Appendix A

Envelope Component U_o-Factor Calculations

Appendix A

Envelope Component U_o-Factor Calculations

Appendix A documents the assumptions and equations used in calculating the envelope component U_o-factors for the MEC*check*™ compliance software, prescriptive packages, and trade-off worksheet (DOE 1995c, 1995b, and 1995a) for the 1992, 1993, and 1995 editions of the Model Energy Code (MEC) (CABO 1992, 1993, and 1995) and the 1998 and 2000 editions of the International Energy Conservation Code (IECC) (ICC 1998 and 2000). Envelope components consist of ceilings, above-grade walls, floors over unheated spaces, basement and crawl space walls, and slab-on-grade foundations.

The code[(a)] generally presents envelope component requirements in U_o-factors. The U_o-factor is a measure of the rate of conductive heat transfer per unit area of any material(s). For simplicity, the prescriptive package requirements are given in terms of R-values of insulating materials. The MEC*check* software allows the user to specify most components in terms of R-values. The trade-off worksheet includes tables that allow the user to quickly ascertain an envelope component U_o-factor based on a building description and the R-value of the insulating materials. Specifying inputs and requirements in terms of R-value is advantageous because insulation R-values correspond to the products purchased by builders and inspected by code officials.

Several details of the envelope component construction can impact envelope component U_o-factors. To convert insulation R-values to overall component U_o-factors, assumptions must be made about the typical construction of the envelope components. Note that construction materials and techniques often vary from those assumed here and described below, but these differences will generally not have a significant impact on the resulting U_o-factors.

The general equation for calculating heat flow through building envelope components is

$$U_o = [U_1 \times \text{Area}_1 + U_2 \times \text{Area}_2 + ...] / [\text{Area}_1 + \text{Area}_2 + ...] \quad \text{(A.1)}$$

where the subscripts identify different series of materials that present a different path of heat transfer; e.g., Area_1 is the area between the framing and Area_2 is the area of the framing. The U-factor is the inverse of the sum of all the material R-values for each path of heat transfer and includes the insulating value of surface air films. Equation (A.1) is sufficiently accurate unless any of the construction material is highly conductive (e.g., steel framing).

As an example, for envelope components with wood frame construction, Equation (A.1) becomes

(a) The term, "the code," refers to the 1992, 1993, and 1995 editions of the MEC and the 1998 and 2000 editions of the IECC in this Appendix.

$$U_o = \frac{Area_{STUDS} / \sum R_{FRAMING\ PATH} + Area_{INSULATION} / \sum R_{INSULATION\ PATH}}{Area_{STUDS} + Area_{INSULATION}} \quad (A.2)$$

A.1 Ceilings

Two common types of roof/ceiling construction are ceilings separated from roofs by an attic space and ceilings without attics (flat, vaulted, or cathedral). Because of construction differences, the U_o-factors for these two ceiling types are slightly different for equal insulation R-values. Prior to Version 3.2 of the MEC*check* compliance materials, no differentiation was made between ceilings with and without attics because the U_o-factor for the two types of roof/ceiling construction is sufficiently close. All ceiling U-factors were calculated using the ceilings-with-attic construction as described in this section. A comparison of U_o-factors for ceilings with and without attics is given in Section A.1.1.

MEC*check* 3.2 and later versions include the distinction between ceilings with and ceilings without an attic, primarily to improve clarity for the user as to which type of ceiling assembly they should select. Some code officials reported confusion from users about how to enter ceilings without attics, and some users were selecting the raised-truss option for ceilings without attics. Therefore, we modified the software to include the following ceiling options:

- Flat Ceiling or Scissor Truss
- Cathedral Ceiling (no attic)
- Raised or Energy Truss
- Structural Insulated Panels (SIPs)
- Other

Additionally, the software displays an illustration of a raised-truss ceiling if the user selects that option. The illustration helps clarify the definition of a raised-truss ceiling.

A.1.1 Flat Ceiling or Scissor Truss; Raised or Energy Truss

This section describes the algorithm used for flat ceilings and scissor trusses, as well as raised-truss ceilings. In versions prior to MEC*check* 3.2, this same algorithm was used for ceilings with and without attics, entered in the software as an *All Wood Joist/Rafter/Truss* assembly. Refer to Section A.1.2 for the algorithm used for cathedral ceilings in MEC*check* 3.2 and later versions.

The analysis assumed the use of blown fiberglass insulation, although batt insulation in ceilings is also common. Insulation was assumed to cover the ceiling joists so that "voids" were negligible. Equivalent batt and blown insulation R-values achieve similar U_o-factors, so the assumption of insulation type has little effect. Ceiling joists or rafters were assumed to be at 24 in. on center (O.C.), occupying 7% of the ceiling area for both ceiling types (ASHRAE 1989).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) recommends an attic ventilation rate of 0.5 cfm/ft^2 of ceiling area to control moisture (ASHRAE 1989). A fully vented attic was assumed with a still-air film resistance above the insulation and a 1-in. space between the insulation and the roof near the eaves for ventilation (the venting negates the R-value of the roof materials). A prefabricated truss system was assumed because this system is most common in new residential construction (Anderson and McKeever 1991). For truss members, 2x4 framing (DeCristoforo 1987) and a roof slope of 4/12 were assumed. Table A.1 shows the heat flow paths for ceilings, and Equation (A.3) uses these results to compute the final U_o-factor of the ceiling component.

Table A.1. Heat Flow Paths for Ceilings

Description	R-Value at Joists	R-Value at Insulation
Percentage of Ceiling Area	7%	93%
Attic Air Film	0.61	0.61
Batt or Blown Insulation	Rij	Ric
Sheathing	Rs	Rs
Joists	4.38	--
1/2-in. Drywall	0.45	0.45
Inside Air Film	0.61	0.61
Total Path R-Value	**6.05 + Rij + Rs**	**1.67 + Ric + Rs**

$$\text{Ceiling } U_o\text{-Value} = \frac{0.07}{6.05 + \text{Rij} + \text{Rs}} + \frac{0.93}{1.67 + \text{Ric} + \text{Rs}} \tag{A.3}$$

where Rij = the effective overall R-value of the insulation above the ceiling joists as computed by Equation (A.5).
Ric = the effective overall R-value of the ceiling cavity insulation between joists as computed by Equation (A.4).
Rs = the rated R-value of the insulating sheathing (if any).

The effective insulation R-value may be less than the rated R-value because of limited space at the eaves. Equations (A.4) and (A.5) account for the limited space for insulation at the eaves, which can be alleviated by raising the trusses or using an oversized truss. For a standard truss, the space available at the eaves was assumed to be 3.86 in. A standard truss was assumed in determining the prescriptive packages. For a raised truss, the space available at the eaves was assumed to be 15.86 in. (3.86 in. + 12.0 in.). Equation (A.4) shows how the effective overall R-value of the ceiling cavity insulation (Ric) is calculated. The effective insulation R-value is equal to the rated R-value if adequate space for the full insulation thickness exists at the eaves.

$$\text{Ric} = \frac{\text{Ric}_{\text{no min al}}}{1 + \left(\frac{\text{yic}_{\text{full}}}{\text{roof height}}\right) \ln\left(\frac{\text{yic}_{\text{full}}}{\text{yic}_{\text{eave}}}\right) - \left(\frac{\text{yic}_{\text{full}} - \text{yic}_{\text{eave}}}{\text{roof height}}\right)} \tag{A.4}$$

where $\text{Ric}_{\text{nominal}}$ = the rated R-value of the cavity insulation.
yic_{full} = the full thickness in inches of the cavity insulation
= $\text{Ric}_{\text{nominal}}$ / 2.5 (for blown fiberglass).
yic_{eave} = the thickness in inches of the cavity insulation at the eaves. The space available at the eaves is assumed to be 3.86 in. for a standard truss. If yic_{full} is greater than 3.86 in., yic_{eave} is set to 3.86 in. For a raised truss, the space available is assumed to

be 15.86 in. (3.86 in. + 12.0 in.). If yic_{full} is greater than 15.86 in., yic_{eave} is set to 15.86 in.

roof height = the maximum height in inches at the center line of the house. A 56-in. height was assumed, which corresponds to a 28-ft roof with a rise of 1 ft for each 3 ft across.

Equation (A.5) shows how the effective overall R-value of insulation is calculated for the insulation above the ceiling joists (Rij). Equation (A.5) is the same as Equation (A.4), except 3.5 in. is subtracted from the full insulation depth to account for the insulation displaced by the 2x4 joist. If the truss is not raised, the height of the insulation at the eaves cannot be greater than 0.36 in. (3.86 in. - 3.5 in.). If the truss is raised, the height of the insulation above the eaves cannot be greater than 12.36 in. (15.86 in. - 3.5 in.).

$$Ric = \frac{Ric_{nominal}}{1+\left(\frac{yij_{full}}{\text{roof height}}\right)\ln\left(\frac{yij_{full}}{yij_{eave}}\right)-\left(\frac{yij_{full}-yij_{eave}}{\text{roof height}}\right)} \qquad (A.5)$$

where $Rij_{nominal}$ = the R-value of the insulation above the joist, which is the rated insulation R-value ($Ric_{nominal}$) minus the joist height (assumed to be 3.5 in.) x the resistance (assumed to be 2.5°F·ft^{2}h/Btu·in.).

= $Ric_{nominal} - (3.5 \times 2.5)$

yij_{full} = the full thickness of the insulation above the joist (in inches).

= $(Ric_{nominal} / 2.5) - 3.5$.

yic_{eave} = the thickness (in inches) of the insulation above the joists at the eaves. The space available at the eaves is assumed to be 0.36 in. for a standard truss (3.86 in. – 3.5 in.). If yij_{full} is greater than 0.36 in., yij_{eave} is set to 0.36 in. For a raised truss, the space available is assumed to be 12.36 in. (15.86 in. – 3.5 in.). If yij_{full} is greater than 12.36 in., yij_{eave} is set to 12.36 in.

roof height = the maximum height in inches at the center line of the house. A 56-in. height was assumed, which corresponds to a 28-ft roof with a rise of 1 ft for each 3 ft across.

Table A.2 shows some U_o-factors for ceilings calculated using this methodology. These U_o-factors are used in the calculations to determine the prescriptive packages.

Table A.2. Sample U_o-Factors for Ceilings

Nominal R-Value	Average Insulation R-Value (Ric)	Insulation R-Value Above Joists (Rij)	U_o-Factor of Ceiling Including Framing
11	11.0	2.2	0.082
19	18.5	9.2	0.051
30	27.3	15.9	0.035
38	32.5	19.1	0.030
38 + Raised Truss	38.0	29.2	0.025
49	38.0	22.2	0.026
49 + Raised Truss	48.6	39.9	0.020

A.1.2 Cathedral Ceiling (no attic)

For ceilings without attics in MEC*check* 3.2 and later versions, the analysis assumed a fully vented ceiling with a still-air film resistance above the insulation. Batt insulation was assumed because vaulted ceilings typically have inadequate space for blown insulation. The rafters were modeled as 2x8 or 2x10 studs at 24 in. O.C. However, the effective thickness of the rafters was set equal to the thickness of the insulation because heat flows directly out the side of the wood beyond the depth of the insulation. Table A.3 shows the heat flow paths for ceilings without attics, and Equation (A.6) uses these results to compute the final U_o-factor of the ceiling component.

Table A.3. Heat Flow Paths for Ceilings Without Attics

Description	R-Value at Rafters	R-Value at Insulation
Percentage of Ceiling Area	7%	93%
Ceiling Air Film	0.61	0.61
Batt Insulation	--	Ri
Sheathing	Rs	Rs
Rafters	Rr	--
1/2-in. Drywall	0.45	0.45
Inside Air Film	0.61	0.61
Total Path R-Value	**1.67 + Rr + Rs**	**1.67 + Ri + Rs**

$$\text{Ceiling } U_o\text{-Value} = \frac{0.07}{1.67 + Rr + Rs} + \frac{0.93}{1.67 + Ri + Rs} \qquad (A.6)$$

where Rr = the R-value of the wood rafters, which was assumed to be the thickness of the cavity insulation multiplied by 1.25. The thickness of the batt cavity insulation was assumed to be equal to the R-value of the cavity insulation (Ri) divided by 3.0.
= $1.25 \times (Ri \div 3.0)$.
Ri = the rated R-value of the cavity insulation.
Rs = the rated R-value of the insulating sheathing if any.

A.1.3 Comparison of U_o-Factors for Ceilings With and Without Attics

As described above, all U_o-factors underlying the MEC*check* materials prior to Version 3.2 were based on buildings containing an attic space (i.e., a flat ceiling and a sloped roof). For typical construction, the overall ceiling U_o-factors for buildings with and without attics are very close. The two ceiling types were offered as separate options in MEC*check* 3.2 and later versions primarily for clarification rather than computational accuracy.

Table A.4 compares U_o-factors for ceilings with and without attics as calculated using the methodologies described in Sections A.1.1 and A.1.2. This table shows that, for insulation R-values commonly used in ceilings without attics, the difference in the U_o-factors between the two construction types is small.

Table A.4. Comparison of U_o-Factors for Ceilings With and Without Attics

Batt Insulation R-Value	U_o-Factor for Ceilings With Attics	U_o-Factor for Ceilings Without Attics	Difference Between Construction Types
19	0.051	0.052	2%
30	0.035	0.034	3%

A.1.4 Structural Insulated Panels

At the time of this report, we were unable to find studies or reports on roof construction of structural insulated panels (SIP). An approximate roof SIP adjustment is made by using the wall correction factors. For a discussion of the algorithms used for wall, ceiling, and floor SIPs, refer to Section A.2.5.

A.2 Walls

This section describes the calculation of wall U_o-factors, excluding windows and doors.

A.2.1 Wood-Frame Walls

Wall materials were assumed to be plywood siding, plywood and/or foam insulation sheathing on the framing exterior, batt insulation, wood framing, and 1/2-in. gypboard on the interior. Walls with rigid foam insulation were assumed to have plywood sheathing for 20% of the wall area to account for structural support at corners. In the prescriptive packages, walls with insulation R-values equal to or less than R-15 were modeled as having 2x4 studs at 16 in. O.C. and walls with insulation R-values greater than R-15 were modeled as having 2x6 studs at 16 in. O.C.

The 1992 MEC references the *1985 ASHRAE Handbook: Fundamentals* (CABO 1992; ASHRAE 1985). The 1993 MEC references the *1989 ASHRAE Handbook: Fundamentals* (CABO 1993; ASHRAE 1989). The percentage of wood-frame walls that constitute the framing area cited by these documents is the same and was used for the wood-frame wall calculations in the 1992 and 1993 MEC*check* materials. Based on the assumptions in the ASHRAE handbooks, the 16 in. O.C. translates to a framing percentage of 15% of the opaque wall area and the 24 in. O.C. translates to a framing percentage of 12% of the opaque wall area. The 1995 MEC and later editions of the code reference the *1993 ASHRAE Handbook: Fundamentals* (CABO 1995; ASHRAE 1993). The 1993 ASHRAE handbook contains higher wood-frame wall framing percentages—25% of the opaque wall area for 16-in. O.C. framing and 22% of the opaque wall area for 24-in. O.C. framing. Wall construction heat flow paths are shown in Table A.5. Equation (A.7) shows how opaque wall U_o-factors are calculated for the 1992 and 1993 MEC, and Equation (A.8) shows how opaque wall U_o-factors are calculated for the 1995 MEC and the 1998 and 2000 IECC (ICC 1998 and 2000). Table A.6 shows wall U_o-factors for 16-in. O.C. walls and common insulation R-values. These U_o-factors are used in the calculations to determine the prescriptive packages.

Table A.5. Heat Flow Paths for Wood-Frame Walls

Description	R-Value at Studs	R-Value at Insulation
Outside Air Film	0.25	0.25
Plywood Siding	0.59	0.59
Sheathing	Rs	Rs
Wood Studs	Rw	--
Insulation[(a)]	--	Ri
1/2-in. Gypboard	0.45	0.45
Inside Air Film	0.68	0.68
Total Path R-Value	**1.97 + Rs + Rw**	**1.97 + Rs + Ri**
(a) If the nominal R-value is less than R-11, R-0.9 is added to account for the air space.		

For the 1992 and 1993 MEC:

$$\text{Wall } U_o\text{-Factor} = \left[\frac{0.15 \text{ or } 0.12}{1.97 + Rs + Rw} + \frac{0.85 \text{ or } 0.88}{1.97 + Rs + Ri}\right] 0.80 + \left[\frac{0.25 \text{ or } 0.12}{1.97 + 0.83 + Rw} + \frac{0.85 \text{ or } 0.88}{1.97 + 0.83 + Ri}\right] 0.20 \tag{A.7}$$

For the 1995 MEC, and 1998 and 2000 IECC:

$$\text{Wall } U_o\text{-Factor} = \left[\frac{0.25 \text{ or } 0.22}{1.97 + Rs + Rw} + \frac{0.75 \text{ or } 0.78}{1.97 + Rs + Ri}\right] 0.80 + \left[\frac{0.25 \text{ or } 0.22}{1.97 + 0.83 + Rw} + \frac{0.75 \text{ or } 0.78}{1.97 + 0.83 + Ri}\right] 0.20 \tag{A.8}$$

where Rs = the R-value of the insulating sheathing (entered in the software as continuous insulation). If no insulating sheathing is indicated, the sheathing is assumed to be plywood with an R-value of 0.83. If insulating sheathing is used, only 80% of the net wall is assumed to be covered by the insulating sheathing. The other 20% is assumed to be covered with plywood (R-value = 0.83).

Rw = the R-value of the wood framing members. The R-value of the wood framing members was assumed to be R-4.38 for 2x4 construction and R-6.88 for 2x6 construction.

Ri = the rated R-value of the cavity insulation.

Table A.6. Sample U_o-Factors for 16-in. O.C. Wood-Frame Walls

Batt Insulation R-Value	Sheathing Insulation R-Value	Framing R-Value	1992 and 1993 MEC Wall U_o-Factor[(a)]	1995 MEC, 1998 and 2000 IECC Wall U_o-Factor[(a)]
11	0.83	4.38	0.083	0.089
13	0.83	4.38	0.075	0.082
19	0.83	6.88	0.055	0.060
21	0.83	6.88	0.051	0.057
19	4	6.88	0.047	0.055
19	5	6.88	0.046	0.054
19	7	6.88	0.043	0.052

(a) Wall U_o-factors calculated for compliance with the 1995 MEC and 1998 and 2000 IECC are higher than those for the 1992 and 1993 MEC because of the higher assumed wood framing area.

A.2.2 Steel-Frame Walls

Equation (A.1), which calculates heat loss rates through parallel paths of heat transfer (i.e., framing and insulation), is not accurate for steel-frame walls because of the high conductivity of the steel studs. Combined stud/insulation R-values (Re), which more accurately account for the metal stud conductivity, were calculated from Table 502.2.1b of the 1995 MEC (CABO 1995). Table A.7 shows these combined stud/insulation R-values, which are referred to as equivalent R-values. Given these equivalent R-values, the steel-frame wall U_o-factors are the inverse of the sum of the wall layer R-values as shown in Table A.8 and Equation (A.9).

Table A.7. Equivalent R-Values for Steel-Frame Walls

Nominal R-Value of Insulation	Equivalent R-Value (16-in. framing spacing)	Equivalent R-Value (24-in. framing spacing)
0.0 - 10.9	0.0	0.0
11.0 - 12.9	5.5	6.6
13.0 - 14.9	6.0	7.2
15.0 - 18.9	6.4	7.8
19.0 - 20.9	7.1	8.6
21.0 - 24.9	7.4	9.0
25.0+	7.8	9.6

Table A.8. Heat Flow Paths for Steel-Frame Walls

Description	R-Value
Outside Air Film	0.25
Plywood Siding	0.59
Sheathing	Rs
Equivalent R-Value[(a)]	Re
1/2-in. Gypboard	0.45
Inside Air Film	0.68
Total Path R-Value	**1.97 + Rs + Re**
(a) If the nominal R-value is less than R-11, R-0.9 is added to account for the air space.	

$$\text{Steel-Frame Wall } U_o\text{-Value} = \frac{1.0}{1.97 + Rs + Re} \tag{A.9}$$

where Rs = the R-value of the insulating sheathing. If no insulating sheathing is indicated, the sheathing is assumed to be plywood with an R-value of 0.83. The entire wall was assumed to be covered with insulation sheathing.

Re = the equivalent R-value, determined by the rated cavity insulation R-value and the spacing of the framing members. Table A.7 lists the equivalent R-values used.

A.2.3 Mass Walls

MEC*check* 3.0 uses the same three mass wall types for above-grade mass walls, basement walls, and crawl space walls. Table A.9 lists these wall types and gives the R-value assigned to that uninsulated wall type in MEC*check*. The following sections describe how these assembly types were chosen, how their uninsulated wall R-values were assigned, and how the U_o-factors for the entire mass wall assemblies are calculated for the proposed building in the MEC*check* software. This section does not address how the MEC requirements for high-mass walls are calculated. Section 6.3.3 of this document explains how the software incorporates the credit the MEC gives to high-mass walls.

Table A.9. MEC*check* Mass Wall Types and R-Values

Mass Wall Type	Uninsulated Wall R-Value
Solid Concrete or Masonry	R-1.6
Masonry Block with Empty Cells	R-1.8
Masonry Block with Integral Insulation	R-2.4

MEC*check* also includes an option for log walls, which are also considered mass walls (see Section A.2.4).

Selection of Mass Wall Types

In looking at the small differences between the three mass wall R-values given in Table A.9, it is arguable whether the three mass wall options are necessary. They could be combined into a single category as was done in previous versions of MEC*check*. However, input received from Wisconsin state officials indicated a concern with users incorrectly entering the R-value of masonry core inserts under the Cavity R-Value field. Offering the *Masonry Block with Integral Insulation* option helps alleviate this confusion in the software and gives some credit to builders using the insulated block. When *Masonry Block with Integral Insulation* is selected, the software further issues a warning message that informs users NOT to enter the R-value of the inserts because they are already accounted for. Using these three options more closely aligns MEC*check* with the COM*check*-EZ options because these same mass wall types and their definitions match those used for COM*check*-EZ. However, COM*check*-EZ distinguishes between wall thickness, with walls <8" and walls >8" being separate assemblies.

Wisconsin officials further expressed concern that their builders using filled blocks were not receiving enough credit. Wisconsin builders are apparently using blocks with R-values of up to R-5. While our conclusions did not justify generically assigning an R-5 to filled block products, MEC*check* does support an "Other" wall category that can be used to enter these and other specialty mass wall products that substantially exceed the default R-values assigned.

As discussed in the following sections, differences in concrete wall characteristics (such as thickness, density, and web characteristics) generally have less than an R-1 impact, but clearly some of the systems described in the section entitled, "Other Wall R-Values," have a more significant impact. Direct support for these specialty products is not provided in MEC*check*. More detailed coverage of these options would allow users to more accurately model mass wall types. Not including these options could make it more difficult for builders to use the specialty products and does not help support the more energy-efficient products mentioned. However, adding these options would complicate the software for other users. Concrete above-grade exterior walls only comprise about 4.4% of residential construction, with most of this construction in the south (*1995-Residential Energy Consumption Survey*). Specialty systems would comprise an even smaller percentage. Making MEC*check* more complex in an attempt to address the needs of this small percentage and all of the other variations on mass walls is not advised. Again, the "Other" wall option can be used.

Another difficulty in directly supporting specialty products is determining the R-value to assign to those products. In some cases, manufacturer-reported values for some specialty products may be inflated. As an example, ICON block inserts were reported by the manufacturer to have a system R-value of 5.8, but tests revealed a measured R-value of only 3.5 (Energy Design Update 1993). High-mass products may report an "effective" R-value that gives a substantial credit for thermal mass, while the credit for thermal mass is provided elsewhere in the code (and in MEC*check*) and should not be included in the R-value.

Solid Concrete or Masonry Wall R-Value

Solid Concrete or Masonry wall types are defined as solid precast or poured-in-place concrete as well as concrete masonry units (CMUs) with grouted cells having grout in 50% or more of the CMU cells. The R-value of grouted masonry more closely resembles solid concrete than masonry with empty cells.

According to Martha Van Geem of Construction Technology Laboratories, Inc., 144 lb/ft^2 concrete is by far the most common in residential construction.[a] For basements, the nominal thickness of plain concrete walls should be 8 in. or more for walls 7 ft. or more below grade[b]. Tables A.10 and A.11 show R-values for solid concrete of various densities and thicknesses from ASHRAE Standard 90.1R, Appendix A (ASHRAE 1996) and U-factors for stone and gravel or stone aggregate concretes from the *1997 ASHRAE Handbook: Fundamentals* (ASHRAE 1997, page 24.7), respectively.

Table A.10. R-Values (U-Factors) from Standard 90.1R

	Solid Concrete	
Density (lb/ft^3)	**6-in. Thickness**	**8-in. Thickness**
85	R-2.3 (0.44)	R-2.7 (0.37)
115	R-1.5 (0.65)	R-1.8 (0.57)
144	R-1.2 (0.81)	R-1.4 (0.74)

Table A.11. U-Factors from ASHRAE 1997 Fundamentals Handbook

	Stone and Gravel or Stone Aggregate Concretes		
Density (lb/ft^3)	**R-Value per in.**	**Median R-Value for 8 in.**	**R-Value with Air Films (0.25+0.68)**
130	0.08-0.14	0.88	1.81
140	0.06-0.11	0.68	1.61
150	0.05-0.10	0.60	1.53

The variation of R-value over common ranges of density and thickness is less than R-1. This small variance does not merit breaking down the wall assembly categories further by density or thickness.

Using the ASHRAE 1997 handbook as the primary reference, Solid Concrete and Masonry assembly types for both above-grade and below-grade walls assume an 8-in. wall and are assigned an R-value of R-1.6 for the uninsulated wall. This value includes air films of R-0.25 + R-0.68.

(a) Assumptions and equivalent R-values for solid concrete constructions based on a personal communication with Martha Van Geem, Construction Technology Laboratories, Inc. Calculation of concrete wall based on energy calculations and data.

(b) See *Building Foundation Design Handbook*, Table 7-11, page 184 (Carmody 1998).

Masonry Block with Empty Cell Wall R-Value and Masonry Block with Integral Insulation Wall R-Value

Masonry Block with Empty Cells is defined as CMUs with at least 50% of the CMU cells free of grout.

Masonry Block with Integral Insulation is defined as CMUs with integral insulation such as perlite or rigid foam inserts.

Bruce Wilcox indicated that 8-in. medium-weight, partially-grouted CMU was commonly used for residential construction.[a] Kosny and Christian (1995) report that "normal-weight" (120-to-144 lb/ft^2) blocks are by far the most common. Steve Szoke indicated the high end of medium-weight blocks are common, and suggested using ungrouted as a default.[b] Tables A.12 and A. 13 show the R-values and U-factors from ASHRAE Standard 90.1R (ASHRAE 1996) and U-factors from the *1997 ASHRAE Handbook: Fundamentals* (ASHRAE 1997).

Table A.12. R-Values and U-Factors (including air films) from Standard 90.1R

Density (lb/ft^3) and Thickness	Solid Grouted	Partial Grouted, Cells Empty	Partial Grouted, Cells Insulated	Unreinforced, Cells Empty	Unreinforced, Cells Insulated
85					
6 in.	R-1.8 (0.57)	R-2.2 (0.46)	R-2.9 (0.34)	R-2.5 (0.40)	R-5.0 (0.20)
8 in.	R-2.0 (0.49)	R-2.4 (0.41)	R-3.6 (0.28)	R-2.7 (0.37)	R-6.6 (0.15)
115					
6 in.	R-1.5 (0.66)	R-1.9 (0.54)	R-2.4 (0.41)	R-2.2 (0.46)	R-3.8 (0.26)
8 in.	R-1.7 (0.58)	R-2.1 (0.48)	R-2.8 (0.35)	R-2.3 (0.43)	R-4.8 (0.21)
135					
6 in.	R-1.4 (0.73)	R-1.7 (0.60)	R-2.0 (0.49)	R-1.9 (0.53)	R-2.9 (0.35)
8 in.	R-1.5 (0.65)	R-1.8 (0.55)	R-2.4 (0.42)	R-2.0 (0.49)	R-3.6 (0.28)

Table A.13. U-Factors from ASHRAE 1997 Fundamentals Handbook

Type	Normal Weight Aggregate (sand and gravel), 8 in.	
	R-Value of Block Only	R-Value with Air Films (0.25+0.68)
Empty	0.97-1.11	1.90-2.04
Perlite Fill	2.0	2.93

(a) Assumptions and equivalent R-values for block masonry constructions were based on a personal communication with Bruce Wilcox, Berkeley Solar Group.

(b) Assumptions and equivalent R-values for block masonry constructions were based on a personal communication with Stephen Szoke, Portland Cement Association.

Vermiculite Fill	1.37-1.92	2.30-2.85

Kosny and Christian (1995) report 2-core 12-in. blocks have an R-value of slightly less than R-2 (apparently this R-value does not include air films).

Over common densities, the density and thickness does not make much difference—less than R-1. Insulated cells do not have a significant impact, particularly when grouting is used, suggesting that it is not important to allow the user to specify these inputs. However, MEC*check* 3.0 **does** include an option for *Masonry Block with Integral Insulation* for reasons sited in the previous section entitled, "Selection of Mass Wall Types."

We used the Standard 90.1R table to establish default values because the table covers the variety of concrete blocks. The software currently assumes an 8–in. 135-lb/ft^3 block with partial grouting based on a recommendation by Bruce Wilcox and because assuming partial grouting is more conservative than assuming no grouting. The software option for *Masonry Block with Empty Cells* allows for up to 50% grouting. R-1.8 is used for this option, based on *Partial Grouted, Cells Empty* in the Standard 90.1R table. R-2.4 is used for *Masonry Block with Integral Insulation*, based on *Partial Grouted, Cells Insulated* in the Standard 90.1R table. These values include air films of R-.25 + R-.68.

Other Wall R-Values

Several mass walls types could be classified as specialty products. The following results from Kosny and Christian (1995) describe specialty mass wall products, some of the features of these products, and their impact on R-value.

Improved Block Design with Insulation Fill: A "cut web" design with 12-in. normal-density block has an R-value of R-5.4, more than double the R-value of a 2-core 12-in. block. A similar multicore block is rated at R-3.5 if the core is left uninsulated and R-6.8 if the core is insulated. Self-locking blocks with continuous insulation in the middle (like a sandwich) have tested R-values of about R-8 to R-10. Product literature for one such product (Thermalock) reports R-14 for 8-in. blocks, R-18 for 10-in. blocks, and R-24 for 12-in. blocks. Supposedly, these products are to be installed with no thermal bridge by mortar, but we do not know if this type of installation is typical.

Density: Density is more-or-less bimodal. The most commonly used heavy concrete has densities ranging from about 120 to 140 lb/ft^3. Other products, such as autoclaved aerated concrete (AAC, e.g., hebel block), lightweight expanded clay aggregate, and expanded polystyrene bead concrete, have much lower densities. Table A.14 shows the density and R-value of specialty products.

Table A.14. Density and R-Value of Specialty Products

	Density	**R-Value per in.**
Expanded Shale, Clay, and Slate Concrete	80-100	0.27 to 0.40
Lightweight Expanded Clay Aggregate Concrete	28-40	0.90 to 1.07
Wood Concrete	28-40	0.41 to 0.90

Autoclaved Aerated Concrete	30-40	0.95
Expanded Polystyrene Bead Concrete	25-70	0.89 (30 lb/ft^3)

Mortar Joints: Kosny and Christian (1995) report that mortar has little effect on hollow, normal-weight, 2-core, 12-in. blocks–the R-value is reduced by less than 1%. If the cores are insulated, the mortar can result in a 2% to 5% reduction in R-value. Kosny and Christian report the mortar joint covers 4% to 10% of the total wall vertical area and assume an R-value of 0.2 per in. The use of mortar in any concrete walls with high R-values (insulation inserts, low-density concretes) can cause a major decrease to the R-value if it establishes a bridge across the insulation.

Mass Wall U_o-Factors

U_o-factors for mass walls are determined by adding an R-value for the uninsulated wall and the insulation system (which accounts for air films and other materials). For exterior insulation, the insulation was assumed to cover the entire wall. Equation (A.10) computes the U-factor of a mass wall with interior and/or exterior insulation. For interior insulation, an interior furring system was assumed. Table A.15 lists equivalent R-values for interior furring and insulation systems.

$$\text{Mass Wall } U_o = \frac{1}{\text{Reff} + \text{Rwall} + \text{Rcont}} \tag{A.10}$$

where Reff = the effective R-value of an interior furring and insulation system as determined by the rated R-value of the cavity insulation.
Rwall = the R-value of the uninsulated wall (as determined in the previous sections).
Rcont = the rated R-value of the exterior continuous insulation.

Table A.15. Effective R-Values for Interior Furring Systems[(a)]

Nominal R-Value	Thickness of Framing (in.)	Effective R-Value
0	0.75	1.4
1	0.75	1.4
2	0.75	2.1
3	0.75	2.7
4	1.0	3.4
5	1.5	4.4
6	1.5	4.9
7	2.0	5.9
8	2.0	6.4
9	2.5	7.4
10	2.5	7.9
11	3.5	9.3
12	3.5	9.8
13	3.5	10.4
14	3.5	10.9
15	3.5	11.3
16	5.5	13.6
17	5.5	14.2
18	5.5	14.7
19	5.5	15.3
20	5.5	15.8
21	5.5	16.3

(a) The framing thickness varies with R-value. All values include 0.5-in. gypsum wallboard on the inner surface (interior surface resistances not included). The framing was assumed to be 24-in. on-center, and the insulation was assumed to fill the furring space. The framing was assumed to have an R-value of 1.25/in.

A.2.4 Log Walls

Log wall U_o-factors are based on log thickness plus any additional insulation entered by the user. Table A.16 correlates log wall thicknesses and nominal U_o-factors. Equation (A.11) is used to determine the U_o-value of the log walls plus additional insulation entered by the user (assumed to cover the entire wall).

$$\text{Log Wall U-Factor} = \frac{1.0}{\text{Log R-Value} + \text{Insulation R-Value}} \tag{A.11}$$

where Log R-value = the midpoint of the nominal R-value range given in Table A.16.

Table A.16. Log Wall R-Values and U_o-Factors[a]

Nominal Log Thickness (in.)	Average Weight lb/ft^2[b]	Heat Capacity Btu/ft^2[c]	Nominal R-Value[d]	Nominal U_o-Factor
5	14	6	6.4-7.4	0.149
6	14	6	7.5-8.3	0.125
7	24	9	8.6-1.0.0	0.108
8	24	9	9.7-11.3	0.095
9	24	9	10.8-12.6	0.086
10	32	12	11.0-13.9	0.080
12	32	12	14.1-16.5	0.065
14	32	12	16.3-19.1	0.057
16	42	16	18.4-20.8	0.051

(a) Reproduced from a personal communication from T.J. Cadenas, Steven Winter Associates, Inc.

(b) Average weight computed on the basis of a wood density range at 12% moisture content of 21.7 lb/ft^3 for west coast woods and cedar to 41.2 lb/ft^3 for southern pine (ASHRAE 1985).

(c) Computed on the basis of wood specific heat at 12% moisture content of 0.39 Btu/lb°F at 75°F (ASHRAE 1985).

(d) R-values assume a resistance per inch range of 1.1-1.3 plus 0.85 for film resistance. A wood density range of 21.7 lb/ft^3 at 12% moisture content for west coast woods and cedar to 41.2 lb/ft^3 for southern pine. A specific heat of 0.39 Btu/lb·°F at 12% moisture content (ASHRAE 1985).

Note that the MEC and IECC contain a mass wall credit for walls having a heat capacity greater than or equal to 6 $Btu/ft^2 \cdot °F$. The code states that, "Solid wood walls having a mass greater than or equal to 20 lb/ft^2 have heat capacities equal to or exceeding 6 $Btu/ft^2 \cdot °F$." According to the data in Table A.16, 5-in. and 6-in. log walls are borderline in meeting these criteria, with the heat capacity given just at the lower boundary but the weight falling below 20 lb/ft^2. Because it was unclear whether 5-in. and 6-in. log walls met the mass wall criteria, we originally excluded them as an option in MEC*check*. However, input from Vermont users suggested that this log size is commonly used in log home construction in Vermont and that it should be included in MEC*check*. MEC*check* 3.0 now allows the user to select 5-in. and 6-in. log walls, but the mass wall credit **is not** applied to them.

A.2.5 Structural Insulated Panels

Wall Panels

SIPs typically have ½-in. fiberboard sheathings and an EPS foam core. Panels have an edge stiffener, which also is used as the nailing strip for connections. Corners and window/door openings all require the foam core be replaced with wood framing members. MEC*check* instructs users to provide the manufacturer-reported R-value of the SIP panel in the continuous R-value field. Manufacturer-reported R-values are typically clear-wall R-values–they do not include connections and framing effects.

For SIP panels, Oak Ridge National Laboratory (ORNL) has reported the difference between the clear-wall R-value and overall wall R-value as 12.5% (ASHRAE Transactions V. 104, Table 5). The ORNL Whole-Wall Thermal Performance Calculator estimates the whole-wall R-value to be 88.3% of the clear-wall R-value in a typical single-family dwelling (an 11.7% difference) (ORNL 2001).

From these results, we adopted an adjustment factor of 12.5% for use in MEC*check* for calculating the overall R-value of SIP exterior walls, which is the more conservative of the two results. Because the manufacturer-reported R-values do not include air films, we assumed the heat flow paths shown in Table A.17.

Table A.17. Assumed Heat Flow Paths for Wall Panels

Description	R-Value
Outside Air Film	0.25
Wall Panels	Rm * 0.875
1/2-in. Gypboard	0.45
Inside Air Film	0.68
Total Path R-Value	1.38 + (Rm * 0.875)
Rm = the manufacturer's reported R-value.	

Floors Panels

No studies or reports are available for floor construction of SIP panels. An approximate floor adjustment is made using wall correction factors listed in the Whole-Wall Thermal Performance Calculator for stress-skin walls. The only heat flows listed in this table considered applicable to the floor are the clear-wall (42.42 Btu/h·ºF) and wall/floor (1.86 Btu/h·ºF) heat flows. Adding these heat flows gives 44.28 Btu/h·ºF, which is approximately 96% of the clear-wall heat flow. Therefore, an adjustment of 4% is warranted.

The floor joists consist of ½-in. fiberboard web. Based on the percentage of joist web area of a typical 4-x 8-ft panel, the fiberboard web comprises about 1% of the floor area. The adjustment factor is increased by 1% to account for the heat flow through the webs, which are not a factor in wall construction.

Assuming that the MEC*check* user provides a clear-wall R-value of the stress-skin floor panel, a total adjustment factor of 5% was adopted for use in calculating the overall R-value of SIP floors (a 4% adjustment plus 1% for the webs). Because the manufacturer-reported R-values do not include air films, we assumed the heat flow paths shown in Table A.18.

Table A.18. Assumed Heat Flow Paths for Floor Panels

Description	R-Value
Unheated Space Air Film	0.92
Floor Panels	Rm * 0.95
Carpet and Pad	1.23
Inside Air Film	0.92
Total Path R-Value	3.07 + (Rm * 0.95)
Rm = the manufacturer's reported R-value.	

Roof Panels

No studies or reports are available for roof construction of SIP panels. An approximate roof adjustment is made using wall correction factors listed in the Whole-Wall Thermal Performance Calculator for stress-skin walls. A conservative approach assumes that the window, door, and corner framing of the walls are analogous to the roof ridge framing in the ceilings. If the heat flow through the wall/floor framing is removed from consideration, the total heat flow from this table would be 46.21 Bth/h·°F (48.07 - 1.86). This heat flow is approximately 92% of the clear-wall heat flow, so an adjustment of 8% is warranted. An additional 1% was added for the wood portion of the joist members, as was done for floors.

Assuming that the MEC*check* user provides a clear-wall R-value of the stress-skin ceiling panel, a total adjustment factor of 9% was adopted for use in calculating the overall R-value of SIP ceilings (an 8% adjustment plus 1% for the webs). Because the manufacturer-reported R-values do not include air films, we assumed the heat flow paths shown in Table A.19.

Table A.19. Assumed Heat Flow Paths for Roof Panels

Description	R-Value
Ceiling Air Film	0.61
Roof Panels	Rm * 0.91
1/2-in. Drywall	0.45
Inside Air Film	0.61
Total Path R-Value	1.67 + (Rm * 0.91)
Rm = the manufacturer's reported R-value.	

A.2.6 Insulated Concrete Forms

Insulated concrete Forms (ICFs) consist of two rigid-board insulation sheathings that serve as a permanent form for poured-in-place concrete walls. The insulation sheathings are connected by plastic or metal links that keep the sheathings in position and also serve as stirrups or reinforcements for the concrete wall. MEC*check* instructs users to provide the manufacturer-reported R-value of ICFs in the continuous R-value field. Manufacturer-reported R-values are typically clear-wall R-values–they do not include connections and framing effects.

The ORNL tests (ASHRAE Transactions V. 104, Table 5), show that the difference between the clear-wall R-value and the overall wall R-value is 9.5%. These ORNL calculations take into account the additional framing in corners, window/door frames, and wall/roof and wall/floor interfaces. A typical ICF wall analyzed using the ORNL Whole-Wall Thermal Performance Calculator shows that the whole-wall R-value is 89% of the clear-wall R-value (an 11% difference) (ORNL 2001).

Assuming that the MEC*check* user provides a clear-wall R-value of an ICF construction, an adjustment factor of 11% was adopted for use in determining the overall effective R-value, which is the more conservative of the two results. Tables A.20 and A.21 lists the R-values used to calculate the overall effective R-Value for above- and below-grade ICF walls.

Table A.20. Above-Grade ICF Walls

Description	R-Value
Outside Air Film	0.25
ICF Clear Wall	Rm * 0.89
1/2-in. Gypboard	0.45
Inside Air Film	0.68
Total Path R-Value	1.38 + (Rm * 0.89)
Rm = the manufacturer's reported R-value.	

Table A.21. Below-Grade ICF Walls

Description	R-Value
ICF Clear Wall	Rm * 0.89
Inside Air Film	0.68
Total Path R-Value	0.68 + (Rm * 0.89) + Soil Impact
Rm = the manufacturer's reported R-value.	

A.3 Floors Over Unheated Spaces

A.3.1 All-Wood Joist/Truss

We assumed that floors over unheated spaces are constructed of batt insulation, wood framing, a ¾-in. wood subfloor, and carpet with a rubber pad. The floor joists were modeled as 2x10 studs at 16-in. O.C. (DeCristoforo 1987) occupying 10% of the floor area. The effective depth of the joists for the thermal calculation was set equal to the depth of the insulation. This thickness was used because heat flows directly out of the sides of the joists beyond the depth of the insulation. Table A.22 shows the heat flow paths for floors over unheated spaces, and Equation (A.12) uses these results to compute the final floor component U_o-value. Table A.23 shows some U_o-factors for floors over unheated spaces as calculated by this methodology. These U_o-factors are used in the calculations to determine the prescriptive packages.

Table A.22. Heat Flow Paths for Floors Over Unheated Spaces

Description	R-Value at Joists	R-Value at Insulation
Percentage of Floor Area	10%	90%
Unheated Space Air Film	0.92	0.92
Insulation	--	Ri
Joists	Rj	--
Carpet and Pad	1.23	1.23
¾-in. Wood Subfloor	0.94	0.94
Inside Air Film	0.92	0.92
Total Path R-Value	4.01 + Rj	4.01 + Ri

$$\text{Floor } U_o\text{-Value} = \frac{0.1}{4.01 + Rj} + \frac{0.9}{4.01 + Ri} \tag{A.12}$$

where Rj = the R-value of the wood joists, which was assumed to be the thickness of the cavity insulation multiplied by 1.25. The thickness of the batt cavity insulation was assumed to be equal to the R-value of the cavity insulation (Ri) divided by 3.0.

= 1.25 x (Ri ÷ 3.0).

Ri = the rated R-value of the cavity insulation.

Table A.23. Sample U_o-Factors for Floors Over Unheated Spaces

Batt R-Value	U_o-Value of Floor Including Framing
0	0.250
11	0.072
13	0.064
19	0.047
30	0.033

A.3.2 Structural Insulated Panels

No studies or reports were found for floor construction of SIPs. An approximate floor SIP adjustment is made by using the wall correction factors. For a discussion of the algorithms used for wall, ceiling, and floor SIPs, refer to Section A.2.5.

A.4 Basement Walls

The methodology for calculating heat loss through basement walls was adapted from the *1993 ASHRAE Handbook: Fundamentals* (ASHRAE 1993, p. 25.10-25.11). Both the proposed and required UA calculations take into account the effect of the soil surrounding below-grade walls.

The soil R-value is computed for each 1-ft increment of wall below grade, based on the user's *Wall Height* and *Depth Below Grade* inputs. Table A.24 gives the heat loss factors for an uninsulated wall as given in the 1993 ASHRAE handbook (ASHRAE 1993). The combined R-value of the uninsulated wall and air-films in the ASHRAE values was determined to be approximately R-1.6. Column D of Table A.24 gives the R-value attributed to the soil at each 1-ft. increment after the wall R-value of R-1.6 has been deducted.

A.4.1 Proposed UA Calculation

To compute the proposed UA, the foundation dimensions and insulation characteristics are obtained from the user.

- height of wall
- depth below grade
- depth of insulation
- R-value of insulation
- wall area.

The "depth of insulation" refers to the distance the insulation extends vertically from the top of the foundation wall downward. No additional credit is given for insulation depths greater than the height of the wall.

The basement perimeter is also used in the UA calculation and is estimated from Equation A.13.

$$\text{Perimeter} = \frac{\text{Wall Area}}{\text{Wall Height}} \tag{A.13}$$

The proposed wall UA is calculated as:

$$\text{proposed UA} = \sum_{n}^{i=1}\left(\frac{1}{\text{wall R-value[i]} + \text{soil R-value[i]}}\right) * \text{area[i]} \tag{A.14}$$

where wall R-value[i] = the R-value of the wall assembly for increment i, based on the wall type and the insulation configuration.

soil R-value[i] = the R-value of the soil for increment i, based on the depth below grade of increment i (see Table A.24).

area[i] = the perimeter times the height, which is 1 for a complete increment, but may be a fraction of 1, depending on the configuration.

n = the wall height, rounded up to the nearest whole number.

Equation A.14 is calculated separately for the above-grade UA (in which case the soil R-value is 0) and the below-grade UA. The total building UA is the sum of these separate calculations. For partial increments, the area is adjusted to reflect only the area under consideration. For example, if the user defines a wall 1.5 ft above-grade, then the above-grade portion is computed based on two increments, with the second increment having only one-half the area of the first increment (perimeter * 0.5). Likewise, partial increments are computed if the user's depth of insulation does not fall in whole-number increments, in which case the wall R-value may vary over the increment. Table A.24 gives the soil R-values used in Equation A.14, based on the depth of the increment under consideration.

Table A.24. Soil R-Values

A	B	C	D
Depth Below Grade (ft)	**Heat Loss (Btu/ft^2·h·°F) for Uninsulated Wall**	**R-Value of Uninsulated Wall and Soil (1 / B)**	**R-Value of Soil Only (C – 1.6)**
0-1	0.410	2.439	0.839
1-2	0.222	4.505	2.905
2-3	0.155	6.452	4.852
3-4	0.119	8.403	6.803
4-5	0.096	10.417	8.817
5-6	0.079	12.658	11.058
6-7	0.069	14.493	12.893
7-8	0.061	16.393	14.793
8-9	0.055	18.182	16.582
9-10[a]	0.049	20.408	18.808
(a) Depths below 10 ft assume the 9-to-10-ft soil R-value.			

A.4.2 Required UA Calculation

The MEC does not consider the surrounding soil in determining the basement wall U_o-factor requirements (Table 502.2.1, Footnote 5 in the 1992 and 1993 MEC [CABO 1992, 1993]; Table 502.2.1a, Footnote 5 in the 1995 MEC [CABO 1995]; Table 502.2, Footnote 'e' in the 1998 and 2000 IECC [ICC 1998, 2000). To directly compare the required U_o-factor specified by the code (which does not include soil) to the proposed building U_o-factor (which does include soil), the code requirement is adjusted to include the impact of the soil.

The required wall UA is calculated as:

$$\text{required UA} = \sum_{n}^{i=1} \left(\frac{1}{\frac{1}{\text{MEC } U_o} + \text{soil R-value}[i]} \right) * \text{area}[i] \qquad \text{(A.15)}$$

where $MECU_o$ = the MEC/IECC basement wall U_o requirement for the given location.
soil R-value[i] = the R-value of the soil for increment i, based on the depth below grade of increment i (see Table A.24).
area[i] = the perimeter times the height, which is 1 for a complete increment, but may be a fraction of 1, depending on the configuration.
n = the wall height, rounded up to the nearest whole number.

A.4.3 Wall R-Value Calculations

Solid Concrete and Masonry Block Basement Walls

Table A.25 shows the R-values used for uninsulated solid concrete and masonry block walls. The uninsulated wall R-value assigned to these three wall types is the same as is used for above-grade mass walls. Refer to Section A.2.3 for the derivation of these values.

Table A.25. Basement Wall Types and R-Values

Mass Wall Type	Uninsulated Wall R-Value
Solid Concrete or Masonry	R-1.6
Masonry Block with Empty Cells	R-1.8
Masonry Block with Integral Insulation	R-2.4

The insulated wall R-value is

$$\text{Basement Wall Rval} = \text{Reff} + \text{Rwall} + \text{Rcont} \tag{A.16}$$

where Reff = the effective R-value of an interior furring and insulation system as determined by the rated R-value of the cavity insulation (see Table A.15).
Rwall = the R-value of the uninsulated wall (see Table A.25).
Rcont = the rated R-value of the continuous insulation.

Wood-Frame Basement Walls

Wood-frame basement wall R-values are established similarly to above-grade wood-frame walls (see Section A.2.1). Due to differences in the code-referenced ASHRAE standards, the 1992 and 1993 MEC (CABO 1992, 1993) framing factors are different from the framing factors used by the 1995 MEC (CABO 1995) and the 1998 and 2000 IECC (ICC 1998, 2000).

Table A.26 gives the assumed heat flow paths for basement wood-frame walls. Equation A.17 gives the wall U_o for the 1992 and 1993 MEC, and Equation A.18 gives the wall U_o for the 1995 MEC and 1998 and 2000 IECC. In both cases, 2x6 16-in. O.C. construction is assumed. A wall R-value is obtained by inverting the results of these equations.

Table A.26. Heat Flow Paths for Wood-Frame Basement Walls

Description	R-Value at Studs	R-Value at Insulation
Outside Air Film	0.25	0.25
Plywood	0.77	0.77
Continuous Insulation	Rcont	Rcont
Wood Studs	6.88	--
Cavity Insulation	--	Rcavity
1/2-in. Gypboard	0.45	0.45
Inside Air Film	0.68	0.68
Total Path R-Value	9.03 + Rcont	2.15 + Rcont + Rcavity

For the 1992 and 1993 MEC:

$$\text{Basement Wall } U_o = \left[\frac{0.15}{9.03 + \text{Rcont}} + \frac{0.85}{2.15 + \text{Rcavity} + \text{Rcont}}\right] \tag{A.17}$$

For the 1995 MEC and 1998 and 2000 IECC:

$$\text{Basement Wall } U_o = \left[\frac{0.25}{9.03 + \text{Rcont}} + \frac{0.75}{2.15 + \text{Rcavity} + \text{Rcont}}\right] \tag{A.18}$$

Insulated Concrete Forms

For ICF walls, the depth of insulation is assumed to be the same as the wall height. Below-grade ICF wall R-values are calculated as:

$$\text{ICF R-value} = 0.68 + \text{Rm} \times 0.89 \tag{A.19}$$

where Rm = the manufacturer's reported R-value, as entered by the user. (Refer to Section A.2.6 for additional information on ICFs.)

Other Basement Walls

For *Other* wall types, the depth of insulation is assumed to be the same as the wall height. The user must enter and be prepared to justify an assembly U-factor. The wall R-value is

$$\text{Other Wall R-value} = \frac{1}{\text{Assembly U-factor}} \tag{A.20}$$

A.4.4 Required Basement U_o in Locations Without Requirements

Basement wall requirements in the MEC and IECC do not apply to locations with HDD <1500. In MEC*check*, however, the user may receive credit for insulating basement walls in these locations. In this case, the requirement is assumed to be an uninsulated wall of the type selected by the user, with some exceptions.

A.5 Crawl Space Walls

The methodology for calculating heat loss through crawl space walls is identical to that described above for basement walls.

The crawl space wall calculation requires the same inputs as the basement wall calculation. In computing the code building UA, these same inputs are used except for the insulation R-value. For the code building, the required UA is derived from Equation (A.15), except that the MEC U_o used in this equation comes from the crawl space wall requirement rather than the basement wall requirement.

For crawl space walls having an inside ground surface 12 in. or more below the outside finished ground surface, the code only requires the insulation to extend 12 in. below the outside grade. In this case, the code building in the UA comparison is assumed to be fully insulated above outside grade and insulated to 12 in. below outside grade.

For crawl space walls having an inside ground surface less than 12 in. below outside grade, the code requires the insulation extend downward vertically and inward horizontally a total distance of 24 in. from the outside grade surface. In this case, it is necessary to account for the horizontal insulation required by the code in the MEC*check* software (DOE 1995c). The *1989 ASHRAE Handbook: Fundamentals* does not provide an estimate of the effect of horizontal insulation on the heat loss through the crawl space floor (ASHRAE 1989). Therefore, the horizontal insulation is accounted for in the UA calculation by assuming both the insulation and the wall extend down vertically 24 in. below the outside grade. In the UA calculation, this assumption increases the area of the crawl space wall beyond the actual vertical wall area. This vertical insulation assumption, when the insulation is actually horizontal, is reasonable because the length of the heat flow path through the soil to bypass the insulation is about the same in either case. The same assumption is made for both the code building and the proposed building.

A.6 Slab-On-Grade Floors

To calculate foundation heat losses, heat loss values for slabs were taken from Huang et al. (1988).[a] In this methodology, the heat loss unit for below-grade foundations is in terms of linear feet of perimeter (F-factor) instead of square feet of surface area (U_o-factor). A U_o-factor is multiplied by a surface area and degree-days to obtain the total heat loss. An F-factor is multiplied by a perimeter length and degree-days to obtain the total heat loss. These F-factors are shown in Table A.27. The F-factors are given in the referenced paper for insulation both on the exterior and interior of the foundation wall. The

(a) Sufficient data were not available from this source to model heat losses from common basement and crawl space insulation configurations, so this source was used only for slab-on-grade foundations.

F-factors vary only slightly by insulation placement, so the average of the exterior and interior insulation placement was used. The same F-factors were used for heated and unheated slabs. Huang et al. (1988) did not present F-factors for insulation levels above R-10 for slab insulation 2-ft deep; therefore, F-factors were considered to be constant for insulation levels above R-10 for this configuration. Additionally, F-factors were considered to be constant for all insulation levels above R-20, regardless of insulation depth. This assumption was deemed reasonable because little is gained by the additional insulation (above R-20, most of the heat loss occurs under and around the insulation).

Table A.27. Slab-On-Grade Floor F-Factors

Insulation R-Value	2-ft Insulation Depth	4-ft Insulation Depth
R-0	1.043	1.041
R-5	0.804	0.744
R-10	0.767	0.684
R-15	0.767	0.654
R-20 and Above	0.767	0.636

In the MEC*check* software, slab perimeters can be insulated to any depth up to 4 ft (DOE 1995c). To calculate heat loss for any combination of insulation depth and R-value, quadratic curves were fit through the data in Table A.27. The resulting quadratic Equation (A.21) gives the F-factor as a function of insulation depth. The applicable coefficients for Equation (A.21) are given in Table A.28 and are determined by the insulation R-value. R-values range from R-0 to R-20.

$$\text{F-factor} = \text{intercept} + \text{coef 1} \times \text{depth} + \text{coef 2} \times \text{depth}^2 \qquad \text{(A.21)}$$

where depth = the distance the insulation extends downward (or downward and outward) in feet.

Table A.28. Coefficients for Slab F-Factor Equation (A.21)

R-Value	intercept	coef 1	coef 2
R-0	1.042	0.0013	-0.0004
R-1	1.042	-0.0967	0.0144
R-2	1.042	-0.1293	0.0188
R-3	1.042	-0.1459	0.0207
R-4	1.042	-0.1562	0.0217
R-5	1.042	-0.1635	0.0223
R-6	1.042	-0.1692	0.0227
R-7	1.042	-0.1739	0.0230
R-8	1.042	-0.1781	0.0233
R-9	1.042	-0.1819	0.0236
R-10	1.042	-0.1855	0.0240
R-11	1.042	-0.1836	0.0231
R-12	1.042	-0.1819	0.0222
R-13	1.042	-0.1805	0.0215
R-14	1.042	-0.1792	0.0208
R-15	1.042	-0.1780	0.0203
R-16	1.042	-0.1770	0.0197
R-17	1.042	-0.1760	0.0193
R-18	1.042	-0.1751	0.0188
R-19	1.042	-0.1743	0.0184
R-20	1.042	-0.1735	0.0180

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Appendix B

Prescriptive Packages Prototype House Sensitivity Analysis

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Prescriptive Packages Prototype House Sensitivity Analysis

Although the prescriptive packages apply to all residential dwellings except high-rise multifamily buildings, the analysis used to create the packages was performed using only two building prototypes (see Section 5.2.3) combined with four different foundation insulation configurations. To establish the prescriptive packages, specific envelope component areas had to be assumed for the prototypes. If the relative areas of each envelope component vary significantly from those assumed for the prototypes, the prescriptive packages lose some accuracy in matching (i.e., meeting or slightly exceeding) the Model Energy Code (MEC) envelope requirements. For example, a prescriptive package having relatively low wall R-value requirements and relatively high R-value requirements for other components may not comply with the MEC for a house with a very high amount of wall area. To quantify the impact of applying the prescriptive packages to different house types, we conducted a sensitivity analysis using five different single-family houses with the envelope dimensions given in Table B.1. Section B.1 documents the results of the sensitivity analysis. All analyses were based on 1992 MEC requirements (CABO 1992).

A secondary aspect of this sensitivity analysis was an assessment of the relative accuracy of two different methods for treating window area in the prescriptive packages: 1) treating the window area as a percentage of the gross exterior wall area and 2) treating the window area as a percentage of the conditioned floor area. The accuracy of these two methods is discussed in Section B.2.

Table B.1. Prototype Houses Used in Sensitivity Analysis

Split Level House (baseline used to create the prescriptive packages)	
Gross Wall Area	1736 ft^2
Ceiling Area	1418 ft^2
Floor Area	1418 ft^2
Perimeter	155 ft^2
Door Area	56 ft^2
Conditioned Floor Area	1890 ft^2
Window Area (% of wall area)	15%
Moderate-Size Ranch House	
Gross Wall Area	1488 ft^2
Ceiling Area	1890 ft^2
Floor Area	1890 ft^2
Perimeter	186 ft^2
Door Area	56 ft^2
Conditioned Floor Area	1890 ft^2
Window Area (% of wall area)	15%
Moderate-Size Two-Story House	
Gross Wall Area	1984 ft^2
Ceiling Area	945 ft^2
Floor Area	945 ft^2
Perimeter	124 ft^2
Door Area	56 ft^2
Conditioned Floor Area	1890 ft^2
Window Area (% of wall area)	15%
Small Ranch House	
Gross Wall Area	1072 ft^2
Ceiling Area	990 ft^2
Floor Area	990 ft^2
Perimeter	134 ft^2
Door Area	36 ft^2
Conditioned Floor Area	990 ft^2
Window Area (% of wall area)	12%
Large Two-Story House	
Gross Wall Area	3360 ft^2
Ceiling Area	2700 ft^2
Floor Area	2700 ft^2
Perimeter	210 ft^2
Door Area	56 ft^2
Conditioned Floor Area	5400 ft^2
Window Area (% of wall area)	18%

B.1 Sensitivity to House Dimensions

The intent in developing the prescriptive packages was that a home meeting the requirements of any of the prescriptive packages would meet the MEC envelope requirements; i.e., the whole-building UA of the resulting home should be equal to or slightly below the whole-building UA of the same home built to comply exactly with each of the MEC envelope component requirements. This analysis attempts to answer the question, "How accurate are the prescriptive packages in terms of meeting or slightly exceeding the MEC requirements when applied to common house designs with different dimensions?"

B.1.1 Methodology

To determine the impact of applying the prescriptive packages to alternative house types, the difference given by Equation (B.1) was computed for the prescriptive packages developed for all climate zones in the continental United States (Zones 1-17).[a]

$$\text{Percent Difference} = \frac{\text{MEC UA} - \text{Package UA}}{\text{MEC UA}} \times 100 \qquad \text{(B.1)}$$

where MEC UA = the maximum whole-building UA allowed by the MEC for the house type under consideration.

Package UA = the whole-building UA of the house type under consideration when built to the specifications of a given prescriptive package.

The prescriptive packages were applied to each of the five basic home types shown in Table B.1 using three different foundation types, for a total of 15 house configurations. At the time of this sensitivity analysis, a total of 374 prescriptive packages were proposed for 17 zones across the country.[b] Of these, 358 prescriptive packages were used in the analysis.[c] For each house configuration, Equation (B.1) was computed for each of the 358 packages and each of the following three foundations types:

1) a crawl space with floor insulation
2) a basement with insulated walls
3) a slab-on-grade foundation.

(a) Packages for Zones 18 and 19, which apply only to Alaska, had not yet been developed at the time this analysis was done.

(b) This analysis was based on the Version 1.0 Prescriptive Packages developed for the 1992 MEC.

(c) Sixteen packages were removed from the sensitivity analysis because they exceeded the MEC requirements by a large margin and therefore had a large effect on the average differences. For example, in Zones 1 and 2, several packages were offered with no floor insulation requirement (R-0). These packages tend to comply by a large margin if the foundation is a basement or slab-on-grade, even though these foundation types have no insulation.

Note that Equation (B.1) can give both positive and negative differences. A negative difference indicates that the house built to the MEC requirements has a lower UA than the house built to the levels specified by the prescriptive package under question. Therefore, a negative difference indicates that the prescriptive package does not comply with the thermal envelope requirements of the MEC for the particular house type. A positive difference indicates that the prescriptive package exceeds the MEC thermal envelope requirements.

Two types of averages across all the climate zones and prescriptive packages were generated:

1) Table B.2 shows average absolute percent differences that were generated by Equation (B.2). To derive these averages, the absolute value of the individual differences for each package were summed and then divided by the number of packages.

$$\text{Average Absolute \% Diff.} = \frac{\sum_{i=1}^{358} \left| \frac{\text{MEC UA} - \text{Package UA}[i]}{\text{MEC UA}} \right|}{358} \times 100 \qquad \text{(B.2)}$$

2) Table B.3 shows the average difference without using absolute values. Table B.3 indicates whether the packages, on average, exceed or fall short the MEC UA requirements. A positive number indicates the MEC requirements are exceeded on average. A negative number indicates the MEC requirements are not met on average. Equation (B.3) was used to calculate the overall average percent differences shown in Table B.3. To derive these averages, the individual differences for each prescriptive package were summed and then divided by the number of prescriptive packages (358).

$$\text{Average Absolute \% Diff.} = \frac{\sum_{i=1}^{358} \left(\frac{\text{MEC UA} - \text{Package UA}[i]}{\text{MEC UA}} \right)}{358} \times 100 \qquad \text{(B.3)}$$

Table B.2. Average Absolute Value of Percent Difference

Home Type	Percent Error		
	Floors	**Basement**	**Slabs**
Split Level	1.4	1.7	1.1
Moderate Ranch House	1.8	1.6	1.5
Moderate Two-Story House	2.8	2.5	2.3
Small Ranch House	1.2	1.8	1.3
Large Two-Story House	4.1	3.6	3.2

Table B.3. Average Percent Difference

Home Type	Percent Error		
	Floors	**Basement**	**Slabs**
Split Level	1.3	1.6	0.6
Moderate Ranch House	0.4	0.9	-0.4
Moderate Two-Story House	2.2	2.3	1.7
Small Ranch House	1.1	1.6	0.5
Large Two-Story House	4.1	3.6	3.1

B.1.2 Interpreting the Results

Table B.2 indicates the average differences of the absolute values of the percentage differences between prescriptive package requirements and the MEC requirements are reasonably small, with a maximum difference of 4.1% and a difference of less than 2% for most house/foundation configurations. The percentage differences were not large enough to warrant additional sets of prescriptive packages for different prototypes.

A positive difference in Table B.3 indicates that on the average the prescriptive packages exceed the MEC requirements. A negative difference indicates that on the average the prescriptive packages do not meet the MEC requirements for the given house configuration. The values in Table B.3 indicate that only one house configuration (the moderately-sized ranch house with a slab foundation) produced a very small negative average of -0.4%. The maximum average percent difference across all house types examined was 4.1% in the direction of exceeding the MEC requirements.

Table B.3 indicates that the prescriptive packages are conservative in the sense that they generally result in homes that slightly exceed the MEC requirements. The differences for the split-level house should be very close to zero because the prescriptive packages were based on that prototype. The average difference is 1.3% for floor foundations, 1.6% for basement foundations, and 0.6% for slab foundations. The reason these packages exceed the MEC requirements is that only commonly available R-values were used in the analysis, making it virtually impossible to exactly meet but not exceed the MEC requirements. For example, although a package might comply with R-17 floor insulation, the requirement was listed as R-19 because R-19 was the closest complying floor insulation level that was used in the analysis.

B.2 Sensitivity to Window Area Calculation

The total heat loss rate (the UA) of any residential building is greatly affected by the window area for two reasons. First, windows normally have much greater heat loss rates (i.e., much lower R-values) than the other major envelope components (opaque walls, ceilings, and foundations). Second, window area can vary greatly from house to house; low-end houses tend to have a small amount of window area while luxury houses can have a huge amount of window area. The window area must be accounted for in the prescriptive packages─simply presenting a window U-factor requirement without a window area limitation will not allow compliance with the MEC to be determined.

The window area cannot be represented in square feet (e.g., 100 ft^2, 150 ft^2, etc.) in the prescriptive packages because this representation does not account for the window area relative to the area of the other components. We considered two different methods for addressing the window area:

1. window area as a percentage of conditioned floor area
2. window area as a percentage of gross wall area.

Presenting the prescriptive packages as a percentage of the conditioned floor area is simpler for the builder because the conditioned floor area is usually simpler to calculate than the exterior wall area and is normally a known quantity. However, reviewers responded overwhelmingly in favor of computing the window area as a percentage of gross wall area. To help formulate a decision on this issue, we reviewed the impact the two calculation methods had on achieving compliance across all climates zones for the various single-family house types and foundation types. We determined that representing the window area as a percentage of wall area is more accurate in matching (meeting or slightly exceeding) the MEC requirements.

The MEC requirements are a function of the wall area, the ceiling area, and the foundation area. The problem with representing the window area as a percentage of the conditioned floor area is that the conditioned floor area is not an equal proportion of the total envelope area for different house types. The conditioned floor area of the split-level house is 41% of the total envelope area, but the conditioned floor area of the large two-story house is much higher—62% of the total envelope area. The prescriptive packages were generated for the split-level house. If the window area is represented by a percentage of the conditioned floor area, the 358 packages fail to comply with the MEC by an average of 14.8% for the large two-story house with a window area of 18% of the conditioned floor area. This matching of the MEC requirements is much poorer than the 4.1% difference for the two-story house with the windows area represented as a percentage (18%) of wall area (see Table B.2). The window area as a percentage of conditioned floor area approach is also less accurate for the other single-family house prototypes. Window area is represented as a percentage of wall area in the prescriptive packages primarily because of the greater accuracy in matching the MEC requirements.

B.3 References

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