PNNL-14864-1-2

Methodology for Developing the RES*check*™ Software through Version 3.7

R. Bartlett
L. M. Connell
R. G. Lucas
R. W. Schultz
Z. T. Taylor
J. D. Wiberg

October 2005

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

♲ This document was printed on recycled paper.

PNNL-14864-1-2

Methodology for Developing the REScheck^{TM} Software through Version 3.7

R. Bartlett
L. M. Connell
R. G. Lucas
R.W. Schultz
Z. T. Taylor
J. D. Wiberg

October 2005

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The Energy Policy Act of 1992 (EPAct, Public Law 102-486) establishes the 1992 Model Energy Code (MEC), published by the Council of American Building Officials (CABO), as the target for several energy-related requirements for residential buildings (CABO 1992). The U.S. Department of Housing and Urban Development (HUD) and the U.S. Department of Agriculture (via Rural Economic and Community Development [RECD] [formerly Farmers Home Administration]) are required to establish standards for government-assisted housing that "meet or exceed the requirements of the Council of American Building Officials Model Energy Code, 1992." CABO has issued 1992, 1993, and 1995 editions of the MEC (CABO 1992, 1993, and 1995).

Effective December 4, 1995, CABO assigned all rights and responsibilities for the MEC to the International Code Council (ICC). The first edition of the ICC's International Energy Conservation Code (ICC 1998) issued in 1998 therefore replaced the 1995 edition of the MEC. The 1998 IECC incorporates the provisions of the 1995 MEC and includes the technical content of the MEC as modified by approved changes from the 1995, 1996, and 1997 code development cycles. The ICC subsequently issued the 2000 edition of the IECC (ICC 1999). Many states and local jurisdictions have adopted one edition of the MEC or IECC as the basis for their energy code.

In a Federal Register notice issued January 10, 2001 (FR Vol. 99, No. 7, page 1964), the U.S. Department of Energy (DOE) concluded that the 1998 and 2000 editions of the IECC improve energy efficiency over the 1995 MEC. DOE has previously issued notices that the 1993 and 1995 MEC also improved energy efficiency compared to the preceding editions.

To help builders comply with the MEC and IECC requirements, and to help HUD, RECD, and state and local code officials enforce these code requirements, DOE tasked Pacific Northwest National Laboratory (PNNL)(a) with developing the MEC*check*™ compliance materials. In November 2002, MEC*check* was renamed RES*check*™ to better identify it as a residential code compliance tool. The "MEC" in MEC*check* was outdated because it was taken from the Model Energy Code, which has been succeeded by the IECC. The "RES" in RES*check* is also a better fit with the companion commercial product, COM*check*™.

The easy-to-use RES*check* compliance materials include a compliance and enforcement manual for all the MEC and IECC requirements and three compliance approaches for meeting the code's thermal envelope requirements—prescriptive packages, software, and a trade-off worksheet (included in the compliance manual). The compliance materials can be used for single-family and low-rise multifamily dwellings. The materials allow building energy efficiency measures (such as insulation levels) to be "traded off" against each other, allowing a wide variety of building designs to comply with the code.

This report explains the methodology used to develop Version 3.7 of the RES*check* software developed for the 1992, 1993, and 1995 editions of the MEC, and the 1998, 2000, and 2003 editions of

---

(a) Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under contract DE-AC06-76RLO 1830.

the IECC. Although some requirements contained in these codes have changed, the methodology used to develop the RES*check* software for these five editions is similar.

RES*check* assists builders in meeting the most complicated part of the code—the building envelope U_o-, U-, and R-value requirements in Section 502 of the code. This document details the calculations and assumptions underlying the treatment of the code requirements in RES*check*, with a major emphasis on the building envelope requirements.

Contents

Summary iii
1.0 Introduction 1.1
2.0 Differences in Various Editions of the MEC and IECC 2.1
3.0 Methodology Summary 3.1
4.0 Simplifying Miscellaneous Code Requirements 4.1
  4.1 Simplified Duct R-Value Requirements 4.1
    4.1.1 1992 MEC Duct Requirements 4.1
    4.1.2 1993 and 1995 MEC and IECC Duct Requirements 4.2
    4.1.3 2003 IECC Duct Requirements 4.2
  4.2 Simplified Vapor Retarder Exemption 4.3
5.0 Software Approach 5.1
  5.1 Proposed Building UA Calculation 5.1
  5.2 Code Building UA Calculation 5.1
  5.3 Individual Component UA Calculations 5.3
    5.3.1 Ceiling UA 5.3
    5.3.2 Wall UA 5.4
    5.3.3 Mass Wall UA 5.4
    5.3.4 Floor-Over-Unheated-Space UA 5.6
    5.3.5 Basement Wall UA 5.6
    5.3.6 Crawl Space Wall UA 5.7
    5.3.7 Slab-On-Grade Floor UA 5.7
  5.4 Solar Heat Gain Compliance 5.7
  5.5 Weather Data Used in the Software 5.8
6.0 Equipment/Envelope Trade-Off 6.1
  6.1 Background and Assumptions 6.2
    6.1.1 Select Prototype Building 6.2
    6.1.2 Estimate Energy Consumption 6.3
    6.1.3 Select Climate Zones 6.3
  6.2 Develop Equipment Efficiency Trade-Off 6.3
    6.2.1 Identify MEC Baseline 6.4
    6.2.2 Calculate Baseline Energy Consumption 6.5
    6.2.3 Identify Adjusted U_o 6.5
    6.2.4 Identify Trade-Off Ratios and HDD Relationships 6.6
    6.2.5 Aggregate Zones 6.9
7.0 References 7.1

Appendix A - Envelope Component Uo-Factor Calculations A.1

Appendix B – Arkansas B.1

Appendix C – Georgia C.1
Appendix D – Massachusetts D.1
Appendix E – Minnesota E.1
Appendix F – New Hampshire F.1
Appendix G – New Jersey G.1
Appendix H – New York H.1
Appendix I – SES/Pima County I.1
Appendix J – Vermont J.1
Appendix K – Wisconsin K.1
Appendix L – AreaCalc L.1

Figures

6.1 Heating Trade-Off Ratio vs. Heating Degree-Days 6.7

6.2 Cooling Trade-Off Ratio vs. Heating Degree-Days 6.8

Tables

Table 4.1. 2003 IECC Duct Requirements 4.3

Table 4.2. Locations Not Requiring Vapor Retarders on Warm-in-Winter Side 4.4

Table 5.1. Construction Types Offered by RES*check* Software and Required Inputs 5.2

Table 5.2. MEC and IECC Building Component Requirements 5.3

Table 5.3. Input Ranges Allowed by RES*check* Software 5.4

Table 6.1. ARES Cities Available for Each Climate Zone 6.4

Table 6.2. MEC Baseline Prototype Configurations 6.5

Table 6.3. Zonal Trade-Off Ratios 6.10

1.0 Introduction

The Energy Policy Act of 1992 (EPAct, Public Law 102-486) establishes the 1992 Model Energy Code (MEC), published by the Council of American Building Officials (CABO), as the target for several energy-related requirements for residential buildings (CABO 1992). The U.S. Department of Housing and Urban Development (HUD) and the U.S. Department of Agriculture (via Rural Economic and Community Development [RECD] [formerly Farmers Home Administration]) are required to establish standards for government-assisted housing that "meet or exceed the requirements of the Council of American Building Officials Model Energy Code, 1992." CABO has issued 1992, 1993, and 1995 editions of the MEC (CABO 1992, 1993, and 1995).

Effective December 4, 1995, CABO assigned all rights and responsibilities for the MEC to the International Code Council (ICC). The first edition of the ICC's International Energy Conservation Code (IECC) issued in 1998 (ICC 1998) therefore replaced the 1995 edition of the MEC. The 1998 IECC incorporates the provisions of the 1995 MEC and includes the technical content of the MEC as modified by approved changes from the 1995, 1996, and 1997 code development cycles. The ICC has subsequently issued the 2000 edition of the IECC (ICC 1999). Many states and local jurisdictions have adopted one edition of the MEC or IECC as the basis for their energy code.

To help builders comply with the MEC and IECC requirements, and to help HUD, RECD, and state and local code officials enforce these code requirements, DOE tasked Pacific Northwest National Laboratory (PNNL) with developing the MEC*check*™ compliance materials. In November 2002, MEC*check* was renamed RES*check*™ to better identify it as a residential code compliance tool. The "MEC" in MEC*check* was outdated because it was taken from the Model Energy Code, which has been succeeded by the IECC. The "RES" in RES*check* is also a better fit with the companion commercial product, COM*check*™.

The easy-to-use RES*check* compliance materials include a compliance and enforcement manual for all the MEC and IECC requirements and three compliance approaches for meeting the code's thermal envelope requirements─prescriptive packages, software, and a trade-off worksheet (included in the compliance manual). The compliance materials can be used for single-family and low-rise multifamily dwellings. The materials allow building energy efficiency measures (such as insulation levels) to be "traded off" against each other, allowing a wide variety of building designs to comply with the code.

PNNL developed RES*check* compliance materials for three different editions of the MEC (CABO 1992, 1993, and 1995) and the three editions of the IECC (ICC 1998, 1999, and 2003). This report explains the methodology used to develop Version 3.6 of the RES*check* software developed for these editions of the MEC and IECC. Although some requirements contained in the MEC and IECC have changed over time, the methodology used to develop the RES*check* software for these three editions is similar.

Section 2.0 of this report summarizes the differences in the various editions of the MEC and IECC. Section 3.0 provides a summary of the methodology used to develop the RES*check* software. Section 4.0 gives the technical basis for the simplified presentation of some of the code's miscellaneous requirements in the RES*check* materials. The methodology for the RES*check* software is discussed in Section 5.0. Section 6.0 discusses the methodology for trading increased heating or cooling efficiency for lowered envelope efficiency in the RES*check* software. All references cited in this report are identified in Section 7.0. Appendix A documents the assumptions and equations used in the calculation of the envelope component U_o-factors for the RES*check* software. Documentation for specific state energy codes supported in the RES*check* software has been added to this report as additional appendices. These appendices are intended to provide technical documentation for features and changes made for state-specific codes that differ from the standard features that support compliance with the national model codes. Documentation for the AreaCalc software is also included as an appendix.

2.0 Differences in Various Editions of the MEC and IECC

The 1993 MEC (CABO 1993) contains much more stringent requirements for walls in multifamily buildings than the 1992 MEC (CABO 1992). For mild climates, the 1993 MEC contains more stringent requirements for walls in single-family houses and ceilings in all residential buildings. The 1993 MEC also has different duct insulation requirements (see Section 4.1) and other minor differences from the 1992 MEC. However, these differences did not affect the methodology used to develop the RES*check* software.

The 1995 MEC (CABO 1995) is similar to the 1993 MEC, but the 1995 MEC references the *1993 ASHRAE Handbook: Fundamentals* (ASHRAE 1993), whereas the 1993 MEC references the *1989 ASHRAE Handbook: Fundamentals* (ASHRAE 1989a). The 1993 handbook specifies that wood-frame walls have a higher percentage of framing area than that specified in the 1989 handbook. The wall framing area percentages from the ASHRAE handbooks were used in the calculation of overall wall U-factors (U_o-factors) in the RES*check* materials. Because wood framing has a lower R-value than cavity insulation, using the increased framing area percentage results in a higher wall U_o-factor requirement when determining compliance with the 1995 MEC relative to the 1993 (or 1992) MEC. The differences in wall U_o-factors are shown in Appendix A. Otherwise, the methodology used to develop the RES*check* materials for the 1993 and 1995 MEC is identical.

The 1998 IECC (ICC 1998) contains a variety of revisions to the 1995 MEC. The most notable revision is that glazed fenestration products (windows and doors) in new housing in locations with less than 3500 heating degree-days (HDDs) (approximately the southern quarter of the United States) must have an average solar heat gain coefficient (SHGC) of 0.4 or less. Other code changes include a requirement for heat traps on water heaters and provisions for skylight shaft insulation. Also, new prescriptive compliance paths have been added, including paths for small additions and window replacements. None of these code changes affect any of the calculations or methodology underlying RES*check*; the only changes to RES*check* are the addition of these new requirements in the “Inspection Checklist” printout produced by the software. The 2000 IECC (ICC 1999) contains relatively minor changes in requirements compared to the 1998 IECC. Exposed foundation insulation is required to have a weather-resistant protective coating. Additional requirements have been added for replacement windows. The duct sealing requirements have been revised. None of these changes affect the methodology used to develop RES*check*. The 2003 IECC (ICC 2003) includes steel-frame joist/rafter assembly ceilings, steel-frame truss assembly ceilings, and steel-frame floors over unheated spaces.

3.0 Methodology Summary

Users can use one of the three RES*check* products (prescriptive packages, software, or trade-off worksheet) to demonstrate compliance with the MEC thermal envelope U_o[a] (thermal transmittance) requirements. We developed all three approaches to use trade-offs of energy efficiency measures against each other, allowing a wide variety of building designs to comply with the code.[b] Trade-offs allow parts of a residential building to not meet individual MEC envelope component requirements if other components exceed the requirements, as long as the annual energy consumption does not increase (the code allows these trade-offs). The RES*check* materials thus promote design flexibility while still meeting code requirements.

The code's component performance approach (Chapter 5) specifies maximum U_o-factor requirements for walls, ceilings, floors, crawl space walls, and basement walls, and minimum R-value requirements for slab perimeter insulation. Section 502.1.1 of the MEC and Section 502.2.2 of the IECC state that the U_o-factor or U-factor of a given assembly may be increased or the R-factor of a given assembly may be decreased if the total heat gain or loss for the entire building does not exceed the total resulting from conformance to these requirements. Chapter 4 of the code goes even further by allowing any design that does not increase annual energy consumption relative to the component performance approach of Chapter 5 to comply (the code addresses space heating and cooling and water heating).

The RES*check* products are heavily based on U-factor x Area (UA, the heat loss/gain rate) calculations for each building assembly to determine the whole-building UA for the building design. The whole-building UA from a building conforming to the code requirements (the code building) is compared against the UA from the user's building design (the proposed building). If the total heat loss (represented as a UA) through the envelope of the user's building design does not exceed the total heat loss from the building conforming to the code, then the user's design passes. The following equation is used to compute both the UA for the user's proposed building and the UA for the code building:

$$\text{Whole-Building UA} = U_1 \times \text{Size}_1 + U_2 \times \text{Size}_2 + \ldots + U_n \times \text{Size}_n \tag{3.1}$$

where U_n = the U-factor or F-factor of component n (component U-factors and F-factors may be different for the proposed and code buildings).

Size_n = the area (ft^2) or the perimeter (ft) of component n (component sizes are the same for both the proposed and code buildings).

(a) Throughout this document, the term "U_o" is the overall *conductive* thermal transmission coefficient of an envelope component or the envelope of the entire residential structure. This coefficient excludes, for example, the effects of mechanical ventilation and natural air infiltration.

(b) In this document, "the code" refers to the 1992, 1993, and 1995 editions of the MEC (CABO 1992, 1993, and 1995) and the 1998, 2000, and 2003 editions of the IECC (ICC 1998, 2000, and 2003).

The prescriptive packages and software offer trade-offs for high-efficiency heating and cooling equipment. This type of trade-off is allowed in Chapter 4 of the code. This credit is applied as a percentage reduction of the user's proposed building UA. Additional trade-offs are planned for future versions of the RES*check* materials.

4.0 Simplifying Miscellaneous Code Requirements

Some of the requirements in the code are presented as a function of climate and it is not readily apparent what specific requirement applies for any given location. To make the code simpler to use, these requirements are more clearly presented in the RES*check* materials. This section gives the technical basis for the simplified presentation of some of the code's miscellaneous requirements. These miscellaneous requirements are presented in the RES*check* software's *Inspection Checklist*. This section does not address the thermal transmittance requirements for the thermal envelope, which are covered in Sections 5.0 through 7.0.

4.1 Simplified Duct R-Value Requirements

The code requires that ducts be insulated, with some exceptions.

4.1.1 1992 MEC Duct Requirements

A calculation is required to determine the duct insulation R-value requirement in the 1992 MEC. This calculation is not intuitive and often results in a minimum R-value requirement that does not match the R-values of commercially available products. The R-value requirement can also vary within different locations in a house.

The required duct insulation R-value in the 1992 MEC is equal to the design temperature differential between the air in the duct and the duct surface temperature divided by 15.

$$\text{Insulation R - Value} = \frac{\Delta t}{15} \tag{4.1}$$

where Δt = the design temperature differential between the air in the duct and the duct surface in degrees Fahrenheit (°F).

Because of the complexity in determining the 1992 MEC duct insulation requirements, we established a simple table of minimum duct insulation R-values for RES*check*. These R-values depend on duct location and climate zone.

To establish simplified duct insulation requirements, we made assumptions about the temperatures of conditioned air in ducts and the air outside the ducts. We assumed supply ducts contain 130°F air in the heating season and 60°F air in the cooling season, and return ducts contain 70°F air in the heating season and 75°F air in the cooling season. We obtained design temperatures at 2.5% and 97.5% conditions for approximately 700 U.S. locations (ASHRAE 1993). As specified in Table 503.9.1 of the 1992 MEC, the heating season attic temperature was set to 10°F above the outdoor design temperature. This same temperature was used for ducts located in crawl spaces. Unheated basement temperatures were assumed to be halfway between 70°F and the outdoor design temperature in the heating season. For the cooling season, attic temperatures were set at 140°F, as specified in Table 503.9.1 for attics with moderate roof slopes. For crawl spaces and basements, cooling season temperature differences between duct air and outside duct surfaces are small. The minimum duct insulation requirements are therefore determined by heating season temperature differences.

We calculated minimum duct R-value requirements based on the temperatures described above. We grouped all ducts together, except for ducts in unheated basements. We rounded these R-values to match commonly available duct insulation products. We set unheated basement R-value requirements to R-6 in Zone 1, although R-4 is required, to simplify the duct R-value table. This setting will have little effect because few buildings with basements are built in Zone 1, which includes southern Florida and Hawaii (NAHB 1991). We set return duct R-value requirements equal to supply duct requirements for simplicity and to reduce confusion at the building site. Note that the total surface area of return ducts is typically much smaller than the total surface area of supply ducts.

4.1.2 1993 and 1995 MEC and IECC Duct Requirements

The duct insulation requirements in the 1993 and 1995 MEC and the 1998 and 2000 IECC differ from those in the 1992 MEC. The insulation R-value requirements in these later four editions are identical to those in *ASHRAE/IES Standard 90.1-1989* (ASHRAE 1989b). These codes contain a table with separate R-value requirements for ducts inside the building envelope boundary or in unconditioned spaces, and ducts outside the building. For ducts inside the building envelope boundary or in unconditioned spaces, R-5 is required when the temperature difference between the heated or cooled air in the duct and the temperature at design conditions of the space where the duct is located is 40°F or more. Because temperatures of heated air in ducts will exceed 100°F (except perhaps for heat pumps) and temperatures in unconditioned spaces (e.g., unheated basements, crawl spaces, and attics) will normally drop below 60°F during the winter, we assumed a temperature difference of 40°F to occur in all climate zones. Therefore, R-5 insulation is required. The 40°F difference will also occur for ducts in attics during the summer in most climates.

For ducts outside the building, the duct R-value requirements depend on both cooling degree-days (CDD), base 65°F, and heating degree-days (HDD), base 65°F. We determined average CDDs (weighted by housing starts) for each of the 19 U.S. climate zones from climate data for 881 cities. Note that in Table 2 of the RES*check* Basic Requirements Guide, the requirements in Zones 5 through 14 are actually lower than the requirements in Zones 1 through 4 because the CDD values in Zones 1 through 4 result in higher R-value requirements for cooling mode than for heating mode.

4.1.3 2003 IECC Duct Requirements

In the 2003 IECC, the duct requirements were changed to differentiate between supply and return ducts. The requirements are listed in Table 4.1.

Table 4.1. 2003 IECC Duct Requirements

	Insulation R-Value			
	Ducts in unconditioned attics or outside building		**Ducts in unconditioned basements, crawl spaces, garages, and other unconditioned spaces**	
Annual Heating Degree Days	**Supply**	**Return**	**Supply**	**Return**
< 1500	8	4	4	0
1,500 to 3,500	8	4	6	2
3,501 to 7,500	8	4	8	2
> 7500	11	6	11	2

4.2 Simplified Vapor Retarder Exemption

Section 502.1.4 of the 1992, 1993, and 1995 MEC, Section 502.1.2 of the 1998 IECC, and Section 502.1.1 of the 2000 and 2003 IECC require that vapor retarders be installed on the warm-in-winter side of the thermal insulation in walls, ceilings, and floors. The following locations in hot and humid climates are exempted from this requirement:

- locations where 67°F or higher wet-bulb temperatures occur for 3000 or more hours during the warmest six consecutive months of the year, or

- locations where 73°F or higher wet-bulb temperatures occur for 1500 or more hours during the warmest six consecutive months of the year.

Most builders and code officials will not have access to temperature data of this type and will therefore be unable to determine whether a building qualifies for the exemption.

To simplify this exemption, we evaluated Test Reference Year (TRY) and Weather Year for Energy Calculation (WYEC) data for over 200 locations. Based on these data, locations exempted from the vapor retarder requirement on the warm-in-winter side of the wall were presented by state and climate zone. (The climate zones, presented in the maps that accompany the Prescriptive Packages, fall along county boundaries [DOE 1995b].)

The TRY and WYEC data provided annual totals of all hours above the cutoff wet-bulb temperatures and all the hours were assumed to occur in the warmest six consecutive months of the year. All cities in Florida, Hawaii, Louisiana, and Mississippi had more than the required number of hot and humid hours, therefore qualifying for the exemption. Six states had some locations that qualified for the exemption and some locations that did not qualify. Table 4.2 shows the number of hours at or above the cutoff wet-bulb temperatures for cities in these six states with the HDD for each city. All other states had no locations that qualified for the exemption. Based on the results shown in Table 4.2, we selected climate zones in the six southern states that qualify for the exemption.

Table 4.2. Locations Not Requiring Vapor Retarders on Warm-in-Winter Side

Location	Number of Hours Wet-Bulb Temperature At or Above 67°F	Number of Hours Wet-Bulb Temperature At or Above 73°F	HDD, Base 65°F
Alabama			
Mobile	3975	2182	1702
Montgomery	3281	1859	2224
Arkansas			
Fort Smith	2993	1548	3478
Little Rock	3070	1874	3155
Florida			
All locations	--	--	--
Georgia			
Augusta	3088	1398	2565
Macon	3173	1420	2334
Savannah	3585	1959	1847
Hawaii			
All locations	--	--	--
Louisiana			
All locations	--	--	--
Mississippi			
All locations	--	--	--
North Carolina			
Cape Hatteras	3270	1826	2698
Cherry Point	3235	1494	2556
South Carolina			
Charleston	3581	1918	1866
Columbia	3139	1547	2242/2649
Texas			
Austin	3908	2445	1688
Brownsville	5884	4109	635
Dallas	5505	4005	1016
Del Rio	3449	2140	2407
Forth Worth	4040	1783	1506
Houston	3147	1545	2407
Kingsville	4358	3009	1599
Laredo	5432	4030	911
Lufkin	4815	3205	1025
Port Arthur	4140	2527	1951
San Antonio	4299	2955	1499
Sherman	4109	2371	1644
Waco	3089 3621	1516 2139	289 2179
Tennessee			
Memphis	3244	1653	3082

5.0 Software Approach

The RES*check* software performs a simple UA calculation for each building assembly in the user's proposed building to determine the overall UA of the building (DOE 1995c). The UA that would result from a building conforming to the envelope component requirements in Chapter 5 of the MEC and IECC is compared against the UA for the proposed building (CABO 1992, 1993, 1995; ICC 1998, 1999). If the total envelope UA of the proposed building does not exceed the total envelope UA for the same building conforming to the code, then the software declares that the building complies. Additionally, the software allows credit for space heating and cooling equipment efficiencies above the code minimums.

In addition to meeting the UA compliance some locations must also meet a solar heat gain coefficient (SHGC) compliance for the fenestration components of a building. This requirement will be in effect when the heating degree days (base 65) is less than 3500 and the selected code is 1998 IECC, 2000 IECC, 2003 IECC, or one of the state-based codes that are based on either of these codes.

Sections 5.1 through 5.3 describe the methodology used by the RES*check* software in determining the UA for the proposed building, the code building, and individual building components. Section 6.4 fully describes the solar heat gain compliance requirement. The last section briefly discusses the weather data used in the software.

5.1 Proposed Building UA Calculation

Equation (3.1) in Section 3.0 is used to compute whole-building UAs. Although this equation uses envelope component U_o-factors, the RES*check* software does not allow the user to enter these U_o-factors directly (except for glazing and door assemblies and "other" assembly types). Table 5.1 lists all of the construction types offered by the software and shows which inputs are required ("x") by the software to establish the component U_o-factors and sizes used in Equation (3.1). The calculations for determining component U_o-factors from the insulation R-values are described in Appendix A.

5.2 Code Building UA Calculation

The overall UA for the proposed building is compared against the UA from a building just meeting the code requirements, referred to here as the "code building" (the dimensions entered by the user apply to both the proposed building and the code building). The code building U_o-factors for each envelope component are determined by the code requirements (Chapter 5 of the MEC and IECC).

Table 5.2 correlates each building component allowed by the RES*check* software and its corresponding requirement as given in figures near the end of the MEC. All MEC requirements for the components listed below are given in terms of component U_o-factors, with three exceptions: 1) the slab requirements are given as an insulation R-value, 2) the basement and crawl space wall requirements are given as the U-factor of the wall components and surface air films, and 3) the MEC gives a credit to high-mass walls (e.g., log, concrete) such that they have less-stringent U_o-factor requirements than low-mass walls (e.g., wood-frame walls).

Table 5.1. Construction Types Offered by RES*check* Software and Required Inputs

Component Description	**Cavity Insulation R-Value**	**Continuous Insulation R-Value**	**Assembly U-Factor**	**Size**
Ceiling Assemblies				
Flat Ceiling or Scissor Truss	x	x		Gross Area (ft^2)
Cathedral Ceiling (no attic)	x	x		Gross Area (ft^2)
Raised or Energy Truss	x	x		Gross Area (ft^2)
Structural Insulated Panels (SIPs)		x		Gross Area (ft^2)
Other	x		x	Gross Area (ft^2)
Above-Grade Walls				
Wood Frame, 16 in. O.C.	x	x		Gross Area (ft^2)
Wood Frame, 24 in. O.C.	x	x		Gross Area (ft^2)
Steel Frame, 16 in. O.C.	x	x		Gross Area (ft^2)
Steel Frame, 24 in. O.C.	x	x		Gross Area (ft^2)
Solid Concrete or Masonry				
Exterior Insulation	x	x		Gross Area (ft^2)
Interior Insulation	x	x		Gross Area (ft^2)
No Insulation				Gross Area (ft^2)
Masonry Block with Empty Cells				
Exterior Insulation	x	x		Gross Area (ft^2)
Interior Insulation	x	x		Gross Area (ft^2)
No Insulation				Gross Area (ft^2)
Masonry Block with Integral Insulation				
w/ Additional Exterior Insulation	x	x		Gross Area (ft^2)
w/ Additional Interior Insulation	x	x		Gross Area (ft^2)
w/ No Additional Insulation				Gross Area (ft^2)
Log (5 to 16-in. diameters)	x			Gross Area (ft^2)
Structural Insulated Panels		x		Gross Area (ft^2)
Insulated Concrete Forms		x		Gross Area (ft^2)
Other			x	Gross Area (ft^2)
Basement and Crawl Space Walls(a)				
Solid Concrete or Masonry	x	x		Gross Area (ft^2)
Masonry Block with Empty Cells	x	x		Gross Area (ft^2)
Masonry Block with Integral Insulation	x	x		Gross Area (ft^2)
Wood Frame	x	x		Gross Area (ft^2)
Insulated Concrete Forms		x		Gross Area (ft^2)
Other			x	Gross Area (ft^2)
Floors				
All-Wood Joist/Truss	x	x		Gross Area (ft^2)
Slab-On-Grade(b)		x		Perimeter (ft)
Structural Insulated Panels		x		Gross Area (ft^2)
Other			x	Gross Area (ft^2)
Windows, Skylights, Doors				
Windows			x	Assembly Area (ft^2)
Skylights			x	Assembly Area (ft^2)
Doors			x	Assembly Area (ft^2)

(a) The user is required to enter the wall height, depth below grade, and depth of insulation on the wall for basement and crawl space constructions, as well as the depth below inside grade for crawl space walls.
(b) The user is required to enter the depth of the installed insulation.

Table 5.2. MEC and IECC Building Component Requirements

Component Description	MEC/IECC Requirement	1992 MEC Figure Number	1993 and 1995 MEC Figure Number	1998 and 2000 IECC Figure Number
Ceilings	Roof/Ceilings	Fig. 2	Fig. 2	Fig 502.2 (2)
Stress-Skin Ceiling Panels	Roof/Ceilings	Fig. 2	Fig. 2	Fig 502.2 (2)
Wood- or Metal-Frame Walls	Walls	Fig. 1	Fig. 1	Fig. 502.2 (1)
Concrete, Masonry, or Log Walls	Walls With Mass Credit	Fig. 1, Tables 502.1.2a,b, and c	Fig. 1, Tables 502.1.2a,b, and c	Fig. 502.2 (1) Fig. 502.1.1 (1998 IECC)
Stress-Skin Wall Panels	Walls	Fig. 1	Fig. 1	Fig. 502.2.1.1.2 (2000 IECC)
Windows and Glass Doors	Walls	Fig. 1	Fig. 1	Fig. 502.2 (1)
Skylights	Roof/Ceilings	Fig. 2	Fig. 2	Fig. 502.2 (2)
Opaque Doors	Walls	Fig. 1	Fig. 1	Fig. 502.2 (1)
Floor Over Unheated Spaces	Floor Over Unheated Spaces	Fig. 6	Fig. 4	Fig. 502.2 (4)
Floor Over Outdoor Air	Roof/Ceilings	Fig. 2	Fig. 2	Fig. 502.2 (2)
Heated Basements	Basement Walls	Fig. 8	Fig. 6	Fig. 502.2 (6)
Heated or Unheated Slab	Slab-On-Grade	Fig. 3	Fig. 3	Fig. 502.2 (3)
Heated Crawl Spaces	Crawl Space Walls	Fig. 7	Fig. 5	Fig 502.2 (5)

5.3 Individual Component UA Calculations

To compute the whole-building UA, a UA must first be established for each component listed by the user (multiple entries of the same component type may be listed). In general, the U_o-factor for all components except glazing, doors and “other” assembly types is computed based on an insulation R-value entered by the user. For some components, R-values for cavity insulation and continuous insulation are entered separately. Many construction assumptions are defaulted (supplied by the software). The calculations used for each component U_o-factor and the assumptions used to arrive at these calculations are described in Appendix A. The following sections describe the inputs expected by the software for each calculation, and how the inputs are used in the UA calculation.

Table 5.3 lists the limitations on these inputs─if the user tries to enter a value outside the ranges specified in this table, RES*check* issues a warning message and restores the number to its previous value.

5.3.1 Ceiling UA

The U_o-factor for ceilings is computed based on the cavity insulation R-value and the continuous insulation R-value (if used), which are entered by the user. Section A.1 in Appendix A describes this computation.

Table 5.3. Input Ranges Allowed by RES*check* Software

Type of Input	Allowable Range
Cavity Insulation R-Value	0 – 60
Continuous Insulation R-Value	0 – 40
Glazing and Door U-Factor	>0.0 – 2.00 (0.0 is invalid)
Basement Wall Height	0 – 12 ft
Basement Insulation Depth	0 – 12 ft
Basement Depth Below Grade	0 – 12 ft
Slab Insulation Depth	0 – 6 ft
Crawl Space Wall Height	0 – 7 ft
Crawl Space Insulation Depth	0 – 7 ft
Crawl Space Depth Below Grade	0 – 7 ft
Crawl Space Inside Depth Below Grade	0 – 7 ft

5.3.2 Wall UA

The U_o-factor for all frame walls is based on the R-value of cavity insulation and the continuous insulation R-value (if used). Section A.2 in Appendix A describes this computation. If the user does not enter a continuous insulation (sheathing) R-value (or enters a value of 0.0), the software assumes a sheathing R-value of 0.83. This default value gives credit for some minimal type of sheathing material (such as plywood) under the siding. The continuous insulation is assumed to cover 80% of the building, with the other 20% being covered by structural sheathing (also defaulted to R-0.83).

5.3.3 Mass Wall UA

This section explains how the RES*check* software incorporates the credit the code gives to high-mass walls. Section A.2.3 of Appendix A explains how U_o-factors for common types of high-mass walls are calculated for the proposed building (i.e., "Your UA") in the software.

In most locations, the code allows walls having a heat capacity greater than or equal to 6 Btu/ft^2·°F to have a higher U_o-factor than low-mass wood- or metal-frame walls (see Tables 502.1.2a-502.1.2c of the MEC; Tables 502.1.1(1)-502.1.1(3) of the 1998 IECC; and Tables 502.2.1.1.2(1)-502.2.1.1.2(3) of the 2000 and 2003 IECC). Masonry or concrete walls weighing at least 30 lb/ft^2 and solid-wood walls weighing at least 20 lb/ft^2 are eligible for this credit (the area to be considered is the exterior surface area of the mass wall). In the software, eligible mass wall components receive this credit as an increase in the code building UA (the mass wall required U_o-factor is greater than the low-mass wall required U_o-factor). Brick veneers or log walls constructed of logs less than 7 in. thick currently do not receive this credit.

The U_o-factor for all mass walls except log walls is based on the R-value of the insulation, the type of mass wall (solid concrete or block masonry), and the location of the insulation (exterior or interior). For log walls, the U_o-factor is based on the thickness of the logs plus any additional insulation that might be used. (The area considered is the exterior surface area of the mass wall.) Section A.2.3 in Appendix A describes the computation for determining mass wall U_o-factors. The methodology used to incorporate the increase in wall U_o-factor allowable for high-mass walls into the RES*check* software is discussed below.

5.3.3.1 Determine Opaque Wall Requirement

The net opaque wall requirement (U_w) is used to determine the amount of credit given for mass walls. As shown in Equation (5.1), the U_w for mass walls is determined from the low-mass wall U_o requirement from Figure 1 of the MEC or Figure 502.2(1) of the IECC and the wall, window, and door components the user has entered.

$$U_w = \frac{U_{o_{MEC}} \text{ x } A_o - U_g \text{ x } A_g - U_d \text{ x } A_d}{A_w} \tag{5.1}$$

where U_w = opaque wall requirement
$U_{o_{MEC}}$ = gross wall requirement from Figure 1 in the MEC or Figure 502.2(1) in the IECC
A_o = sum of the areas of all wall, door, and window components
U_g = proposed glazing U-factor (the "U_g x A_g" term may be expanded to include several glazing components)
A_g = total glazing area
U_d = proposed door U-factor (the "U_d x A_d" term may be expanded to include several door components)
A_d = total door area
A_w = net opaque wall area, including mass and other (nonmass) wall components.

5.3.3.2 Determine Gross Wall UA

Once the U_w requirement is determined, the adjusted U_w requirement for mass walls ($U_{w_{ADJUSTED}}$) is obtained from Tables 502.1.2a-502.1.2c of the MEC; Tables 502.1.1(1)-502.1.1(3) of the 1998 IECC; and Tables 502.2.1.1.2(1)-502.2.1.1.2(3) of the 2000 IECC. The U_w requirement is given as the top row of each of these three tables. The adjusted U_w is determined from these tables by reading down the column that the U_w falls into to the row with the proper HDD. If the U_w falls outside the range of the tables (0.04 to 0.20 in the MEC and 1998 IECC; 0.04 to 0.24 in the 2000 IECC), the U_w adjustment for the closest U_w in the table is used. This adjusted U_w will be higher than the U_w determined from Equation (5.1) for all but very cold climates. Note that the code tables have U_w requirements in discrete steps of 0.02. When the U_w falls between columns in the table, the $U_{w_{ADJUSTED}}$ is found by interpolation.

The U_o-factor used for the mass walls in increased by the difference between $U_{W_{ADJUSTED}}$ and U_w:

$$\text{NEW MASS WALL Uo} = U_{O_{MEC}} + (U_{W_{ADJUSTED}} - U_w) \tag{5.2}$$

where $U_{O_{MEC}}$ = gross wall requirement (from MEC Figure 1 or IECC Figure 502.2(1))

$U_{W_{ADJUSTED}}$ = opaque mass wall requirement from tables

U_w = opaque wall requirement before adjusting (from Equation 5.1).

5.3.4 Floor-Over-Unheated-Space UA

The U_o-factor for floors over unheated spaces is based on the R-value of the cavity and/or continuous insulation. Section A.3 in Appendix A describes this computation.

5.3.5 Basement Wall UA

The basement wall code requirement applies only to the net basement wall area (not including basement windows and/or doors).

In determining compliance with the basement wall U-factor requirements, Footnote 5 in Table 502.2.1 of the MEC and Footnote e in Table 502.2 of the IECC specifies that the basement wall U-factor calculation be based on the R-values of only the wall components and surface air films. Adjacent soil is not considered when computing the basement wall U-factor. However, because the soil will affect annual energy consumption, RES*check* accounts for the heat flow through the adjacent soil in the proposed building. Note that the code building U-factor requirement for basement walls is also adjusted for soil resistance, so that the heat transfer from the proposed building basement wall and the code building basement wall are consistently calculated. Section A.4 in Appendix A describes the basement wall U-factor computation. The software uses the R-value of the insulation, the wall height, the depth below grade, and the depth of the insulation as inputs into this computation.

Section 502.2.1.6 of the 1992 MEC and Section 502.2.6 of the 1993 and 1995 MEC state the following:

> The exterior walls of basements below uninsulated floors shall have a transmittance value not exceeding the value given in Table No. 502.2.1 to a depth of 10 feet below the outside finish ground level, or to the level of the basement floor, whichever is less.

Section 502.2.1.6 of the IECC contains similar text.

It appears that the code does not allow for or give any credit to basement walls insulated only part way down the wall. However, note that the insulation depth requirement is given in relation to Table 502.2.1, where the basement wall U-factor requirement appears. This presentation implies that the insulation depth requirement is intended to clarify the U-factor requirement for basement walls.

The basement wall with insulation only part way down can be considered to be two “assemblies” (the top part insulated and the bottom part not insulated), with a distinct UA for each assembly. This situation is permissible if the total heat loss for the entire building (the overall UA) remains the same or is reduced; i.e., if this lack of insulation at the bottom of the basement wall is adequately compensated for by extra insulation in any other part of the building envelope. Therefore, the software allows for and gives credit to basement walls insulated from the top of the wall to any depth (i.e., full basement wall insulation is not required). The basement UA for the code building is calculated assuming the insulation goes the full depth of the basement wall.

5.3.6 Crawl Space Wall UA

As with basements, a footnote in the code specifies crawl space wall U-factor requirements that are based on the resistance of only the wall components and surface air films. Adjacent soil is not considered, although it impacts the heat flow. However, when computing the U-factor of crawl space wall components, the software accounts for the heat flow through the adjacent soil for the same reason given above for basement walls. Section A.5 in Appendix A describes this computation. The software uses the R-value of the insulation, the wall height, the depth below grade, the depth below inside grade, and the depth of the insulation as inputs into this computation.

5.3.7 Slab-On-Grade Floor UA

If a slab-on-grade floor component (referred to as "slab") is selected, the user is required to enter the slab floor perimeter. RES*check* computes an F-factor for slab assemblies based on the R-value of the slab insulation and the depth of the insulation. An F-factor is the heat loss rate through the slab per foot of perimeter (Btu/ft·h·°F). Section A.6 in Appendix A describes this computation. For the proposed building, the user may enter any insulation depth from 0 to 6 ft. If the insulation will actually extend beyond 4 ft, the user does not receive any additional credit toward compliance. For the code building, the depth is either 2 ft (for locations with less than 6000 HDD) or 4 ft (for locations with equal to or more than 6000 HDD).

The code specifies requirements for slab floors in terms of the R-value of the slab insulation and the depth of the insulation. To directly compare the slab F-factor computed by RES*check* with the required R-value as specified by the code, the code R-value requirement is converted to an equivalent F-factor. For the code building, the code R-value requirement and the required insulation depth are used as inputs into the RES*check* slab F-factor calculation (Section A.6 in Appendix A). For the proposed building, the insulation R-value and depth of insulation entered by the user are the inputs into the RES*check* slab F-factor calculation.

5.4 Solar Heat Gain Compliance

In addition to meeting the UA compliance some locations must also meet solar heat gain coefficient (SHGC) compliance for the fenestration components of a building. This requirement will be in effect when the heating degree days (base 65) is less than 3500 and the selected code is 1998 IECC, 2000 IECC, or one of the state-based codes that are based on either of these codes.

To meet SHGC compliance the area-weighted average SHGC for a proposed building must be less than or equal to 0.40 as documented in the 1998-2002 IECC codes. The user is responsible for entering the SHGC value for each window, skylight, and/or glass door. The SHGC for each assembly type is area-weighted then averaged for the building as a whole.

All SHGC required codes allow adjustments to be made to the area-weighted average SHGC when overhang projections exist and/or, in the case of the Georgia 2004 code, when a shade screen exists. An overhang projection is represented as the ratio of width of the overhang (from exterior of wall to edge of overhang) over height as measured from the bottom of the overhang to the bottom of the fenestration component.

The adjustment to SHGC for overhang projections is based on work developed by the Technical Evaluation Committee for ASHRAE Special Project 53, under subcontract to PNNL in 1985-1988. The underlying data source was the ARES database. This work produced a set of multipliers specific to eight orientations along with a regression analysis based simplified formula. The relative orientation of the component with respect to "North" is first determined in order to select the correct set of coefficients to apply to the simplified multiplier formula. With the selected coefficients applied along with the glazing component projection factor, a multiplier results that can be applied to the component proposed SHGC. Note that projection factors do not apply to skylights.

The multipliers and formula to be applied to the projection factor are:

$$\text{multiplier} = \exp(A * \text{atan}(PF)) + M0 - 1$$

where the multipliers MO and A vary by orientation as follows:

Orientation	M0	A
N	1.033182	-0.0908
NE/NW	1.121773	-0.4656
E/W	1.162932	-0.7521
SE/SW	1.232682	-1.0165
S	1.323909	-1.3817

The adjustment process will occur when a request for the building average adjusted SHGC is requested. The process will loop through all applicable glazing components and for each in turn, compute the projection factor multiplier, factor in the shade screen multiplier depending on its specification then compute the adjusted area-weighted proposed SHGC and sum this into a running total that is then divided by the total fenestration area when all components have been processed.

5.5 Weather Data Used in the Software

The RES*check* software can be set up so the user can select from a list of cities or a list of counties in each state. The "cities" version contains HDD and CDD values for over 22,000 cities. The HDD values are used to determine the requirements for that city, as well as the high-efficiency heating and cooling equipment credit (see Section 6.0). The CDD value is only used to restrict the cooling efficiency credit from some California coastal locations (see Section 6.0). The "counties" version requires the user to select a county, not a city.

The cities' weather data included with the software comes from the Populated Places database which is part of the Geographic Names Information System of the U.S. Geological Survey (USGS 2000) The methodology for selecting locations to include in the software was principally determined on population estimates. More specifically, if a location had a “<1” designator (which indicates low or unknown population) then it was not included in the final list of locations. A complete discussion of the methodology can be found in the supporting document addressing Weather/Location analysis and selection.

6.0 Equipment/Envelope Trade-Off

This section describes the methodology for trading increased heating or cooling efficiency for lowered envelope efficiency used in the RES*check* software. The insulating efficiency of the building envelope is measured, in all cases, by the overall coefficient of thermal transmission, U_o.[(a)]

For both AFUE and SEER trade-offs, the method identifies the appropriate relaxation in the required U_o[(b)] for a given improvement in equipment efficiency so that the overall energy consumption of a building complying via the trade-off is equal to or less than that of a building complying with the code. We refer to this condition of balance between a code-complying building and a modified-efficiency building as energy neutrality. The code allows such trade-offs if energy neutrality is preserved in terms of *site* energy consumption. All trade-offs are therefore designed to satisfy the following equation:

$$\frac{\text{HeatLoad}_{\text{std}}}{\text{AFUE}_{\text{std}}} + \frac{\text{CoolLoad}_{\text{std}} \text{ x } 3.413}{\text{SEER}_{\text{std}}} = \frac{\text{HeatLoad}_{\text{mod}}}{\text{AFUE}_{\text{mod}}} + \frac{\text{CoolLoad}_{\text{mod}} \text{ x } 3.413}{\text{SEER}_{\text{mod}}} \qquad (6.1)$$

where the std subscript refers to a building built to minimally meet the code criteria and the mod subscript refers to a building with modified features. If a heat pump is used, the measure of heating efficiency is HSPF instead of AFUE. Note that heating and cooling loads are adjusted for on-site equipment efficiencies but not for generation and transmission efficiencies.

Envelope insulation levels, glazing solar characteristics, glazing orientation, and other factors determine the heating and cooling loads. These loads are met by heating and cooling equipment assumed to have efficiencies (AFUE or SEER) consistent with NAECA minimums for the standard case and as installed for modified cases (42 USC 6291 et seq).

Determining the appropriate U_o credit that should be granted for a particular increase in HVAC efficiency is somewhat complicated. For example, the effect of higher HVAC efficiency on cooling energy consumption is easily approximated by simple multiplication, but the effect of changing the U_o is more complicated to estimate. The U_o affects both heating and cooling loads in nonlinear ways.

Our approach to solving these problems was to evaluate the energy consumption of a hypothetical building with envelope U_o-factors just meeting the minimum code envelope criteria and with HVAC efficiencies equal to the NAECA minimums. We modified (improved) the HVAC efficiency, and then incrementally adjusted the other building features to find the U_o increase that would just balance the total

---

(a) Throughout this discussion, we use the term “U_o” as it is defined in the code–the overall *conductive* thermal transmission coefficient of a house. This coefficient excludes, for example, the effects of mechanical ventilation and natural air infiltration. This distinction is important when interpreting the allowable changes in U_o.

(b) Note that the “required” U_o is really an implied requirement based on an aggregation of the individual building component U_o-factor requirements of the code. The overall U_o used in developing trade-offs is computed as the area-weighted average of the component U_o-factors of a prototype house that approximates average U.S. construction.

energy consumption. We did this analysis for a range of climates and aggregated the results, to the extent possible, to obtain simple relationships that builders and code enforcement officials can easily use to determine compliance with the code.

In general, the resulting trade-off equation looks like the following:

$$\beta = \frac{\left(\dfrac{U_{o,\,adjusted} - U_{o,\,standard}}{U_{o,\,standard}}\right)}{\left(\dfrac{EFF_{adjusted} - EFF_{standard}}{EFF_{standard}}\right)} \tag{6.2}$$

where $U_{o,standard}$ = U_o-factor implied by code prescriptive criteria
$U_{o,adjusted}$ = U_o-factor allowed with higher equipment efficiency
$EFF_{standard}$ = NAECA minimum equipment efficiency
$EFF_{adjusted}$ = actual (higher) installed equipment efficiency
β = trade-off ratio.

The parenthesized term in the denominator of Equation (6.2) can be thought of as the fractional (percentage) increase in HVAC efficiency (either AFUE or SEER) being proposed by a builder. The β coefficient, which is the primary result of our efficiency trade-off analysis, adjusts that fractional increase in heating and cooling efficiency to give the appropriate fractional increase in U_o that will result in equivalent overall (heating plus cooling) energy consumption. Rearranging Equation (6.2) gives the adjusted U_o requirement for a proposed HVAC efficiency increase:

$$U_{o,\,adjusted} = U_{o,\,standard} \text{ x } \left[1 + \beta \text{ x} \left(\frac{EFF_{adjusted} - EFF_{standard}}{EFF_{standard}}\right)\right] \tag{6.3}$$

A β term of one indicates a one-to-one correspondence between a percentage improvement in equipment efficiency and an allowable percentage increase in the envelope U_o. Section 6.1 describes the calculation of β for both heating and cooling equipment.

6.1 Background and Assumptions

The trade-off procedures were developed using assumptions made for a prototype building and its estimated energy consumption based on a particular climate zone.

6.1.1 Select Prototype Building

We developed all trade-off procedures using a prototype building designed to exemplify typical construction practices in the United States. The single-family prototype building described in Section 5.2.3 was used with a window area equal to 15% of the gross wall area. The dimensions of the prototype approximate the average characteristics of new buildings rather than any particular building.

Changing the prototype has only a small effect on the resulting trade-off ratios. In developing the trade-off ratios, we considered only the crawl space foundation type, for which U_o calculations are the simplest. This simplification is acceptable because the trade-off methodology is cast in terms of *percentage change* in the overall U_o, minimizing the differences in influence between various component types. Note that the shading coefficient is fixed at 0.88, regardless of the window U-factor. We assumed the building was built with good air-sealing practices, but without an air infiltration barrier, heat recovery ventilator, or other special infiltration-control measures. Although the average air infiltration rate varies by location because of temperature and wind dependencies, it is between roughly 0.35 and 0.5 air changes per hour (ACH). U_o-factors for the components vary by climate zone (see Section 6.2.3).

6.1.2 Estimate Energy Consumption

In estimating the energy consumption of our prototype building, we used the residential energy database contained within the Automated Residential Energy Standard (ARES) software (Lortz and Taylor 1989). The ARES database was developed from a large number of parametric simulations using DOE-2, a large hourly building energy simulation program (LBNL and LANL 1980). The database is based on simulations for 45 primary locations in the United States and is extended to an additional 836 locations using carefully selected HDD and CDD ratios as load multipliers.

Given building dimensions, component U_o-factors, glazing properties, and window orientations, ARES returns annual heating and cooling loads for a specified location (city). These loads are adjusted by the heating and cooling efficiencies, respectively, and then summed to obtain the total site energy consumption. This total is preserved by the trade-off methodologies.

In our development of trade-off procedures, we used data from all of the 881 ARES locations. These data covered a wide range of U.S. climates and provided a large enough sample to allow identification of meaningful functional relationships between climate parameters (e.g., degree-days, which are used by the code to define envelope requirements for a location) and the trade-off allowances.

6.1.3 Select Climate Zones

The RES*check* compliance tools define 19 climate zones in the United States. These zones (defined in terms of HDD, base 65°F) were selected to provide a wide range of U.S. climates and to coincide with important change points in the code requirements. Table 6.1 shows the zone definitions and the total number of ARES cities by climate zone.

6.2 Develop Equipment Efficiency Trade-Off

We used the same procedure used in the previous section to develop trade-off allowances for increased AFUE and SEER, using the following steps:

1. For each climate zone, identify a baseline building configuration that just meets the code requirements; calculate its overall coefficient of conductive heat transfer (U_o).

Table 6.1. ARES Cities Available for Each Climate Zone

Climate Zone	HDD, Base 65°F, Range	Number of ARES Cities Available
1	0-499	16
2	500-999	26
3	1000-1499	23
4	1500-1999	57
5	2000-2499	57
6	2500-2999	81
7	3000-3499	67
8	3500-3999	43
9	4000-4499	44
10	4500-4999	52
11	5000-5499	67
12	5500-5999	77
13	6000-6499	87
14	6500-6999	71
15	7000-8499	84
16	8500-8999	11
17	9000-12999	17
18	13000 - 13999	0
19	14000 +	1

2. Calculate the total annual energy consumption of the baseline prototype in each of the 881 ARES cites, assuming NAECA minimum HVAC efficiencies.

3. For each of several possible increased HVAC efficiencies, identify how much the prototype's U_o can be relaxed (increased) while keeping total annual energy consumption at or below that of the baseline prototype.

4. For each HVAC efficiency level, calculate the ratio of the fractional U_o change to the fractional efficiency change, referred to as the trade-off ratio.

Each step is described below, with a presentation of the results for AFUE and SEER trade-offs.

6.2.1 Identify MEC Baseline

The first step in developing allowable U_o increases in trade for HVAC efficiency improvements was to identify the baseline MEC requirements for each MEC climate zone and design a package of component options that minimally meet the 1992 MEC requirements when applied to our prototype. Although numerous building configurations will meet the 1992 MEC requirements in each zone, we selected only one configuration to serve as the baseline. Because the final trade-off procedure is designed in terms of percentage changes, this baseline is a reasonable simplification.

Table 6.2 shows the baseline packages used in the various climate zones. Each package has a maximum window area equal to 15% of the floor area, equally distributed on the four cardinal orientations. Note that the selected packages do not necessarily represent the minimum possible complying packages for the zones–other combinations of ceiling, wall, floor, and window options may exist that are less expensive to build, yet still comply with the code's U_o requirement. Because our results are expressed in terms of allowable percentage changes, it is not crucial that the base case building exactly match the code's criteria–only that it be close.

6.2.2 Calculate Baseline Energy Consumption

We calculated annual heating and cooling loads for the base case building using the ARES energy database (Lortz and Taylor 1989). These loads were then directly divided, respectively, by the NAECA-minimum AFUE and SEER. We assumed, in all cases, that heating is provided by a gas furnace and cooling by an electric, direct-expansion air conditioner.

6.2.3 Identify Adjusted U_o

We identified the adjusted U_o that ensures neutrality in a relatively simple manner. Because we intended to generalize the U_o increase justified by a given HVAC efficiency increase, we did not constrain the U_o-factors of individual building components to correspond to discrete products. For example, we allowed the wall U_o-factor to correspond to something between R-13 and R-19, although no readily available products may exist that would result in the U_o-factor. Because different buildings will have different complying combinations of ceiling, wall, and floor insulation and window U_o-factors, it was not crucial that our analysis land on any particular combination.

Table 6.2. MEC Baseline Prototype Configurations

Zone	Ceiling R-Value	Wall R-Value	Crawl Space R-Value	Window U-Factor	Overall U_o
1	13	11	11	1.07	0.136
2	11	11	11	0.75	0.120
3	13	11	11	0.75	0.117
4	19	11	11	0.70	0.108
5	19	13	11	0.60	0.099
6	19	13	19	0.55	0.088
7	19	13	19	0.50	0.085
8	30	13	13	0.45	0.082
9	30	13	19	0.45	0.077
10	30	13	19	0.40	0.074
11	30	13	19	0.35	0.071
12	38	15	19	0.35	0.068
13	38	15	26	0.35	0.064
14-19	38	19	30	0.40	0.061

To adjust the U_o for a given HVAC efficiency change, we constrained all building components to change *together* in searching for an energy-neutral configuration. We established a reasonable upper boundary on the possible U-factor (lowest conceivable R-value) of each building component. We then incrementally changed all component U_o-factors by the same fraction *f* of the difference between the baseline U_o-factor and the reasonable upper limit, and calculated the resulting total annual energy consumption. We applied a simple nonlinear minimization algorithm to identify the value of *f* that achieved total consumption most nearly equal to that of the baseline. Thus, the adjusted U_o was based on a house with slightly less insulation in the ceiling, walls, and floors, and with windows having a slightly higher U-factor. This procedure avoided problems of the differential impact of similar U_o-factor changes in ceilings and walls, for example.

The above procedure was applied independently for AFUE and SEER changes. We analyzed AFUE values of 80% through 100% (increases of 2.5% to 28.2% over the NAECA minimum) and SEER values of 11 through 14 (increases of 10% to 40% over the NAECA minimum). These values roughly represent the range of commonly available products. However, we observed no significant correlation between the magnitude of the efficiency increase and the resulting trade-off ratios.

6.2.4 Identify Trade-Off Ratios and HDD Relationships

6.2.4.1 Heating

For each of the ARES cities and each of several AFUE levels, we calculated the trade-off ratio according to Equation (6.2). Figure 6.1 shows a scatter plot of the results. Note that the trade-off ratio exceeds 1.0 for much of the United States. This result implies, for example, that a 10% increase in the AFUE justifies more than a 10% increase in the U_o. This apparently counterintuitive result stems from the code definition of U_o that excludes the effects of infiltration. An AFUE increase affects energy use resulting from both the conductive loads and the infiltration loads. A change in insulation level affects only the conductive loads. If the trade-off ratio was defined in terms of the total building UA, including infiltration effects, we would expect the trade-off ratio to be less than 1.0.(a)

If the trade-off ratio is defined in terms of the total building UA (assuming an average infiltration rate of 0.35 ACH), the ratio asymptotically approaches 1.0 in the very cold locations, as expected [see Footnote (a)]. A few ratios exceeding 1.0 remain because the actual ACH implicit in the ARES energy database, based on DOE-2's calculations that include both temperature and wind effects, is not known exactly (LBNL and LANL 1980). The building tightness features were selected so that average air

---

(a) We would expect a ratio less than 1.0 because the heating load is a nonlinear function of the home's UA, which is because changing the UA changes a home's balance temperature─the outdoor temperature below which the home needs heat to maintain its temperature above the thermostat setpoint. Changing the balance point changes the appropriate base temperature to which degree-days must be calculated to accurately estimate energy consumption. In effect, changing the UA changes heating loads in two ways that compound one another─changing the UA changes the rate of heat loss from the building during heating hours and changes the number of heating hours. Thus, a certain percentage increase in the UA should result in a larger percentage increase in heating loads.

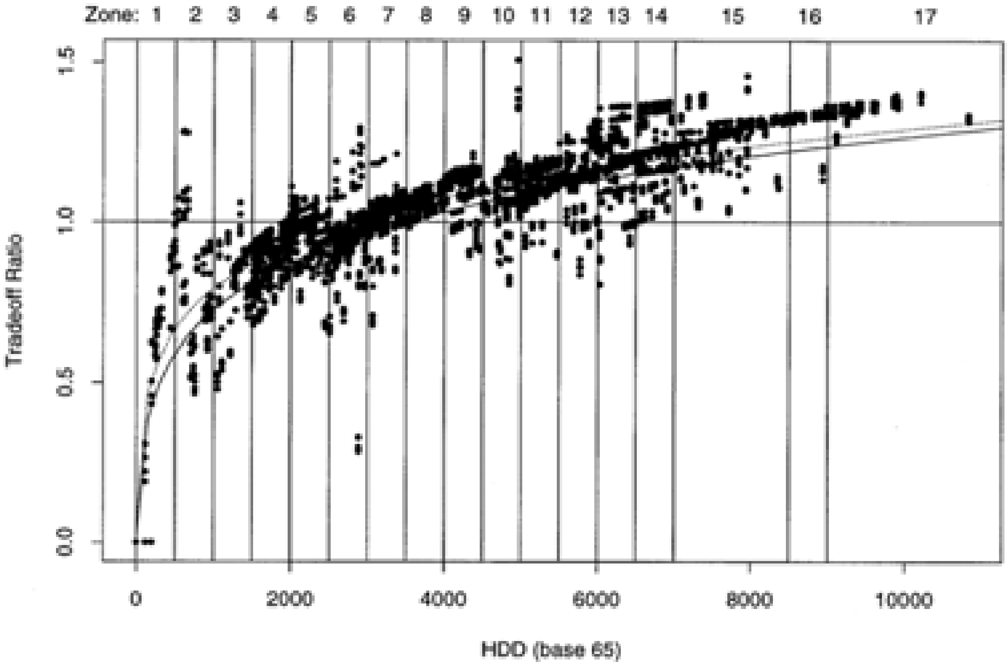


Figure 6.1. Heating Trade-Off Ratio vs. Heating Degree-Days

exchange rates would be close to 0.35 for most locations, but the rates are higher in many locations because the driving forces (e.g., wind, temperature difference) vary with climate.

A clear trend exists with respect to HDDs, although some scatter exists because of differences in solar, wind, summer temperature, and humidity characteristics between locations. The dotted line drawn through the points in Figure 6.1 is based on a linear regression of the trade-off ratio against a polynomial in the logarithm of HDDs:

$$\text{Trade-Off Ratio} = 0.0526 + 0.0225 \times \ln(\text{HDD} + 1) + 0.0122 \times [\ln(\text{HDD} + 1)]^{-2} \quad (6.4)$$

The regression predicts the adjusted U_o requirement with an R^2 of 0.94.[a] The solid line is discussed in Section 6.2.5.

6.2.4.2 Cooling

Figure 6.2 shows a similar scatter plot for the cooling trade-off ratio. The cooling ratio dramatically exceeds 1.0 in the very warm climates. This ratio is expected because an increase in air- conditioning efficiency impacts the total cooling load, only a small fraction of which is due to conductive heat gain through the building envelope. Increasing the U_o-factor in such cooling-dominated climates has little effect on overall cooling loads. The increase has a greater effect on heating loads, but the trade-off ratio

---

(a) An R^2 of 0.94 indicates that Equation (6.4) (and the dotted line plotted in Figure 6.1) is a good fit to the data points shown.

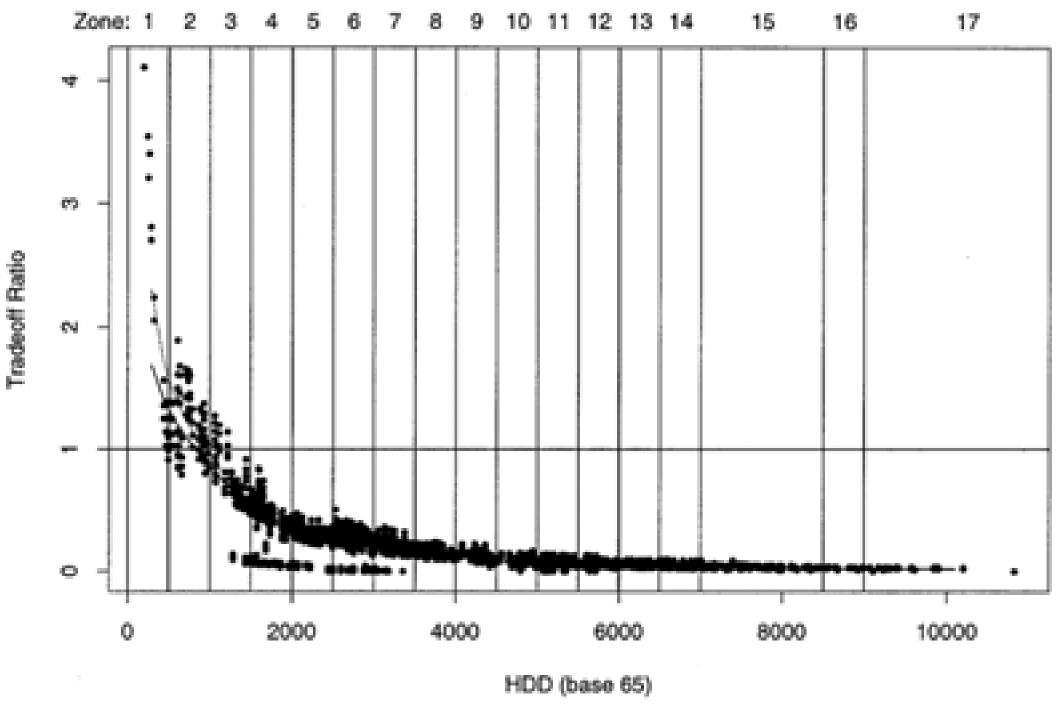


Figure 6.2. Cooling Trade-Off Ratio vs. Heating Degree-Days

can greatly exceed 1.0 where the heating loads are very small compared to the cooling loads. In practice, any advantages derived from increasing the U_o-factor to improve the cooling ratio are realized only in Hawaii and southern portions of Florida.

Note that the cooling trade-off ratio drops rapidly with increasing HDDs. In locations where heating dominates the loads, very little U_o degradation is justified by an increase in SEER. The cloud of zero-ratio points near 1500 to 3000 HDD represents coastal cities of California. The Pacific influence on these cities gives them unusually small cooling loads relative to their heating loads. These coastal locations are clearly exceptions to the cooling trade-off ratio curve fit (shown by the line in Figure 6.2). These locations are treated as exceptions (county by county) in the various RES*check* trade-off materials. These locations are assigned the cooling trade-off ratio corresponding to Zone 17 (see below) in the software and receive no credit in the prescriptive packages and the trade-off approaches (the trade-off approach does not have any equipment/envelope trade-offs).

The dotted line drawn through the points on Figure 6.2 represents a nonparametric curve fit through the data. The fit is defined by a sequence of data pairs (i.e., HDD, trade-off ratio), so no equation for the line can be shown. Using the data pairs and linear interpolation between adjacent pairs, the fit predicts the adjusted U_o requirement with an R^2 of 0.77. If data on additional climate variables (e.g., solar gains, humidity, and wind) were available for the ARES cities, a better-fitting equation could be developed. However, because the MEC recognizes only HDD in determining U_o requirements, such an equation would have dubious value.

6.2.5 Aggregate Zones

To simplify implementing the trade-off procedure, it is often necessary to hold the trade-off ratio fixed within a particular climate zone or code jurisdiction. We produced such ratios for each of the 19 climate zones. A problem arose with the variation of trade-off ratios within a climate zone. We biased our selection of zonal ratios so that the resulting number of buildings in a zone that did not meet the code was minimized or at least guaranteed to be significantly smaller than the number of buildings that met or exceeded the code's base requirements. Some buildings did not meet the code for two reasons. First, the curve fits shown by the dotted lines in Figures 6.1 and 6.2 represent the average U_o change justified by an efficiency increase as a function of HDD, but scatter clearly exists above and below the curves. Thus, in some locations the fit gives too much credit for efficiency improvements while in other locations with similar degree-days it gives too little credit. Second, the actual number of HDDs varies within each climate zone.

To address the first problem, we conducted a second regression analysis that gave more weight to the lower trade-off ratios than to the higher trade-off ratios. The ratios are weighted so that the lowest ratio in each climate zone gets 100% influence and the highest gets none. The weight for each city between the extremes was assigned linearly with respect to the percentile in which the city fell, resulting in the lowest 50% of the ratios having 75% of the influence on the fitted curve. The resulting regression equation for heating is

$$\text{Trade-Off Ratio} = 0.0148 + 0.0019 \times \ln(\text{HDD} + 1) + 0.0145 \times [\ln(\text{HDD} + 1)]^2 \qquad (6.5)$$

Equation (6.5) is shown as the solid line in Figure 6.1. We developed a second cooling curve in a similar manner. As before, the cooling curve fit was based on a nonparametric regression so no equation describing the curve fit exists. The cooling curve is shown as the solid line in Figure 6.2.

To account for varying degree-days within a zone, we based our zonal trade-off ratios on takeoffs from the regression curves at the "conservative" ends of each zone; i.e., we obtained the heating ratios by evaluating Equation (6.5) at the lower end of each zone's HDD range. We obtained cooling ratios by a takeoff from the solid line in Figure 6.2 at the upper end of each zone's HDD range. Note that the cooling ratios primarily affect the low-HDD climates. The results of these takeoffs are the zonal ratios we established as the primary implementation of our HVAC efficiency trade-off procedure (shown in Table 6.3).

Table 6.3. Zonal Trade-Off Ratios

Zone	**Heating Trade-Off Ratio**	**Cooling Trade-Off Ratio**
1	0.01	1.32
2	0.59	0.87
3	0.72	0.52
4	0.81	0.33
5	0.87	0.26
6	0.92	0.22
7	0.96	0.15
8	1.00	0.13
9	1.03	0.08
10	1.06	0.05
11	1.09	0.05
12	1.11	0.05
13	1.13	0.04
14	1.15	0.03
15	1.17	0.02
16	1.22	0.02
17-19	1.24	0.02

7.0 References

American Council for an Energy-Efficient Economy (ACEEE). 1992. *The Most Energy-Efficient Appliances 1992-93*. Washington, D.C.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1985. *1985 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1989a. *1989 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1989b. *ASHRAE/IES Standard 90.1-1989*, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings." Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1993. *1993 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

Conner CC and RG Lucas. 1994. *Technical Support Document for Proposed 1994 Revision of the MEC Thermal Envelope Requirements*. PNL-9400, Pacific Northwest Laboratory, Richland, Washington.

Council of American Building Officials (CABO). 1992. *Model Energy Code; 1992 Edition*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1993. *Model Energy Code; 1993 Edition*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1995. *Model Energy Code; 1995 Edition*. Falls Church, Virginia.

Energy Policy Act of 1992 (EPAct). Public Law 102-486, 106 Stat 2776, as amended.

Gas Appliance Manufacturers Association (GAMA). April 1994. *Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*. GAMA Efficiency Certification Program, Cortland, New York.

International Code Council (ICC). 1998. *International Energy Conservation Code; 1998.* Falls Church, Virginia.

International Code Council (ICC). 1999. *International Energy Conservation Code; 2000.* Falls Church, Virginia.

International Code Council (ICC). 1998. *International Energy Conservation Code; 1998.* Falls Church, Virginia.

International Code Council (ICC). 2003. *International Energy Conservation Code; 2003.* Falls Church, Virginia.

Lawrence Berkeley National Laboratory (LBNL) and Los Alamos National Laboratory (LANL). 1980. *DOE 2.1 B Reference Manual, Parts 1 and 2*. Berkeley, California.

Lortz VB and ZT Taylor. 1989. *Recommendations for Energy Conservation Standards for New Residential Buildings - Volume 2: Automated Residential Energy Standards—User's Guide - Version 1.1*. PNL-6878 Vol. 2, Pacific Northwest Laboratory, Richland, Washington.

National Appliance Energy Conservation Act (NAECA) of 1987. Public Law 100-12, as amended, 42 USC 6291 et seq.

National Association of Home Builders (NAHB) Research Foundation, Inc. 1991. *1991 NAHB Research Foundation Special Report*. Lexington, Massachusetts.

National Climatic Data Center. 1992. *CLIM 81 1961-90 Normals*. TD-9641, Asheville, North Carolina.

National Fenestration Rating Council (NFRC). 1991. *NFRC 100-91: Procedures for Determining Fenestration Product Thermal Properties (currently limited to U-values)*. Silver Spring, Maryland.

National Fenestration Rating Council (NFRC). 1993. *Certified Products Directory*. 2nd ed., Silver Spring, Maryland.

U.S. Bureau of Census, U.S. Department of Commerce (DOC). 1988. *County & City Data Book - 1988 - PLACES*. Washington, D.C.

U.S. Bureau of Census, U.S. Department of Commerce (DOC). 2000. *Characteristics of New Housing: 1999*. C25/99-A, Washington, D.C. Available URL: http://www.census.gov/ftp/pub/const/www/charindex.html.

U.S. Bureau of Census, U.S. Department of Commerce (DOC). 2001. *Characteristics of New Housing*. Available URL: http://www.census.gov/ftp/pub/const/www/charindex.html#singlecomplete.

U.S. Department of Energy (DOE). 1995a. *1993 MECcheck™ Manual, 1993 Model Energy Code Compliance Guide, Version 2.0*. PNNL-11087, Washington, D.C.

U.S. Department of Energy (DOE). 1995b. *1993 MECcheck™ Prescriptive Packages, 1993 Model Energy Code, Version 2.0*. PNNL-11087, Washington, D.C.

U.S. Department of Energy (DOE). 1995c. *1993 MECcheck™ Software User's Guide, 1993 Model Energy Code, Version 2.0*. PNNL-11087, Washington, D.C.

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 RES*check*™ compliance software, prescriptive packages, and trade-off worksheet (DOE 1995d, 1995c, and 1995b) for the 1992, 1993, and 1995 editions of the Model Energy Code (MEC) (CABO 1992, 1993, and 1995) and the 1998, 2000, and 2003 editions of the International Energy Conservation Code (IECC) (ICC 1998, 1999, and 2003). 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 RES*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

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

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" in this Appendix refers to the 1992, 1993, and 1995 editions of the MEC and the 1998 and 2000 editions of the IECC.

$$U_o = \frac{\text{Area}_{\text{STUDS}} / \sum R_{\text{FRAMING PATH}} + \text{Area}_{\text{INSULATION}} / \sum R_{\text{INSULATION PATH}}}{\text{Area}_{\text{STUDS}} + \text{Area}_{\text{INSULATION}}} \qquad \text{(A.2)}$$

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 RES*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.

RES*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 RES*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 RES*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**

$$\text{Ceiling } U_o = \frac{0.07}{6.05 + \text{Rij} + \text{Rs}} + \frac{0.93}{1.67 + \text{Ric} + \text{Rs}} \qquad \text{(A.3)}$$

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.

$$\text{Ric} = \frac{\text{Ric}_{\text{nominal}}}{1 + \left(\frac{\text{yic}_{\text{full}}}{\text{roof height}}\right) \ln\left(\frac{\text{yic}_{\text{full}}}{\text{yic}_{\text{eave}}}\right) - \left(\frac{\text{yic}_{\text{full}} - \text{yic}_{\text{eave}}}{\text{roof height}}\right)} \qquad \text{(A.4)}$$

where $\text{Ric}_{\text{nominal}}$ = the rated R-value of the cavity insulation.
yic_{full} = the full thickness in inches of the cavity insulation

= $\mathrm{Ric}_{\mathrm{nominal}}$ / 2.5 (for blown fiberglass).

$\mathrm{yic}_{\mathrm{eave}}$ = 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 $\mathrm{yic}_{\mathrm{full}}$ is greater than 3.86 in., $\mathrm{yic}_{\mathrm{eave}}$ 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 $\mathrm{yic}_{\mathrm{full}}$ is greater than 15.86 in., $\mathrm{yic}_{\mathrm{eave}}$ 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.).

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

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

= $\mathrm{Ric}_{\mathrm{nominal}}$ – (3.5 x 2.5)

$\mathrm{yij}_{\mathrm{full}}$ = the full thickness of the insulation above the joist (in inches).

= ($\mathrm{Ric}_{\mathrm{nominal}}$ / 2.5) – 3.5.

$\mathrm{yic}_{\mathrm{eave}}$ = 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 $\mathrm{yij}_{\mathrm{full}}$ is greater than 0.36 in., $\mathrm{yij}_{\mathrm{eave}}$ 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 $\mathrm{yij}_{\mathrm{full}}$ is greater than 12.36 in., $\mathrm{yij}_{\mathrm{eave}}$ 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.

A.1.3 Cathedral Ceiling (no attic)

For ceilings without attics in RES*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

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

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.

$$Ceiling\,U_o = \frac{0.07}{1.67 + Rr + Rs} + \frac{0.93}{1.67 + Ri + Rs} \tag{A.6}$$

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 x (Ri ÷ 3.0).

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

Rs = the rated R-value of the insulating sheathing if any.

A.1.2 Comparison of U_o-Factors for Ceilings With and Without Attics

As described above, all U_o-factors underlying the RES*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

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**

overall ceiling U_o-factors for buildings with and without attics are very close. The two ceiling types were offered as separate options in RES*check* 3.2 and later versions primarily for clarification rather than computational accuracy.

Table A.6 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.

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.1.5 Steel-Frame Joist/Rafter Assembly Ceilings

Section 502.2.1.2 of the 2003 IECC includes steel-frame joist/rafter assembly ceilings. Because of the high conductivity of the steel framing members, a correction factor is applied to the cavity insulation R-values (Ric) to more accurately account for the metal stud conductivity. The correction factors used are shown in the following two tables. Applying a correction factor to cavity insulation, the steel-frame ceiling U_o-factors are the inverse of the sum of the ceiling layer R-values as determined and shown by Equation (A.7). When the cavity R-value falls between the stated R-values of Tables A.4 and A.5 (ICC 2003, Table 502.2.1.2), a linearly interpolated correction factor will be computed.

$$\text{Steel-Frame Ceiling } U_o = \frac{1.0}{1.67 + \text{Rs} + (Fcor * Ric)} \tag{A.7}$$

where Rs = the R-value of the insulating sheathing.

Fcor = Correction factors for Roof/Ceiling assemblies as given by Table 502.2.1.2 (ICC 2003, page 27)

Ric = Cavity insulation between ceiling members

Table A.4. Correction Factors for Steel Framed Roof / Ceiling Joist / Rafter Assemblies (16-in. framing spacing)

Member Size	R-19	R-30	R-38	R-49
2 x 4	0.90	0.94	0.95	0.96
2 x 6	0.70	0.81	0.85	0.88
2 x 8	0.35	0.65	0.72	0.78
2 x 10	0.35	0.27	0.62	0.70
2 x 12	0.35	0.27	0.51	0.62

Table A.5. Correction Factors for Steel Framed Roof / Ceiling Joist / Rafter Assemblies (24-in. framing spacing)

Member Size	R-19	R-30	R-38	R-49
2 x 4	0.95	0.96	0.97	0.97
2 x 6	0.78	0.86	0.88	0.91
2 x 8	0.44	0.72	0.78	0.83
2 x 10	0.44	0.35	0.69	0.76
2 x 12	0.44	0.35	0.61	0.69

Table A.6. Heat Flow Path for Steel framed Joist / Rafter Ceilings

Description	R-Value at Insulation
Attic Air Film	0.61
Batt or Blown Insulation	Ric
Sheathing	Rs
Joists	--
½-in. Drywall	0.45
Inside Air Film	0.61
Total Path R-Value	**1.67 + Ric + Rs**

A.1.6 Steel-Frame Truss Assembly Ceilings

For steel-framed truss ceiling assemblies the correction factor applied to cavity insulation is 0.864 as indicated in Equations 5-7 - 5-9 of the IECC 2003. The "Total Path R-value" (excluding cavity and sheathing R-values) is dependent on the user-provided sheathing R-value. Specifically, the conditions shown in Table A.7 will be applied.

Table A.7. **Construction material R-Values for Steel framed Truss Ceilings (excluding cavity and sheathing R-values)**

Sheathing R-value	BOA
< 3.0	0.33
>= 3.0 and less than 5.0	1.994
>= 5.0	2.082

$$\text{Steel-Frame Ceiling } U_o = \frac{1.0}{\text{BOA} + \text{Rs} + (0.864 * Ric)} \qquad \text{(A.8)}$$

where Rs = the R-value of the insulating sheathing.
BOA= Balance of assembly R-values (construction materials) as determined by Table A.7
Ric = Cavity insulation between ceiling members

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 RES*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.9. Equation (A.9) shows how opaque wall U_o-factors are calculated for the 1992 and 1993 MEC, and Equation (A.10) shows how opaque wall U_o-factors are calculated for the 1995 MEC and the 1998, 2000, and 2003 IECC (ICC 1998, 1999, 2003). Table A.10 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.8. 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%

For the 1992 and 1993 MEC:

$$\text{Wall } U_o = \begin{matrix} \left[\dfrac{0.15 \text{ or } 0.12}{1.97 + Rs + Rw} + \dfrac{0.85 \text{ or } 0.88}{1.97 + Rs + Ri}\right] 0.80 \; + \\ \left[\dfrac{0.25 \text{ or } 0.12}{1.97 + 0.83 + Rw} + \dfrac{0.85 \text{ or } 0.88}{1.97 + 0.83 + Ri}\right] 0.20 \end{matrix} \qquad \text{(A.9)}$$

For the 1995 MEC, and 1998 and 2000 IECC:

$$\text{Wall } U_o = \begin{matrix} \left[\dfrac{0.25 \text{ or } 0.22}{1.97 + Rs + Rw} + \dfrac{0.75 \text{ or } 0.78}{1.97 + Rs + Ri}\right] 0.80 \; + \\ \left[\dfrac{0.25 \text{ or } 0.22}{1.97 + 0.83 + Rw} + \dfrac{0.75 \text{ or } 0.78}{1.97 + 0.83 + Ri}\right] 0.20 \end{matrix} \qquad \text{(A.10)}$$

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.9. 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.		

Table A.10. 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.11 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.12 and Equation (A.11).

Table A.11. 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.12. 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.	

$$\text{Steel-Frame Wall } U_o = \frac{1.0}{1.97 + \text{Rs} + \text{Re}} \qquad \text{(A.11)}$$

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.11 lists the equivalent R-values used.

A.2.3 Mass Walls

RES*check* 3.0 uses the same three mass wall types for above-grade mass walls, basement walls, and crawl space walls. Table A.13 lists these wall types and gives the R-value assigned to that uninsulated wall type in RES*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 RES*check* software. This section does not address how the

MEC requirements for high-mass walls are calculated. Section 5.3.3 of this document explains how the software incorporates the credit the MEC gives to high-mass walls.

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

Table A.13. RES*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

A.2.3.1 Selection of Mass Wall Types

In looking at the small differences between the three mass wall R-values given in Table A.13, 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 RES*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 RES*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, RES*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 RES*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 (DOE 1995a). Specialty systems would comprise an even smaller percentage. Making RES*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 RES*check*) and should not be included in the R-value.

A.2.3.2 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.14 and A.15 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.

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.

Table A.14. 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)

(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 (Labs et al. 1998).

Table A.15. U-Factors from ASHRAE 1997 Fundamentals Handbook

Density (lb/ft^3)	Stone and Gravel or Stone Aggregate Concretes		
	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

A.2.3.3 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.16 and A.17 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.16. 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)

(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.

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.17. U-Factors from ASHRAE 1997 Fundamentals Handbook

	Normal Weight Aggregate (sand and gravel), 8 in.	
Type	**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
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, RES*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.

A.2.3.4 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 (e.g., hebel block) (*Environmental Building News* 1996), lightweight expanded clay aggregate, and expanded polystyrene bead concrete, have much lower densities. Table A.18 shows the density and R-value of specialty products.

Table A.18. 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.

A.2.3.5 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.12) 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.19 lists equivalent R-values for interior furring and insulation systems.

Table A.19. 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.

$$\text{Mass Wall U}_o = \frac{1}{\text{Reff} + \text{Rwall} + \text{Rcont}} \tag{A.12}$$

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.

A.2.4 Log Walls

The proposed U-factor calculation for log walls has been updated in REScheck 3.7 Release 1 to address the concern over the lack of mass wall credit for 5-in and 6-in diameter log walls. To make the calculation for log wall density more accurate, a separate specific gravity (SG) is now available and used to calculate conductivity, R-value, and heat capacity for each wood species listed in Table A.20. This distinction makes it possible for some species of wood with 5-in and 6-in nominal diameters to receive mass wall credit in the software and is based on the work of the ICC log wall standard consensus process.

Using the known green specific gravity (Gu), as shown in Table A.20, the density and conductivity for each species are calculated. The moisture constant (a) is calculated from the Moisture Content at Fiber Saturation (MCfs) and the Moisture Content of Service (MCs) which varies by climate zone. This is used to calculate the specific gravity (G) for each species in Equation A.14 [Equation 3-5 from the Wood Handbook FPL-GTR-113 (USDA 1999)].

$$a = (MCfs-MCs)/MCfs \tag{A.13}$$

Where

MCfs for each species is determined by Table 304.2.1 (a) of the ICC IS-Log Standard (ICC 2005)

MCs varies by climate zone based on the IECC 2004/2006 climate zones.
MCs = 10% for Dry climate
MCs = 13% for Moist climates
MCs = 15% for Marine climates
MCs = 14% for Warm-Humid climates
MCs = 12% for all other climates

$$G = Gu / (1- (0.265 \cdot a \cdot Gu)) \tag{A.14}$$

Where

Gu is given in Table A.1 for each species
a is calculated based on Equation A.13

The proposed thermal addition to the ICC IS-Log committee also includes improved methods for calculating the R value of log walls based on the Wood Handbook (USDA 1999) Equation 3-7. Thermal conductivity is calculated as shown in equation A.15.

$$k = G (B + C(MCs)) + A \tag{A.15}$$

where A = 0.129 (Specific gravity greater than 0.30)
B = 1.34 (Design temperature at 75 F)
C = 0.028 (Moisture content less than 25%)

Table A.20 shows the calculated conductivity based on equation A.13 and the assumed specific gravity for the species.

Table A.20. The calculated conductivity and assumed specific gravity for species found in the revised RES*check* are shown.

Wood Species Group	Species Label	Specific Gravity (Gu)	Calculated k for Dry Climate (Btu-in/(h-ft2-F)	Calculated k for Moist Climate Btu-in/(h-ft2-F)	Calculated k for Warm-Humid Climate Btu-in/(h-ft2-F)	Calculated k for Marine Climate Btu-in/(h-ft2-F)
White Cedar (WC)	WC	0.3	0.6422	0.664316	0.671607	0.678857
Red Cedar (RC)	RC	0.31	0.660297	0.683031	0.690522	0.697971
Western Red Canadian Cedar (WRC-N)	WRC-N	0.31	0.650231	0.669576	0.675904	0.682174
Western Red Cedar (WRC)	WRC	0.31	0.650231	0.669576	0.675904	0.682174
Sugar Pine (SUP)	SUP	0.34	0.714999	0.739532	0.747606	0.75563
Incense Cedar (IC)	IC	0.35	0.73337	0.758485	0.766747	0.774956
Eastern White Pine (EWP)	EWP	0.35	0.73337	0.758485	0.766747	0.774956
Western White Pine (WWP)	WWP	0.35	0.73337	0.758485	0.766747	0.774956
White Fir (WF)	WF	0.37	0.770321	0.796571	0.805201	0.813771
W. Spruce-Pine-Fir (WSPF)	WSPF	0.37	0.770321	0.796571	0.805201	0.813771
E. Spruce-Pine-Fir (ESPF)	ESPF	0.38	0.788901	0.815706	0.824514	0.83326
Eastern Softwoods (ESW)	ESW	0.38	0.788901	0.815706	0.824514	0.83326
Eastern Spruce (ES)	ES	0.38	0.788901	0.815706	0.824514	0.83326
Western Softwoods (WS)	WS	0.38	0.788901	0.815706	0.824514	0.83326
Hem-Fir (HF)	HF	0.39	0.807552	0.834901	0.843884	0.852803
Lodgepole Pine (LPP)	LPP	0.39	0.807552	0.834901	0.843884	0.852803
Ponderosa	PP	0.39	0.807552	0.834901	0.843884	0.852803

Pine (PP)						
Red-Canadian Pine (RP-N)	RP-N	0.39	0.807552	0.834901	0.843884	0.852803
Yellow Cedar (YC)	YC	0.42	0.863932	0.892856	0.902346	0.911761
Red Pine (RP)	RP	0.42	0.863932	0.892856	0.902346	0.911761
Baldcypress (CYP)	CYP	0.43	0.882869	0.912299	0.92195	0.931524
Douglas Fir-Larch (DFL)	DFL	0.45	0.918526	0.948129	0.957818	0.96742
Loblolly Pine (LBP)	LBP	0.47	0.959346	0.990697	1.000961	1.011135
Shortleaf Pine (SLP)	SLP	0.47	0.959346	0.990697	1.000961	1.011135
Mixed Southern Pine (MSP)	MSP	0.48	0.97865	1.010455	1.020864	1.031179
Southern Pine (SP)	SP	0.48	0.972637	1.002473	1.012211	1.021849
Tamarack (TAM)	TAM	0.49	0.998029	1.030278	1.040827	1.051279
Longleaf Pine (LLP)	LLP	0.54	1.096057	1.13036	1.141558	1.152642
Slash Pine (SHP)	SHP	0.54	1.096057	1.13036	1.141558	1.152642
Red Oak (RO)	RO	0.57	1.155799	1.191199	1.202741	1.214156
White Oak (WO)	WO	0.62	1.256948	1.29394	1.305974	1.317865

For a wall to receive the Mass Wall credit in the IECC, the wall must have a heat capacity (HC) of 6 Btu/ft^2 F. Assuming the specific heat of wood (c) is 0.39 Btu/lb-F, the heat capacity is calculated from the species density as shown in Equation A.16.

$$D = 62.4 \cdot [G / (1+ (0.009 \cdot G \cdot MCs))] \cdot (1+ MCs/100) \qquad (A.16)$$

Where

D is log density (lb/ft^3) based on section 302.2.3.7 of ICC IS-LOG

$$HC = D \cdot c \cdot (Nd/12) \qquad (A.17)$$

Where

D is log density (lb/ft^3) based on section 302.2.3.7 of ICC IS-LOG
c is specific heat 0.39 lb-F for all species
Nd is the Nominal Width of the log wall in inches

A.2.5 Structural Insulated Panels

A.2.5.1 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. RES*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 1998). 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 RES*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.21.

Table A.21. 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.	

A.2.5.2 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·°F) and wall/floor (1.86 Btu/h·°F) heat flows. Adding these heat flows gives 44.28 Btu/h·°F, 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 RES*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.22.

A.2.5.3 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 RES*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.23.

Table A.22. 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.	

Table A.23. 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. RES*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 1998), 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 RES*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.24 and A.25 lists the R-values used to calculate the overall effective R-Value for above- and below-grade ICF walls.

Table A.24. 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.25. 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.26 shows the heat flow paths for floors over unheated spaces, and Equation (A.18) uses these results to compute the final floor component U_o-value. Table A.27 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.

$$Floor\ U_o = \frac{0.1}{4.01 + Rj} + \frac{0.9}{4.01 + Ri} \tag{A.18}$$

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.26. 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

Table A.27. 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.3.3 Steel-Frame

Section 502.2.1.3 of the 2003 IECC includes steel-frame floors over unheated spaces. Because of the high conductivity of the steel framing members, a correction factor is applied to the cavity insulation R-values (Ric) to account for the metal stud conductivity. The correction factors shown in the following two tables are used. Applying a correction factor to cavity insulation, the steel-frame floor U_o-factors are the inverse of the sum of the floor layer R-values as determined and shown by Equation (A.19). When cavity R-value falls between the stated R-Values of Table A.28 (ICC 2003, Table 502.2.1.3a) and Table A.29 (ICC 2003, Table 502.2.1.3b), a linearly interpolated correction factor is computed. Cavity insulation credit is limited by the framing member size as indicated by "NA" in Tables A.28 (ICC 2003, Table 502.1.1.3a) and A.29 (ICC 2003, Table 502.2.1.3b). The user is permitted to enter higher R values, but an information message will be presented to indicate that the maximum R value credit will be that defined in Tables A.28 (ICC 2003, Table 502.1.1.3a) and A.29 (ICC 2003, Table 502.2.1.3b).

Table A.28 Correction Factors for Steel Framed Floor Assemblies (16-in. framing spacing)

Member Size	R-19	R-30	R-38
2 x 6	0.70	NA	NA
2 x 8	0.35	NA	NA
2 x 10	0.35	0.27	NA
2 x 12	0.35	0.27	0.24

Table A.29 Correction Factors for Steel Framed Floor Assemblies (24-in. framing spacing)

Member Size	R-19	R-30	R-38
2 x 6	0.78	NA	NA
2 x 8	0.44	NA	NA
2 x 10	0.44	0.35	NA
2 x 12	0.44	0.35	0.32

Table A.30. Heat Flow Paths for Steel framed Floor Assemblies (Over Unheated Spaces)

Description	R-Value at Insulation
Unheated Space Air Film	0.92
Insulation	Ric
Sheathing	Rs
Joists	--
Carpet and Pad	1.23
¾-in. Wood Subfloor	0.94
Inside Air Film	0.92
Total Path R-Value	4.01 + Ri + Rs

$$\text{Steel-Frame Floor } U_o = \frac{1.0}{4.01 + \text{Rs} + (Fcor * Ric)} \qquad \text{(A.19)}$$

where Rs = the R-value of the insulating sheathing.
Fcor = Correction factors for floor assemblies as given by Table 502.2.1.3 of ICC 2003
Ric = Cavity insulation between ceiling members

Note: Floors over outside air are evaluated the same as Ceilings/Roofs as stated in Section 502.2.1.3 of the 2003 IECC.

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.31 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.20).

$$\text{Perimeter} = \frac{\text{Wall Area}}{\text{Wall Height}} \tag{A.20}$$

The proposed wall UA is calculated as:

$$\text{proposed UA} = \sum_{n}^{i=1} \left(\frac{1}{\text{wall R-value[i]} + \text{soil R-value[i]}} \right) * \text{area[i]} \tag{A.21}$$

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.31).
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.21) 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.31 gives the soil R-values used in Equation (A.21), based on the depth of the increment under consideration.

Table A.31. 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 and 1999]. 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:

$$\text{required UA} = \sum_{n}^{i=1} \left(\frac{1}{\frac{1}{\text{MEC U}_o} + \text{soil R-value[i]}} \right) * \text{area[i]} \qquad \text{(A.22)}$$

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.31).

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

A.4.3.1 Solid Concrete and Masonry Block Basement Walls

Table A.32 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.32. 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

$$\text{Basement Wall Rval} = \text{Reff} + \text{Rwall} + \text{Rcont} \tag{A.23}$$

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.19).
Rwall = the R-value of the uninsulated wall (see Table A.32).
Rcont = the rated R-value of the continuous insulation.

A.4.3.2 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 and 1999).

Table A.33 gives the assumed heat flow paths for basement wood-frame walls. Equation (A.24) gives the wall U_o for the 1992 and 1993 MEC, and Equation (A.25) 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.

For the 1992 and 1993 MEC:

$$\text{Basement Wall } U_o = \left[\frac{0.15}{9.03 + \text{Rcont}} + \frac{0.85}{2.15 + \text{Rcavity} + \text{Rcont}}\right] \tag{A.24}$$

For the 1995 MEC and 1998 and 2000 IECC:

$$\text{Basement Wall } U_o = \left[\frac{0.25}{9.03 + \text{Rcont}} + \frac{0.75}{2.15 + \text{Rcavity} + \text{Rcont}}\right] \tag{A.25}$$

Table A.33. 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

A.4.3.3 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:

$$\text{ICF R-value} = 0.68 + \text{Rm} \times 0.89 \tag{A.26}$$

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

A.4.3.4 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

$$\text{Other Wall R-value} = \frac{1}{\text{Assembly U-factor}} \tag{A.27}$$

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 RES*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.22), 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 RES*check* software (DOE 1995d). 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.34. The F-factors are given in the referenced paper for insulation both on the exterior and interior of the foundation wall. The 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

---

(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.

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).

In the RES*check* software, slab perimeters can be insulated to any depth up to 4 ft (DOE 1995d). To calculate heat loss for any combination of insulation depth and R-value, quadratic curves were fit through the data in Table A.34. The resulting quadratic Equation (A.28) gives the F-factor as a function of insulation depth. The applicable coefficients for Equation (A.28) are given in Table A.35 and are determined by the insulation R-value. R-values range from R-0 to R-20.

Table A.34. 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

$$\text{F-factor} = \text{intercept} + \text{coef 1} \times \text{depth} + \text{coef 2} \times \text{depth}^2 \qquad \text{(A.28)}$$

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

Table A.35. Coefficients for Slab F-Factor Equation (A.28)

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

A.7 References

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1985. *1985 ASHRAE Handbook: Fundamentals.* Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1989. *1989 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1993. *1993 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) 1996. *BSR/ASHRAE/IESNA Standard 90.1-1989R,* "Energy Code for Buildings Except Low-Rise Residential Building." First Public Review Draft, March 1996, Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1997. *1997 ASHRAE Handbook: Fundamentals*. Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1998. *ASHRAE Transactions*, vol. 104, part 2 (TO-98-25-4), Table 5. Atlanta, Georgia.

Anderson RG and DB McKeever. 1991. *Wood Used in New Residential Construction in the United States*. American Plywood Association; American Wood Council; National Forest Products Association; Southern Forest Products Association; Western Wood Products Association; and the Forest Service, U.S. Department of Agriculture, Washington, D.C.

Labs K, J Carmody, and R Sterling. 1988. *Building Foundation Design Handbook*. Underground Space Center, University of Minnesota, Minneapolis, Minnesota.

Council of American Building Officials (CABO). 1992. *Model Energy Code; 1992 Edition*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1993. *Model Energy Code; 1993 Edition*. Falls Church, Virginia.

Council of American Building Officials (CABO). 1995. *Model Energy Code; 1995 Edition*. Falls Church, Virginia.

DeCristoforo RJ. 1987. *Housebuilding--A Do-It-Yourself Guide*. Sterling Publishing Co., Inc., New York.

Energy Design Update. March 1993. Aspen Publishers, Inc., New York.

Environmental Building News. March/April 1996. "Autoclaved Aerated Concrete: Is North America Finally Ready?" Vol. 5, No. 2. Available URL: http://www.buildinggreen.com/products/aaconcrete.html

Huang YJ, LS Shen, JC Bull, and LF Goldberg. 1988. "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program." *In ASHRAE Annual Meeting (Technical Papers),* vol. 94, part 2, pp. 936-958, CONF-880627. June 25-29, 1988, Ottawa, Canada.

International Code Council (ICC). 1998. *International Energy Conservation Code; 1998.* Falls Church, Virginia.

International Code Council (ICC). 1999. *International Energy Conservation Code; 2000.* Falls Church, Virginia.

International Code Council (ICC). 2003. *International Energy Conservation Code; 2003.* Falls Church, Virginia.

International Code Council (ICC). June 2005. *ICC Standard on Log Construction; Public Comment Draft*. ICC IS-LOG. Country Club Hills, Illinois.

Kosny J and JE Christian. 1995. *Steady-State Thermal Performance of Concrete Masonry Unit Walls Systems; Thermal Performance of the Exterior Envelope of Buildings VI.* Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Oak Ridge National Laboratory (ORNL). August 2001. *Whole-Wall Thermal Performance Calculator*. Available URL: http://www.ornl.gov.

U.S. Department of Agriculture (USDA), Forest Service, Forest Products Laboratory. March 1999. *Wood Handbook, Wood as an Engineering Material*. FPL-GTR-113. Madison, Wisconsin.

U.S. Department of Energy (DOE). 1995a. *Housing Characteristics 1993-Residential Energy Consumption Survey*. DOE/EIA-0314(93). Washington, DC.

U.S. Department of Energy (DOE). 1995b. *1993 MECcheck*^{TM} *Manual, 1993 Model Energy Code Compliance Guide, Version 2.0*. PNL-11087, Washington, D.C.

U.S. Department of Energy (DOE). 1995c. *1993 MECcheck*^{TM} *Prescriptive Packages, 1993 Model Energy Code, Version 2.0*. PNL-11087, Washington, D.C.

U.S. Department of Energy (DOE). 1995d. *1993 MECcheck*^{TM} *Software User's Guide, 1993 Model Energy Code, Version 2.0*. PNL-11087, Washington, D.C.

Appendix B

Arkansas

Appendix B

Arkansas

The 2004 Arkansas Energy Code is based on the 2003 IECC with the release of RES*check* 3.6 Version 1a. The Arkansas code has no functional differences from the 2003 IECC, and is implemented in RES*check* to give exactly the same results with the exception of building-level SHGC compliance. However, the Arkansas implementation does require SHGC inputs where applicable (i.e., locations with heating degree days less than 3500).

Appendix C

Georgia

Appendix C

Georgia

The Georgia Residential Code is based on the 2000 IECC.

C.1 Compliance Calculations

The Georgia code gives an R-2.75 credit for slabs with carpet or hardwood on plywood. The software assumes a continuous R-value of 2.75 to a depth of 2 ft. if the user selects this option. Otherwise, the software assumes zero insulation.

All SHGC required codes allow adjustments to be made to the area-weighted average SHGC when overhang projections exist and/or, in the case of the Georgia 2004 code, when a shade screen exists. An overhang projection is represented as the ratio of width of the overhang (from exterior of wall to edge of overhang) over height as measured from the bottom of the overhang to the bottom of the fenestration component. In the RES*check* 3.5 software the shade screen multiplier applied is 0.80 as per industry recommendation until additional research can be completed. This multiplier was adopted as being representative of the most conservative approximation. That is, solar heat gain can be reduced by at most 20%.

As per direction from Georgia state representatives, the shade screen adjustment must recognize half, full, or no shade screen specifications. No shade screens implies no adjustment is made. A full shade screen specification requires that a multiplier of 0.45 be applied to the component proposed SHGC. A half shade screen specification requires that only half the glazing component area be considered in the SHGC adjustment for shade screens. Note that shade screen adjustments do not apply to skylight or glass door components.

C.2 Compliance Reports

Slab entries in the *Compliance Report* have an additional selection: *Other* or *w/ Carpet or Hardwood on Plywood*.

The *Inspection Checklist* differs in the following sections, as requested by the state: Air Leakage, Vapor Retarder, Duct Insulation, and Heating and Cooling Equipment Sizing. A decorating glazing exemption is also included.

Appendix D

Massachusetts

Appendix D

Massachusetts

The Massachusetts Energy Code is based on the 1995 MEC.

D.1 Compliance Reports

The *Inspection Checklist* differs from the 1995 MEC in the following sections, as requested by the Massachusetts Energy Office: Vapor Retarders, Air Leakage, Duct Insulation, Duct Construction, Heating and Cooling Equipment Sizing.

Appendix E

Minnesota

Appendix E

Minnesota

The 2000 Minnesota Energy Code is based on the 1995 MEC.

E.1 Calculations

The Minnesota code requirements are:

Assembly	1999 Minnesota Code	2000 Minnesota Code (changed values only)
1& 2 Family Assembly		
Roof/Ceiling	0.026	
Combined Wall (includes foundation windows/doors)	0.11 (if foundation walls are >= R-10) 0.10 (if any foundation wall < R-10)	
Basement & Crawl Wall	R-10	
Floors Over Unconditioned	0.04	0.033
Slab-On-Grade Uo	R-10	
Slab-On-Grade Depth of Ins.	60" (North/Zone 1) 42" (South/Zone 2)	
Multifamily		
Wall	0.145 (North/Zone 1) 0.148 (South/Zone 2)	0.129 0.131

The minimum U-factor and maximum R-value limits are as follows. The U-factor limits are applied as area-weighted averages. The R-5 foundation minimum is applied as the sum of cavity and continuous insulation. Any combination of cavity plus continuous insulation meeting or exceeding R-5 will meet the requirement.

Assembly	Minimum U_o or Maximum R-Value
Skylights	0.55
Glazing	0.37 for windows and glass doors (except foundation windows 5.6 ft2 or less) 0.51 for foundation windows 5.6 ft2 or less
Foundation Wall & Slab	R-5 (any combination of cavity + continuous)
Floors Over Unconditioned	0.033

The engine has two additional boolean variables to distinguish between the Minnesota glazing types: *foundation* and *small*.

The Minnesota code for the slab *depth of insulation* extends to 60”. Previously, the RES*check* slab calculations were only considered valid up to 48”. The method for extending F-value calculation for depths beyond 48” are included in Appendix A. The depth of insulation range limits for all codes was extended to 72” in May 1996.

E.2 Compliance Reports

Minnesota’s *Inspection Checklist* is so different from the 1995 MEC checklist, the state provided its own file.

Appendix F

New Hampshire

Appendix F

New Hampshire

The New Hampshire Energy Code is based on the 1995 MEC (RES*check* 3.5.1 and 3.5.1a) and the 2000 IECC in RES*check* 3.5.1b+.

F.1 Weather Data

New Hampshire uses a single HDD65 for their entire state, based on the value of Concord, NH. They do not support a cities or counties list.

Appendix G

New Jersey

Appendix G

New Jersey

The New Jersey Energy Subcode is based on the 1995 MEC.

Appendix H

New York

Appendix H

New York

The New York State Energy Conservation Construction Code is based on the 2001 IECC.

H.1 Calculations

Electric Homes: The New York code requirements for electrically heated homes are given in the following table. The NY code requirements are given in the second column, primarily as R-values. Since code requirements based on R-value will vary with assembly type, the software instead enforces the roof, above-grade wall, and floor requirements as a U-factor based on the code R-values and assuming a specific construction type. he assumed construction type is also listed in the table:

Assembly	**NY Single & Multifamily R-Value Requirement**	**Assumed Assembly Type**	**Corresponding U-value Requirement**
Roof/Ceiling	R-49	Wood truss	0.026
Wall	R-26	Wood-framed walls, 16"oc	0.052
Glazing U-Factor	0.31		0.31
Floor Over Unheated	R-30	Wood truss floor over unconditioned space	0.033
Basement Wall Depth of Insulation	R-19 7 ft. below outside grade or to top of slab		R-19[(a)]
Slab Edge Depth of Insulation	R-15 4 ft.		R-15

(a) The required U-factor varies with wall type, using the following equation:

$$\mathrm{Re}\,qUo = \frac{1}{effective(19) + uninsulatedWallRvalue}$$

where effective(19) = the effective R-value of a furring system with R-19 insulation. Refer to Appendix A for a table of effective R-values. This table lists the effective R-value of R-19 cavity insulation as R-15.3. uninsulatedWallRvalue = the R-value of the uninsulated wall. These R-values are listed in Appendix A, but are duplicated here for the three concrete/masonry wall types:

Wall Type	Uninsulate 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

Non-Electric Homes: The New York requirements for non-electric homes is the same as the IECC 2001, except for the depth of insulation requirement for foundation walls. For basement walls, the 2001 IECC requires insulation the full wall height or 10 ft. whichever is less. The New York basement wall depth of insulation requirements are from the top of the wall to the depth specified in the following table.

HDD65	Depth Below Grade (in.)
Up to 6000	24”
6001-8000	48”
8001 and up	84”

For crawl space walls, the 2001 IECC requirements depend on the configuration of the wall and its relation to the outside and inside grade. For New York, the depth requirement is a total minimum vertical or vertical and horizontal distance of 24” from the outside finish ground level.

H.2 Compliance Reports

The *Inspection Checklist* differs from the 1995 MEC in the following sections, as requested by the state: Vapor Retarders, Duct Insulation, Duct Construction, Temperature Controls, Electric Systems, Fireplaces, and Service Water Heating.

Appendix I

SES/Pima County

Appendix I

SES/Pima County

The codes listed as Sustainable Energy Standard, Pima County for Locations < 4000 ft, and Pima County for Locations >= 4000 ft are based on the 2000 IECC. The two Pima County codes are identical to the 2000 IECC, except that they are based on a single HDD65 value (see Weather Data). The Sustainable Energy Standard has several modifications, as described below.

I.1 Weather Data

The Pima county codes do not require a location file. The HDD value assigned is based on the code selected:

Code	**HDD65**
2000 IECC for locations < 4000 ft	2100
2000 IECC for locations >= 4000 ft	7000
Sustainable Energy Standard	7000

I.2 Calculations

To force the engine to use the HDD65 values associated with each code, the GUI can set the HDD65 location variable directly. This will cause the engine's *use location file* variable to be set to FALSE. When the code is changed again, the *use location file* variable must be explicitly set back to TRUE, or the engine will not use HDD values based on location.

With respect to the solar heat gain calculations, the SES code will implement its own version (i.e., 0.39 and 0.5 depending on the orientation of the window) and the non-SES codes will implement the SHGC calculation that factors in projection factor impacts.

I.3 Compliance Reports

The *Inspection Checklist* for the SES code differs from the 2000 IECC in the following sections, as requested by the jurisdiction: Heating and Cooling Equipment, Glazing, Plans, Air Leakage, Vapor Retarder, Duct Construction, Water Heating, Metering, Wood Burning Stoves and Fireplaces, Circulating Hot Water Systems, and Swimming Pools.

Appendix J

Vermont

Appendix J

Vermont

The 1997 Vermont Residential Building Energy Standards is based on the 1995 MEC.

J.1 Weather Data

Vermont enhanced their list of cities and mapped all of them to the weather data for one of five locations: Burlington, Chelsea, Newport, St. Johnsbury, or Vernon.

J.2 Calculations

The Vermont code requirements apply the following modifications to the MEC 1995 code requirements:

Code Requirement	**Percentage of the 1995 MEC UA**
Single-Family Homes	Total UA 5% Below 1995 MEC
Multifamily Homes	Total UA 10% Below 1995 MEC
Log Wall Homes	Total UA 20% Above 1995 MEC

J.3 Compliance Reports

The *Inspection Checklist* differs from the 1995 MEC in the following sections, as requested by the state: Vapor Retarder, Domestic Hot Water, and Dampers.

Appendix K

Wisconsin

Appendix K

Wisconsin

The Wisconsin Uniform Dwelling Code is based on the 1995 MEC.

K.1 Weather Data

Wisconsin uses counties and does not support a cities version. Their code is based on a single zone (Zone 15). You will not see changes in the Max. UA when switching locations, like you do for most codes. The locations were left in, however, because the heating loads calculation in the *Loads* folder varies by zone. Wisconsin has four zones, and the outdoor design temperatures used in the loads calculation vary for each of the four zones.

K.2 Calculations

The Wisconsin code has the following requirements:

	Non-Electric	**Electric**
Ceiling	0.026	0.020
Wall	0.0110	0.080
Basement	0.091	0.091
Crawl Space	0.060	0.060
Floor over unheated	0.050	0.050
Floor over outside air	0.033	0.033
Slab – Unheated	R-6.5	R-10
Slab – Heated	R-8.5	R-10

K.3 Compliance Reports

The *Inspection Checklist* differs from the 1995 MEC in the following sections, as requested by the state: Air Leakage, Ventilation, Vapor Retarder, Duct Insulation, Duct Construction, Temperature Controls, Humidity Control, Circulating Hot Water Systems, and Pipe Insulation.

Appendix L

AreaCalc

Appendix L

AreaCalc

L.1 Introduction

L.1.1 About AreaCalc

AreaCalc is an automated building take-off tool that can be used to assist builders, architects, contractors, and others in the building industry to perform area take-offs. AreaCalc was designed to work with the RES*check* software, although it may be used for other applications.

The AreaCalc software allows users to construct a library of commonly-used windows, skylights, and doors. Users can enter these components directly, or once the library is created, they can simply select an assembly from the library and enter the quantity to be installed in the building. The software computes the gross area of all assemblies.

AreaCalc may also be used to sum the areas of wall and ceiling components to compute a gross wall or ceiling area. The gross areas of ceilings, basement and crawl space walls, and floors may also be summed. The data input into AreaCalc can be automatically transferred to RES*check* by using the *Transfer Data to REScheck* option under the *Tools* menu.

L.1.2 About This Report

This appendix is designed to explain the features, technical basis and the software development details for the AreaCalc software.

L.2 Computations

The **Window/Wall Percent** is the ratio of total window area divided by the total wall area:

[(WINDOW_AREA / GROSS_WALL_AREA) * 100.0].

The **Area-Weighted Average U-Factor** is the total weighted U-factor divided by the total area of that component. The Total Weighted U-Factor is calculated by multiplying U-factor by the component area:

(WINDOW_AVERAGE_U_FACTOR = sumWeightedUFactorAvg / sumTotalArea) (applicable to windows/skylights only).

The **Area-Weighted Average SHGC** is the total weighted SHGC divided by total area of that component. Total Weighted SHGC is calculated by multiplying SHGC by the component area: (WINDOW_AVERAGE_ SHGC = sumWeighted SHGCAvg / sumTotalArea) (applicable to windows/skylights only).

The **Net Ceiling Area Total** is the total ceiling area minus the total skylight area:

(NET_CEILING_AREA = GROSS_CEILING_AREA - SKYLIGHT_AREA).

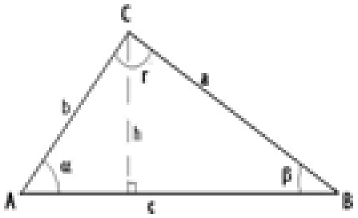
The **Net Wall Area Total** is the total wall area minus total window area minus total door area:

(NET_WALL_AREA = (GROSS_WALL_AREA)- (WINDOW_AREA)- (DOOR_AREA)).

The **Area Subtotal** (total of selected rows) is the sum of the areas of the selected rows that are in the library.

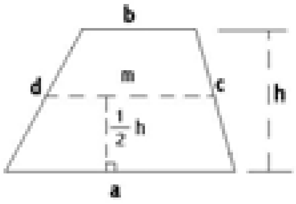
L.3 Common Shapes, Dimensions, and Area Calculations

L.3.1 Triangle



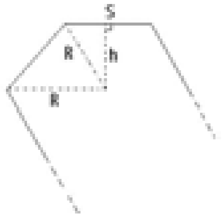
Area = (base X height)/2
Base = c; height = r;

L.3.2 Trapezoid



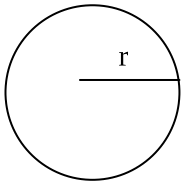
Area = (height)/2 X (width1 + width2)
Height = h; width1 = a; width2 = b;

L.3.3 Hexagon



Area = (Perimeter X height)/2
Perimeter = number of sides X side length = 6 X s;
Height = h;

L.3.4 Circle



Area = Π X Radius ^{2}
Π = pie- constant – 3.17..;
Radius = r;

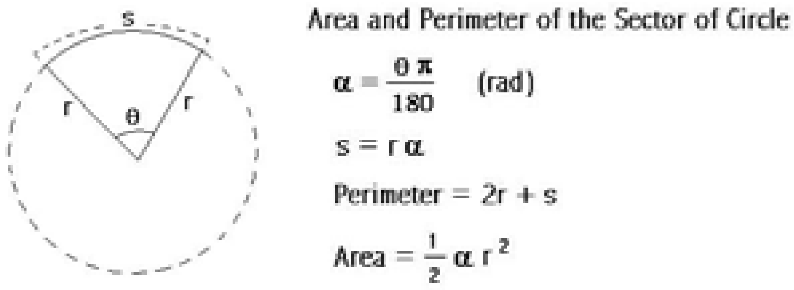
L.3.5 Half Circle

Area= Area of circle /2;
Perimeter = (perimeter of circle/2) + diameter

L.3.6 Quarter Circle

Area = Area of circle/4
Perimeter = (perimeter of circle/4) + (2 x radius)

L.3.7 Sector of Circle (not implemented)



Area and Perimeter of the Sector of Circle

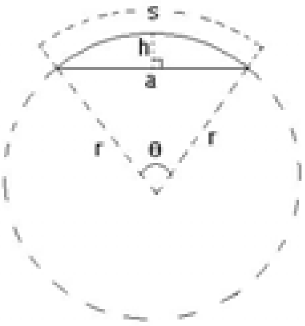
$$\alpha = \frac{\theta \pi}{180} \quad \text{(rad)}$$

$$s = r\alpha$$

$$\text{Perimeter} = 2r + s$$

$$\text{Area} = \frac{1}{2} \alpha r^2$$

L.3.8 Segment of Circle (not implemented)



Area and Perimeter of the Segment of Circle

$$\alpha = \frac{\theta \pi}{180} \quad \text{(rad)}$$

$$a = 2\sqrt{2hr - h^2}$$

$$a^2 = 2r^2 - 2r^2 \cos\theta$$

$$s = r\alpha$$

$$h = r - \frac{1}{2}\sqrt{4r^2 - a^2}$$

$$\text{Perimeter} = a + s$$

$$\text{Area} = \frac{1}{2}\left[sr - a\,(r - h) \right]$$