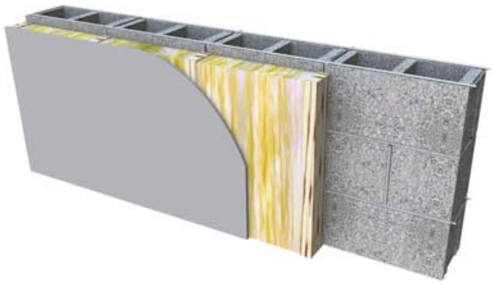
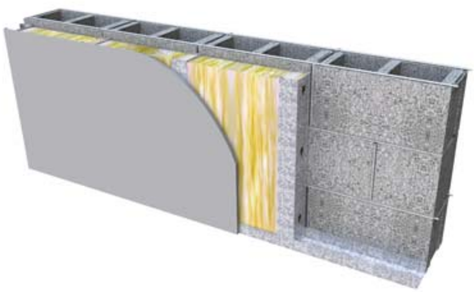
Table 3—R-Values of Finish Systems (continued)[A]





Wood furring, insulation (between furring) and $^1/_2$ in. gypsum wallboard:	Furring strip spacing: 16 in. o.c.	Furring strip spacing: 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 [E]	9.6	10.2
R-13 batt [E]	10.8	11.6
R-15 batt [E]	11.9	12.9
R-19 batt [E]	15.9	16.9
R-21 batt [E]	17.1	18.3
Metal furring, insulation (between furring), and $^1/_2$ in. gypsum wallboard[D]:		
R-11 batt [E]	6.0	7.1
R-13 batt [E]	6.5	7.7
R-15 batt [E]	6.9	8.3
R-19 batt [E]	7.6	9.1
R-21 batt [E]	7.9	9.5

EXAMPLE:

8-in. (203-mm) concrete masonry, 115 pcf (1,842 kg/m^3), cores empty, finished with 2 in. (51 mm) continuous extruded polystyrene insulation, $1^1/_2$-in. metal furring (for electrical rough-in) and $^1/_2$-in. gypsum wallboard.

From Table 1, the R-value of the concrete masonry is 2.1 hr·ft^2·°F/Btu (0.37 m^2·K/W). From Table 3, the R-value of the interior insulation and finish is 11.4 hr·ft^2·°F/Btu (2.03 m^2·K/W).

The total R-value of this wall is: R = 2.1 + 11.4 = 13.5 hr·ft^2·°F/Btu (2.40 m^2·K/W).

The total U-factor is: U = 1/13.5 = 0.074 Btu/hr·ft^2·°F (0.416 W/m^2·K).

[A] Add values to the appropriate R-value in Table 1, or to the partially grouted R-value determined using Tables 1 and 2. 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 Ref. 2, Appendix A.

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

Table 4—Thermal Data Used to Develop Tables

Material:	Thermal resistivity (R-value per inch), $hr \cdot ft^2 \cdot {}^oF/Btu \cdot in$ ($m^2 \cdot K/W \cdot 25.4$ mm)
Vermiculite	2.27 (0.40)
Perlite	3.12 (0.55)
Expanded polystyrene	4.00 (0.70)
Extruded polystyrene	5.00 (0.88)
Cellular polyisocyanurate, gas-impermeable facer	6.50 (1.14)
Polyurethane foamed-in-place	5.91 (1.04)
Wood	1.00 (0.18)
Concrete:	
85 pcf	0.23-0.34 (0.041-0.060)
95 pcf	0.18-0.28 (0.032-0.049)
105 pcf	0.14-0.23 (0.025-0.041)
115 pcf	0.11-0.19 (0.019-0.033)
125 pcf	0.08-0.15 (0.014-0.026)
135 pcf	0.07-0.12 (0.012-0.021)
140 pcf	0.06-0.11 (0.010-0.019)
Mortar	0.10 (0.018)

Material	R-value, $hr \cdot ft^2 \cdot {}^oF/Btu$ ($m^2 \cdot K/W$)
$^1/_2$ in. (13 mm) gypsum wallboard	0.45 (0.08)
Inside surface air film	0.68 (0.12)
Outside surface air film	0.17 (0.03)
Nonreflective air space	0.97 (0.17)
Reflective air space	2.80 (0.49)
$^5/_8$ in. (16 mm) cement stucco	0.13 (0.02)
$^5/_{16}$ in. (7.9 mm) synthetic stucco	0.20 (0.05)

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