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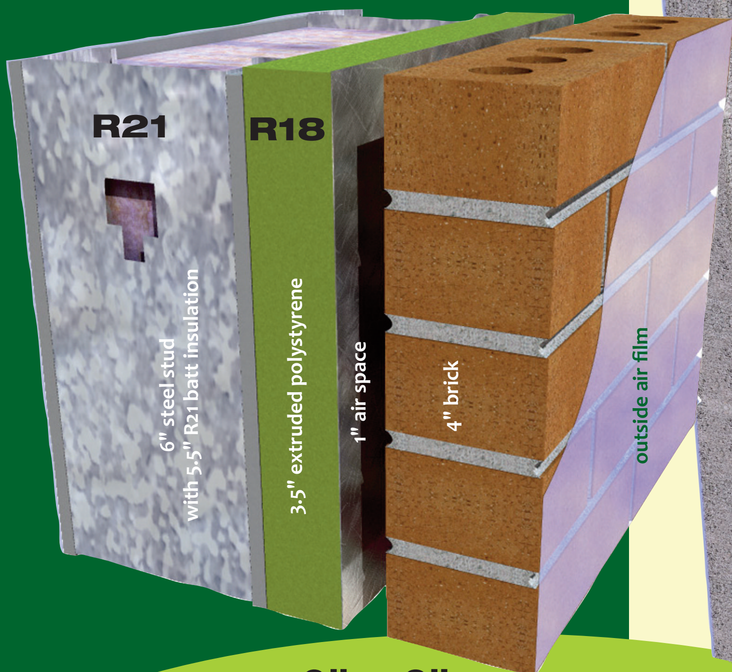
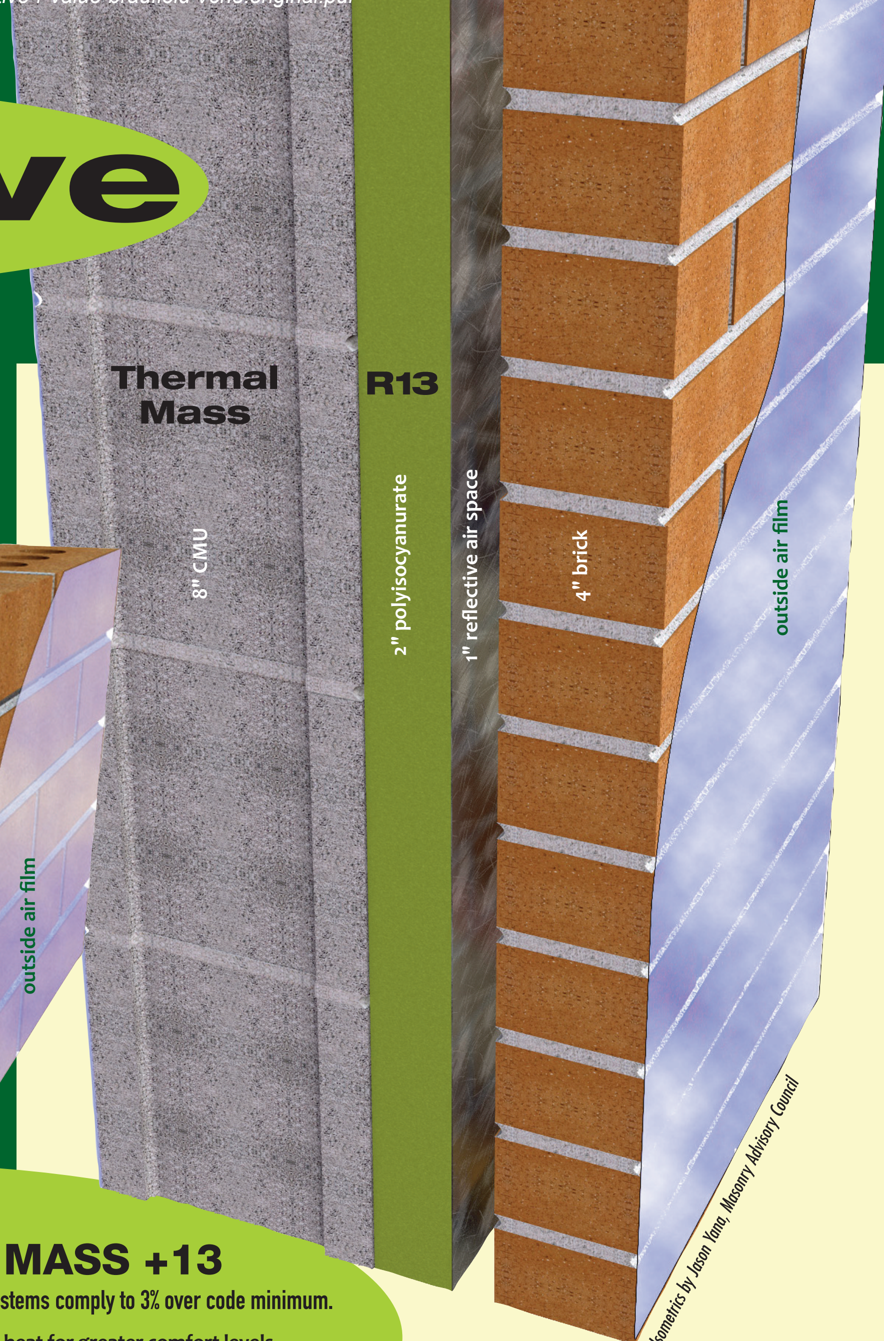
the Effectiveness of Effective R-Value

Energy efficiency of masonry's thermal mass is recognized by code

by Maribeth Bradfield, PE, LEED AP





9" ≠ 2"

R21 + R18 ≠ THERMAL MASS +13

Equal compliance, but not equal cost, nor equal comfort. | Both wall systems comply to 3% over code minimum.

Allow masonry's mass, which slowly warms and slowly releases heat for greater comfort levels, to substitute for the additional R26 and 7" of insulation necessary when using a steel stud wall.

To optimize energy performance, 3.5" of insulation and 1" air space can bring a brick and block cavity wall to R30.19. That is a nearly 300% increase over code. No other wall system comes close to the performance delivered by the effectiveness of masonry's effective R-Value.

A quick online search for *effective* or *equivalent* R-values reveals a wide range of results. Depending on the industry and the building assembly being marketed (or marketed against), effective R-values can mean: the combination of *standard* R-value and air leakage (or lack thereof); R-value of insulation adjusted to account for thermal bridging; R-value plus thermal mass effects; R-value plus thermal mass plus air infiltration; and probably other combinations as well.

Within the masonry industry, effective R-value most often means an R-value adjusted to account for masonry's thermal mass (see sidebar on page 15 for an overview). From a technical standpoint, R-value and thermal mass are intrinsic to masonry and other mass materials, but we define and measure them as if they're independent of each other. Of the two, R-value is easier to define, because it is reported under strictly defined conditions so it remains the same whether you're in Fairbanks AK or Orlando FL. Also, as consumers, most of us are more aware of what an R-value is. Thermal mass, on the other hand, is more complex. One approach mass industries have traditionally taken is to try to convert the thermal mass effect into an added R-value. Hence, *effective R-value* commonly means traditional steady state R-value plus the extra energy efficiency you get because of the thermal mass. This is the definition of effective R-value that will be addressed in this article. How practical is this information? The answer depends on what the effective R-value is based and what the intended application is.

R-Values: Standard & Effective R-values, by definition, reflect how much conduction heat transfer occurs under steady state conditions. For building materials, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has standardized the conditions under which the R-value is to be reported: mean temperature of 75°F, constant interior temperature, constant exterior temperature, still air on the inside of the assembly (which adds an R0.68) and a 15 mph wind on the exterior (which adds an R0.17).

So, a reported R-value of 10 hr x ft^2 x °F/BTU means that every one square foot of the assembly under consideration resists 10 BTU of heat each hour for every one degree Fahrenheit temperature difference from one side to the other. This assumes that neither the interior nor exterior temperature changes and it excludes heat transfer due to air movement (convection) as well as radiation heat transfer.

In the real world, actual heat transfer through a wall assembly may vary with: interior temperature, exterior temperature, mean temperature, whether or not air is moving across the interior or exterior surface, thermal storage capacity of the assembly (also called thermal mass), moisture condition of the wall and air movement through the assembly.

The *standard* R-value does not account for these various factors. It accounts only for conduction through the assembly under the strict ASHRAE-defined conditions. It is not intended to predict in-situ energy use. Rather, it is a standardized baseline for comparison. Within these strictures, the R-value is a useful tool for comparing various building assemblies on an *apples to apples* basis.

R-value is a widely known term by both building industry professionals as well as homeowners, making it a common language that is easily understood. Unfortunately, R-value has also (incorrectly) become synonymous with energy efficiency and has been marketed as the de-facto definition of energy efficiency. Industries wishing to bring attention to energy saving attributes that are not as widely known or understood, such as reduced air leakage or thermal mass, have attempted to *convert* these other energy efficiency attributes into the easily-understood R-value. Hence, the effective R-value was born.

Because thermal mass can significantly improve energy efficient performance above that predicted by the steady state R-value (see sidebar), thermal mass industries have sought ways to incorporate benefits of thermal mass into the easily-understood R-value. Mass industries in particular have developed and reported various effective R-values that reflect how thermal mass makes the assembly more energy efficient.

Unfortunately, there is no standard definition of effective R-value as there is for the standard R-value. A major hurdle to standardizing the effective R-value is the host of variables that significantly effect thermal mass. Improvement of energy efficiency due to thermal mass varies with climate, building design, building use, amount of thermal mass and where insulation is located relative to the mass. To evaluate an effective R-value, or to compare two effective R-values, one needs to know on what conditions they are based.

Effective R-Values For masonry cavity and other mass wall systems, effective R-values typically include the steady state R plus an estimate of the thermal mass effect. For example, the statement *this wall has an effective R-value of 14* typically means *this wall has the same energy performance as an R14 frame (or other non-mass) wall.* In other words, the effective R-value provides a basis to discuss the potential impact of thermal mass on energy efficiency, using a term (R-value) that is readily understood.

Thermal Mass

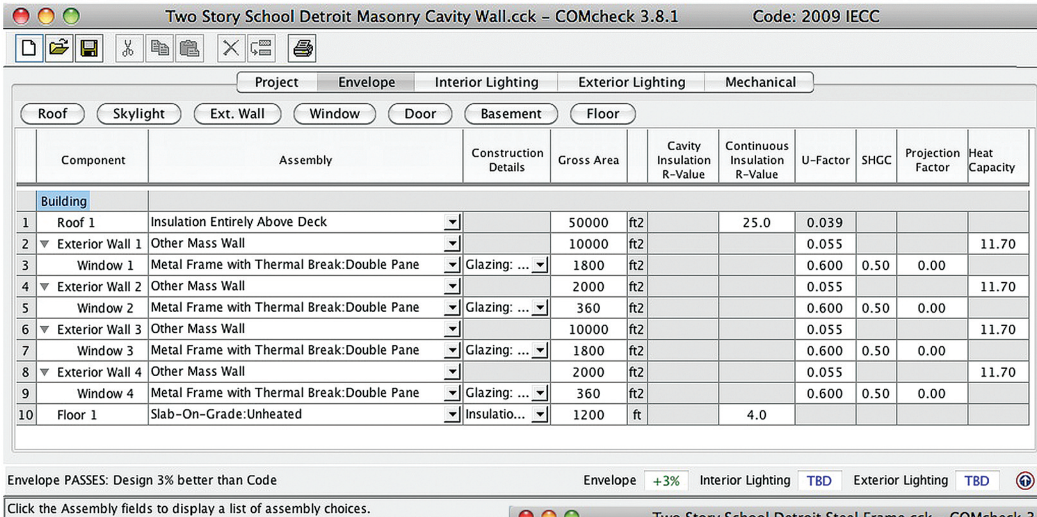
Thermal performance of concrete masonry walls is heavily influenced by its thermal mass. Thermal mass (also called thermal inertia) refers to the ability of some materials to absorb and store heat. These materials heat up and cool down slowly, which can help mitigate heat loss, shift peak energy use to off-peak hours and improve comfort by reducing indoor temperature swings. Thermal mass is a transient phenomenon: as temperatures across a wall change, heat flows vary. Some of the heat can be stored within the wall for release later.

Due to their thermal mass, concrete masonry buildings use less energy for heating and cooling than do non-mass buildings with the same R-value. Thermal mass improves energy performance beyond what can be predicted using only the R-value. For this reason, energy codes and most building energy modeling software include the effects of thermal mass when determining energy compliance or performance.

The significance of thermal mass, or the quantity of the thermal mass benefit, varies with a host of factors, including

- **local climate**
- **amount of thermal mass in the building**
- **building type**
- **amount and orientation of fenestration (solar gains)**
- **building occupancy**
- **other internal building heat loads such as from lighting and office equipment**

In order to accurately quantify the thermal mass benefit, these factors must be taken into consideration.



Two Story School Detroit Masonry Cavity Wall.cck – COMcheck 3.8.1 Code: 2009 IECC

Project | Envelope | Interior Lighting | Exterior Lighting | Mechanical

Roof | Skylight | Ext. Wall | Window | Door | Basement | Floor

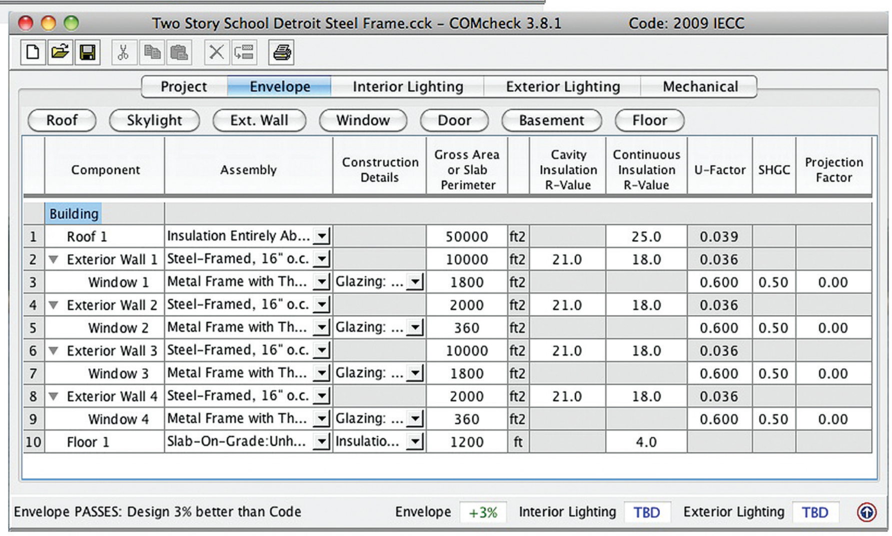
	Component	Assembly	Construction Details	Gross Area		Cavity Insulation R-Value	Continuous Insulation R-Value	U-Factor	SHGC	Projection Factor	Heat Capacity
	Building										
1	Roof 1	Insulation Entirely Above Deck		50000	ft2		25.0	0.039			
2	Exterior Wall 1	Other Mass Wall		10000	ft2			0.055			11.70
3	Window 1	Metal Frame with Thermal Break:Double Pane	Glazing: ...	1800	ft2			0.600	0.50	0.00	
4	Exterior Wall 2	Other Mass Wall		2000	ft2			0.055			11.70
5	Window 2	Metal Frame with Thermal Break:Double Pane	Glazing: ...	360	ft2			0.600	0.50	0.00	
6	Exterior Wall 3	Other Mass Wall		10000	ft2			0.055			11.70
7	Window 3	Metal Frame with Thermal Break:Double Pane	Glazing: ...	1800	ft2			0.600	0.50	0.00	
8	Exterior Wall 4	Other Mass Wall		2000	ft2			0.055			11.70
9	Window 4	Metal Frame with Thermal Break:Double Pane	Glazing: ...	360	ft2			0.600	0.50	0.00	
10	Floor 1	Slab-On-Grade:Unheated	Insulatio...	1200	ft		4.0				

Envelope PASSES: Design 3% better than Code Envelope +3% Interior Lighting TBD Exterior Lighting TBD

Click the Assembly fields to display a list of assembly choices.

Figure 1: COMcheck Results for a School in Detroit with Masonry Cavity Walls

Because the wall system is a user-defined wall, the user enters the overall U-factor of the wall, 0.055 in this case. This corresponds to an overall R-value of 18.2 for this wall (also see Table 1).



Two Story School Detroit Steel Frame.cck – COMcheck 3.8.1 Code: 2009 IECC

Project | Envelope | Interior Lighting | Exterior Lighting | Mechanical

Roof | Skylight | Ext. Wall | Window | Door | Basement | Floor

	Component	Assembly	Construction Details	Gross Area or Slab Perimeter		Cavity Insulation R-Value	Continuous Insulation R-Value	U-Factor	SHGC	Projection Factor
	Building									
1	Roof 1	Insulation Entirely Ab...		50000	ft2		25.0	0.039		
2	Exterior Wall 1	Steel-Framed, 16" o.c.		10000	ft2	21.0	18.0	0.036		
3	Window 1	Metal Frame with Th...	Glazing: ...	1800	ft2			0.600	0.50	0.00
4	Exterior Wall 2	Steel-Framed, 16" o.c.		2000	ft2	21.0	18.0	0.036		
5	Window 2	Metal Frame with Th...	Glazing: ...	360	ft2			0.600	0.50	0.00
6	Exterior Wall 3	Steel-Framed, 16" o.c.		10000	ft2	21.0	18.0	0.036		
7	Window 3	Metal Frame with Th...	Glazing: ...	1800	ft2			0.600	0.50	0.00
8	Exterior Wall 4	Steel-Framed, 16" o.c.		2000	ft2	21.0	18.0	0.036		
9	Window 4	Metal Frame with Th...	Glazing: ...	360	ft2			0.600	0.50	0.00
10	Floor 1	Slab-On-Grade:Unh...	Insulatio...	1200	ft		4.0			

Envelope PASSES: Design 3% better than Code Envelope +3% Interior Lighting TBD Exterior Lighting TBD

Figure 2: COMcheck Results for a School in Detroit with Steel Frame Walls

Because the wall system used in this COMcheck run is selected from the database within the program, the user enters the R-value(s) of insulation added to the wall, and the program calculates the overall wall U-factor (0.036 in this case).

As discussed in the sidebar, the thermal mass impact varies with climate, building design, wall design, etc, so an effective R-value should either be reported as a range (to include various climates, building types, etc) or the specific assumptions used to determine the effective R-value should be included with the value.

Thermal mass can significantly improve energy efficient performance above that predicted by the steady state R-value.

Thermal mass benefits tend to be more significant in warmer climates vs colder, and in commercial buildings vs low-rise residential. So, an effective R-value for a school in Lexington KY is meaningless for a small retail facility in Madison WI. Knowing the underlying assumptions used to determine the effective R-value allows the designer to determine how applicable the information is for the project under consideration.

Determining Effective Rs

Trying to determine an accurate estimate of the thermal mass benefit typically requires a rather rigorous computer simulation. The mass building is modeled and the energy performance of the building as a whole is simulated over a year's worth of weather data. The result is an estimate of the annual heating and cooling energy use for that building. Next, walls of the building model are changed to non-mass walls and the wall R-value is increased (to make up for the lack of thermal mass). Computer simulations are run with increasing wall R-values until the annual energy use of the frame wall building matches that of the mass building. **If our baseline mass wall had an R-value of 7 hr x ft² x °F/BTU, and the frame wall needed an R12 to meet the same annual energy use, we would say that the mass wall has an effective R12, for the particular building and climate analyzed.**

Changing the building parameters or climate will change the effective R-value.

So, determining an effective R-value can be a labor intensive exercise and, as stated previously, there are no standards to govern its determination. To streamline the process, some users have adapted simpler software to produce an estimate of the effective R-value for mass wall assemblies.

COMcheck is a public domain program developed by the US Department of Energy to determine commercial building energy code compliance. COMcheck does not provide annual energy use as an output, as the more rigorous programs do. Rather, it provides a percentage by which the building under consideration passes or fails the chosen energy code. Similar to the analysis described above, the building with mass walls can be entered with percentage passing noted. Walls are then changed to non-mass walls. R-value is increased until the same passing percentage is achieved. This is illustrated in the example shown.

Table 1: Comparison of Walls Used in COMcheck Examples[A]

Wall Elements	R-Values for Masonry Cavity Wall	R-Values for Steel Stud Wall
interior surface air film	0.68	0.68
½" gypsum wallboard	N/A	0.45
8" CMU backup wythe	1.15	N/A
6" steel studs with R21 batt insulation	N/A	6.75[B]
continuous rigid insulation	13.0[C]	18.0[D]
sheathing	N/A	0.38
air space	N/A	0.97
reflective cavity air space	2.80	N/A
4" brick veneer	0.40	0.40
exterior surface air film	0.17	0.17
Total Wall R-value	18.2	27.8
Total R-value of insulation added	13.0	39.0
Total inches of insulation to be purchased	2.0	5.5 + 3.5 = 9
Approximate insulation material cost per sf	$1.49	$3.98 + $1.89=$5.87

[A]Note that both walls demonstrate the same level of compliance under the 2009 IECC based on the COMcheck results described.

[B]The R-value of this layer accounts for the thermal bridging through the steel studs.

[C]This R13 comes from 2" of polyisocyanurate rigid insulation. This number would change with different thicknesses, brands and/or types of insulation.

[D]This R18 comes from 3.5" of extruded polystyrene rigid insulation. This number would change with different thicknesses, brands and/or types of insulation.

Figure 1 shows the COMcheck envelope compliance page, with data entered to reflect a two-story school in Detroit (IECC climate zone 5) constructed with masonry cavity walls. The energy code is the 2009 IECC. The wall entered reflects a 8" concrete masonry backup wythe, 2" of polyisocyanurate cavity insulation and a 4" brick veneer. This wall has an overall R-value of:

- 18.2 hr x ft² x °F/BTU
- a heat capacity of 11.7 BTU/ft² x °F (refs. 2 and 3, respectively).

Note that when user-entered data for a mass wall is entered, the user enters the overall wall U-factor (U-factor is the inverse of R-value, so the U-factor corresponding to an R18.2 = 1/18.2 = 0.055). This U-factor includes both masonry and insulation. The bottom of the screen shows that this building passes the code by 3%.

Figure 2 shows a similar COMcheck run, except walls have been changed to steel stud. Insulation between the studs (*Cavity insulation R-value* in Figure 2) and continuous insulation R-value were added until the same 3% passing was achieved. Note that for this wall construction, COMcheck asks for the insulation R-value, rather than the overall wall U-factor as for the cavity wall. Figure 2 shows that in order for the building with steel stud walls to pass by 3%, the wall U-factor needs to be 0.036, or R27.8. Comparing Figures 1 and 2 shows that the R18.2 masonry cavity wall school has the same passing percentage as the R27.8 steel stud wall school.

Again, this result is applicable only for this two-story school with the masonry cavity walls described herein, and located in Detroit. However, the analysis does highlight the performance difference between the two wall systems, as well as the dramatic impact of thermal losses through the steel studs. Table 1 compares the two wall constructions, and it is easy to see that the masonry wall requires R13 added insulation to achieve the same passing percentage as the steel stud wall with R39 of added insulation.

It is important to note that the energy codes on which COMcheck is based take into consideration building economics in addition to thermal mass when determining compliance. In other words, a comparison based on COMcheck is not a strict energy use comparison. In the example above, it would be incorrect to say that the R27.8 steel framed wall has the same energy efficiency as the R18.2 cavity wall. A more accurate statement is that **the two walls demonstrate the same level of compliance under the 2009 IECC**. This is another reason why knowing the basis of the effective R-value is critical to understanding what it means.

Code Compliance Today's energy codes provide several options for compliance:

1) via the R-value of added insulation

2) the overall U-factor of the assembly

3) using a systems approach such as COMcheck

4) using a whole building analysis, such as that required by USGBC's Leadership in Energy and Environmental Design (LEED) program.

When setting these code requirements, the impact of thermal mass has already been included. This is one reason why mass walls, such as masonry cavity, have lower code-required R-values – the code recognizes that thermal mass adds to the energy efficiency of the assembly, so less insulation is required. This is reflected in the values listed in Table 2.

Table 2: Examples of Required Prescriptive Above Grade Wall U-factors for Commercial Buildings from the 2009 IECC[E]

Wall Assembly Type	Climate Zone 5 (including southern MI, northern IL, IN and most of OH and PA and more)		Climate Zone 6 (including parts of northern MI and southern WI, MN and more)	
	U-factor	R-value	U-factor	R-value
Mass	0.090	11.1	0.080	12.5
Metal Framed	0.064	15.6	0.064	15.6
Wood Framed and Other	0.064	15.6	0.051	19.6

[E]U-factors are taken from Table 502.1.2. R-values were calculated as the inverse of the U-factor. Note that in this table, both U-factors and R-values refer to the entire wall assembly, not to the insulation alone.

Because thermal mass is already included when setting the energy code requirements, it is not appropriate to use an effective R-value for code compliance. In fact, the *2009 International Energy Conservation Code* (IECC) defines R-value and U-factor as being the *standard* steady-state R-value. Therefore, using an effective R-value for code compliance is in violation of the code.

For masonry cavity wall systems, effective R-values typically include the steady state R plus an estimate of the thermal mass effect.

Details Matter Although there are restrictions on its use, the effective R-value can be a useful indication of thermal mass effects. As long as effective R-values of various assemblies are determined in the same manner and for the same conditions (climate, building design, etc), they can be used as a comparative tool to evaluate the combined effect of steady state heat transfer and thermal mass.

Effective R-values are only as good as the information on which they are based. They can be helpful when evaluating various mass and non-mass wall assemblies, as long as the criteria used to develop the effective R-values are the same across the various mass systems being compared, and as long as those criteria are applicable to the project under consideration.

References

[1]International Energy Conservation Code, International Code Council, 2009.

[2]R-Values of Multi-Wythe Concrete Masonry Walls, TEK 6-1B. National Concrete Masonry Association, 2009.

[3]Heat Capacity (HC) Values of Concrete Masonry Walls, TEK 6-16A. National Concrete Masonry Association, 2008.

[4]ASHRAE Fundamentals Handbook. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2009.

[5]COMcheck software. Available for download at energycodes.gov/comcheck.

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