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Methodology for Developing the MEC*check*™ Materials through Version 3.3

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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. 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.

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 has 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. 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 code officials enforce these code requirements, DOE directed Pacific Northwest National Laboratory (PNNL)(a) to develop the MEC*check*™ compliance materials. The easy-to-use 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.X of the MEC*check* compliance materials developed for the 1992, 1993, and 1995 editions of the MEC, and the 1998 and 2000 editions of the IECC. Although some requirements contained in these codes have changed, the methodology used to develop the MEC*check* materials for these five editions is similar.

The MEC*check* materials assist 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

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the calculations and assumptions underlying the treatment of the code requirements in MEC*check*, with a major emphasis on the building envelope requirements.

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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) has 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 2000). 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, and to help HUD, RECD, and state and local officials enforce the MEC requirements, DOE tasked Pacific Northwest National Laboratory (PNNL) with developing the MEC*check*™ compliance materials. The easy-to-use 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—paper-based prescriptive packages, software, and a trade-off worksheet (included in the compliance manual). The 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 MEC and IECC. To make the requirements more understandable, the format in which the requirements are presented was changed from the original format in the codes.

We have developed MEC*check* compliance materials for three different editions of the MEC (1992, 1993, and 1995) and the two editions of the IECC (1998 and 2000). This report explains the methodology used to develop Version 3.X of the MEC*check* compliance materials 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 MEC*check* materials for these three editions is similar.

Section 2.0 of this report summarizes the differences in the different editions of the MEC and IECC. Section 3.0 provides a summary of the methodology used to develop the MEC*check* materials. Section 4.0 gives the technical basis for the simplified presentation of some of the code's miscellaneous requirements in the MEC*check* materials. The methodology for the MEC*check* paper-based prescriptive packages, software, and a trade-off worksheet are discussed in Sections 5.0, 6.0, and 7.0, respectively. Section 8.0 discusses the methodology for trading increased heating or cooling efficiency for lowered envelope efficiency in the MEC*check* prescriptive packages and software. All references cited in this report are identified in Section 9.0. Appendix A documents the assumptions and equations used in the calculation of the envelope component U_o-factors for the MEC*check* software, prescriptive packages, and trade-off worksheet. The results of a sensitivity analysis to quantify the impact of building prototypes are detailed in Appendix B.

2.0 Differences in the Editions of the MEC and IECC

The 1993 MEC contains much more stringent requirements for walls in multifamily buildings than the 1992 MEC. 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 MEC*check* materials.

The 1995 MEC 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 MEC*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 MEC*check* materials for the 1993 and 1995 MEC is identical.

The 1998 IECC 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 ones for small additions and window replacements. None of these code changes affect any of the calculations or methodology underlying MEC*check*; the only changes to MEC*check* are the addition of these new requirements in the *Inspection Checklist* printout produced by the software. The 2000 IECC 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 affect the methodology used to develop MEC*check*.

3.0 Methodology Summary

Users can use one of the three MEC*check* products (prescriptive packages, software, or a 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 MEC*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 MEC*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:

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

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 of 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 and the 1998 and 2000 editions of the IECC.

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 MEC*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 MEC*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 MEC*check* materials on forms titled, "Summary of Basic Requirements," and in the MEC*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 8.0.

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 MEC*check*. These R-values depend on duct location and climate zone (climate zones are discussed in Section 5.0).

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 MEC*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.

4.2 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 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 on 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 4.1 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 4.1, we selected climate zones in the six southern states that qualify for the exemption.

Table 4.1. 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 Prescriptive Package Approach

The prescriptive package materials contain tables of prescriptive compliance options (packages) that comply[a] with the thermal envelope requirements for each of the 19 climatic zones in the United States. The prescriptive packages offer a simple prescriptive compliance method that is easy to use and understand. This method requires only minimal calculations and offers several predetermined alternatives for builders.

We divided the United States into 19 climate zones and created a map for each state showing the climate zones in that state as part of the prescriptive package materials. Zones were drawn along county boundaries. County boundaries were considered more amenable to enforcement than the HDD-based requirements (which can vary significantly within a county). Builders, code officials, and homeowners may not know the HDD of every building location, but they will know the county in which the building is located.

For each zone, we developed a variety of prescriptive packages meeting the code's annual energy consumption target. (The energy target is established by the requirements in Chapter 5 of the code). The packages are presented as combinations of insulation R-values, window U-factors and areas, and heating and cooling equipment efficiency levels. Builders may choose any prescriptive package in their zone. If the building meets the prescriptive requirements of the chosen package, it will be determined to comply with the code's thermal envelope requirements.

We generated separate prescriptive packages for showing compliance with the 1992 and 1993 MEC because some of the thermal envelope requirements differ. We also generated separate prescriptive packages for compliance with the 1995 MEC because of changes in how wall U_o-factors are calculated. We developed another set of packages for the 1998 and 2000 editions of the IECC to incorporate packages actually included in those codes. The same basic methodology was used to develop the prescriptive packages for all five codes.

We reviewed existing state energy codes to determine preferred code formats and combinations of insulation levels in the code requirements. The results of this review indicated that using the prescriptive packages based on climate zone was an approach often used by the states.

The prescriptive packages were developed based on the following objectives:

- The prescriptive packages should represent common building practices. Packages should NOT specify energy efficiency measures that are difficult or impossible to purchase or build. The package requirements should be listed in terms describing

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(a) Strict compliance with the MEC requirements is not assured for all buildings because of the simplifications inherent in the prescriptive package approach. Some buildings complying with a prescriptive package may fail to comply with the code requirements by a small margin for some locations and building designs. However, the large majority of buildings complying with a prescriptive package will comply with the code.

commonly available products, such as insulation R-value or the rated (labeled) U-factor of a window or door.

- The number of calculations required by the builder or code official should be kept to an absolute minimum─complicated calculations and a computer are not needed.

Section 5.1 describes the process used to determine climate zones and generate the state maps with climate zones. Section 5.2 describes how the prescriptive packages were generated for each of these zones.

5.1 Development Process for Climate Zones and State Maps

For most thermal envelope components, the code requirements vary as a continuous function of HDD. The presentation of code requirements by HDD is unclear to many builders and code officials─many will not know the HDD for their location or even what an HDD is. To simplify this presentation, these continuously changing requirements had to be converted into simple requirements for climate zones containing groups of counties in each state. The process used to create these climate zones is discussed below.

5.1.1 Define HDD Zone Boundaries Inherent in the MEC

First, we identified HDD values where a significant change in code requirements existed. For each of the three foundation types,(a) we made plots of the HDD against the whole-house U_o of a typical, prototype house (described in Section 5.2.3) as determined by the code requirements at that HDD. These plots for single-family houses (one- and two-family dwellings) are shown in Figures 5.1, 5.2, and 5.3. The plots are based on the 1992 MEC requirements. The 1993 and 1995 MEC and IECC codes have only minor changes to wall and ceiling requirements. A review of these plots revealed some important HDD levels that are used to establish "natural boundaries" between climate zones. These boundaries (discussed below) are inherent in the MEC and IECC requirements, regardless of the prototype used.

- Buildings with floors over unheated spaces have natural boundaries at 1000 and 2500 HDD because of vertical drops in the floor requirements at those locations (see MEC [CABO 1992], Chapter 7, Figure 6).

- Basements have natural boundaries at 1500, 8500, and 9000 HDD. Requirements for basement insulation start at 1500 HDD (no basement requirements exist below 1500 HDD). At 8500 HDD, basement requirements drop sharply (become more stringent) and then level out at 9000 HDD. After 9000 HDD, basement wall requirements remain constant.

(a) Version 2.0 and later Prescriptive Packages actually offer four different foundation types. However, the crawl space wall foundation option was not offered at the time the climate zones were developed.

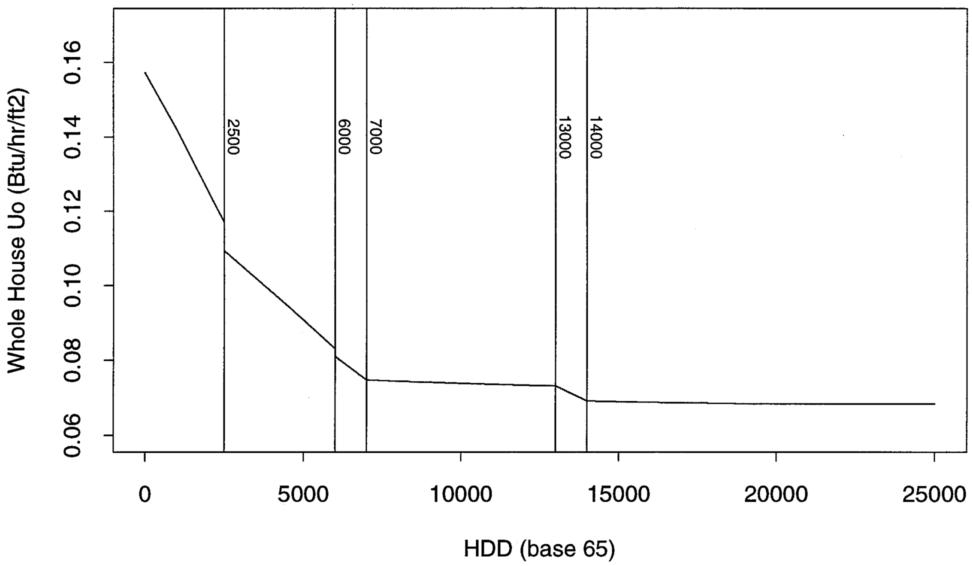

Figure 5.1. 1992 MEC Single-Family Whole-House U_o Requirement vs. HDD: Slab-On-Grade

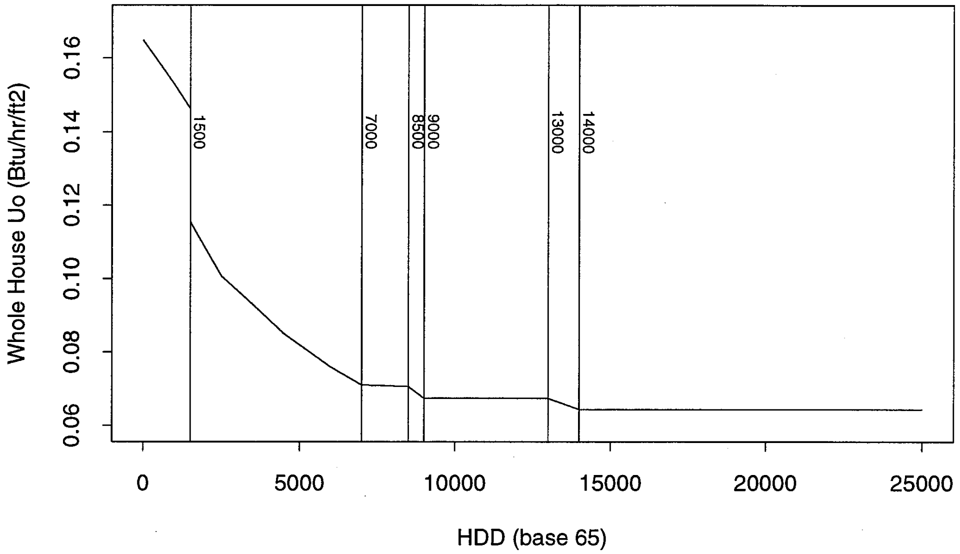

Figure 5.2. 1992 MEC Single-Family Whole-House U_o Requirement vs. HDD: Basement Walls

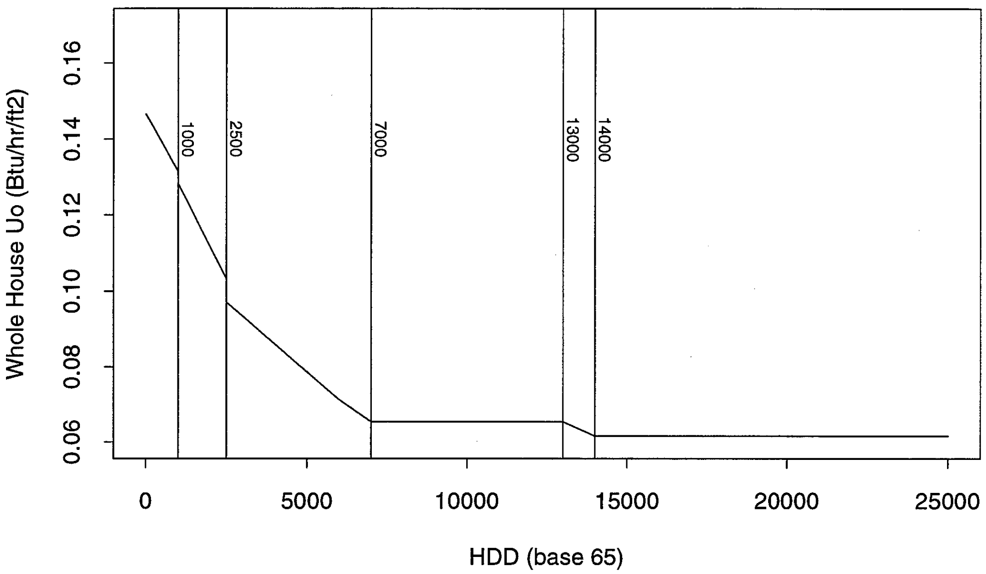

Figure 5.3. 1992 MEC Single-Family Whole-House U_o Requirement vs. HDD: Floors Over Unheated Spaces

- Slabs have three natural boundaries. At 500 HDD, requirements start for heated slab insulation. At 2500 HDD, requirements start for unheated slab insulation. At 6000 HDD, the insulation depth requirement changes from 2 to 4 ft.

- Ceiling, wall, and floor requirements do not change between 7000 and 13000 HDD. Wall requirements drop slightly from 13000 HDD to 14000 HDD, where they once again become constant. These requirement changes make 7000 HDD, 13000 HDD, and 14000 HDD logical zone boundaries.

- The highest HDD average for any county in the United States was determined to be 20200 (North Slope, Alaska). Zones 18 and 19 are only in Alaska. Zone 19 covers a broad HDD range (14000+), but the MEC requirements are fairly constant over this range.

5.1.2 Define HDD Range for Each Zone

After examining the code requirements by HDD described above and the HDDs for towns and cities throughout the United States, we determined that establishing climate zones in intervals of 500 to 1000 HDD was reasonable. After generating maps with zone intervals at 500 and 1000 HDD, we selected the 500 HDD interval. This selection was partially based on reviewers suggestions that zones at 1000 HDD are too large and that the smaller zone size better captures the “micro-climates” found in many states. A 500 HDD interval was also considered advantageous because it included the HDD levels in the code that establish the inherent boundaries discussed above.

Table 5.1 shows the HDD range used for each zone. Some zones above 7000 HDD span a larger HDD interval (greater than 500 HDD) because most MEC envelope requirements do not change much above 7000 HDD. Therefore, Zone 15 ranges from 7000 HDD to 8499 HDD. Zone 16 (8500 HDD to 8999 HDD) only spans 500 HDD because the code basement requirements become significantly more stringent over this interval and become constant after 9000 HDD. Zone 17 spans 9000 to 12999 HDD—again a region where the code requirements are relatively constant. Zone 18 spans 1000 HDD because of the drop in wall requirements over that interval. Zone 19 contains all climates 14000 HDD and higher.

Table 5.1. HDD Range for Each Climate Zone

Zone Number	HDD Range
1	0 - 499
2	500 - 999
3	1000 - 1499
4	1500 - 1999
5	2000 - 2499
6	2500 - 2999
7	3000 - 3499
8	3500 - 3999
9	4000 - 4499
10	4500 - 4999
11	5000 - 5499
12	5500 - 5999
13	6000 - 6499
14	6500 - 6999
15	7000 - 8499
16	8500 - 8999
17	9000 - 12999
18	13000 - 13999
19	14000 +

5.1.3 Generate State Maps

To create a state map with climate zones defined along county boundaries, an HDD value had to be assigned to each county. To complete this task, we obtained climate data and the locations at which the data were monitored from the National Oceanic and Atmospheric Administration (NOAA) (National Climatic Data Center 1992). Initially, each county was placed in its zone by taking the mean of all HDD data points in that county. Inaccurate results for some counties were produced using this method because HDD data points that were not obtained at population centers (i.e., observation towers on top of mountains) gave misleading results. Therefore, we obtained population data from the U.S. Bureau of the Census (1988). We created 4724 locations, which can be characterized by HDD values, the county in which that value was monitored, and the population of the city (if the data point represented a city or town). The population data combined with the HDD data allowed the mean for each county to be weighted by population. For counties without population data corresponding to the NOAA HDD monitoring locations, we used the median of the HDD data points in that county instead of the mean. For the few counties without any HDD data (about 10% of all counties—generally small, sparsely populated), we used the median HDD value of the five nearest counties.

To determine the correct zone for all counties, we calculated the population-weighted average HDD for each county. The results were then manually examined to determine if some minor alterations were appropriate to smooth out the resulting zones or to consolidate population centers. For example, some counties were climatic "islands" surrounded by counties in other zones. If this type of county's HDD average was very close to that of the neighboring counties (usually within 10%), then that county was often placed in the same zone as its neighbors. It was also beneficial to have metropolitan areas in the same zone when these areas crossed county lines, which lead to the adjustment of a few counties. We reviewed all adjustments to guarantee that the results were conservative; i.e., that the net result of adjusting county climate zones was to move more population-weighted data points into higher zones than into lower zones.

5.2 Methodology for Development of Prescriptive Packages

The prescriptive packages are sets of envelope component insulation R-values, window area and U-factors, and heating and cooling equipment efficiency levels. For most climate zones, more than 20 packages are available as options. The methodology used to develop these prescriptive packages is described below.

5.2.1 Establish Insulation Levels for Use in Analysis

We used the following insulation levels in our analysis. These levels were established based on an examination of state codes and commercially available products and materials.

- **Ceiling Insulation R-Values**(a) - R-13, R-19, R-26, R-30, R-38, R-49
- **Wall Insulation R-Values**(a),(b) - R-11, R-13 through R26 and R-28
- **Window U-Factors**(c) - 1.07, 0.90, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30

(a) R-7 insulation was not included for ceilings or walls because builders have indicated it is no longer commonly available.

(b) Wall insulation R-values represent the sum of wall insulation plus insulating sheathing. See Table 5.6 for more details.

(c) Window U-factor levels were based on distributions found in the National Fenestration Rating Council (NFRC) database (NFRC 1993). Window U-factors between 1.07 and 0.75 were uncommon. Most windows have U-factors between 0.30 and 0.75. Windows with a U-factor of 0.90 were included at the recommendation of one reviewer.

- **Floor R-Values** - R-0, R-11, R-13, R-15, R-19, R-21, R-26, R-30
- **Basement and Crawl Space Wall R-Values** - R-0 and R-2 through R-30
- **Slab R-Values** - R-0 and R-2 through R-20
- **Door U-Factors**(a) - 0.47 (single family) and 0.53 (multifamily)
- **Single-Family Window Areas as a Percent of Wall Area**(b) - 12%, 15%, 18%, 22%, or 25%
- **Multifamily Window Area as a Percent of Wall Area** - 12%, 15%, 20%, 25%, 30%.

5.2.2 Examine State Code Prescriptive Requirements

We examined the state energy efficiency codes for single-family buildings to get information on the most commonly used insulation levels and component combinations. Most states with their own unique energy efficiency codes (states that did more than adopt an existing national code by reference) have codes that contain simple prescriptive requirements (e.g., minimum insulation levels). Some states offer a choice of several prescriptive packages, while others divide their states into multiple climate zones. A clear majority of the states with unique codes based their prescriptive requirements on nominal R-values instead of U-factors. Table 5.2 shows the different state code formats and the number of state codes based on each format.

Table 5.2. Formats for State-Developed Codes(a)

Code Format	Number of States
Unique State Developed Code	22
R-Value Prescriptive Paths Only	14
U-Factor Prescriptive Paths Only	2
R-Value and U-Factor Paths	5
Performance Path Only	1
Requirements Vary by Climate Zone	7
Multiple Packages	4
(a) Table based on contacts made through September 1994.	

(a) The door U-factor used in the analysis was 0.47 for single-family homes and 0.53 for multifamily homes. The door U-factor requirement given in the state map footnotes is 0.35 for both building types. This stricter requirement was used to allow for an entry door exemption (see Section 5.2.4 for more details).

(b) Larger window areas are typically reported in the southern states, such as Florida and California. Therefore, we generated 25% window area packages for locations with HDD up to 2500 (Zones 1 through 5) and 22% window area packages for all other locations.

Other information from the state codes influenced the assumptions made in the analysis. When state codes placed a limit on window area, this limit was most commonly 15% of the wall area; thus, we used this window area for several packages. The most common door U-factor requirement in the state codes was 0.4, which we initially used as the default door U-factor requirement in our analysis. The use of this U-factor was reinforced because all solid-wood and metal doors listed in the *1993 ASHRAE Handbook: Fundamentals* are rated at or below a U-factor of 0.4 (ASHRAE 1993). We later lowered this requirement to 0.35 to allow for an entry door exemption (see Section 5.2.4 for more details).

5.2.3 Select Prototype Single-Family and Multifamily Buildings

We generated the prescriptive packages for single-family and multifamily buildings separately based on what was considered prototypical for each type of construction. This section describes the dimensions used for each prototype.

Single-Family Prototype

The single-family prototype used to develop the prescriptive packages was a cross between a ranch-style home and a two-story building, and can be considered a split-level house (Conner and Lucas 1994). Because one- and two-story houses are about equally common for new construction nationwide, this prototype represented an average of all new houses. We examined four different foundation types, as differentiated in the code: floors over unheated crawl spaces, heated basements, slab floors, and heated crawl spaces. The door area was set at 56 ft^2. Table 5.3 shows the areas and perimeters used for the prototype building.

Table 5.3. Single-Family Prototype Areas and Perimeters

Component	Area or Perimeter	Comment
Ceiling	1418 ft^2	standard truss
Wood-Frame Walls	1736 ft^2	gross wall area
Floor	1418 ft^2	
Basement Walls	1240 ft^2	8-ft wall, 5 ft below grade
Crawl Space Walls	465 ft^2	36-in. wall, 10 in. below grade
Slab	155 ft	(perimeter)
Conditioned Floor Area	1890 ft^2	
Window Area	208, 260, 312, 382, or 434 ft^2	12%, 15%, 18%, 22%, or 25% of the gross wall area
Doors	56 ft^2	approximately three doors

Once the single-family packages were generated, we conducted a sensitivity analysis to quantify the impact of other building prototypes. The results of this analysis are detailed in Appendix B.

Multifamily Prototype

The median floor area of all new dwelling units (including rental and nonrental properties) in multifamily dwellings has been around 1000 ft^2 for many years according to *Characteristics of New Housing: 1999* (DOC 1999). This publication lists the percentage of new multifamily dwelling units by building size relative to the number of units per building (shown in Table 5.4).

Table 5.4. Percentage of New Multifamily Dwelling Units by Number of Units per Building

Number of Dwelling Units in Multifamily Buildings	Percent of New Multifamily Dwelling Units
2-4	11
5-9	17
10-19	27
20-29	24
30-49	9
50 or more	12

These data indicate that the median number of units falls in the 10 to 19 range. We used a prototype with average characteristics for new multifamily construction in developing the prescriptive packages for multifamily buildings. Because the code's scope is limited to multifamily buildings three stories or less in height, we used a two-story prototype as an average. The prototype for the multifamily dwelling was based on 14 dwelling units—each unit 28 ft by 18 ft with 8-ft ceilings and a floor area of 1008 ft^2 in a two-story arrangement. The total building dimensions were 252 ft by 28 ft. When showing compliance with the code, the building is examined as a whole—each dwelling unit is not considered individually.

The window area as a percentage of wall area varies greatly depending on the size and shape of the building. For small buildings, the window area may be quite low. The window area may be much higher for a long row of apartments, particularly if the building has an internal corridor. Because window areas in multifamily buildings are, on the average, larger than in single-family buildings, the packages were based on window areas of 12%, 15%, 20%, 25%, and 30% of the wall area (the 12% area was only used in the colder zones). The total door area for the building was set at 518 ft^2 (approximately two doors per unit). Table 5.5 shows the areas and perimeters for the whole building.

We assumed the single-family and multifamily prototypes had basement walls insulated to the full height of the wall—no trade-offs are offered for depth of insulation. The basement wall requirements were calculated based on a basement with 8-ft-high walls with 5 ft of the walls below grade. We selected the 5 ft depth below grade as an intermediate depth between a fully buried basement and a partially buried basement (if the wall is more than 50% above grade, it is not considered a basement wall). In comparing the proposed building to the code building, both UAs are computed based on the same dimensions and depth below grade.

Table 5.5. Multifamily Prototype Areas and Perimeters

Component	Area or Perimeter	Comment
Ceiling	7056 ft^2	standard truss
Wood-Frame Walls	8960 ft^2	gross wall area
Floor	7056 ft^2	
Basement Walls	4480 ft^2	8-ft wall, 5 ft below grade
Crawl Space Walls	1680 ft^2	36-in. wall, 10 in. below grade
Slab	560 ft	(perimeter)
Conditioned Floor Area	14112 ft^2	
Window Area	1075, 1344, 1792, 2240, or 2688 ft^2	12%, 15%, 20%, 25%, or 30% of the gross wall area
Doors	518 ft^2	

We calculated the crawl space wall requirements based on 36-in.-high walls buried 10 in. below grade. The code building and the proposed building were assumed to be insulated to 50 in. (26 in. on the above-grade portion of the wall and 24 in. total vertical plus horizontal distance from the outside grade surface). The code building and the proposed building UA were computed based on these assumptions. Although these crawl space dimensions may be uncommon, they were chosen to be conservative. Because the wall is less than 12-in. below grade, the stricter code insulation depth requirements apply.

5.2.4 Determine Assumptions Underlying Prescriptive Packages

To establish the prescriptive packages, various assumptions had to be made for each of the envelope components─windows, skylights, doors, ceilings, walls, and foundations, as well as equipment efficiency.

Windows

The window area was computed as a percentage of the gross wall area. The window area for the single-family packages was set to one of the following levels: 12%, 15%, 18%, and 22% (or 25%). The 25% window area option was used for locations up to 2500 HDD and the 22% window area option was used for locations with 2500+ HDD. Large window areas seem to be more common in the south (particularly California and Florida), which is why the larger percentage (25%) was used for the first five zones.

The window area for the multifamily packages was set to one of the following levels: 12%, 15%, 20%, 25%, and 30% of the wall area (the 12% level was only used in the colder zones).

We used a U-factor of 1.07 in the analysis for single-pane, aluminum-frame windows. Because few windows will have higher U-factors than 1.07, we substituted the term “any” for the actual U-factor rating of 1.07. The intent was to simplify the materials─the “any” option means builders and code officials will not have to confirm the rating of these windows.

An exemption for 1% of the total glazing area is allowed in Footnote 1 (on the back side of the prescriptive packages) (DOE 1995b). This exemption simplifies the compliance and inspection problems introduced when using decorative glass. If the amount of decorative glass is clearly under 1%, the builder will not have to resort to a weighted average for windows because of this small amount of glass (for which a U-factor rating may be difficult to obtain). In generating the packages, 1% of the total glazing area is assumed to have a U-factor of 1.07.

Skylights

In the code, skylights are subject to the same U_o requirement as ceilings, and windows are subject to the same U_o requirement as walls. For simplicity in the prescriptive packages, we combined skylights and vertical windows─Footnote 1 in the prescriptive packages allows skylights to be included with vertical glazing (windows) (DOE 1995b). If this simplification were not made, the number of packages would have to been increased dramatically to allow different skylight areas and U-factors.

This simplification can cause a slight failure in the prescriptive packages matching code requirements if skylights are installed because the packages allow the skylights to only meet the wall requirements and not the more stringent ceiling requirements. For example, consider the single-family prototype described in Section 5.2.3 with a 15% window-to-wall area, or a window area of 260 ft^2. Assume one house has all this 260 ft^2 of window area as vertical windows and a second, otherwise identical, house has 240 ft^2 of vertical windows and 20 ft^2 of skylights. These two houses are treated identically in the prescriptive packages─as if all the glazing area is vertical windows and therefore subject to the gross wall requirements. In reality, the 20 ft^2 of skylights in the second house should have to comply with the more stringent ceiling requirements. The error introduced by lumping skylights in with windows should be minimal for most houses. For the prototype house with the skylight area of 20 ft^2 in a climate with 4000 HDD, the prescriptive packages will meet or exceed the UA requirement by 0.6% less than if the skylight area was correctly subjected to the ceiling U_o requirements.

Doors

For single-family buildings, the door area was set at 56 ft^2 (approximately three doors) and the aggregate door (including both opaque and glazed portions) U-factor was set at 0.47. However, the door U-factor requirement for the prescriptive packages is 0.35. This stricter requirement was used to offset the exemption offered for any one door. The following calculation shows that the overall U_o-factor for three doors is 0.47 if the opaque portion U-factors of the doors are 0.35, and if one of the doors (the exempt door) has 50% of its area as single-pane, U-1.07 glazing. This equates to 46.7 ft^2 of opaque door area (two and one-half doors) and 9.3 ft^2 of glazing area (half of one door).

$$56\ ft^2 \times 0.47 = (46.7\ ft^2 \times 0.35) + (9.3\ ft^2 \times 1.07) \tag{5.1}$$

For multifamily buildings, the door area was set at 518 ft^2 (approximately two doors per unit, 28 doors total), which equates to 18.5 ft^2 per door. For each unit, one of the two doors was assumed to have 50% glazing. The following calculation shows that two doors with a U-factor of 0.53 are equivalent to two doors with a U-factor of 0.35, with one of the doors having 50% of its area as single-pane glazing (this equates to 27.75 ft^2 of opaque door area [1.5 doors] and 9.25 ft^2 of glazing area). The U-factor for the opaque portion for both doors was assumed to be 0.35 and the glazing U-factor was assumed to be 1.07.

$$37\ ft^2 \times 0.53 = (27.75\ ft^2 \times 0.35) + (9.25\ ft^2 \times 1.07) \quad (5.2)$$

Ceilings

In the analysis, we assumed limited space for attic insulation at the eaves, above the outside walls (see Appendix A). The ceiling U_o-factor calculation used in this analysis assumes some compression of R-38 and R-49 insulation in an attic without a raised or oversized truss. Footnote 3 in the prescriptive packages allows for a credit if the insulation achieves the full insulation thickness at the eaves over the exterior walls (DOE 1995b). With the assumptions used here, the U_o-factor for R-38 insulation in a standard truss is comparable to R-30 in a raised truss, and the U_o-factor for R-49 insulation in a standard truss is comparable to R-38 in a raised truss. Note that adding extra insulation in the center of the attic will not fully compensate for less insulation thickness at the eaves. Table 5.6 compares the U_o-factors for these constructions.

Table 5.6. Comparison of U_o-Factors for Ceiling Construction Types

Ceiling Construction	Insulation R-Value	U-Factor
Ceiling With Standard Truss	R-38	0.030
Ceiling With Raised Truss	R-30	0.032
Ceiling With Standard Truss	R-49	0.026
Ceiling With Raised Truss	R-38	0.025

Walls

We had to determine how to present the many combinations of wall cavity insulation and insulating sheathing used by builders today in a limited number of prescriptive packages. Specifying a total wall insulation R-value and allowing the builder to simply add the cavity and insulating sheathing R-values together to determine the total wall insulation R-value solved this problem.

Table 5.7 indicates that the error resulting by this method is marginal for reasonable combinations. For example, an R-19 requirement can be met with any of the last three combinations listed in the table. The wall U-factors used to generate the prescriptive packages assumed only cavity insulation with R-0.83 plywood sheathing. The error introduced by this assumption when foam sheathing insulation is used is at most 7%.

Table 5.7. Combinations of Wall Cavity Insulation Plus Insulating Sheathing[(a)]

Cavity R-Value + Sheathing R-Value	**U_o-Factor of Opaque Wall**
R-11 + R-2	0.076
R-13	0.075
R-11 + R-4	0.068
R-13 + R-2	0.069
R-15	0.069
R-13 + R-6	0.057
R-15 + R-4	0.058
R-19	0.054

(a) Based on framing area factors from the 1985 and 1989 ASHRAE Handbook of Fundamentals (referenced in the 1992 and 1993 MEC, respectively) (ASHRAE 1985; ASHRAE 1989a).

The wall R-value requirements in the prescriptive tables are for wood-frame walls. Metal-frame walls are less energy-efficient than wood-frame walls because of the high conductivity of metal. Metal walls were incorporated into a table in Appendix C of the MEC*check* Prescriptive Packages that correlates a given wood-frame wall insulation level with a metal wall insulation plus sheathing level (DOE 1995b). This table allows the user to transpose any package based on wood-frame walls to an “equal” package based on metal walls. The table uses the correction factors given in Table 502.2.1b of the 1995 MEC (CABO 1995).

Foundations

Packages were first generated for buildings with a floor-over-unheated space foundation (i.e., an unheated crawl space or unheated basement). The insulation level was selected for the other three foundation insulation configurations (slab-on-grade with perimeter insulation, basements with wall insulation, and crawl space with wall insulation), making sure the packages still complied. Thus, the foundations are interchangeable for any given package. For example, assume the following package complies in a climate zone:

- R-30 ceiling
- R-13 wall
- 0.40 window
- R-19 floor.

While keeping the ceiling, wall, and window specifications the same, R-values for basement wall insulation, crawl space wall insulation, and slab perimeter insulation had to be selected so the package still complied regardless of the foundation insulation configuration. For each package, the insulation requirements for each foundation insulation configuration are usually different because the code has different requirements.

The slab equations used in the analysis are only valid for R-values up to R-20—the basement wall and crawl space wall equations are valid for R-values up to R-30. In some cases, packages with high R-value floors require slab, basement wall, or crawl space wall R-values greater than these maximums. In these cases, no slab, basement wall, and/or crawl space wall insulation levels will comply with these packages. These situations appear as dashes (--) on the prescriptive tables.

Equipment Efficiency

Additional prescriptive packages are included to account for credit offered for high-efficiency heating and/or cooling equipment. High-efficiency cooling equipment was defined as having a seasonal energy efficiency rating (SEER) of 12 or more. A high-efficiency furnace was defined as a furnace with an annual fuel utilization efficiency (AFUE) of at least 90% or a heat pump with a heating seasonal performance factor (HSPF) of at least 7.8. A review of the appliances listed in the Gas Appliance Manufacturer's Association (GAMA) Directory indicated that an AFUE of 90% represented the lower end of the range for gas condensing furnaces (GAMA 1994). The 90% efficiency cutoff was deemed a good choice for gas furnaces but is too high to include currently available boilers and oil furnaces.

Table 5.8 shows the upper ranges of efficiency for high-efficiency equipment found in the American Council for an Energy-Efficient Economy's (ACEEE's) list of the most energy-efficient appliances (ACEEE 1992). Oil-fueled equipment represents only 4% and hot water/steam boilers represent only 6% of the national market (DOC 1993). The number of boilers and oil furnaces being used did not warrant the additional packages necessary to include a lower-efficiency cutoff for boilers and oil furnaces, but credit is allowed for such equipment in the MEC*check* software (DOE 1995c).

Table 5.8. Upper Efficiency Ranges for High-Efficiency Equipment

Equipment Type	Upper Efficiency Range	NAECA[a] Minimum
Gas - Furnace	94%	78%
Gas - Hot Water Boiler	84%	80%
Gas - Steam Boiler	81%	75%
Oil - Furnace	85%	78%
Oil - Hot Water Boiler	86%	80%
Oil - Steam Boiler	83%	80%

(a) National Appliance Energy Conservation Act (NAECA) of 1987 (42 USC 6291).

5.2.5 Generate Prescriptive Packages

We generated the prescriptive packages by creating permutations of all insulation levels and window U-factor levels, all window areas, two heating efficiencies (normal and high), and two cooling efficiencies (normal and high). For each zone, packages meeting the code requirements for that zone were generated. Requirements for each climate zone were based on the upper end of the HDD range. For example, the MEC requirements for Zone 7 were based on HDD = 3499. The requirements for Zone 19 were based on HDD = 20000.

For each potential package, we computed four whole-building UA values for the two prototypes for each foundation type (floor over unheated space, slab floor, basement wall, and crawl space wall). We compared these UA values to the UA of the same building built exactly to the code requirements. Equations (5.3) and (5.4) were used to compute the UA for each building type. Equations used for computing the ceiling, wall, and foundation U_o-factors are described in Appendix A. For packages meeting the high-efficiency heating and/or cooling requirements, a percentage reduction was credited to the proposed building UA, resulting in a lower UA than would be computed without the credit (see Section 8.0).

UA Calculation for Buildings With Floors Over Unheated Spaces, Basement Walls, and Crawl Space Walls

$$UA = U_c \text{ x } Area_c + U_{ow} \text{ x } Area_{ow} + U_g + Area_g + U_d \text{ x } Area_d + U_f \text{ x } Area_f \tag{5.3}$$

where U_c = ceiling U-factor
$Area_c$ = ceiling area
U_{ow} = opaque wall U-factor
$Area_{ow}$ = opaque wall area
U_g = glazing U-factor
$Area_g$ = glazing area
U_d = door U-factor
$Area_d$ = door area
U_f = floor, basement wall, or crawl space wall U-factor
$Area_f$ = floor, basement wall, or crawl space wall area.

UA Calculation for Slab Floors

$$UA = U_c \text{ x } Area_c + U_{ow} \text{ x } Area_{ow} + U_g \text{ x } Area_g + U_d \text{ x } Area_d + F_s \text{ x } P_s \tag{5.4}$$

where U_c = ceiling U-factor
$Area_c$ = ceiling area
U_{ow} = opaque wall U-factor
$Area_{ow}$ = opaque wall area
U_g = glazing U-factor
$Area_g$ = glazing area
U_d = door U-factor
$Area_d$ = door area

F_s = slab F-factor
P_s = slab perimeter.

5.2.6 Select Final Packages

We generated the MEC*check* packages using the code requirements at the maximum HDD for any given zone (see Table 5.1). This HDD level is referred to below as the HDD "target." For example, Zone 7 spans a range of 3000 HDD to 3499 HDD—the HDD target for Zone 7 is 3499 HDD. We determined the HDD level where each candidate package exactly met the requirements and compared that level to the target HDD for each zone. We applied the following rules to eliminate candidate packages that were not sufficiently close to a zone's HDD target to be acceptable:

1. The maximum HDD(a) for code compliance for each of the three foundation types could not be more than 30 HDD below the zone's target HDD. This rule ensured that packages may fail to comply only for locations within 30 HDD of a zone's target HDD, and then this potential failure to comply can only be by a small margin. For example, in Zone 7, all candidate packages failing to comply with the code at 3469 HDD (30 less than 3499 HDD) were eliminated from consideration.

2. The maximum HDD for code compliance for each of the three foundation types could not exceed the target by more than 300. This rule ensured the package was not overly strict for the zone under consideration. However, this rule was not applied to zones at or above 7000 HDD because all component requirements except slabs and basements become constant at 7000 HDD. A very small increase in the insulation R-value of the foundation can therefore cause an enormous increase in the HDD maximum for that package. Making the HDD maximum so that all three foundations fall within the zone HDD target by no more than 300 HDD becomes impossible. For example, one package generated for Zone 15 (7000 to 8499 HDD) had a slab R-value requirement of R-5. The slab prototype actually complied with the code up to 10269 HDD. However, if the slab R-value was lowered to R-4, the slab prototype only complied up to 8244 HDD, which was too low to be acceptable for Zone 15.

In generating the MEC*check* packages based on the 1993 and 1995 MEC and the 1998 and 2000 IECC, we changed Rules 1 and 2 to use overall UA rather than HDD as a method of eliminating packages from consideration. This change was an improvement over the HDD approach because the UA is a more direct measure for comparing the thermal efficiency of a package to the code minimum requirements. All packages with an overall UA 3% or more below or 0.5% or more above the UA required by the code at the highest HDD level for each zone were eliminated from consideration. Packages with overall UAs 3% or more below the required UA were deemed to exceed the code requirements by too large a margin. Packages with overall UAs 0.5% or more above the required UA were deemed to fail to meet the code requirements by an acceptable margin. The 3% below rule was not always used in the mildest zones because packages with minimal requirements often had UAs more than 3% below the required UA.

(a) The "maximum HDD" is the highest HDD value at which the package complies with the requirements for all foundation types.

We assigned a cost to the generated packages based on the predominant foundation type for the zone under consideration. Costs were assigned by estimating the cost per square foot of each energy conservation measure in the building's thermal envelope, multiplying by the respective area, and summing these costs for all components in the thermal envelope. Although the cost data were not conclusive enough to use as a sole measure for selecting the final packages, they were deemed appropriate to estimate the cost of a package and eliminate the most costly of all qualifying packages to reduce the number of generated packages to a more manageable list. For example, it was not unusual to end up with 200 or more packages for a single window area in a single zone that all satisfied the HDD or UA target. When this situation occurred, the packages were sorted by cost and truncated. The overall impact of applying cost measures to the packages was to eliminate packages that were relatively costly to build.

We used the following criteria in selecting the final packages from the remaining candidate packages:

1. We attempted to include several packages with wall insulation requirements at R-13 (or optionally R-11 and R-15) so builders are not forced to use 2x6 construction.

2. We offered a broad range of window U-factors, although the window U-factor was somewhat determined by the climate zone and the rest of the package. For example, it was necessary to use windows with lower U-factors for packages with higher window areas.

3. When possible, we chose the most commonly available R-values. For example, the automated process that generates packages was set up to select from the following floor R-values: R-0, R-11, R-13, R-15, R-19, R-21, R-26, and R-30. However, the state codes and other input suggest that R-19 is one of the most common floor insulation levels. Therefore, R-19 was preferred over the other R-values when reasonable. In most cases, R-13, R-19, R-30, and R-38 were favored for ceilings and R-13 was favored for walls.

4. We attempted to offer packages with no foundation insulation requirements for slabs and basement walls in response to complaints by builders that they are being forced to insulate foundations. Packages with no slab insulation are available in zones where slab-on-grade foundations are common. Noninsulated basements could be offered only in zones with low HDD.

5. We attempted to include packages that were similar to prescriptive requirements from the existing state energy codes.

6.0 Software Approach

The MEC*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, 2000). 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.

This section describes the methodology used by the MEC*check* software in determining the UA for the proposed building, the code building, and individual building components, and briefly discusses the weather data used in the software.

6.1 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 MEC*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 6.1 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.

Table 6.1. Construction Types Offered by MEC*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)

Table 6.1. Construction Types Offered by MEC*check* Software and Required Inputs

Component Description	**Cavity Insulation R-Value**	**Continuous Insulation R-Value**	**Assembly U-Factor**	**Size**
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.

6.2 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 6.2 correlates each building component allowed by the MEC*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 6.2. 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 ECC)
Stress-Skin Wall Panels	Walls	Fig. 1	Fig. 1	Fig. 502.2.1.1.2 (2000 ECC)
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)

6.3 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 6.3 lists the limitations on these inputs—if the user tries to enter a value outside the ranges specified in this table, MEC*check* issues a warning message and restores the number to its previous value.

Table 6.3. Input Ranges Allowed by MEC*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

6.3.1 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.

6.3.2 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).

6.3.3 Mass Wall UA

This section explains how the MEC*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 $Btu/ft^2 \cdot {}^\circ F$ 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 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 MEC*check* software is discussed below.

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 (6.1), 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.

$$U_w = \frac{U_{o_{MEC}} \text{ x } A_o - U_g \text{ x } A_g - U_d \text{ x } A_d}{A_w} \tag{6.1}$$

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.

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 (6.1) 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:

$$\text{NEW MASS WALL Uo} = U_{O_{MEC}} + (U_{W_{ADJUSTED}} - U_w) \tag{6.2}$$

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 6.1).

6.3.4 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.

6.3.5 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, MEC*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.

6.3.6 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.

6.3.7 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. MEC*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 MEC*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 MEC*check* slab F-factor calculation (Appendix A, Section A.6). For the proposed building, the insulation R-value and depth of insulation entered by the user are the inputs into the MEC*check* slab F-factor calculation.

6.4 Weather Data Used in the Software

The MEC*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 3000 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 8.0). The CDD value is only used to restrict the cooling efficiency credit from some California coastal locations (see Section 8.0). The “counties” version requires the user to select a county, not a city. See Section 5.1.2 for a discussion on how the HDD and CDD values for counties were determined.

The cities’ weather data included with the software comes from the National Oceanic and Atmospheric Administration (NOAA, www.noaa.gov). Some of the city names were edited to remove confusing and unclear text from the names; e.g., “WSO AP” (indicating airport weather station locations). Where two or more weather stations existed for a single city, we typically used the data for the first-listed location.

7.0 Trade-Off Approach

The trade-off approach involves a calculation of a whole-building UA for both the proposed building and the code building on a one-page worksheet. If the proposed building has a lower UA than the code building, the proposed building complies with the code (see Section 3.0 for a discussion on calculating the whole-building UA). Unlike the other MEC*check* compliance approaches, the trade-off approach requires the user to calculate the proposed building and the code building UAs (see Equation 3.1).

Chapter 4 of the MEC*check* Manual documents how to complete the trade-off worksheet (DOE 1995a). The user obtains the requirements for each envelope component from Table 11 of the *Trade-Off Worksheet User's Guide* (Table 7.1 is a reproduction of Table 11). These requirements are taken from the code for each of the 19 climate zones developed for the prescriptive packages (the HDD level for each climate zone is shown in Table 5.1). The envelope requirements at the highest HDD for each of the 19 zones establish the requirements in Table 11 of the *Trade-Off Worksheet User's Guide.* For

Table 7.1. U-Factor and F-Factor Requirements for 1993 and 1995 MEC by Climate Zone (Reproduction of Table 11 of the *Trade-Off Worksheet User's Guide*)

Climate Zone	Ceiling U-Factor	Single-Family Wall U-Factor	Multi-Family Wall U-Factor	Floor U-Factor	Basement Wall U-Factor	Unheated Slab F-Factor	Heated Slab F-Factor	Crawl Space Wall U-Factor
1	0.047	0.25	0.38	0.08	0.360	1.04	1.04	0.477
2	0.044	0.23	0.35	0.08	0.360	1.04	0.79	0.137
3	0.042	0.21	0.31	0.07	0.360	1.04	0.79	0.137
4	0.039	0.20	0.28	0.07	0.121	1.04	0.79	0.137
5	0.036	0.18	0.25	0.07	0.113	1.04	0.79	0.124
6	0.036	0.17	0.22	0.05	0.106	0.82	0.79	0.111
7	0.036	0.16	0.22	0.05	0.098	0.82	0.79	0.098
8	0.036	0.16	0.22	0.05	0.090	0.82	0.79	0.085
9	0.033	0.15	0.22	0.05	0.082	0.82	0.79	0.071
10	0.031	0.14	0.22	0.05	0.081	0.81	0.79	0.058
11	0.028	0.13	0.22	0.05	0.080	0.81	0.79	0.058
12	0.026	0.13	0.22	0.05	0.079	0.80	0.79	0.058
13	0.026	0.12	0.20	0.05	0.078	0.74	0.71	0.058
14	0.026	0.11	0.18	0.05	0.077	0.73	0.70	0.058
15	0.026	0.11	0.15	0.05	0.075	0.72	0.69	0.058
16	0.026	0.11	0.15	0.05	0.052	0.71	0.69	0.058
17	0.026	0.11	0.12	0.05	0.052	0.69	0.67	0.058
18	0.026	0.10	0.12	0.05	0.052	0.68	0.66	0.058
19	0.025	0.10	0.12	0.04	0.052	0.66	0.65	0.058

example, climate zone 5 covers 2000 to 2499 HDD; the requirements in Table 11 are the code requirements at 2499 HDD. Presenting the requirements by climate zone eliminates several steps for users. Users do not have to determine the HDD for their location; they simply have to look up the climate zone for their county. Also, users do not have to determine the envelope component requirements from the figures in the code.

In Table 11 of the *Trade-Off Worksheet User's Guide*, the requirements for foundation components were converted from the code requirements to more accurate measures of heat loss/gain. This conversion allows more accurate trade-offs for basement walls, slab-on-grade perimeters, and crawl space wall insulation levels. The foundation requirements take into account the effects of soil (see Appendix A for the details on how the requirements were converted to U-factors and F-factors that account for heat loss through the foundation and surrounding soil).

To assist users, extensive tables of envelope component U_o-factors(a) are given in the *Trade-Off Worksheet User's Guide*. These tables provide component U_o-factors (or F_o-factors in the case of slab-on-grade perimeters) as a function of insulation R-values, eliminating the need for users to do complicated calculations of U_o-factors (see Appendix A for the general methodology used to calculate these component U_o-factors and F_o-factors). The assumptions made specifically for the tables in Chapter 4 of the *Trade-Off Worksheet User's Guide* for use with the trade-off approach are described below.

Windows, Doors, and Skylights

Tables 9 and 10 of the *Trade-Off Worksheet User's Guide* provide U-factors that can be used for windows, doors, and skylights for products that have not been rated in accordance with National Fenestration Rating Council 100-91, *(NFRC 100-91: Procedures for Determining Fenestration Product Thermal Properties (currently limited to U-values))*. These tables are equivalent to Tables 102.3a and 102.3b in the 1995 MEC; Tables 102.3(1) and 102.3(2) in the 1998 IECC; and Tables 102.5.2(1) and 102.5.2(2) in the 2000 IECC.

Basement Walls

The trade-off worksheet requires the user to insulate basements to the full height of the wall. The basement wall R-value to U-factor conversion table (Table 6 in the *Trade-Off Worksheet User's Guide*) and the basement wall U-factor requirements (Table 11 in the *Trade-Off Worksheet User's Guide*) were computed based on fully insulated 8-ft basement walls that extend 5 ft below grade. Both of these tables have U-factors that account for the resistance of the soil. The assumption of depth below grade has little effect because the same assumption is used in the U-factor tables for the proposed home and the code requirements. Note that the code classifies a basement wall that is less than half below grade as an above-grade wall, not a basement wall.

(a) U_o-factors are given as U-factors with no subscript "o" on the trade-off worksheet. These U-factors represent overall U-factors for each component, accounting for all heat flow paths for the component.

Crawl Space Walls

The trade-off worksheet requires the user to insulate crawl space walls to the full depth specified in the code. The crawl space wall R-value to U-factor conversion table (Table 8 in the *Trade-Off Worksheet User's Guide*) and the crawl space wall U-factor requirements (Table 11 in the *Trade-Off Worksheet User's Guide*) were computed based on the same assumptions as the prescriptive packages─36-in. walls with an inside ground surface 10 in. below the outside grade. Because the inside ground surface is less than 12 in. below the outside ground surface, the crawl space wall U-factor requirements were calculated assuming insulation extends a total distance of 24 in. below the outside grade (see Section A.5 of Appendix A for more information on how this calculation is done).

Slab-On-Grade Foundations

The slab-on-grade heat loss values for the proposed design (Table 7 in the *Trade-Off Worksheet User's Guide*) and the requirements for the code building (Table 11 in the *Trade-Off Worksheet User's Guide*) are both presented in terms of F-factors. The F-factor is the heat loss per linear foot of perimeter of the slab (Btu/ft·h·°F). The F-factor multiplied by the slab perimeter gives the UA of the slab. Table 4-7 of the *Trade-Off Worksheet User's Guide* provides two different insulation depth options that can be used in the proposed house UA calculation–2 ft and 4 ft. The F-factor requirements for the code building shown in Table 7.1 are calculated from the 1993/1995 MEC slab insulation R-value and depth requirements (the slab insulation depth requirements are 24 in. for locations below 6000 HDD and 48 in. for locations at or above 6000 HDD).

8.0 Equipment/Envelope Trade-Off

This section describes the methodology for trading increased heating or cooling efficiency for lowered envelope efficiency used in the MEC*check* prescriptive packages and 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:

$$\frac{\text{HeatLoad}_{\text{std}}}{\text{AFUE}_{\text{std}}} + \frac{\text{CoolLoad}_{\text{std}} \text{ x } 3.413}{\text{SEER}_{\text{std}}} = \frac{\text{HeatLoad}_{\text{mod}}}{\text{AFUE}_{\text{mod}}} + \frac{\text{CoolLoad}_{\text{mod}} \text{ x } 3.413}{\text{SEER}_{\text{mod}}} \tag{8.1}$$

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).

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

(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.

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 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:

$$\beta = \frac{\left(\dfrac{U_{o,\ adjusted} - U_{o,\ standard}}{U_{o,\ standard}}\right)}{\left(\dfrac{EFF_{adjusted} - EFF_{standard}}{EFF_{standard}}\right)} \tag{8.2}$$

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 (8.2) 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 (8.2) gives the adjusted U_o requirement for a proposed HVAC efficiency increase:

$$U_{o,\ adjusted} = U_{o,\ standard} \text{ x } \left[1 + \beta \text{ x} \left(\frac{EFF_{adjusted} - EFF_{standard}}{EFF_{standard}}\right)\right] \tag{8.3}$$

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 8.1 describes the calculation of β for both heating and cooling equipment.

8.1 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.

8.1.1 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 8.2.3).

8.1.2 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 (LBL and LASL 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.

8.1.3 Select Climate Zones

The MEC*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 8.1 shows the zone definitions and the total number of ARES cities by climate zone.

Table 8.1. 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

8.2 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).

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.

8.2.1 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 8.2 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.

8.2.2 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.

8.2.3 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 8.2. 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.

8.2.4 Identify Trade-Off Ratios and HDD Relationships

Heating

For each of the ARES cities and each of several AFUE levels, we calculated the trade-off ratio according to Equation (8.2). Figure 8.1 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 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 8.1 is based on a linear regression of the trade-off ratio against a polynomial in the logarithm of HDDs:

$$\text{Trade-Off Ratio} = 0.0526 + 0.0225 \times \ln(\text{HDD} + 1) + 0.0122 \times [\ln(\text{HDD} + 1)]^{-2} \qquad (8.4)$$

The regression predicts the adjusted U_o requirement with an R^2 of 0.94.(b) The solid line is discussed in Section 8.2.5.

(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.

(b) An R^2 of 0.94 indicates that Equation (8.4) (and the dotted line plotted in Figure 8.1) is a good fit to the data points shown.

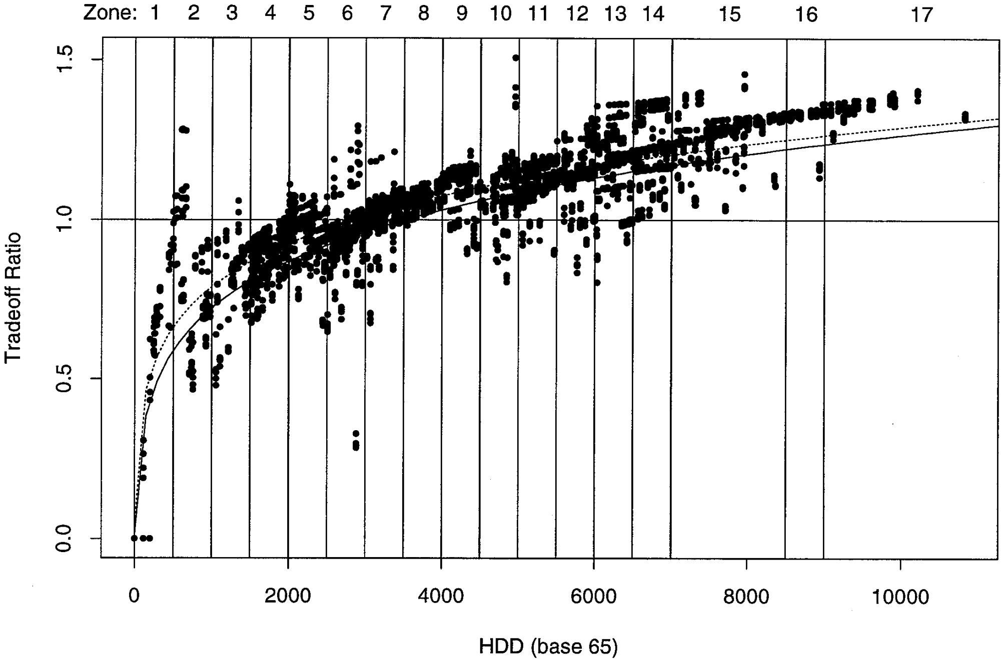

Figure 8.1. Heating Trade-Off Ratio vs. Heating Degree-Days

Cooling

Figure 8.2 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 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 8.2). These locations are treated as exceptions (county by county) in the various MEC*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).

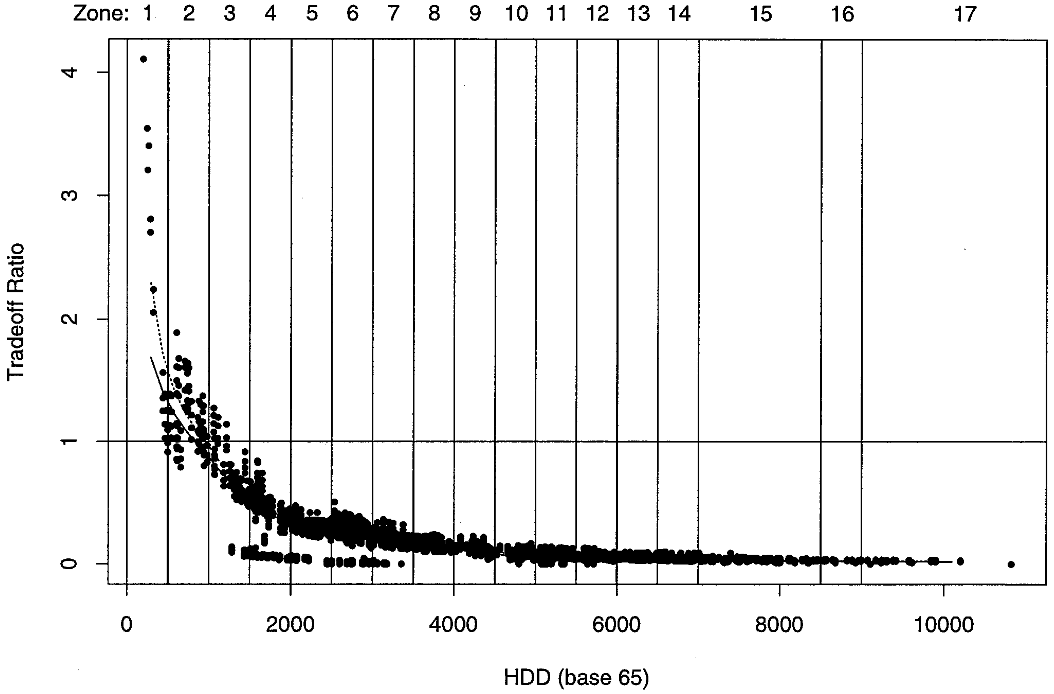

Figure 8.2. Cooling Trade-Off Ratio vs. Heating Degree-Days

The dotted line drawn through the points on Figure 8.2 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_0 requirement with an R^2 of 0.77. If data on additional climate variables (e.g., solar gains, humidity, wind) were available for the ARES cities, a better-fitting equation could be developed. However, because the MEC recognizes only HDD in determining U_0 requirements, such an equation would have dubious value.

8.2.5 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 8.1 and 8.2 represent the average U_0 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

$$\text{Trade-Off Ratio} = 0.0148 + 0.0019 \times \ln(\text{HDD} + 1) + 0.0145 \times [\ln(\text{HDD} + 1)]^2 \tag{8.5}$$

Equation (8.5) is shown as the solid line in Figure 8.1. 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 8.2.

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 (8.5) at the lower end of each zone’s HDD range. We obtained cooling ratios by a takeoff from the solid line in Figure 8.2 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 8.3).

Table 8.3. 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

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