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TECHNICAL SUPPORT DOCUMENT FOR PROPOSED REVISION OF THE MODEL ENERGY CODE THERMAL ENVELOPE REQUIREMENTS

(This document is issued in support of
CABO MEC code change proposals E12-93,
E15-93, and E22-93)

C. C. Conner
R. G. Lucas

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Pacific Northwest Laboratory
Richland, Washington 99352

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FOREWORD

This report is one in a series of documents describing research activities in support of the U.S. Department of Energy (DOE) Building Energy Standards Program (BESP). The Pacific Northwest Laboratory (PNL) leads the program for DOE.

The overall problem being addressed by BESP (and other programs at DOE) is that new commercial and residential buildings now being designed, built and occupied do not use currently available technically feasible and economically justified technologies and practices to eliminate the wasteful use of energy. The BESP seeks to advance the energy conserving design and construction of buildings by promoting and assisting the development and implementation of energy efficient codes and standards that are technically feasible, economically justified and environmentally beneficial. These activities are required of DOE by Title III of the Energy Conservation and Production Act (42 USC 6831 et seq.) as amended by the Energy Policy Act of 1992 (Public Law 102-486). The long-term goal of BESP is to make sustainable, energy-efficient building design and construction common practice.

The program approach to meeting the goal is to initiate and manage individual efforts in standards and guidelines research and development--efforts that are planned and conducted in cooperation with representatives from throughout the buildings community. Projects under way involve practicing architects and engineers, professional societies and code organizations, industry representatives, and researchers from the private sector and national laboratories. Research results and the technical justification for standards criteria are provided to standards development and model code organizations and to federal, state, and local jurisdictions as a basis for updating their codes and standards. This approach helps to ensure that the standards incorporate the latest research results to achieve maximum cost-effective energy savings in new buildings, yet remain responsive to the needs of the affected professions, organizations, and jurisdictions. BESP also assists in the implementation, deployment, and use of the codes and standards.

This report documents the technical basis for proposed revisions to the Council of American Building Officials (CABO) 1993 supplement to the 1992 Model Energy Code (MEC). The revisions proposed are limited to the building thermal envelope requirements for single-family and low-rise multifamily residences. The goal of this work was to develop revised guidelines based on an objective methodology that determined the most cost-effective combination of commonly available energy conservation measures for residences in different U.S. locations.

Other documents produced as part of the DOE energy conservation standards work at PNL are listed in Section 7 of this report.

Readers with questions, comments, or suggestions about this document or the work it describes are encouraged to contact the author(s), program managers, or project managers.

Craig C. Conner
Residential Building Energy Standards
Pacific Northwest Laboratory

Stephen Turchen or Stephen Walder
Office of Codes and Standards
U.S. Department of Energy

SUMMARY

This report documents the development of the proposed revision of the Council of American Building Officials' (CABO) 1993 supplement to the 1992 Model Energy Code (MEC) (referred to as the 1993 MEC) building thermal envelope requirements for single-family and low-rise multifamily residences. The goal of this analysis was to develop revised guidelines based on an objective methodology that determined the most cost-effective (least total life-cycle cost [LCC]) combination of energy conservation measures (ECMs) for residences in different locations. The ECMs with the lowest LCC were used as a basis for proposing revised MEC maximum U_0-value (thermal transmittance) curves in the MEC format.

The changes proposed here affect the requirements for "group R" residences. The group R residences are detached one- and two-family dwellings (referred to as single-family) and all other residential buildings three stories or less (referred to as multifamily). The proposed change amends Figures 1 (walls), 2 (roof/ceilings), and 6 (floors over unheated spaces) in the 1993 MEC (CABO 1992, pp. 66, 67, and 71).

The approach used in developing the proposed MEC revision was a cost-benefit analysis in which the cost of the ECMs were balanced against the benefit of energy savings. The analysis for revising the standard was based on the consumer's perspective. A LCC analysis was used to compare the present value of the total long-run costs for several alternative ECMs and to select the ECM that achieved the lowest LCC for each location studied. For this LCC analysis, the benefit is the energy savings (both space heating and cooling) from the ECMs; the major cost is the ECM cost, including the associated mortgage, fees, and down payment. The resulting ECM optimums specified an overall level of energy conservation for the building envelope that gives the lowest total of construction and operating costs. This LCC optimization was performed for over 800 cities in the United States. The resulting envelope component U_0-values were then presented as a function of heating degree-days in the format used by the existing MEC figures.

The analysis to develop the standard was done with the Automated Residential Energy Standard (ARES) software. ARES software was developed by

the U.S. Department of Energy (DOE) specifically for the generation of residential energy conservation standards. ARES implements a LCC methodology for residential energy conservation decisions. In addition to a LCC model, ARES incorporates an energy simulation model that enables the software to project energy costs for various combinations of ECMs. Given a set of fuel prices, financial and economic parameters, and ECM costs for a building at a specific location, ARES identifies the set of ECMs in which to invest, such that the homeowner's total LCC is minimized.

Several financial, economic, and fuel price parameters were required for the LCC analysis. Long-term average financial parameters, ECM costs, and construction parameters were identified for input into the LCC analysis. The loan parameters selected were a 4.2% real interest rate (8.3% nominal, assuming an inflation rate of 3.9%) over 30 years with a down payment of 10%. The loan period was also used as the analysis period for determining cost-effectiveness. The real discount rate used was 4% (8% nominal). Each state's average residential fuel prices were identified for electricity, fuel oil, natural gas, and liquid petroleum gas (LPG). Residential fuel price escalation rate projections were identified for each U.S. census region. These 30-year average annual fuel escalation rates (real) ranged as follows: electricity, 0.1% to 0.6%; fuel oil, 1.9% to 2.0%; natural gas, 2.0% to 2.4%; and LPG, 1.5% to 1.9%.

The ECM options selected for the analysis represent the conservation investment choices from which the LCC analysis was used to determine the consumer's optimal level of investment in energy conservation. For each type of ECM (e.g., wall insulation), lists of candidate levels, costs, and thermal characteristics were developed. Only commercially available ECMs that had been used to build a significant number of homes were included as candidate options: ceiling insulation options ranged from R-11 to R-49, wall insulation options ranged from R-11 to R-21 batt insulation with up to R-7 sheathing insulation, floor insulation options ranged from R-11 to R-30, and windows options ranged from a U_0-value of 1.31 to 0.35.

Initially, homes that made use of six specific types of heating equipment and fuel combinations were optimized by ARES. The heating equipment types and fuel combinations were natural gas with a forced-air furnace, oil with a forced-air furnace, LPG with a forced-air furnace, electric resistance with a forced-air furnace, electric heat pump with forced-air distribution, and electric baseboard. In all cases central electric air conditioning was assumed. Because only the building envelope was optimized, the National Appliance Energy Conservation Act of 1987 (NAECA) minimum standards for heating and cooling system efficiency were assumed.

A large number of optimizations was performed. Two residence types, single-family and multifamily (three stories or less), were optimized separately for each of the six fuel/equipment types. All 881 cities available in ARES were used in the analysis, providing a density of locations such that any point in the United States was close to a city for which an optimal U_0-value was produced.

The 10,572 individual U_0-values (881 cities, six HVAC/fuel types, two building types) were aggregated to U_0-value curves that can be used in the MEC. The separate optimums for each heating fuel/equipment type were combined into U_0-values for all heating equipment/fuel types based on the frequency with which each type of equipment was present in each region. Single-family and multifamily ceilings and floors were determined to be similar in construction and cost, and were consolidated. Single-family and multifamily wall requirements were markedly different because of the larger fraction of multifamily walls that are generally displaced by windows; therefore, separate multifamily wall requirements were produced. Proposed revised MEC U_0-values for ceilings, single-family walls (type A_1), multifamily walls (type A_2), and floors over unheated spaces are shown in Figures S.1 to S.5, respectively.

The whole-house U_0-value (i.e., the area-weighted average of ceilings, walls, windows, and floors for the prototypes used here) resulting from the standard proposed here was compared to that of the existing 1993 MEC standard for the 881 cities used in this analysis. On average, the existing MEC required an overall single-family home U_0-value of 0.085. The standard proposed here would require a U_0-value of 0.066, a reduction of about 22%.

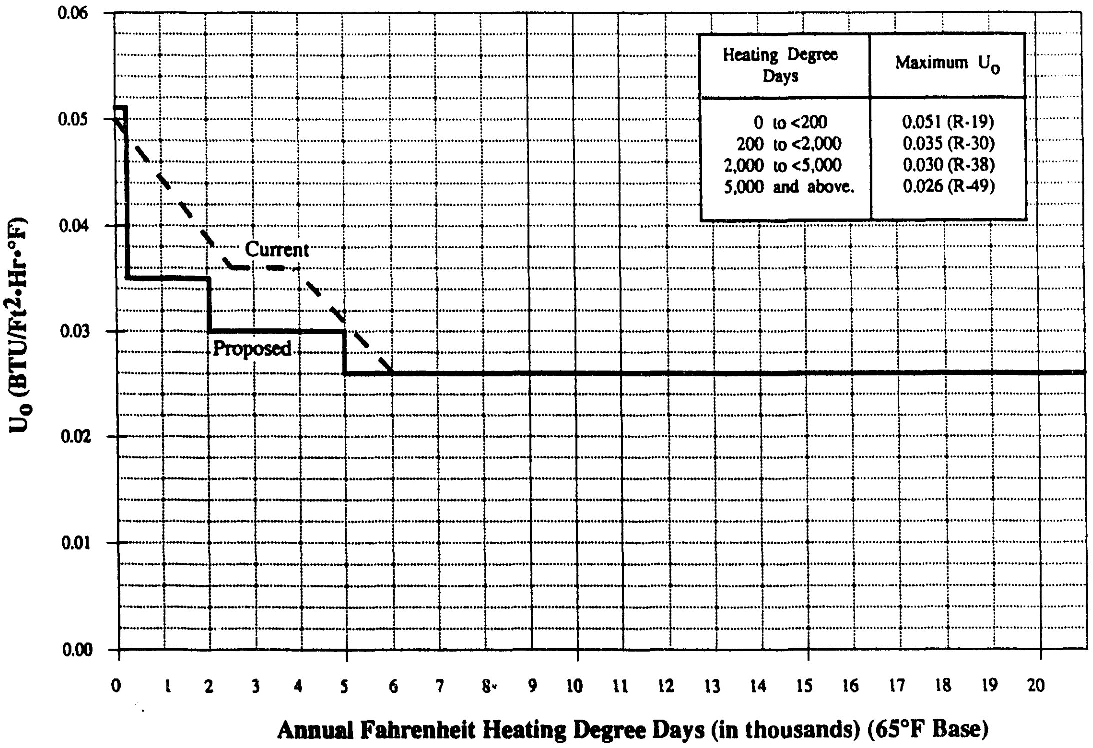


FIGURE S.1. Proposed MEC U_0 Requirement for Roof/Ceilings with Attics

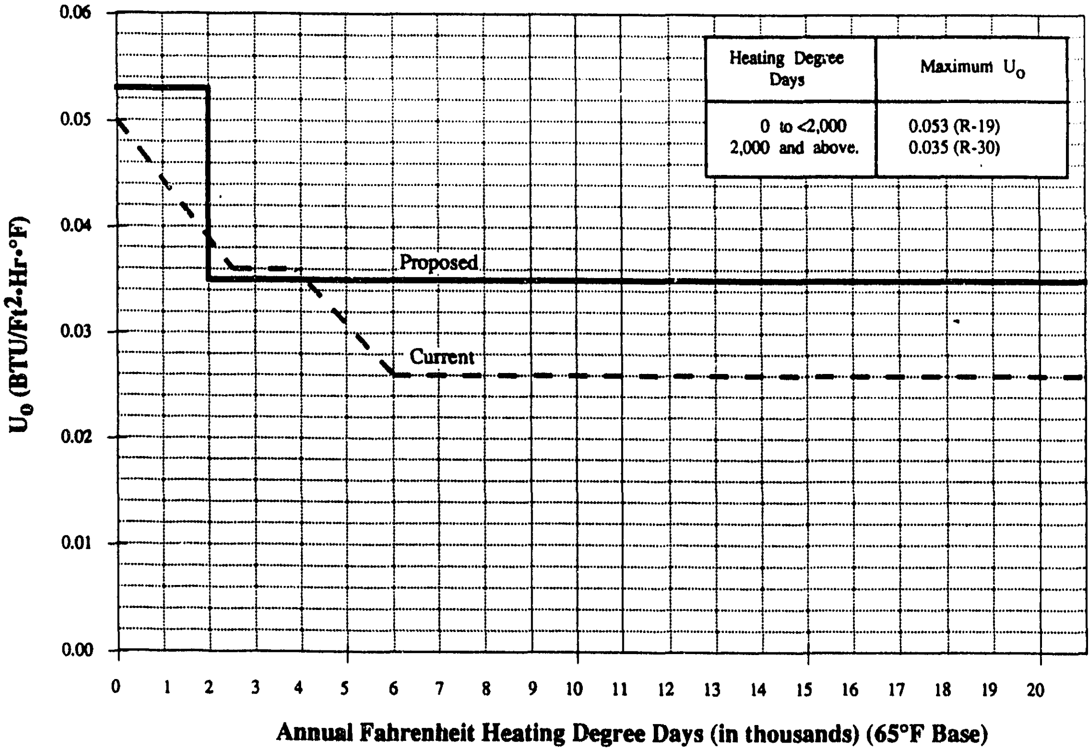
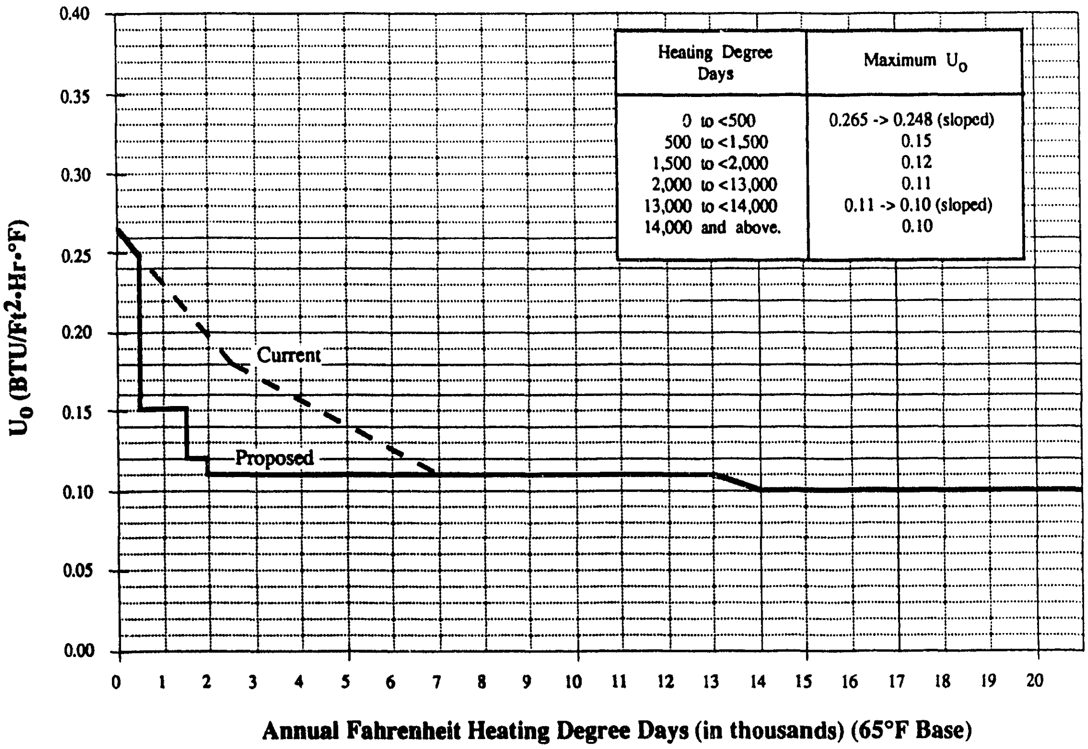
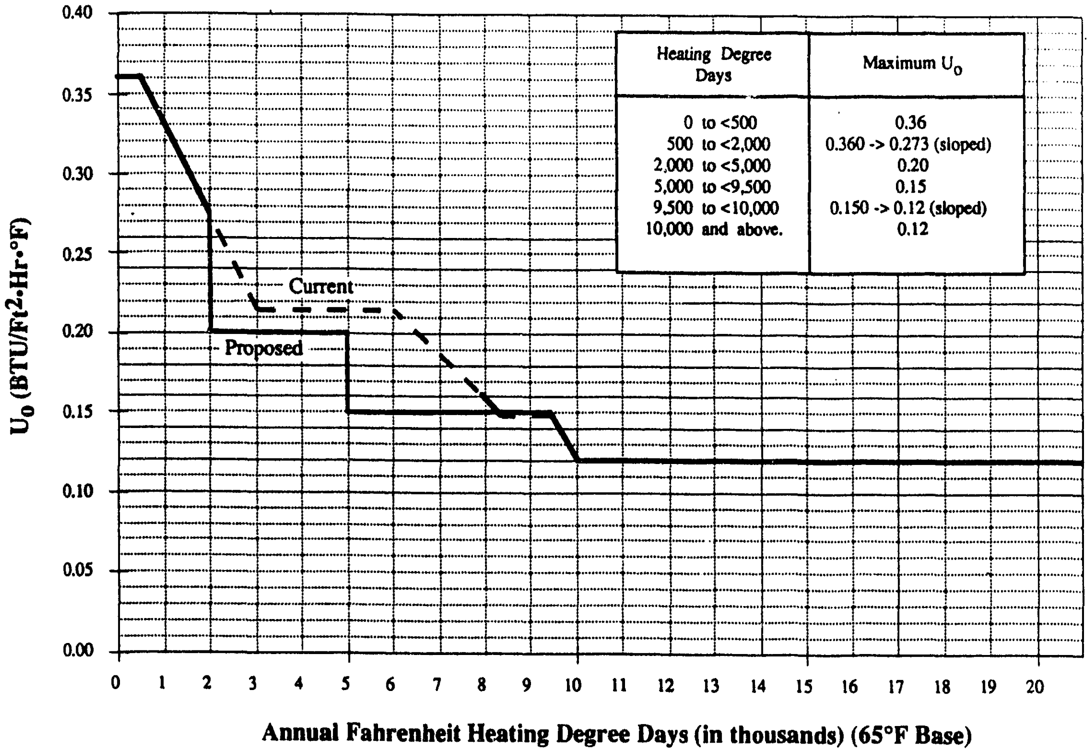


FIGURE S.2. Proposed MEC U_0 Requirement for Vaulted Roof/Ceilings



Heating Degree Days	Maximum U_0
0 to <500	0.265 -> 0.248 (sloped)
500 to <1,500	0.15
1,500 to <2,000	0.12
2,000 to <13,000	0.11
13,000 to <14,000	0.11 -> 0.10 (sloped)
14,000 and above.	0.10

FIGURE S.3. Proposed MEC U_0 Requirement for Single-Family Walls



Heating Degree Days	Maximum U_0
0 to <500	0.36
500 to <2,000	0.360 -> 0.273 (sloped)
2,000 to <5,000	0.20
5,000 to <9,500	0.15
9,500 to <10,000	0.150 -> 0.12 (sloped)
10,000 and above.	0.12

FIGURE S.4. Proposed MEC U_0 Requirement for Multifamily Walls

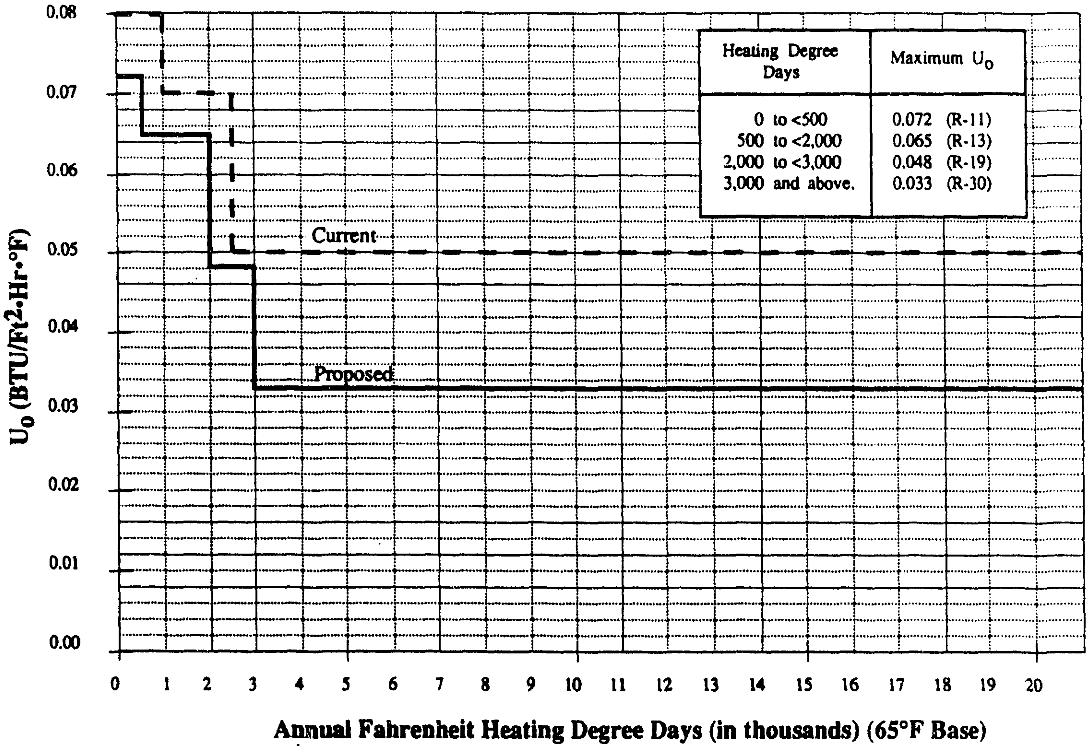


FIGURE S.5. Proposed MEC U_0 Requirement for Floors over Unheated Spaces

For the multifamily prototype, the average proposed U_0-value is 0.084 compared to 0.096 for the 1993 MEC, a reduction of 12%.

The costs and benefits from the consumer's perspective were estimated for the existing MEC and the proposed revision. On a national average, the net life-cycle benefit to the owner, accounting for the mortgage and taxes, is about $1200 for single-family homes. The present value of the benefits of the more stringent requirements (the energy savings) was estimated at $2000 over the life of the home. The proposed standard was estimated to increase nonenergy costs by about $800 for single-family homes. For multifamily units, the net life-cycle benefit is $300, the present value of the energy savings was estimated at $550, and the nonenergy costs increased by about $250.

Based on the analysis documented in this report, revised U_0-value maximums for roof/ceilings, walls, and floors over unconditioned spaces have been submitted to CABO as proposed code modifications.

Envelope ECMs that would generally meet the 1993 Model Energy Code are compared in the next 10 figures to ECMs that would generally meet the proposed revisions. The figures compare complying ECMs in ceilings with attics (S.6 and S.7), ceilings without attics (S.8 and S.9), single-family walls (S.10 and S.11), multifamily walls (S.12 and S.13), and floors over unconditioned spaces (S.14 and S.15). In the wall figures, the assumed average window area is 15% of the floor area (16% of the wall area) for single-family residences and 8% of the floor area (20% of the wall area) for multifamily residences.

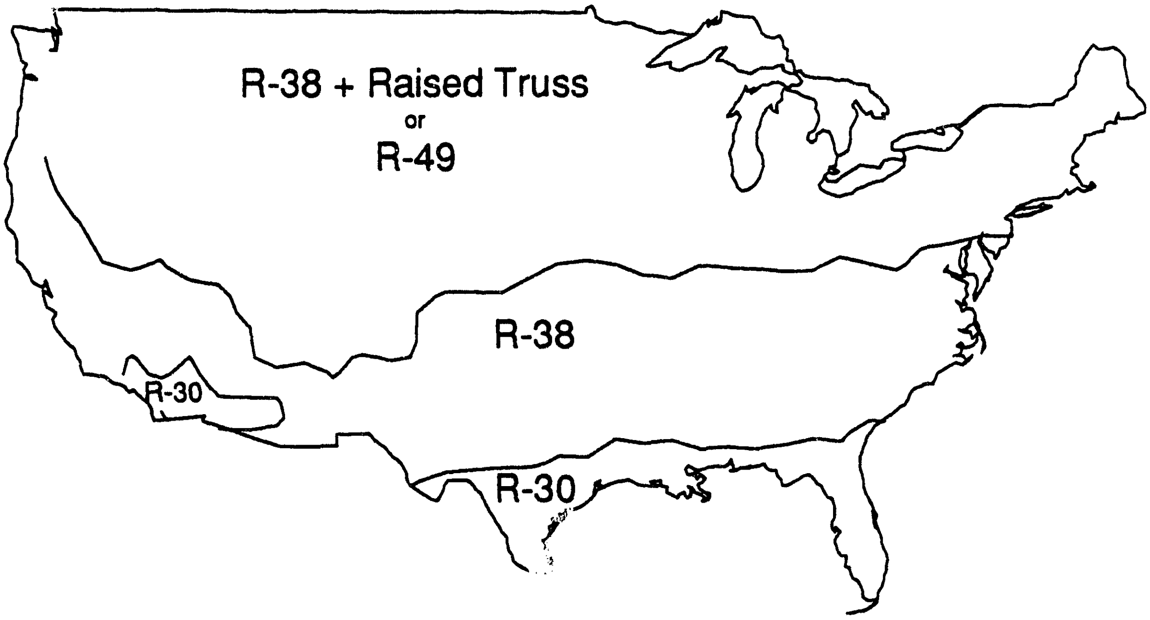


FIGURE S.6. Ceiling-with-Attic Insulation R-value by Region Complying with the Proposed MEC Change

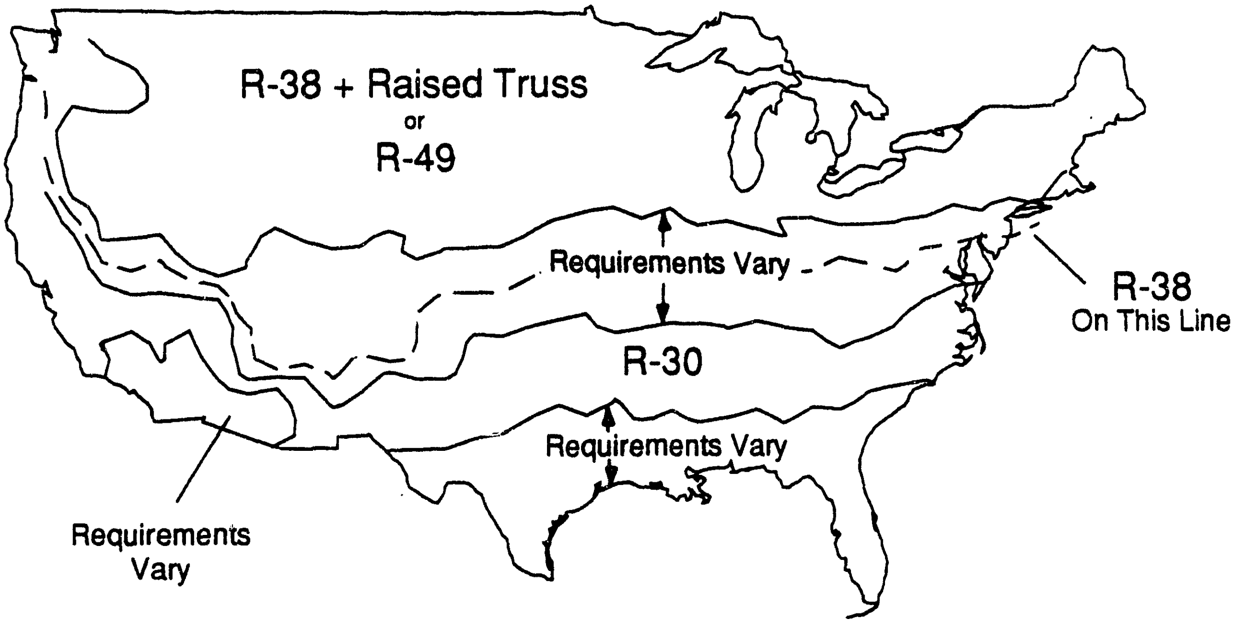


FIGURE S.7. Ceiling-with-Attic Insulation R-value by Region Complying with the 1993 MEC

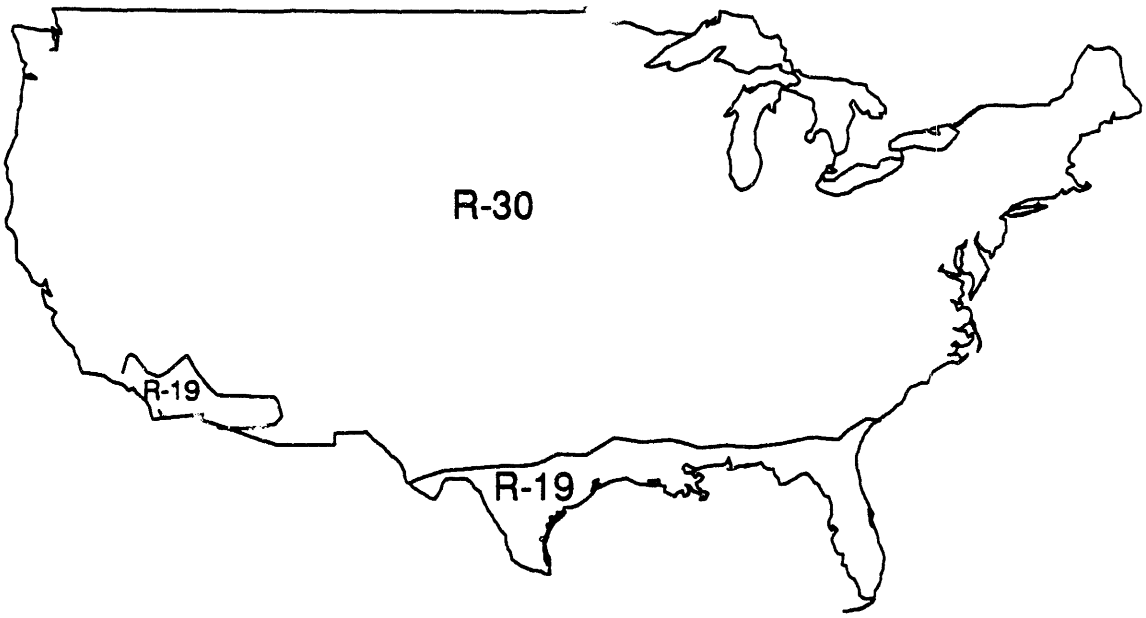


FIGURE S.8. Ceiling without Attics Insulation R-value by Region Complying with the Proposed MEC Change

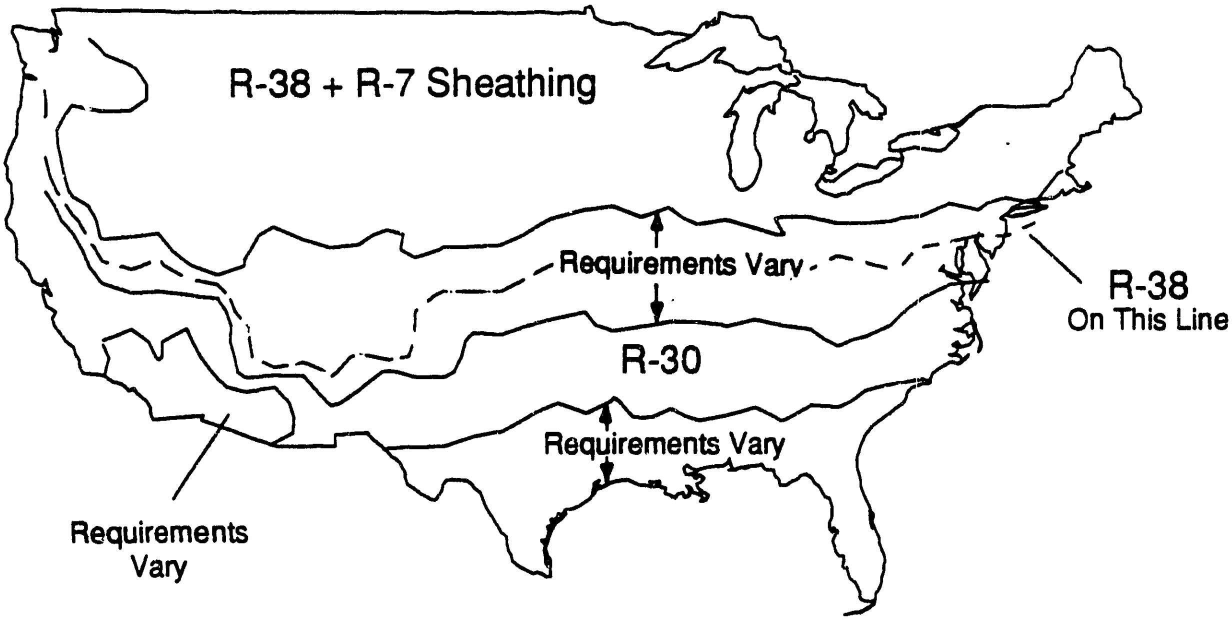


FIGURE S.9. Ceiling without Attics Insulation R-value by Region Complying with the 1993 MEC

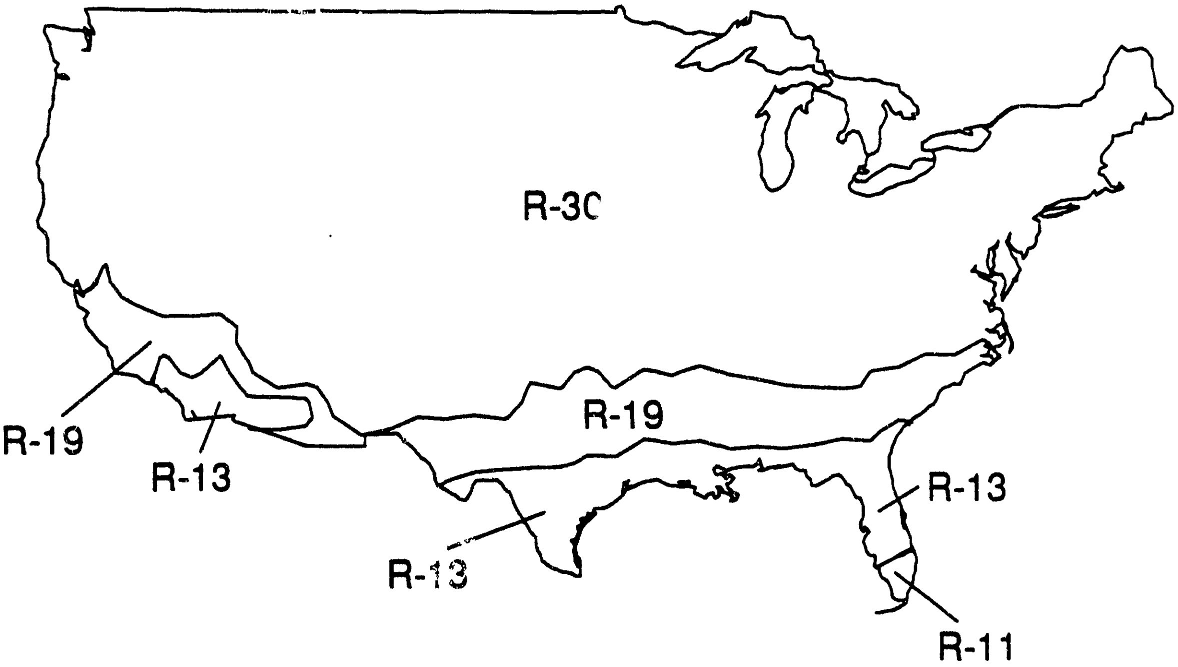


FIGURE S.10. Floor over Unheated Spaces Insulation R-value by Region Complying with the Proposed MEC Change

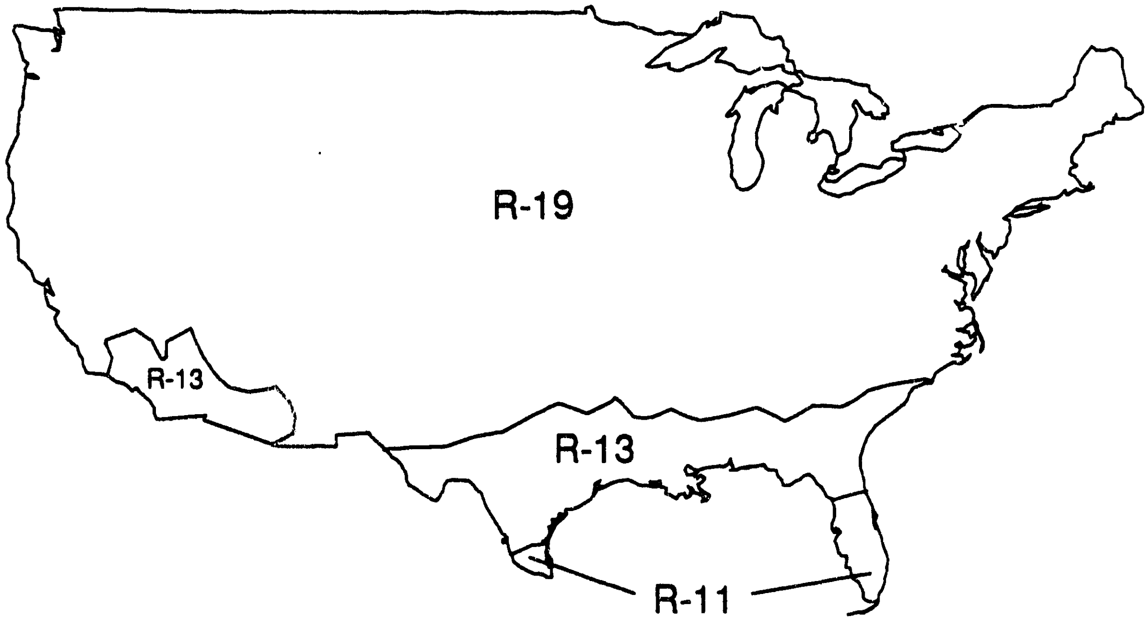


FIGURE S.11. Floor over Unheated Spaces Insulation R-value by Region Complying with the 1993 MEC

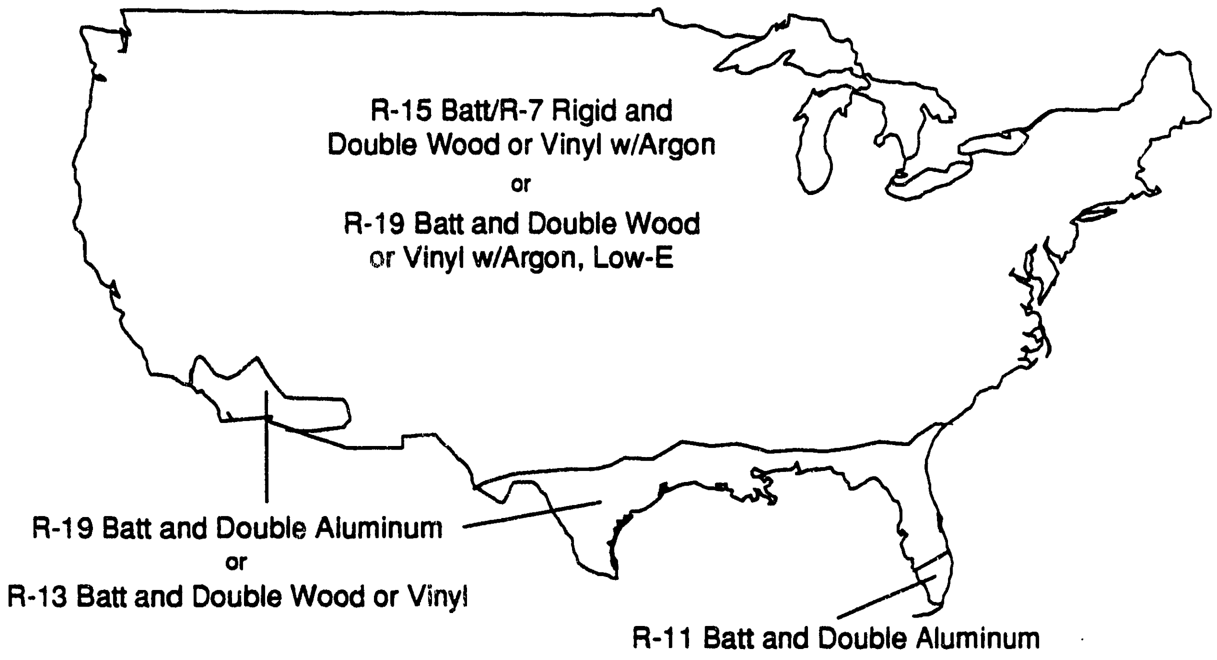


FIGURE S.12. Possible Single-Family Wall Insulation R-values and Window Types by Region Complying with the Proposed MEC Change (assuming an above average window area equal to 15% of floor area)

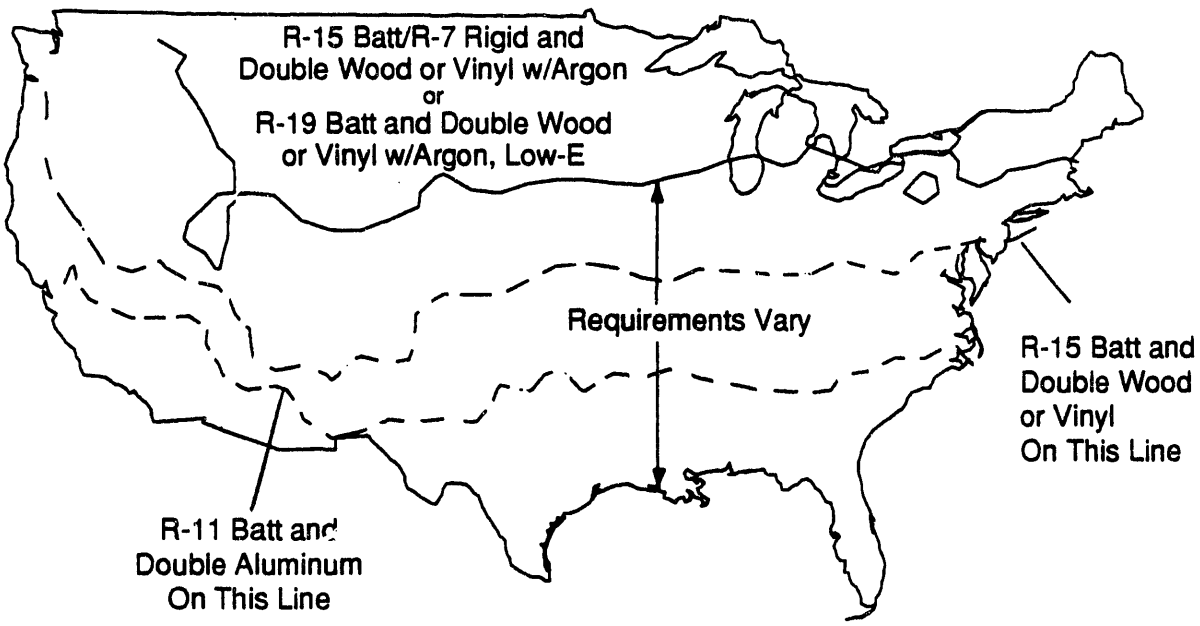


FIGURE S.13. Possible Single-Family Wall Insulation R-values and Window Types by Region Complying with the 1993 MEC (assuming an above average window area equal to 15% of the floor area)

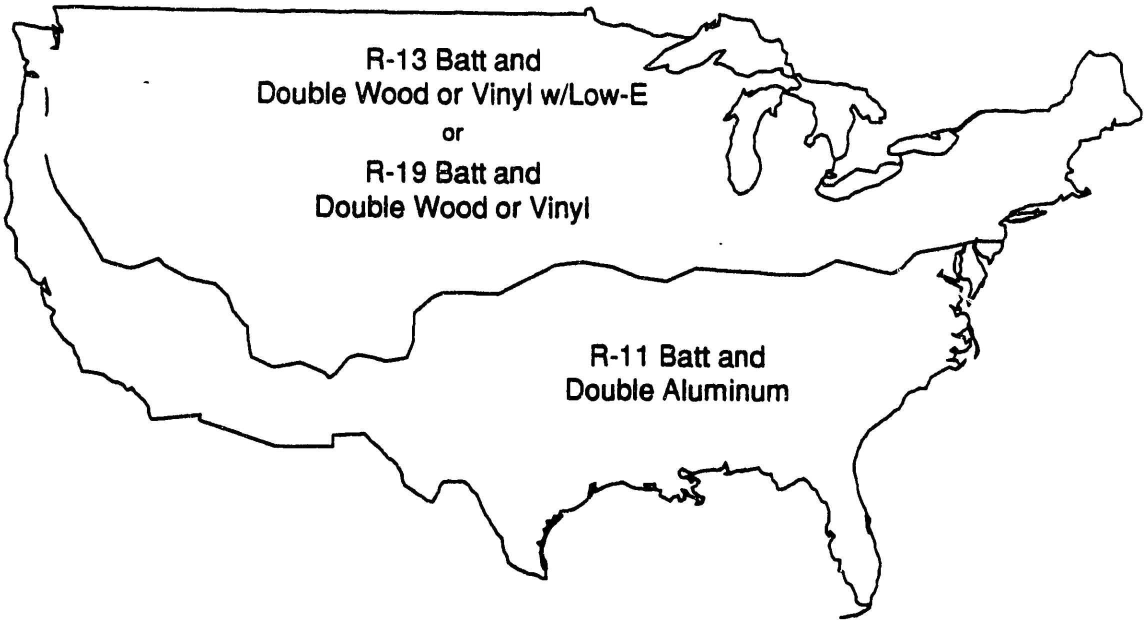


FIGURE S.14. Possible Multifamily Wall Insulation R-values and Window Types by Region Complying with the Proposed MEC Change (assuming a window area equal to 20% of wall area)

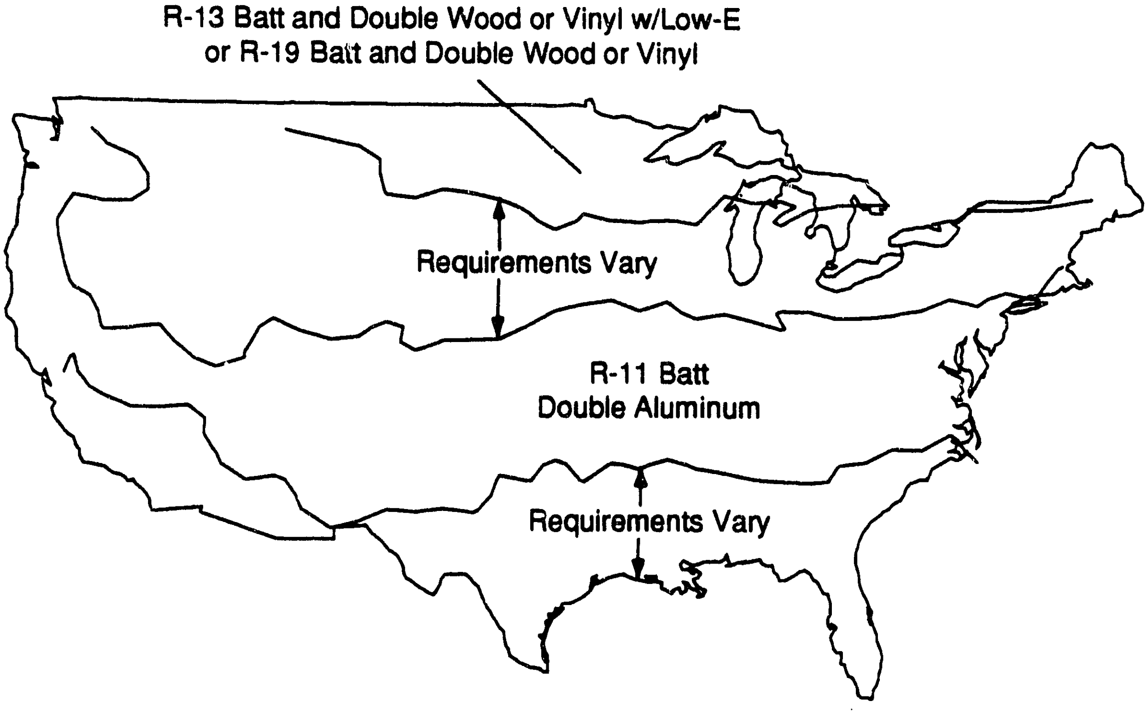


FIGURE S.15. Possible Multifamily Wall Insulation R-values and Window Types by Region Complying with the 1993 MEC (assuming a window area equal to 20% of the wall area)

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FIGURES

TABLES

1.0 INTRODUCTION

This report documents the development of the proposed revision of the Council of American Building Officials' (CABO) 1993 supplement to the 1992 Model Energy Code (MEC) (referred to as the 1993 MEC) building thermal envelope requirements for maximum component U_0-value. The research underlying the proposed MEC revision was conducted by Pacific Northwest Laboratory (PNL)(a) for the U.S. Department of Energy (DOE) Building Energy Standards Program. The goal of this research was to develop revised guidelines based on an objective methodology that determines the most cost-effective (least total cost) combination of energy conservation measures (ECMs) (insulation levels and window types) for residential buildings. This least-cost set of ECMs was used as a basis for proposing revised MEC maximum U_0-values (thermal transmittances). ECMs include window types (for example, double-pane vinyl) and insulation levels (for example, R-19) for ceilings, walls, and floors.

The changes proposed here affect the requirements for "group R" residences. The group R residences are detached one- and two-family dwellings and all other residential buildings, three stories or less. The proposed change would amend Figures 1 (walls), 2 (roof/ceilings), and 6 (floors over unheated spaces) in the 1993 MEC (CABO 1992, amended pp. 66, 67, and 71).

The approach PNL used in developing the proposed MEC revision was a cost-benefit analysis in which all costs and benefits associated with installing ECMS were evaluated. The analysis identifies an overall level of energy conservation for the building envelope with the lowest total of construction and (discounted) operating costs to the owners. This life-cycle cost optimization was performed for a large number of cities in the United States. The resulting envelope component U_0-values were then presented as a function of heating degree-days in the MEC graphical format.

As a rule, our goal was to select the most accurate sources and data as input parameters into the analysis. This normally consisted of utilizing the

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(a) Operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

most recent, most respected, and best documented sources. In most cases, we were able to obtain detailed and well documented sources, such as state-by-state fuel prices. In a few cases, we had very little or no data, such as for heat losses in ducts for multifamily homes. When we lacked good data on parameter values, we used our best judgement in the analysis.

This report is organized as follows. Section 2 presents a brief overview of the life-cycle cost model. Section 3 discusses the choice of the financial, economic, and fuel price parameters used in the life-cycle cost analysis. Section 4 describes the ECMs and their characteristics. Section 5 discusses how the proposed revision was generated and looks at the impacts of the proposed revision. Section 6 has references and Section 7 has a listing of PNL building energy standard documents. Appendixes A through D provide supplemental information.

2.0 LIFE-CYCLE COST MODEL

This section describes the selection of the life-cycle cost (LCC) model used to generate the proposed MEC envelope requirements. Section 2.1 describes a generic LCC analysis. Section 2.2.briefly describes the model selected.

2.1 LIFE-CYCLE COST ANALYSIS

Life-cycle cost analyses are used to compare the present value of total long-run costs associated with several alternative courses of action. The course of action that achieves a chosen objective for the lowest LCC is the preferred alternative. The general approach of the LCC method is to sum the (discounted) costs and benefits of an investment, which, in turn, are calculated based on existing and forecasted economic parameters. For the analysis to be credible, the parameters used in the analysis must properly reflect present or expected market conditions.

The basic cost elements of the generic LCC method for energy-efficiency investments are shown below. All costs and benefits are computed in present-value dollars.

Life-cycle cost = Energy-efficiency improvement costs + Operating costs
+ Maintenance costs - Resale value

The first element of the equation represents the cost of the efficiency measures as represented by purchase price (including installation) or costs to finance over a period of time. The second element of the equation is the cost of operating the building, which represents the cost of the energy required to keep the building comfortable. A reduction in the energy costs is the major benefit of any energy conservation standard. The third element of the equation represents the maintenance outlays required to maintain the investment following its purchase. This represents the maintenance, repair, or replacement expenses required for the ECMs. The final element of the equation is the resale or salvage value of the investment at the end of the analysis period. The ECMs values depreciate based on straight-line depreciation, so the resale value at the end of the period of analysis is equal to the nominal value of the ECM multiplied by the remaining fraction of the ECM lifetime.

2.2 AUTOMATED RESIDENTIAL ENERGY STANDARD

The analysis to develop the proposed MEC changes was done with the Automated Residential Energy Standard (ARES) program. The ARES software is a computer program developed for DOE that contains a LCC methodology for residential energy conservation decisions (Lortz and Taylor 1989). Given a set of fuel price, financial, economic, and ECM cost parameters for a building at a specific location, ARES identifies the set of ECMs in which to invest, such that the homeowner's total LCC is minimized. ARES considers both space heating and cooling in determining the ECMs with the minimum LCC. ARES was designed specifically for the development of residential energy conservation standards.

In addition to a LCC model, ARES incorporates an energy database produced by a simulation model, allowing it to estimate the energy use for a specific selection of ECMs. The energy usage associated with each combination of ECMs becomes an input to the ARES LCC analysis. The incorporation of an energy simulation in ARES removes the requirement for doing separate building energy simulations. The ARES energy simulation is a parameterization of a large data base of DOE-2 simulations (DOE 1989b).

3.0 FINANCIAL, ECONOMIC, AND FUEL PRICE PARAMETERS

In this section, the financial, economic, and fuel price parameter values necessary to develop the cost-effective envelope requirements are specified, justified, and documented. Section 3.1 defines the financial parameters and documents their sources. Section 3.2 deals with the selection of economic parameters. Section 3.3 discusses the selection of fuel price and fuel escalation rates. Most of the financial, economic, and fuel price parameters required for input to this analysis are summarized below.

- New home mortgage parameters
  - mortgage interest rate including loan fees and points (4.2% real or 8.3% nominal assuming 3.9% inflation for single-family, 10% nominal for multifamily)
  - loan term (30 years)
  - down payment (10% for single-family, 30% for multifamily)
- Other rates and economic parameters
  - discount rate (4.0% real or about 8% nominal assuming 3.9% current inflation)
  - marginal federal plus state income tax rates (31% average, see Appendix E)
  - property tax rates (1.36% average, see Appendix E)
  - period of analysis (30 years)
  - building life (50 years for single-family, 30 years for multifamily)
- Residential fuel prices by state (see Appendix A) and annual escalation rates by census region
  - electricity (escalation: 0.1 to 0.6%)
  - fuel oil (escalation: 1.9 to 2.0%)
  - liquid petroleum gas (escalation: 1.5 to 1.9%)
  - natural gas (escalation: 2.0 to 2.4%).

In choosing the parameters for the LCC analysis, the intent was to identify and document the best source available for each parameter. Most of the parameter values are commonly reported statistics and are traceable to other published sources. It should be noted that some of the parameter values vary across time, locations, markets, institutions, circumstances, and/or individuals. In general, the mean or median value was taken for any particular parameter. If multiple sources for a single parameter were identified, an attempt was made to choose the best source, with a preference toward the most respected, most recent, and published sources.

3.1 FINANCIAL PARAMETERS

Several financing parameters affecting the cost and duration of a new home loan need to be defined. These parameters are the mortgage interest rate, loan term, down payment, points, and loan fees.

3.1.1 Mortgage Interest Rate

A mortgage interest rate of **4.2% real** (8.3% nominal assuming 3.9% inflation) was selected for single-family homes in this analysis, based on long-term U.S. Office of Thrift Supervision (OTS) historical averages using 1963-1991 data (OTS 1991). This interest rate includes points and loan fees. This long-term rate is also close to current real mortgage rates. A mortgage interest rate of **5.9% real** (10.0% nominal) was selected for multifamily buildings after discussions with Ronald Nickson of the National Multi Housing Council/National Apartment Association.

3.1.2 Loan Term

The OTS reports an average of 26 years until the loan reaches maturity for fixed-rate mortgages (OTS 1991). This average term indicates that a 30-year mortgage term is likely the most typical; therefore, we used **30 years** as the loan term for this analysis.

3.1.3 Down Payment

The loan-to-price ratio for conventional, fixed-rate, single-family home mortgages is reported as 74.4% for 1991 by the OTS (1991). A similar value is reported by a mortgage insurance company in the U.S. Department of Commerce (DOC) Statistical Abstract (DOC 1991b). The National Association of Realtors (NAR) reports the median down payment of 20% for all home buyers who finance their purchase (NAR 1990). However, numerous comments from independent reviewers suggested that a lower rate, perhaps 10%, was a more appropriate down payment percentage. Therefore, **10%** was used in this analysis. For multifamily buildings, a **30%** down payment was assumed, based on recommendations from Ronald Nickson of the National Multi Housing Council/National Apartment Association.

3.2 ECONOMIC PARAMETERS

For this analysis, a discount rate and a period of analysis needed to be established.

3.2.1 Discount Rate (Alternative Investment Rate)

A life-cycle cost analysis must convert costs and benefits occurring in future years into present-value dollars. To convert future dollars into present dollars, a discount rate needs to be established. Six possible discount rates are discussed here. Two types of rates pertain to a social perspective; four different private rates pertain to an individual's perspective. The six rates are

- the risk-free social rate
- the social rate for the analysis of government programs
- the implicit private discount rate
- the private rate charged for credit for consumer purchases
- the private market rate for personal monetary investment
- the private mortgage loan rate.

To justify using one of the social discount rates, it could be argued that the objective of the MEC is to reduce energy consumption for a state or the nation as a whole. One social rate is the risk-free rate, which is usually specified as the cost of government borrowing (i.e., an ostensibly risk-free market). In this case, the rate on long-term government bonds is one possible rate. As of late 1992, the long-term government bond rate is about 4% real (National Institute of Standards and Technology [NIST] 1992) or about 8% nominal.

Another social rate is used for analyzing energy conservation investments made by government programs and projects. For federal projects, the government will use the Federal Energy Management Program rate of 4.0% real in 1993; this is based on the real return on 30-year treasury bonds (NIST 1992) and is identical to the rate discussed in the previous paragraph. This is the rate that federal government projects would be required to use for energy conservation projects undertaken with federal funds.

An "individual" discount rate is an implicit discount rate identified by observing consumer behavior. This rate represents the private rate of return that an individual consumer requires from a purchase. The strongest argument for this rate is that the purpose of the CABO code is to properly reflect the interests of the consumer in housing "services" and, therefore, the consumer's preferences most appropriately reflect those interests.

The consumer's implicit discount rate (time value of money) is sometimes determined by examining consumer behavior when given a range of options. For instance, consumers can purchase a wide range of air-conditioners at various efficiencies. Data on the mix of air-conditioner efficiencies actually purchased and the purchase prices can be used to define the price the consumer appears to be willing to pay for energy dollar savings resulting from increases in air-conditioner efficiency. In practice, discount rates are difficult to determine, with an extremely wide range of rates having been reported. The rates vary greatly across individuals and income levels. Usually uncertainties, such as whether the consumer has sufficient information to compare options, complicate determining the rate. According to the Electric Power Research Institute (EPRI), discount rates varying from less than 2% to well over 100% have been reported for purchases related to energy efficiency (EPRI 1988, p. 2-22). In our opinion, studies of the implicit discount rates generally would suggest higher discount rates than those found in the monetary investments described below. Because of the wide variation in reported rates and uncertainty about the consumers ability to evaluate the options, the consumer's private rate of time preference, as demonstrated by the evidence of consumer purchases, was considered too indeterminate to use in this analysis.

Another possible rate is the rate charged for other consumer credit, such as credit card purchases. The interest rate charged for credit card purchases usually ranges from greater than 10% to about 20%. The argument for the appropriateness of that rate is based on the fact that many consumer durables (such as washers, dryers, and dishwashers) are purchased through the use of a credit card and paid for over time. An argument against the use of that rate is that, in this analysis, the consumer is actually purchasing additional ECMs in a home, not a new appliance; therefore, the consumer has access to a different credit market than that typically used to purchase a new appliance.

When considering how appropriate credit card interest rates are as a discount rate, the effective interest rate actually paid by consumers and nonmonetary benefits of credit card use need to be considered. Many consumers pay off credit card bills before they are charged interest, indicating that their discount rate is below that charged by the credit card. Additionally, many credit cards have a "grace period" between the consumer purchase and the initiation of the interest charges, lowering the effective interest rate charged. Finally, nonmonetary drivers (such as the need to track expenses) sometimes provide a reason for using credit cards.

One alternative for establishing a discount rate is to select the most common interest-bearing investment made by owners of homes. Passbook savings accounts are probably the most common form of interest-bearing investments for homeowners. The argument could be made that consumer use of passbook savings accounts indicates their discount rates are at or below passbook savings rates. However, the real rate of return (savings interest rate less inflation) often barely exceeds 0%, which is equivalent to the assumption that the value of money received in the future is almost the same as money received in the present. For that reason, we believe the passbook savings rate is clearly too low for this analysis.

Another possible rate is the market rate for monetary investments. Consumers have access to a number of common market rates. These alternative investments can be used for comparison to investments in energy conservation measures. Using the consumer's alternative monetary investments for comparison, "The discount rate should reflect the rate of return that will be foregone if the project in question is undertaken instead of the next best alternative investment opportunity of similar risk; that is, it should reflect the 'opportunity cost' of the project." (Ruegg and Petersen 1987, p. 17). This criterion requires selecting the consumer's best available rate of return with comparable risk and liquidity. Passbook savings accounts generally pay low rates. U.S. Savings Bonds and short- and medium-term certificates of deposit (CDs) interest rates are usually higher. These investments are relatively risk-free and have a moderate to high degree of liquidity.

Another alternative "investment" for the consumer, which is comparable to the market rates for investment, is prepayment of the mortgage. In determining the rate of return from the prepayment alternative, the loss of the tax deduction for mortgage interest (if any) and loan prepayment penalty (if any) need to be considered. (Savings from energy conservation are tax-free.) Assuming no loan prepayment penalty and deduction of the mortgage interest, the net rate available to the homeowner who deducted the interest from his taxes for an "investment" in mortgage prepayment would be about 5.7%,(a) or 1.7% real accounting for the recent 3.9% inflation. Therefore, the prepayment "investment" yields between 5.7% and 8.3% nominal or between 1.7% and 4.2% real with the average value being at the low end because most homeowners take the mortgage tax deduction. This option is risk-free. In contrast to most of the other investments, prepaying the mortgage would cost the consumer liquidity. An argument for using the mortgage interest rate (at a minimum) is that the homebuyer has borrowed money at that rate, demonstrating that his implicit discount rate must be at least that high.

Using the criterion that the standard must be developed based on costs to the owner using the next best alternative investment opportunity, the best rate of return commonly available to the owner of the home is mortgage prepayment yielding a real return of about 1.7% to 4.2%. This range was selected as the possible range for the discount rate for this analysis. Because the long-term treasury bond rate (NIST 1992) is within this range, the real discount rate of 4.0% (8.1% nominal, if a 3.9% inflation rate is included) was used in this analysis. This rate is probably above the rate established by prepayment of the mortgage.

(a) The appropriate federal income tax rate is assumed to be 28%. The average marginal state income tax was estimated to be 3%. The 8.3% return less the tax deductions of 31% (28% federal plus 3% state), yields a 5.7% nominal return.

3.2.2 Inflation Rate

The inflation rate is used to convert between nominal and real rates. It is irrelevant in this analysis, however, because all parameters are compared in real (i.e., preadjusted for inflation) terms.

3.2.3 Period of Analysis and Building Lifetime

A period of analysis equal to the mortgage term of **30 years** was used in the analysis. This is consistent with the Congressional guidance contained in the conference report on the Energy Policy Act legislation (CRH 1992) which states that if a life-cycle cost analysis is conducted, it "should use a 25 or 30 year term to reflect the fact that houses have long useful lives and are commonly financed through 30 year mortgages." The discount rate (4.0% real) diminishes the value of future dollars such that periods far into the future do not have a major impact on the analysis. For example, the effect of the difference between analysis periods of 30 years and 50 years is small.

A building life for single-family homes of **50 years** was assumed for this analysis. The life affects the resale value at the end of the 30-year analysis period. No references were found which give median building lives, but the 1989 American Housing Survey (DOC 1991a) reports that 31% of all existing housing units are 50 years or older. This indicates housing commonly lasts 50 years. A building life of **30 years** was assumed for multifamily homes based on discussions with Ronald Nickson of the National Multi Housing Council/National Apartment Association.

3.2.4 Property Tax Rate

For the analysis, property taxes as a percentage of home value was needed. Property taxes vary widely from state to state and within a particular state. Money magazine (1992) reported state-by-state average property taxes on a "typical Money subscriber," a two-income family of four earning $69,275. Median single-family home values by state were provided by OTS (1991). However because the typical Money subscriber family earning $69,275 is wealthier than a typical family, the OTS home prices were scaled up before calculating the property tax percentage. NAR (1990) reported a national average home value/annual income ratio of 2.3. Therefore, the family earning \$69,275 owns a home that, on average, is worth \$159,332. NAHB (1992a) reports median home prices to be about \$120,000. Home prices were scaled up by 159,332/120,000, or 32.8%, to better represent the home values for this wealthier family. The resultant property tax rate (tax paid/home value) is **1.36%** when averaged across all states. In the analysis, property taxes were individually set for each state and are given in Appendix D.

3.2.5 Income Tax Rate

The marginal income tax rate paid by the homeowner determines the value of the mortgage tax deduction. The homeowner is assumed to itemize deductions, which is most common. The marginal federal tax bracket for most homebuyers is 28%. State taxes for a two-income family earning \$50,000 and \$75,000 were reported in Money magazine (1992). The \$50,000 income level should be reasonably close to median income levels of homeowners, as Consumer Digest (1991) reports two-income family median income at \$51,421 in 1990 and rising. The average tax across all states is **3.0%** of income using the \$50,000 income level. In the analysis, state income taxes were individually set for each state and are given in Appendix D.

3.3 FUEL PRICE PARAMETERS

Both current fuel prices and fuel price escalation rates were required for this analysis.

3.3.1 Fuel Price Data

Residential energy prices from an Energy Information Administration report, State Energy Price and Expenditure Report 1990 (EIA 1992d), were used in the analysis. The 1990 fuel prices for each state were updated for the fuel price escalation in 1991 and 1992 (EIA 1992c).

From the consumer's perspective, the energy cost savings from changes in energy conservation levels are driven by marginal fuel prices, which may not equal average fuel prices. Energy prices are often tied to the consumption rate per household; higher consumption rates can result in lower (or higher) average unit costs for energy. We obtained estimates of marginal to average price ratios, which were used to modify the average prices discussed above.

For electricity, the publication Typical Electric Bills (EIA 1988, p. 22) was used to determine the difference between marginal rates and average rates. Monthly U.S. average residential bills were reported for the 250-, 500-, 750-, 1000-, and 2500-kWh levels. We assumed a constant marginal rate between each of these levels (i.e., the cost of each additional kWh was constant). The Energy Information Administration (1989, p. 63) reports the average annual amount consumed for households using electricity as the main heating fuel for buildings built in 1985 or later to be 14,920 kWh per year, or 1243 kWh per month. On a national average, the electricity usage will be much higher during the heating season for homes with electric heating. Consequently, we assumed 1800 kWh per month. Based upon this consumption rate and the national average electric bill reported by EIA, the marginal rate was estimated to be 8% lower than the average rate. All electricity prices were adjusted by this factor.

For natural gas, NAHB (1992c) reported rates that allowed the marginal to average price ratio to be determined. Residential natural gas prices for January through March 1991 were reported for the 30-, 50-, 100-, 200-, and 300-therm levels for 131 utilities. The average annual amount consumed for households using natural gas as the main heating fuel for buildings built in 1985 or later is 85.8 MBtu, or 71.5 therms per month according to the EIA (1989, p. 56). Of course, the natural gas usage will be higher during heating season. For consumption rates between 50 and 100 therms, NAHB reported 17 utilities with decreasing rates, 2 utilities with increasing rates, and 112 with constant marginal rates. Overall, the marginal rate averaged less than 1% lower at 100 therms than at 50 therms. The same NAHB source reported that most utilities charge monthly meter fees; these fees averaged $5 across the 131 utilities. Assuming an average natural gas monthly bill of $50, the fees are 10% of the total bill. Therefore, we applied an adjustment lowering the SEPER natural gas costs by 10%. No difference between average and marginal fuel prices was assumed for fuel oil and LPG (NAHB 1986).

The fuel prices from EIA (1992d) do not include sales and point-of-purchase taxes (see, for example, EIA [1992d, p. 189]). We were not able to obtain detailed data on these taxes, which can vary from city to city. We estimated the average tax to be 4% and applied this to all fuel costs. The residential fuel prices used in each state for electricity, distillate fuel oil, liquified petroleum gas (LPG), and natural gas are shown in Table A.1 of Appendix A. The summer/winter variation in electricity prices was accounted for as described in Appendix A (Tables A.2 and A.3).

3.3.2 Fuel Price Escalation Rates

The residential fuel price escalation rates (real) displayed in Table 3.1 were taken from a report prepared for the Federal Energy Management Program (FEMP) (NIST 1992). The FEMP projects fuel escalation rates for 5-year periods up to the year 2022 for each fuel used in this analysis. The ARES software, which was used to do the life-cycle analysis, allows only a single fuel escalation rate for each fuel and location. Therefore, the price escalation rates for the 1992 to 2021 period of analysis were resolved to a single value for each fuel and region as shown in Table 3.1. Over the 30-year analysis period, the single fuel escalation rates shown in Table 3.1 will yield the same present value (accounting for the discount rate) for energy savings as the set of rates projected by FEMP. The FEMP projects separate escalation rates for the four U.S. census regions; therefore, separate rates were used in each census region.

TABLE 3.1. Residential Fuel Price Escalation Rates (Percent, Real) 1992 through 2021 by U.S. Census Region

Fuel	North-East	North-Central	South	West
Electricity	0.1	0.4	0.4	0.6
Fuel oil	1.9	2.0	1.9	2.0
Natural gas	2.0	2.4	2.2	2.2
Liquid petroleum gas	1.5	1.9	1.7	1.6

4.0 ENERGY CONSERVATION MEASURES

The analysis used to develop the recommendations for revision of the MEC requires information on specific ECMs. This analysis determines the homeowner's optimal investment in energy conservation by minimizing the sum of the costs (including ECM purchase) and benefits of an investment in energy conservation using a life-cycle cost (LCC) analysis. The ECMs characterized in this report are considered as alternative construction options that can be compared to determine the most cost-effective package of options that, in turn, provides the basis for the revised U_0-values in the code change proposal (all U_0-values in this report account for framing).

The ECM options used in the LCC were selected to represent the range of options available to builders. To be considered an "available" ECM option, the option had to be identified in more than one published data source, for example, in a construction cost estimation guide or the report of a large-scale construction demonstration program. ECM options for which we could identify only a single source or a few experimental homes were not included in the optimization. This does not imply that other options, such as insulation R-values beyond those included here, are not available; rather, it indicates, in our judgment, that a code should be based on existing technology that has been implemented in a significant number of homes. The issue of what ECM options should be considered arises most often at the high efficiency levels (lowest U_0-value). For example, we eliminated R-60 ceilings because we did not find sufficient evidence that they were in use in at least a few locations. We also required that cost information be available for every option we used. If good cost data were lacking, an option was removed. Except for window and high-density insulation costs, we limited ourselves to cost data sources with a national scope.

In determining construction details, we chose from among common construction practices. If more than one practice was common (for example, the use of batt and blown insulation in ceilings), we selected the most cost-effective practice from an energy-efficiency standpoint. Therefore, we did not necessarily select only the most common practice. Instead, we selected the most energy-efficient construction practice commonly in use.

We attempted to cover the range of ECM options available. It was not necessary to include all possible options, but to include a range of options sufficient to represent the range of cost and U_0-value combinations available.

It should be noted that compliance with the MEC can be based on meeting individual component U_0-value requirements, an equivalent overall building U_0-value, or an energy equivalent based on a whole-building energy analysis. Thus, a number of alternative ECM combinations would lead to compliance for any particular home. Because this analysis generated U_0-value requirements, not specified construction practices, those alternatives are not detailed here. Builders would be free to use any type of construction that complied with the MEC component U_0-value, overall U_0-value, or energy-based performance requirements.

This section primarily documents the characterization of the ECM options used in the LCC analysis, including the levels (R-values for the ceilings, opaque walls, and floors; U-values for windows), costs, and some of the construction assumptions. Appendix B provides more detail on the calculation of the U_0-values for each ECM. Section 4.1 presents the ECM levels, costs, and U_0-values. Section 4.2 describes the single-family and multifamily building prototypes. Section 4.3 provides the HVAC systems and efficiencies assumed in the analysis. Section 4.4 briefly describes the analysis that determined the ECMs complying with the 1993 MEC. (This is needed to estimate the economic impacts of the proposed changes, see Section 5.5). Section 4.5 discusses ECM lifetimes.

4.1 ENERGY CONSERVATION MEASURES AND COSTS

ECM option characteristics must be determined for envelope components. These components are ceilings, walls, windows, and floors. For each component, a list of ECM options and associated characteristics was produced, including ECM option description, cost, and U_0-value.

A set of specific candidate ECMs was developed separately for each component, as described below. The first step was to determine the ECM levels available for each component. As noted earlier, only ECM levels included in construction cost databases or large-scale demonstration programs were considered.

The next step was to estimate costs for each option. The costs are incremental costs, i.e., the cost of the change required for an improvement in energy efficiency. The incremental costs include costs of general construction changes required to accommodate an energy-efficiency change (for example, walls with R-19 batt insulation require 2x6 studs instead of 2x4 studs). All costs in the tables in this section represent 1992 national averages and are costs to the home buyer/owner. These costs include materials, installation, and markups for overhead and profit. All costs were modified state by state to account for regional cost differences using state factors reported by Means (1992). Costs from older sources were inflated to current conditions based on the residential construction cost inflation rate (DOC 1992b). All ECM costs reported in the tables below are for single-family houses; costs for multifamily buildings are scaled down from the single-family costs by 5.5% to account for a discount resulting from bulk purchasing of materials (NAHB 1986).

Sections 4.1.1 through 4.1.4 present the U_0-values and incremental costs for each of the ECMs included in the energy analysis. Each ECM cost shown is the cost relative to the least energy efficient level for each component. (Because the LCC minimization selects options based on a comparison of the incremental cost of options, absolute costs are not required in the analysis.) Section 4.1.1 gives the ceiling insulation levels and costs. Section 4.1.2 presents the wall ECMs. Section 4.1.3 presents the insulation levels in floors over unheated spaces. Section 4.1.4 covers window ECMs, and Section 4.1.5 describes the selection of door ECMs.

Appendix B describes the calculation of component U_0-values in detail. The overall U_0-values for wall, floor, and ceiling assemblies were calculated assuming construction techniques currently used in the industry. The U_0-values were determined using material thermal properties and calculation techniques recommended by ASHRAE (ASHRAE 1989), except for windows, which were developed from tested window data.

4.1.1 Ceilings

Two types of ceilings/roofs were analyzed: ceiling/roofs with an attic space and vaulted (cathedral) ceiling/roofs. Ceilings with attic spaces are probably more common, but vaulted ceilings were analyzed separately here because they are significantly different in terms of construction and are much more expensive to insulate to high levels. Levels of ceiling insulation for ceilings with attics included R-11, R-19, R-30, R-38, and R-49. R-38 and R-49 insulation levels were analyzed with and without a raised-heel truss, which provides more space at the eaves for the thicker levels of insulation. Levels of ceiling insulation for the vaulted ceilings included R-11, R-19, high-density R-30, high-density R-38, and the high-density R-30 and R-38 with 1 in. of R-7 rigid sheathing insulation.

Cost data for these insulation levels and construction assemblies were obtained from four national sources and one regional source:

- Means Residential Cost Data 1992 (Means 1992)
- 1992 National Construction Estimator (Craftsman 1992)
- National Association of Home Builders: An Economic Data Base in Support of ASHRAE SPC 90.2: Cost of Residential Energy, Thermal Envelope and HVAC Equipment (NAHB 1986)
- federal residential standards (DOE 1988)
- California Energy Commission (CEC, regional [Eley 1991]).

Comprehensive costs for regular-density fiberglass batt insulation were available from all the sources. Less complete data were available for blown insulation, with NAHB the only comprehensive national source for blown insulation. A regional study of California costs done by the CEC (Eley 1991) reported blown insulation at much lower costs than NAHB costs. Other, less comprehensive, regional sources also reported that costs for blown insulation were at least as low as the NAHB costs, if not lower. Because blown insulation was found to be somewhat more cost-effective than batt insulation, according to all the above sources, and was in common use, blown insulation was assumed in this analysis for ceilings with attics. As the only cost data with a national scope, the NAHB blown insulation data were chosen for the analysis of ceilings with attics even though it had the highest costs[(a)]. Batt insulation was assumed for vaulted ceilings, with Means, NAHB, and the 1992 National Construction Estimator (NCE) costs averaged together for the low-density insulation costs. The only data source for the high-density insulation was CEC; thus, it was used. The Means and NAHB had cost data for rigid foam insulation in vaulted ceilings; these were averaged and used.

For ceilings with attics, raising the roof to allow more space for insulation will obviously increase construction costs. The only national source for the cost of a raised-heel truss versus a standard truss was NAHB ($0.21/ft^2 of ceiling area) so this source was used (NAHB 1986). In addition, the cost of an extra foot of wall sheathing and siding was added to account for the higher wall needed to cover the raised truss. For vaulted ceilings, the rafter stud for the base case was assumed to be equally divided between 2x8 and 2x10. The high-density R-30 and R-38 insulation require 2x10 and 2x12 studs, respectively, to allow room for both insulation and ceiling ventilation (the construction and material costs of the larger studs were included).

Figure 4.1 shows the costs versus U-value for the five different ceiling cost sources for ceilings with attics. Note that all the insulation costs from different sources are reasonably close to each other with the exception of the CEC costs, which are significantly lower. Table 4.1 shows the U_0-values and costs for ceilings with attics used as input into the LCC analysis. Vaulted ceiling costs are given in Table 4.2. Note that insulation costs for vaulted ceilings are much higher than for ceilings with attics.

(a) Recent testing shows low-density blown fiberglass insulation has considerable loss of R-value at very cold temperatures because of convection. However, the annual performance of low-density blown insulation is comparable to other fiberglass insulation types (Energy Design Update 1992).

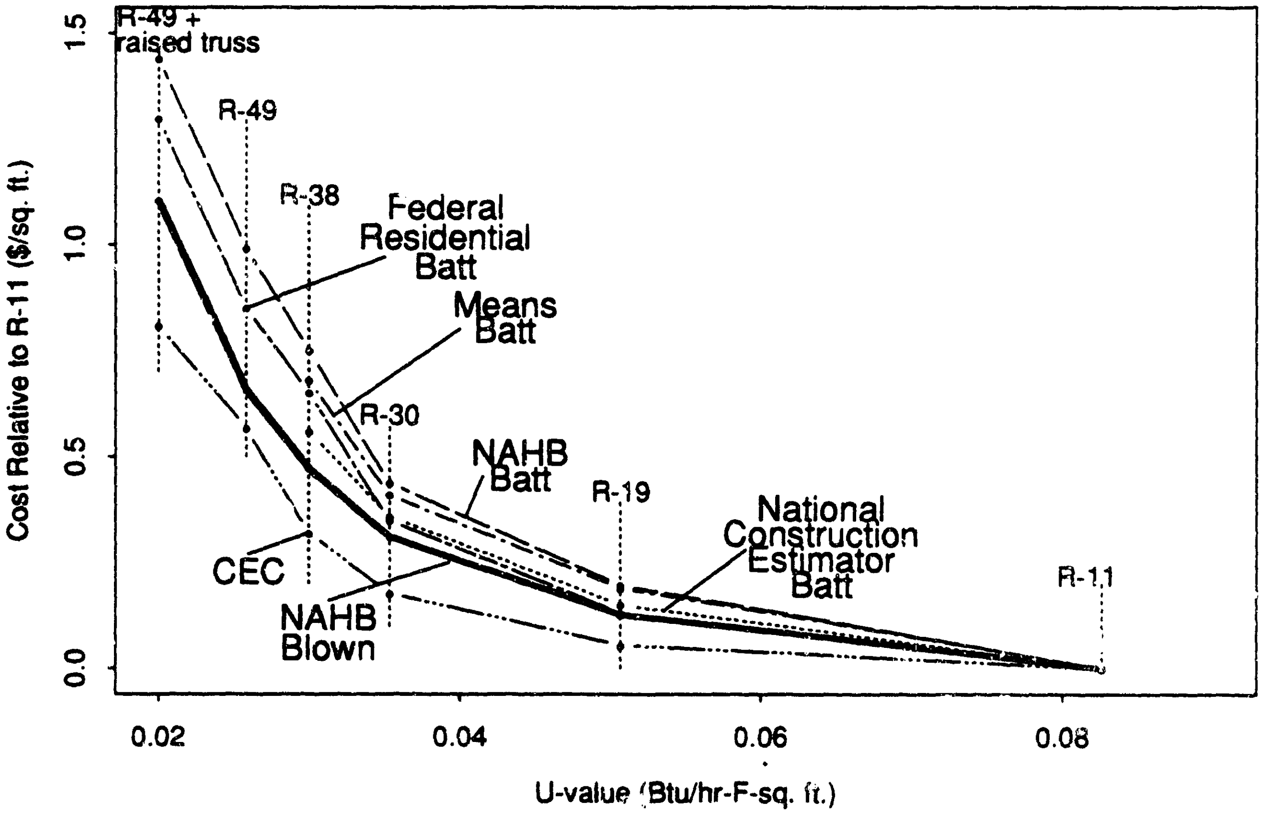

FIGURE 4.1. Ceiling with Attic ECM Costs from Five Sources

TABLE 4.1. Ceiling with Attic U_0-values and Costs

Nominal R-value	Ceiling U_0-value	Cost Relative to R-11 (\$/ft^{2})
R-11	0.0819	0.00
R-19	0.0507	0.13
R-30	0.0353	0.31
R-38	0.0300	0.47
R-38 with raised truss	0.0254	0.92
R-49	0.0259	0.66
R-49 with raised truss	0.0200	1.10

TABLE 4.2. Vaulted Ceiling U_0-values and Costs

Nominal R-value	Ceiling U_0-value	Cost Relative to R-11 ($/ft^2)
R-11	0.0850	0.00
R-19	0.0526	0.17
R-30	0.0351	0.72
R-38	0.0282	1.64
R-30 + R-7	0.0277	1.45
R-38 + R-7	0.0231	2.37

4.1.2 Walls

The base case for walls was R-11 insulation in a 2x4 16-in. on center (O.C.) framed wall with 1/2-in. fiberboard sheathing (R-1.32). Additional ECM measures included R-19 batt insulation; high-density R-13, R-15, and R-21 batt insulation; 3/4 in. of extruded polystyrene (R-4); and 1 in. of isocyanurate (R-7) foam sheathing.

Cost data for these configurations were gathered from three sources which had most of the wall ECMs:

- Means Residential Cost Data 1992 (Means 1992)
- An Economic Data Base in Support of ASHRAE SPC 90.2: Cost of Residential Energy, Thermal Envelope and HVAC Equipment (NAHB 1986)
- California Energy Commission (CEC, regional [Eley 1991]).

The addition of up to 1 in. of foam sheathing was a commonly available option, as evidenced by the NAHB cost data (NAHB 1986), the Means cost data (Means 1992), Energy Crafted Homes (Fryer and Schalch 1992), Residential Construction Demonstration Project homes (Barnett and Thor 1990), and Builder Magazine (NAHB 1991a). In fact, some builders use more than 1 in. of exterior sheathing (this is a method of achieving high R-values without the use of 2x6 walls). The use of more than 1 in. of exterior sheathing is not a widespread practice, however, and was not included as an ECM option. Walls with rigid foam insulation lack structural support and therefore need let-in corner bracing (NAHB 1988) (we assumed that the fiberboard was a type of fiberboard which provided structural support). These bracing costs were obtained from Means (1992) and were \$0.10/ft^2 of wall area for 16-in. O.C. construction and \$0.07/ft^2 of wall area for 24-in. O.C. construction.

Costs for changing from 2x4 to 2x6 framing to accommodate R-19 insulation were included. Construction changes for window and door framing for 2x6 walls proved to be a significant cost. The sole source of cost data for the window and door framing costs was the <u>1992 National Construction Estimator</u>. According to the NCE (Craftsman 1992), the additional cost for window and door framing in 2x6 construction is \$0.07/ft^2 of opaque wall area, assuming 16 windows per single-family home (Toenne 1991). The NCE window-framing cost data were compared against an estimated cost derived from Means cost data and found to be in reasonable agreement, so they were used.

About 22% of the builders using 2x6 construction use 24-in. O.C. spacing rather than 16-in. O.C. spacing, according to a survey conducted in 1988 by the U.S. Forest Products Laboratory (FPL) and the Wood Product Production Council (Anderson and McKeever 1991). 24-in. O.C. spacing is a construction technique which is sometimes advocated as a measure to decrease construction costs, conserve energy, or conserve wood. For example, the NAHB Research Foundation has developed the Optimum Value Engineering (NAHB 1977) building system approach to reduce material and labor costs. NAHB's Optimum Value Engineering approach includes 24-in O.C. spacing for 2x4 or 2x6 framing members. The FPL report also stated that 2x6 studs provide sufficient strength to easily allow 24-in. O.C. construction. We assumed an average of 50% 24-in. O.C. construction and 50% 16-in. O.C. construction for 2x6 framing. The conservative assumption of 50% 24-in. O.C., rather than 100% 24-in. O.C., was used because of comments from external reviewers that 16-in. O.C. construction may be required in certain situations. This 50% assumption had a significant impact because 16-in. O.C. construction is both less energy-efficient and more costly than 24-in. O.C. construction.

An issue related to the use of 2x6 walls instead of 2x4 walls is the effect on the floor area of the building. Assuming that exterior dimensions are equivalent, the usable floor area will decrease by 2 inches on each exterior wall if 2x6 walls are built instead 2x4 walls. The overall reduction in floor area will be quite small. The "cost" to the homeowner of this decrease in floor area is not easily defined. Arguments can be made against including costing this lost floor area in the analysis. Some homebuyers prefer 2x6 walls and would pay extra for them. Homes with 2x6 wall may be more uniform in temperature and more isolated from outside noise. The homebuyer may be willing to accept the slightly smaller floor area for the advantages of 2x6 walls. Analyses underlying other residential standards including ASHRAE 90.2P and the state of California code do not make allowances for reduced floor area (ASHRAE 1990, Eley 1991).

We decided to be conservative and include an estimate of the cost of the reduced floor area for 2x6 exterior walls in our analysis. We assumed the interior floor area remained unchanged for 2x6 construction, but accounted for the extra cost of increasing the exterior dimensions by 2 inches. Means average cost data (1992, primarily pp. 25 and 29) for exterior walls, framing, roofing, foundations, and site work were used to obtain an estimate of this incremental cost. The total costs for these components were calculated for the single-family prototype. This cost was divided by the prototype wall area to obtain a cost of $\$0.27/\text{ft}^2$ of wall area for all single-family ECM levels requiring wall construction with 2x6 studs (the multifamily cost is this same value adjusted down by 5.5% as discussed earlier).

Cost information for standard-density wall insulation levels and the construction changes from Means (1992) and NAHB (1986) were averaged and used in the optimization. Costs for high-density R-15 and R-21 insulation were available from Eley (1991) only, but were very close to costs reported by Xenergy (1992). Means (1992) did not provide a cost for R-13 insulation; therefore, the incremental cost for R-11 to R-13 were based solely on NAHB costs (1986). Figure 4.2 shows the averaged wall ECM costs used here and the individual cost for the two primary data sources--Means (1992) and NAHB (1986). Table 4.3 shows the wall U_o-values and cost increments used here in

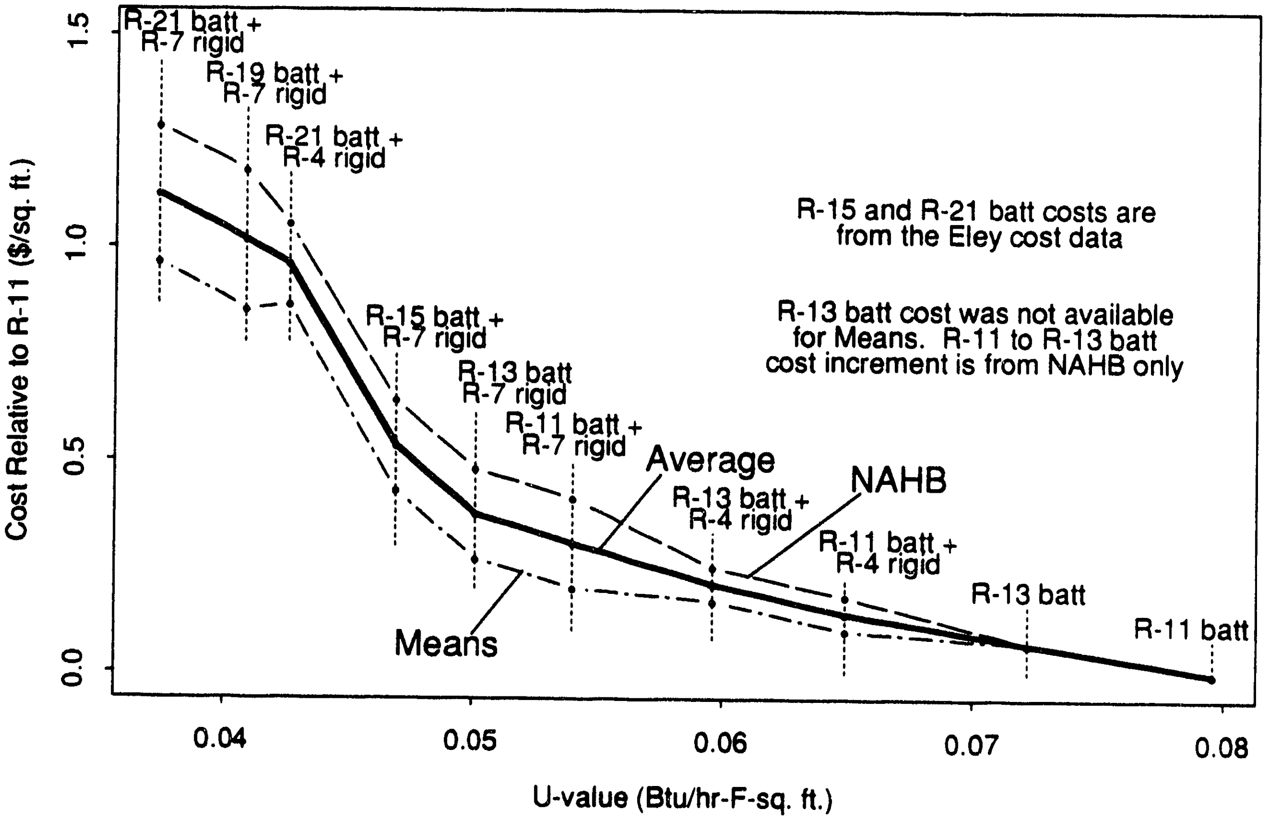

FIGURE 4.2. Wall ECM Costs from Two Sources

order of decreasing U_0-value. Note that not all wall insulation levels shown in Table 4.3 are cost-effective as other insulation levels are less expensive and have lower U_0-values.

4.1.3 Floors over Unheated Spaces

For floors over unheated spaces, the unheated space is either a crawlspace or an unheated basement. (These two types of floors were optimized separately, then the results were averaged to produce the U_0-values for floors over unheated spaces.) Incremental levels of floor insulation were R-0, R-11, R-13, R-19, and R-30. Evidence that an R-30 level of insulation was an ECM option in floors came from the NAHB cost data (1986), the Means cost data (1992), the Energy Crafted Homes (Fryer and Schalch 1992) in the Northeast, and the Super Good Cents program in the Northwest (Boe 1992). For R-30 only, a cost of $\$0.04/ft^2$ for supporting netting (including installation) was

TABLE 4.3. Wall U_o-values and Costs

Nominal Batt Insulation R-value	Rigid Insulation R-value[(a)]	U_o-value of wall	Cost Relative to R-11 ($/ft^2)
11	1.32	0.0796	0.00
13	1.32	0.0722	0.07
11	4	0.0649	0.14
13	4	0.0596	0.21
11	7	0.0540	0.31
19	1.32	0.0544	0.73
13	7	0.0501	0.38
19	4	0.0470	0.85
15	7	0.0469	0.54
21	4	0.0426	0.96
19	7	0.0409	1.02
21	7	0.0374	1.13

(a) The R-value of 1.32 corresponds to 1/2-in. fiberboard.

assumed (Eley 1991), as the R-30 insulation will exceed the thickness of the floor joists for joists with dimensions of less than 2x10.

Cost data for floor insulation were taken from Means (1992) and NAHB (1986). Means did not give a cost for R-13, so the NAHB (1986) cost increment for R-11 to R-13 was assumed. The NAHB (1986) data gave separate costs for crawlspace insulation and unheated basement insulation (i.e., basement ceiling insulation). The crawlspace insulation costs were uniformly $0.04/ft^2 higher than the costs for insulation above unheated basements. (We assumed this cost increase was because of higher installation costs.) Separate costs for crawlspace insulation and basement ceiling insulation were used for the two separate floor types in the LCC analysis. The Means cost data (1992) were averaged with each of the two NAHB (1986) sets of cost data, creating crawlspace insulation costs $0.02/ft^2 more than basement ceiling costs. Figure 4.3 shows insulation costs for the Means and NAHB data for basement

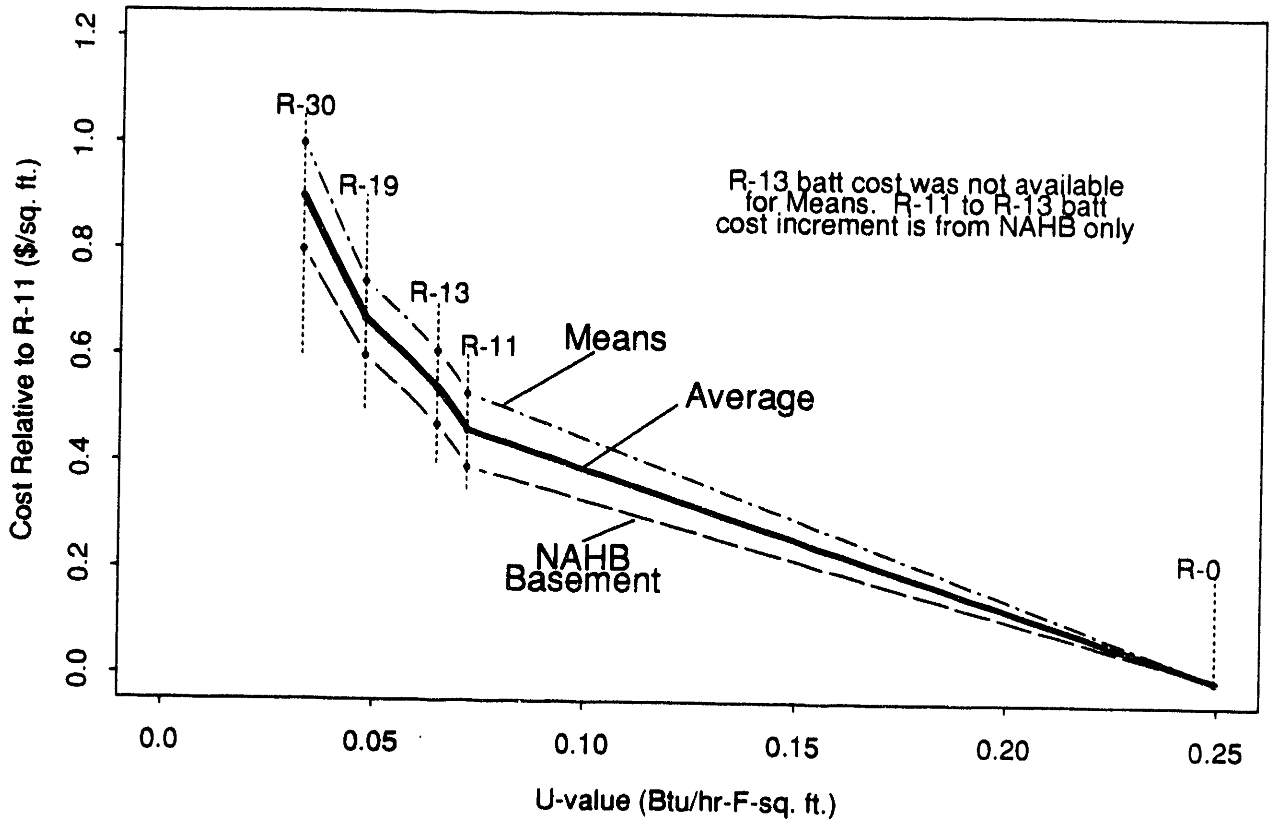

FIGURE 4.3. Floor ECM Costs from Two Sources

ceilings as a function of floor U_0-value. The average of these two data sets is plotted and was used in the analysis. The crawlspace costs are not shown in this figure, but again are about $0.02/ft^2 higher. Table 4.4 shows the floor U_0-values and cost increments used in the LCC analysis.

TABLE 4.4. Basement Ceiling and Crawlspace U_0-values and Costs

Insulation R-Value	U_0-value of floor	Basement Cost Relative to R-0 ($/ft^2)	Crawlspace Cost Relative to R-0 ($/ft^2)
0	0.2494	0.00	0.00
11	0.0719	0.46	0.48
13	0.0648	0.54	0.56
19	0.0478	0.67	0.69
30	0.0328	0.90	0.92

4.1.4 Windows

Window cost data were obtained in a different manner and from different sources than the other ECM cost data. The most important aspect of collecting window cost data is to correctly associate a cost and a U_0-value. Obtaining a cost versus energy-efficiency relationship is more difficult for windows because window costs are greatly affected by nonenergy characteristics such as appearance. Obtaining window efficiency costs is made more difficult by the relatively rapid changes in window technology and energy-efficiency costs. In particular, vinyl framing, low-emissivity (low-E) coatings, and argon-filled windows are rapidly penetrating the market and are dropping in price.

Two sources of window cost data were judged to be the best available. The first was a survey of nine Pacific Northwest window manufacturers for the Washington State Energy Office (WSEO) (Byers 1990). The other source of window cost data was the work done for the California Energy Commission by Eley Associates (1991). We decided to use these two sources for a number of reasons. First, costs for a fairly extensive set of window types were available from multiple manufacturers from both of these sources. (In all cases, there were three or more manufacturers from each of the two sources for each window improvement option of interest.) The data included new energy-efficient technologies such as vinyl sashes, low-E surfaces, and argon gas. The U_0-values from these sources were probably more reliable than older data; particularly the U_0-values in the WSEO report (Byers 1990), which were based on test measurements.

Our examination of windows currently in the market from an energy-efficiency standpoint showed that we could represent the range of costs and efficiencies for the most cost-effective windows with incremental prices for only a few energy-related features. Our base window was a single-pane, aluminum-frame window. The incremental changes in windows that we needed to cost were single- to double-pane; aluminum frame to aluminum with thermal break, vinyl, or wood frame; the addition of low-E coating; and the addition of argon gas. To isolate cost changes for improved energy efficiency, the cost changes for incremental window improvements (such as adding low-E) were determined separately for each manufacturer, so that cost changes were not aggregated across manufacturers until after the cost changes had been identified for each manufacturer. Examining window improvements by manufacturer tended to avoid the large variation in other window characteristics that affect price in inter-manufacturer comparisons. We assumed the costs for any given incremental thermal improvement were constant regardless of other thermal characteristics. For example, the costs of adding a low-E coating to aluminum and vinyl windows were identical. We averaged the WSEO and CEC costs for each window feature. We used the CEC data (Eley 1991) for the cost differential from single- to double-pane (aluminum) windows, as that was not available in the WSEO data.

Current costs for low-E coatings were difficult to establish because of recent technology improvements. For this reason, we did not use the CEC (Eley 1991) or WSEO (Byers 1990) cost data but instead used an estimated cost that was lower. In the last 2 years, there has been a change in the commercially available low-E technologies. Of most interest here is the new "hardcoat" low-emissivity coating, which is both better in performance and lower in price than older "hardcoat" technologies. This new low-E technology has just begun to reach the market and was assumed to be the most cost-effective type of low-E coating. The cost of the new low-E coatings to the glass manufacturer is low, about \$0.50/ft^2 (Gerhardinger and Flagg 1992). Based primarily on this manufacturer's cost, we estimated the retail cost (including overhead and profit) of the new low-E to be \$1/ft^2 to \$2/ft^2 to the consumer. To be more conservative, we placed a price of \$2/ft^2 on low-E glazing. Responses to a limited number of inquiries of retail glazing distributors indicated that some distributors are already at or below \$2/ft^2 (although most are currently above this cost), and that low-E prices are going down. The American Architectural Manufacturers Association (AAMA 1992) indicates that low-E glazing is a widely used window option and its use is increasing with residential market penetration rates, up from 28% in 1988 to 31% in 1991. At least one window manufacturer (Andersen) has moved its whole line to low-E glazing, providing evidence of the penetration of low-E glazing in the market.

It should be noted that the optimization (discussed in Section 5) infrequently selected glazing with low-E; therefore, our low low-E price did not markedly impact the analysis. Part of the reason that low-E was generally not commonly the window type with the lowest LCC was that argon gas is much cheaper than low-E and produced about an equivalent U-value reduction (according to our data). For most of the country, our analysis optimized on the double-vinyl, argon-filled window type (U_0-value = 0.40). The fact that non-air-filled units account for 43% of new residential windows (AAMA 1992) gives evidence that argon-filled windows in new housing are popular and cost-effective.

Many types of windows were not included in our analysis because they were not prevalent in the market or were not the most cost-effective from a strict energy standpoint. For example, triple-pane windows are available from some manufacturers, but were not included in the analysis because of the small number of manufacturers offering such a window, lack of cost data, and less expensive options for obtaining equivalent efficiency. It is worth noting that the thermal efficiency of high-performance double-paned windows included in this analysis equals the thermal efficiency of normal triple-paned glass (see Appendix B).

The incremental cost of wood-framed windows was obtained from the NAHB (1986); this cost was not directly available from the WSEO or Eley data. The cost increase (adjusted for inflation) for standard double-paned wood windows relative to standard aluminum windows was $6.36/ft^2. Inadequate cost data were located for determining the incremental cost of low-E and argon in wood windows. Therefore, the assumption was made that the incremental price of low-E and argon in wood windows was the same for wood and vinyl windows; therefore, only an incremental cost of the wood frame needed to be established.

The window costs in both the WSEO data and the Eley data were the total costs of windows as sold by the manufacturer to mid-sized builders. Installation costs and contractor profit had to be added to these costs. Means (1992) listed an increase in installation costs of $0.82/ft^2 from single- to double-paned 3/16-in. float glass; this factor was included in our costs. No installation cost increases for vinyl, argon, or low-E windows were applied. Means (1992) listed a window installation subcontractor overhead and profit margin of 26% for a standard double-paned window. This was applied to all the window ECMs. A 10% profit for the general contractor (Means 1992) was applied on top of all other costs. Window costs were increased to account for inflation from 1990 to (estimated) 1992 based on the Survey of Current Business construction cost indexes (DOC 1992b).

As mentioned above the relationship between window U_0-value and cost was described for various types of windows. These are shown in Table 4.5. Except for the single-paned aluminum window, the U_0-values are based on testing of numerous windows for the Washington State Energy Code (WSEO 1992). A U_0-value provided by ASHRAE (1989) was used for the single-paned aluminum window. See Appendix B for more information on the window U_0-values used in this analysis.

TABLE 4.5. Window U_0-values and Costs

Window/Sash Type	Window U_0-value	Cost Relative to Single Aluminum ($/ft^2)
Single aluminum	1.31	0.00
Double aluminum	0.61	4.50
Double aluminum/thermal break	0.54	7.35
Double wood	0.52	10.86
Double vinyl	0.49	7.00
Double wood with argon	0.43	11.88
Double wood with low-E	0.42	12.86
Double vinyl with argon	0.40	8.02
Double vinyl with low-E	0.39	9.00
Double wood with argon, low-E	0.37	13.88
Double vinyl with argon, low-E	0.35	10.02

4.1.5 Doors

Opaque door options were examined. The impact of doors on the wall U_0 is relatively small because of the small door area (see Section 4.2). Cost data were available from NAHB (1986) and the University of Washington (Ossinger et al. 1989) for two basic types of doors: solid core, flush wood and insulated steel doors. These data were used to establish the cost of energy efficiency in doors. The wood door had a U-value of 0.39, and the steel door had a U-value of 0.19 (ASHRAE 1989). The steel door had an incremental cost relative to the wood door of $\$1.05/ft^2$. A check of the life-cycle costs for these two doors indicated that the more energy-efficient doors are cost-effective in all climates except Hawaii and, in some cases, southern Florida. Therefore, a door with a U-value of 0.19 was used in the analysis for all locations.

4.2 PROTOTYPE SINGLE- AND MULTIFAMILY HOMES

The prototype dimensions, with the exception of the window area, do not significantly affect the optimization process. The size of the components (ceilings, walls, and floors) has very little impact on the optimum ECMs determined by the LCC analysis as the cost to install an ECM and the energy-saving benefit are constant per unit area of the component. The only major impact the prototype has on the floor, wall, or ceiling/roof U_0-value requirements results from the window area assumption. The size of the building does affect the estimates of the average building costs and benefits (Section 5.5). Only when there are major changes in the residences, e.g., the difference between single-family and multifamily homes, does the energy use per unit area of the building envelope change appreciably. This conclusion was also reached by the ASHRAE SP-53 committee (DOE 1989a, p. A.21), which determined that only three residential building types were required to characterize buildings for the development of standards: multifamily, single-family, and manufactured homes (only the first two apply here). The major difference between single- and multifamily homes is the larger fraction of the walls made up of windows in the multifamily homes. Our analysis indicated that the optimum ceiling and floor ECMs for single- and multifamily prototypes were very close, which justified the use of the same U_o-values for both, as is also done in the current MEC. (The different component areas affect total energy use but do not have a significant impact on the costs and benefits per unit envelope area, which sets the U_o-value requirements.)

The specifications of the two prototypes were based on the most common or average characteristics nationally for new homes/apartments. These characteristics were obtained primarily from DOC (1992a) and the EIA (1992b).

The median floor area for a new single-family home according to DOC (1992a) was 1890 ft^2. The number of single-family new homes built in 1991 with one story versus two stories is virtually identical: 48% have one story, 47% have two stories. Therefore, the envelope component surface areas were determined by averaging a 30-ft by 63-ft one-story prototype and a 27-ft by 35-ft two-story prototype (both of which have a floor area of 1890 ft^2). Eight-ft-high ceilings were assumed. The ceiling area (bordering the unconditioned exterior) averaged 1418 ft^2. The average gross wall area was 1736 ft^2. A total door area of 56 ft^2 (roughly three doors) was used (Johnson 1987).

Windows have much higher U_o-values than do opaque walls. Therefore, the amount of window area has a major effect on the gross wall U_o-value. Obtaining data on window area in new single-family housing proved difficult. An older source (NAHB 1981) reported a national average of 10.3% in 1980. One source (Johnson 1987) indicated a national average window area of about 12% of the floor area. The most current published source we could identify (Mundy 1990) reported an estimated average of 410 ft^2 of flat glass sold per new house. Note that this is the area for the glass, not the window; double-pane glazing requires twice the glass needed for single glazing. In a personal communication, Eric Mundy of the Freedonia Group updated this value for us for 1992. He estimated that the average for 1992 was 430 ft^2 per residence. Accounting for double-paned windows, storm windows, and storm doors (AAMA 1992), we estimated an average of about 220 ft^2 of window area in new houses. This corresponds to a window area roughly 11% to 12% of the floor area for our prototype (or a wall with 12 to 13% glazing). We used a second method to try to estimate the window area in new homes. The same source (Mundy 1990) reported 595 million ft^2 of glass sold in 1990 in the new residential market. Using data on new housing construction from Characteristics of New Housing: 1991 (DOC 1992a), we estimated the average window-to-floor area (across all types of residential housing units) to be roughly 13% to 14%.

All of our sources for single-family window areas indicate a window-to-floor area ratio of 14% or less; however, this is an average value. The distribution of window areas in new housing varies around this average. For our analysis, we assumed a conservative window area of 15% of the floor area (283.5 ft^2, or 16.3% of the gross wall area). This area is conservative in the sense that it raises the combined window/wall U_0-value, allowing compliance with larger than average window areas or lower than optimum wall insulation levels. We feel it is important to allow the architectural freedom to include larger than average window areas. It should be noted that the MEC does not place a limit on the window area, nor do we propose that such a limit be included. The MEC requires compliance with only an overall U_0-value.

The reported median floor area of new multifamily units--980 ft^2 (DOC 1992a)--was used. Note that the MEC applies only to buildings three stories or less in height. This prototype building was assumed to be two-story. Whether the units are townhouses or top-and-bottom units has no effect on our analysis because the MEC requirements are for the entire multifamily building. The most important multifamily prototype assumption is the fraction of wall area that is windows and doors. The prototype was assumed to have a high percentage window-to-wall area ratio of 25%, thereby resulting in a gross wall U_0-value curve that can be complied with, even if the building has large window areas. A 14-unit building was assumed, which is approximately the median number of units per building for new multifamily structures (DOC 1992a). The building dimensions were assumed to be 122.5 ft by 56 ft. This corresponds to a building with a central corridor and 28-ft-deep units on each side of the corridor (the corridor area was ignored). Assuming 8-ft-high ceilings, the gross exterior wall area per unit is 408.0 ft^2. The window area was selected by assuming that 25% of the wall area was window.(a) This gives 102.0 ft^2 of window area, equivalent to 10.4% of the floor area. The door area was assumed to be 40 ft^2, which equates to approximately two exterior doors.

4.3 HVAC SPECIFICATIONS

The analysis focused only on the building envelope; therefore, HVAC efficiencies were fixed. The heating and cooling equipment efficiencies were set at the minimum levels specified by the National Appliance Energy Conservation Act of 1987 (NAECA 1987) as shown in Table 4.6. The analysis included both heating and cooling.

The effect of heating and cooling equipment downsizing is included in our analysis automatically by the ARES software (DOE 1989a). Smaller heating or cooling loads reduce required equipment capacities, and the equipment cost declines accordingly. This equipment cost change is small.

TABLE 4.6. Equipment Efficiencies Used in Analyses

System	Efficiency
Electric Furnace	100%
Fossil Fuel Furnace	0.78 annual fuel utilization efficiency (AFUE)
Heat Pump(a)	6.8 heating season performance factor (HSPF) with 10.0 seasonal energy-efficiency ratio (SEER)
Air Conditioner(a)	10.0 SEER

(a) Both heat pumps and air conditioners are split systems.

(a) In a personal communication, Ron Nickson of the National Multi Housing Council and the National Apartment Association made a preliminary estimate that a window area equal to about 20% of the gross wall area was common in multifamily housing. We conservatively assumed that 25% of a multifamily building's wall area was windows.

4.3.1 Distribution Systems Efficiency

We used a single distribution efficiency factor in our analysis to represent the population of new, residential site-built houses in the United States. This value was determined by reviewing relevant work from recognized experts in the building science technical community and then contacting the respective authors and discussing their findings in light of our objective. These sources were in reasonable agreement, and an average value of 75% efficiency (i.e., 25% loss) was used for the single-family prototype. The technical justification for this factor are presented below.

Residential HVAC distribution efficiencies are represented in ARES as an adjustment used to modify the efficiency of the heating and cooling equipment. The adjustment, represented by Equation (4.1), is a fraction of 1.0, with 1.0 representing a perfectly efficient distribution system.

$$\text{Adjusted HVAC Effic.} = \text{Equipment Effic.} \times \text{Distribution Effic.} \tag{4.1}$$

Recent research and field measurements have shown duct losses to be a major inefficiency. In the past 10 years, many field studies, including blower door measurements of the effective leakage area, have been done to quantify duct characteristics. These measurements, coupled with dynamic simulations of the structure and HVAC systems, allow for improved assessment of energy losses associated with duct characteristics.

The results collected were from different sources and varied in degree of detail. All of the results provided some type of efficiency factor by duct location, and some had factors for heating or cooling conditions. To integrate these results, data that indicate the likely location of the ducting in new single-family housing constructed in 1983 were obtained from a Lawrence Berkeley Laboratory (LBL) report (Andrews and Modera 1991). Based on their data, we assumed that, for new single-family housing, 78% of all ducting is located in unconditioned spaces (attics or crawlspaces), 16% is located in partially conditioned spaces (basements), and 6% is located in conditioned spaces (usually between first and second floors). These assumptions were used to weight the efficiency factors for distribution system locations within residences.

Dr. Merle McBride (a key member of the ASHRAE 90.2 Committee on "Energy Efficient Design of New Low-Rise Residential Buildings") was contacted to discuss the distribution factors shown on pages 131 and 132 of the proposed Standard 90.2P (ASHRAE 1990). Based on his integration of previous work and his knowledge relating to distribution system efficiency, he recommended distribution factors for the three basic duct locations. Dr. McBride identified the primary sources of the three factors as ASHRAE Special Project 43 (SP 43) (ASHRAE 1988), California Energy Commission (May 19, 1987), results from the Owens-Corning Fiberglas Test Homes research program, and his doctoral thesis at Ohio State University.

A second source of distribution loss factors was the Northwest Power Planning Council (NWPPC), which compiled a set of calculated efficiencies determined from energy consumption records for residences with zonal electric heat (i.e., residences without ducts) and residences with central forced-air electric furnace systems (NWPPC 1987). The NWPPC results are simply the ratio of normalized (by floor area) yearly energy consumption for residences using zonal (baseboard) systems and residences using ducted systems. This ratio of space heating energy use gives a direct indication of the distribution system efficiency when compared to the case of zonal heating in which all energy goes to heating the air in the conditioned space.

Dr. Mark Modera of LBL provided us with efficiency factors that were based on simulation and field measurement work at LBL (Modera and Jansky 1992). Duct characteristics are based on blower door testing in 250 California residences. Duct leakiness was represented in the models at 15% of envelope leakage area. Field measurements do not indicate that ducts are being installed tighter in new houses, although overall leakage levels (including nonduct envelope leakage) for the entire building have been reduced in new construction. The leakage factor for basements incorporates results from ASHRAE SP 43 (ASHRAE 1988). These results are based mainly on typical California climate data and residence characteristics. These numbers were presented as numbers acceptable for representing ducts in typical U.S.

residences. An efficiency number was not available for ducts located completely in the conditioned space. For this calculation, we assumed a conservative number of 1.0.

A final source, John Andrews of Brookhaven National Laboratory, indicated to PNL that existing duct systems average between 60% and 70% efficiency (Andrews 1992). This includes systems with uninsulated ducts. His conclusions are based on an extensive literature search and his joint work with LBL. This factor was not used in our average distribution efficiency calculation because it was too general, but it does tend to substantiate other sources.

Table 4.7 shows the single-family distribution factors for three duct locations and the three principal sources. The weighted factor results from use of the duct-location percentages given earlier. The final average of the weighted factors, resulting from the three primary sources, is 0.75. The three sources show reasonable agreement. (The lower numbers from Modera may result from accounting for envelope interactions in his simulation work.) This factor (0.75) was assumed for the single-family analyses.

Very little data were available for multifamily duct losses. Because multifamily structures often have two- or three-story buildings with ducting between floors, we believe the efficiency of multifamily duct is higher than the efficiency of single-family ducts. We estimated the multifamily duct efficiency factor to be 0.875, or half of the single-family duct losses.

TABLE 4.7. Distribution Efficiency Factors

	Location of Ducting			
Source	Unconditioned	Partially Conditioned	Conditioned	Weighted Average
McBride	0.80	0.75	1.00	0.80
NWPPC	0.76	0.66	0.97	0.76
Modera	0.65	0.80	1.00	0.70
Average	**0.73**	**0.74**	**0.99**	**0.75**

4.4 1993 MEC COMPLIANCE ANALYSIS

The comparison of the costs and benefits of the 1993 MEC requirements with the proposed revision (Section 5.5) required that we translate the 1993 MEC requirements into specific ECMs that we could cost. The sets of envelope ECMs complying with the 1993 MEC with the minimum first-cost were identified for each of the 881 cities for use in the impact analysis discussed in Section 5.5. The MEC specifies maximum allowable U_0-values for the wall area, roof/ceiling area, and floors as a function of heating degree-days. Ceiling, wall, and floor measures that most closely meet the 1993 MEC were determined.

The MEC allows tradeoffs between windows and opaque walls, with the requirement that overall wall U_0-values are not exceeded. This analysis used these tradeoffs to minimize construction costs according to our cost data; the wall-window combinations that comply with the U_0-value requirements at the lowest first cost (according to our cost data) were used. The determination of complying measures for roofs/ceilings and floors was more straightforward because there are no tradeoffs to consider within each of these components. We did not perform an optimization analysis of possible tradeoffs across building components (as is allowed by the MEC) to define the overall lowest first-cost measures.

4.5 ENERGY CONSERVATION MEASURE LIFETIMES

The life-cycle cost analysis includes the cost of replacing ECMs in the year in which they are projected to fail. Insulation and window lives are based on a Minnesota Department of Energy and Economic Development (MDEED) report (1984). The value used for insulation is **50 years** (i.e., the building life) and the value for windows is **30 years**. Equipment lives are not needed for this analysis because the equipment types and efficiencies are held constant in all cases.

5.0 PROPOSED MEC CHANGES

This section discusses the creation of the optimum ECM configurations for each city, fuel/equipment type, and prototype; and the aggregation of the results into the proposed MEC revisions. The proposed MEC revisions were determined by aggregating the separate optimal envelope ECMs for each city, fuel/equipment type, and prototype (single- and multifamily) produced by ARES into the MEC format of U_0-value curves as a function of heating degree-days (HDD). This allows a direct comparison of the proposed MEC changes to the 1993 MEC. The sensitivity of the U_0-value optimization to several key assumptions is examined. At the end of this section, we give an estimation of costs and benefits (energy savings) of the proposed MEC changes and a brief discussion on affordability.

5.1 INDIVIDUAL LOCAL OPTIMUMS

Having defined the inputs to the optimization (Sections 3 and 4), the next step was to use ARES to optimize ECMs for all the cities. For each city, six combinations of HVAC equipment and fuel were optimized:

- natural gas with a forced-air furnace
- LPG with a forced-air furnace
- oil with a forced-air furnace
- electric resistance with a forced-air furnace
- electric heat pump with forced-air distribution
- electric baseboard.

All cases assumed electric air conditioning(a). The two home prototypes (single- and multifamily) were optimized separately. The combinations of equipment/fuel types (6) and prototypes (2) resulted in 12 optimizations for each city. Two foundation types (crawlspaces and unheated basements) were optimized separately and averaged together. Ceilings with and without attics were optimized separately.

(a) DOC (1992a) reported that, in 1991, 75% of all new single-family houses had central air conditioning. In the south census zone, where cooling loads are large, 94% had central air conditioning. The assumption of air conditioning in climates where very little cooling is required has almost no effect on the optimization of envelope ECMs.

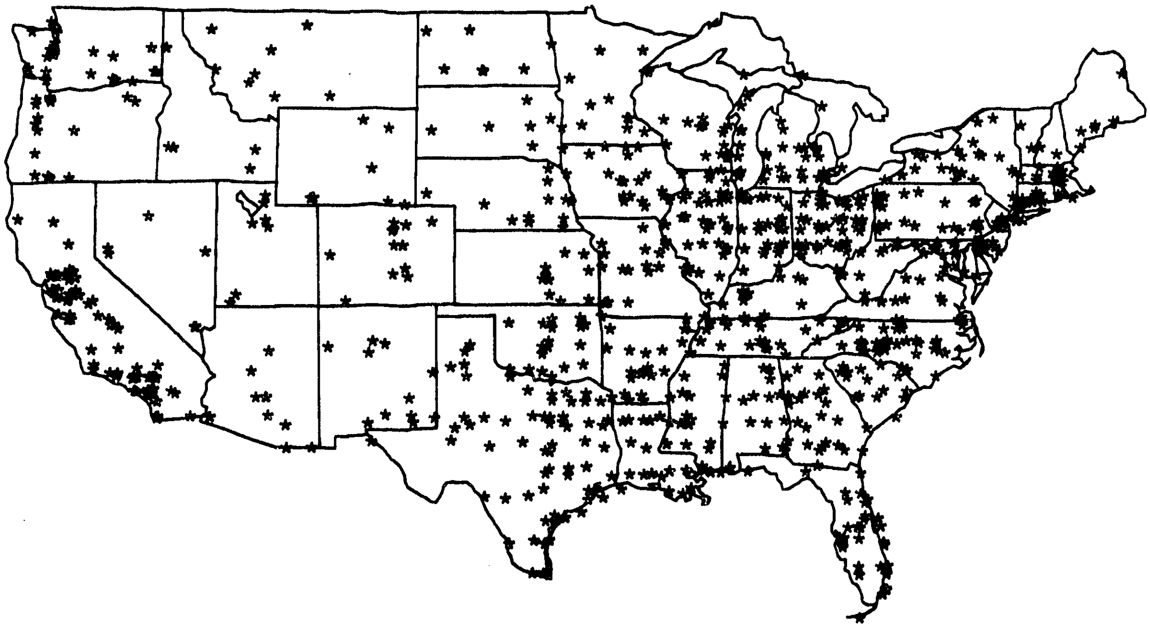

FIGURE 5.1. Approximate Locations of the 881 Cities Used in the Optimization

Rather than selecting a few cities to represent the United States, all 881 cities available in ARES were used. The cities for which optimizations were performed are shown in Figure 5.1 (this figure does not show Alaska or Hawaii), and listed in Appendix C. Selection of all 881 cities included in ARES provides a high density of locations across the United States, alleviating any bias that might have resulted from selecting a small number of cities to represent the entire country. The selection of 881 cities, 6 equipment/fuel types, and 2 prototypes resulted in the output of 10,572 cases with specific optimal U_o-values for each envelope component.[a]

5.2 AGGREGATION ACROSS FUEL TYPES

Consideration was given to whether the proposed standard should apply to all fuel types or if a separate standard should be generated for different

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[a] To facilitate the production of the large number of optimum U-values, software was created to run ARES in a "batch" mode, rather than the interactive mode in which it is usually run.

fuel types. The retention of separate U_0-value requirements for each major fuel/equipment type (natural gas, oil, LPG, electric resistance, and electric heat pump) could be recommended based on the differences in fuel prices. This could result in three standards just for fossil fuel. Oil is significantly more expensive than natural gas; LPG is even more expensive. However, a standard with requirements for several different types of fuels would be overly complex. Therefore, it is clear that some combination of the U_0-value requirements across fuels is required. Two approaches are generally used in developing standards: 1) separate electric and fossil fuel requirements (with electric heat pumps probably included with the fossil fuel requirements); or 2) a combined requirement that applies to all equipment types.

The primary argument for separate fossil fuel and electric resistance U_0-values is the accuracy with which the cost-effective level can be defined. The separate requirements would have lower maximum U_0-values for the more expensive electric resistance heat and higher U_0-values for the less expensive fossil fuels.

Simplicity argues for a combined fuel approach. The current MEC is a combined-fuel code. Separate fossil fuel and electric requirements would require builders of homes which do not all have either electric resistance or fossil fuel heating equipment to build all homes to the tighter requirement or to build two types of homes, one of which could only have fossil-fuel furnaces. A single combined-fuel requirement would also be easier to enforce, because all homes in a region would have the same requirements. It should also be noted that HVAC equipment will often need to be replaced during the lifetime of the home. For this reason, there is some uncertainty in presuming the type of equipment that will be installed when the original equipment wears out.

A final argument for a combined standard results from the mix of types of equipment/fuels actually being installed in new homes. About 60% of new homes have natural gas heating (DOC 1992a), which means our proposed combined fuel standard is heavily weighted toward natural gas. The next most common equipment type is electric heat pump, representing about 23% of new homes. The optimum requirements for a heat pump are similar to those for natural gas.

Because the combined share of the natural gas and heat pump is 83%, the proposed standard is very close to the standard that would be developed for use with the cheapest fossil fuel (natural gas) and almost identical to a standard which would be developed for fossil fuels and heat pumps. The major difference between fuel specific requirements and the proposed requirements would come with the electric resistance standard. However, electric resistance heating is used in about 9% of new homes, so the standard would apply to only that fraction of new homes. Areas having high rates of electric resistance heating also have lower than average electricity costs, which tends to moderate the differences between electric resistance heating and fossil fuel.

Based primarily on 1) the simplicity of having a single maximum envelope component U-value in any particular region, 2) consistency with the current MEC standard, and 3) the fact that the proposed requirements are already heavily weighted to the predominant fuel types, the combined-fuel requirement format was selected.

For the single-family analysis, the results for each city were aggregated across heating fuel/equipment types using fuel/equipment type shares as reported by census region in Characteristics of New Housing 1991 (DOC 1992a). Heating fuel/equipment shares for multifamily housing were available only from Builder Magazine (NAHB 1991b) and these were used. The split between natural gas and LP gas and the split between electric furnace and electric baseboard for both single-family and multifamily were estimated using the American Housing Survey (DOC 1991a). A higher percentage of electric heat in single-family homes (50%) was assumed for the Pacific Northwest (Washington, Oregon, and Idaho) based on a conversation with Tom Eckman of the Northwest Power Planning Council. The multifamily heating fuel/equipment shares for the Pacific Northwest were also based on a conversation with Tom Eckman. Table 5.1 shows the shares by census region for single-family, and Table 5.2 shows the shares for multifamily housing. Note that the percentages can sum to less than 100 because other heating fuel types, such as wood, are not included. These shares were used only for weighting the results.

TABLE 5.1. Single-Family Heating Fuel/Equipment Types by Region (%)

	Oil	Natural Gas	LPG	Electric Furnace	Heat Pump	Baseboard
South	0	42	2	9	41	3
Northeast	32	48	2	2	9	5
Midwest	0	84	1	2	6	3
West	0	69	1	4	12	5
Northwest	0	49	1	18	12	20

TABLE 5.2. Multifamily Heating Fuel/Equipment Types by Region (%)

	Oil	Natural Gas	LPG	Electric Furnace	Heat Pump	Baseboard
South	1	16	0	14	63	5
Northeast	6	68	3	3	13	7
Midwest	0	75	1	4	13	7
West	0	49	1	9	29	12
Northwest	0	10	0	0	5	85

5.3 CREATION OF THE REVISED MEC U_0-VALUE REQUIREMENTS

The proposed MEC maximum U_0-value requirements by component are shown in Figures 5.2 through 5.6 for ceilings (both with attic and vaulted), walls in single-family and multifamily homes, and floors over unheated spaces, respectively. The axes of these figures (HDDs on the horizontal axis and U_0-value on the vertical axis) are the same as those used in the existing MEC. Each dot presents the optimum for a city (weighted by heating fuel types). (A small, artificial scatter has been added to the points on the plots to help separate the individual cities that tend to overlap.) For comparison, Figures 5.2 through 5.6 also show the existing 1993 MEC requirements. Figure 5.7 shows a contour plot of HDDs to help determine the HDDs for any given region of the contiguous United States.

In general, the optimum city U_0-values are significantly below those required by the 1993 MEC. Figure 5.2 shows that for almost all 881 cities,

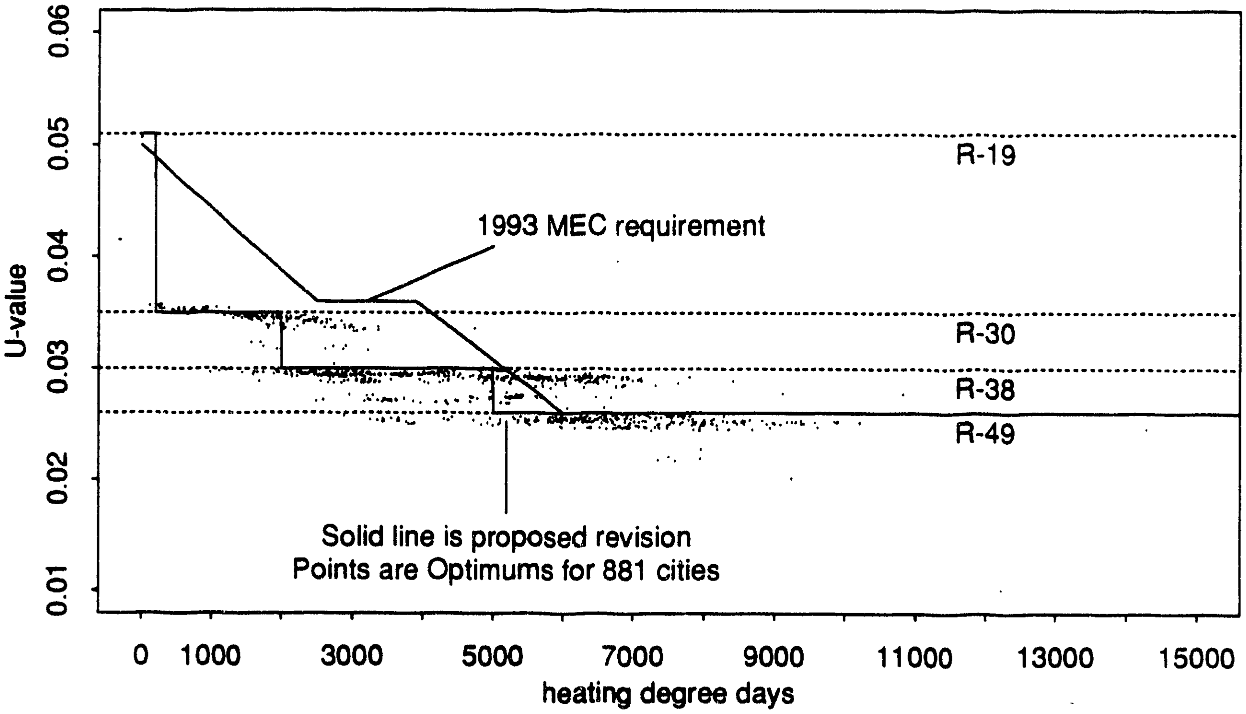

FIGURE 5.2. Proposed MEC U_0 Requirement for Roof/Ceilings with Attics

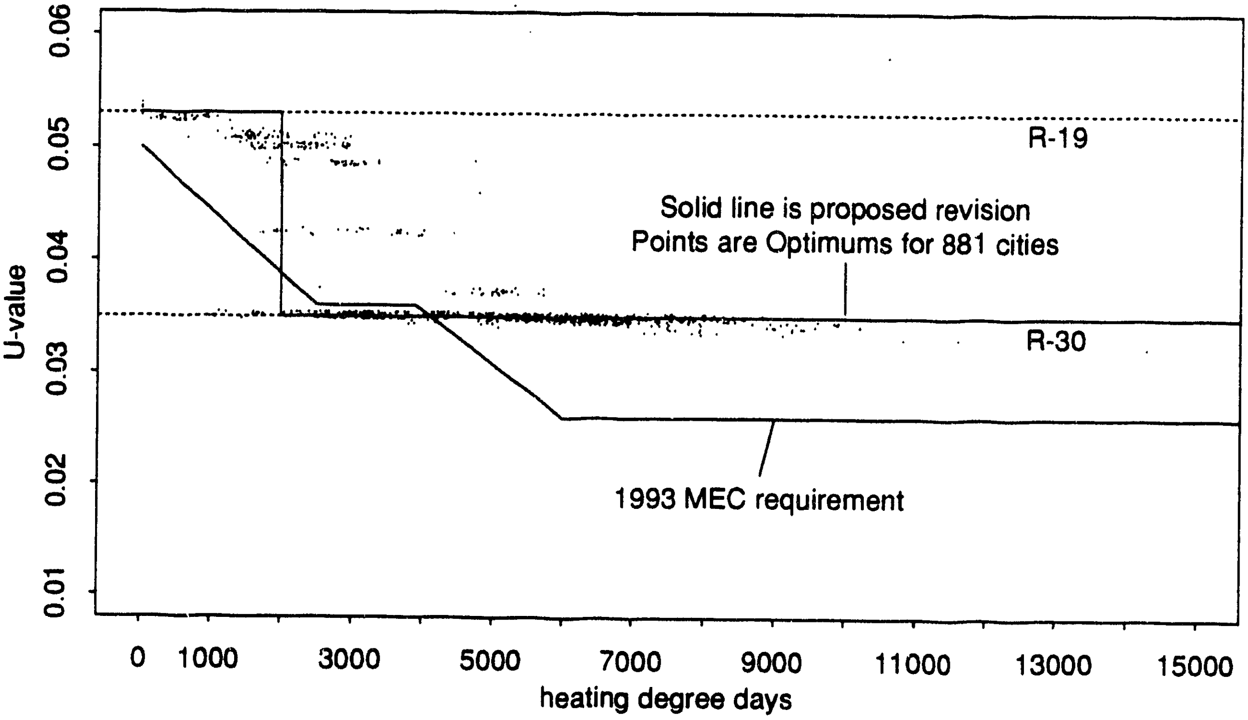

FIGURE 5.3. Proposed MEC U_0 Requirement for Roof/Ceilings without Attics

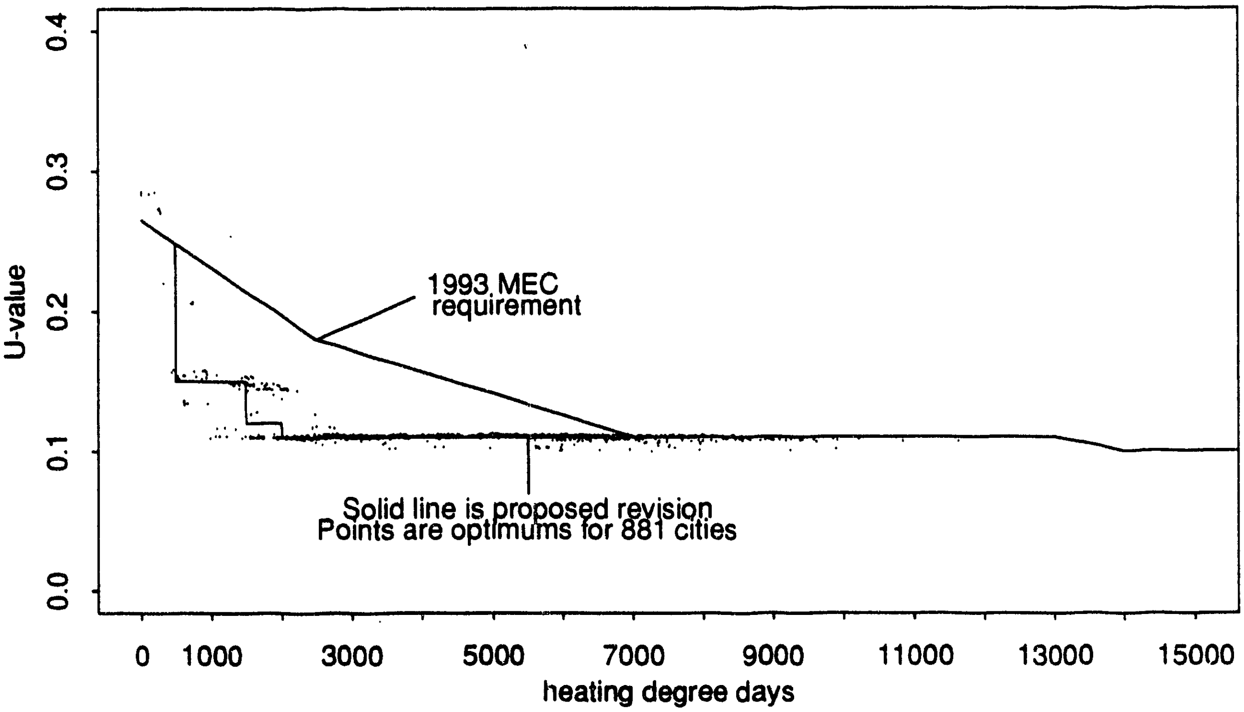

FIGURE 5.4. Proposed MEC U_0 Requirement for Single-Family Walls

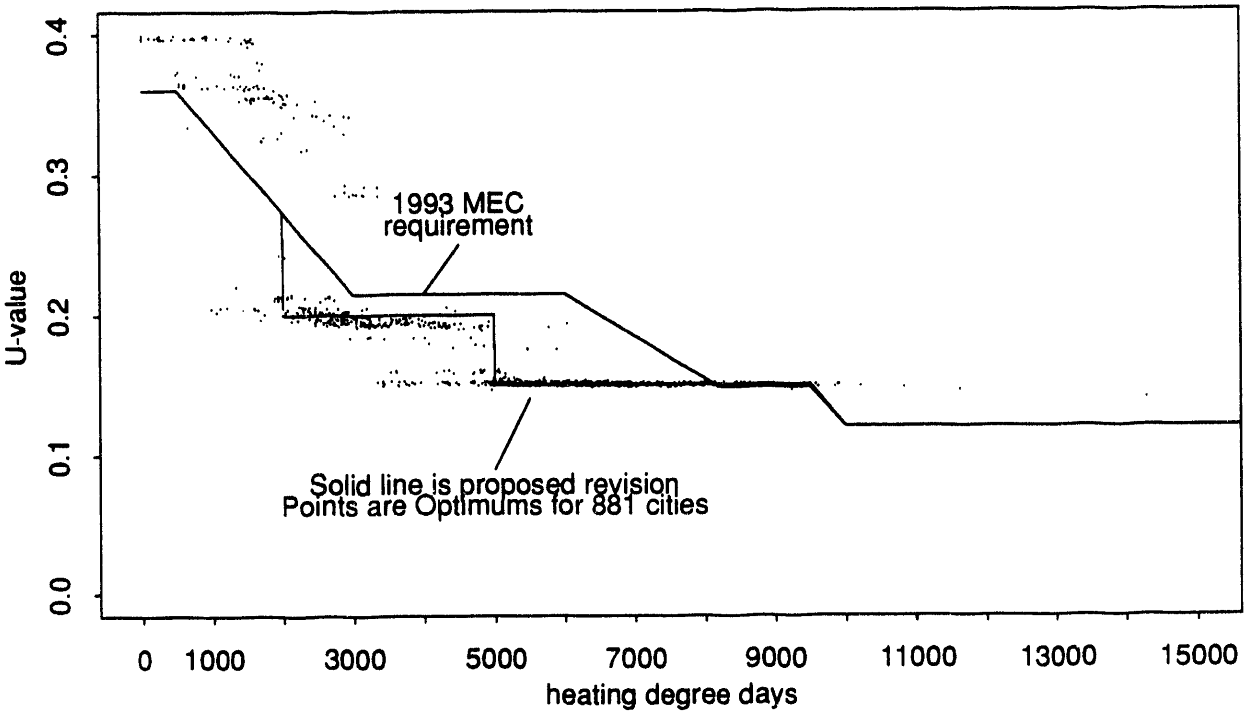

FIGURE 5.5. Proposed MEC U_0 Requirement for Multifamily Walls

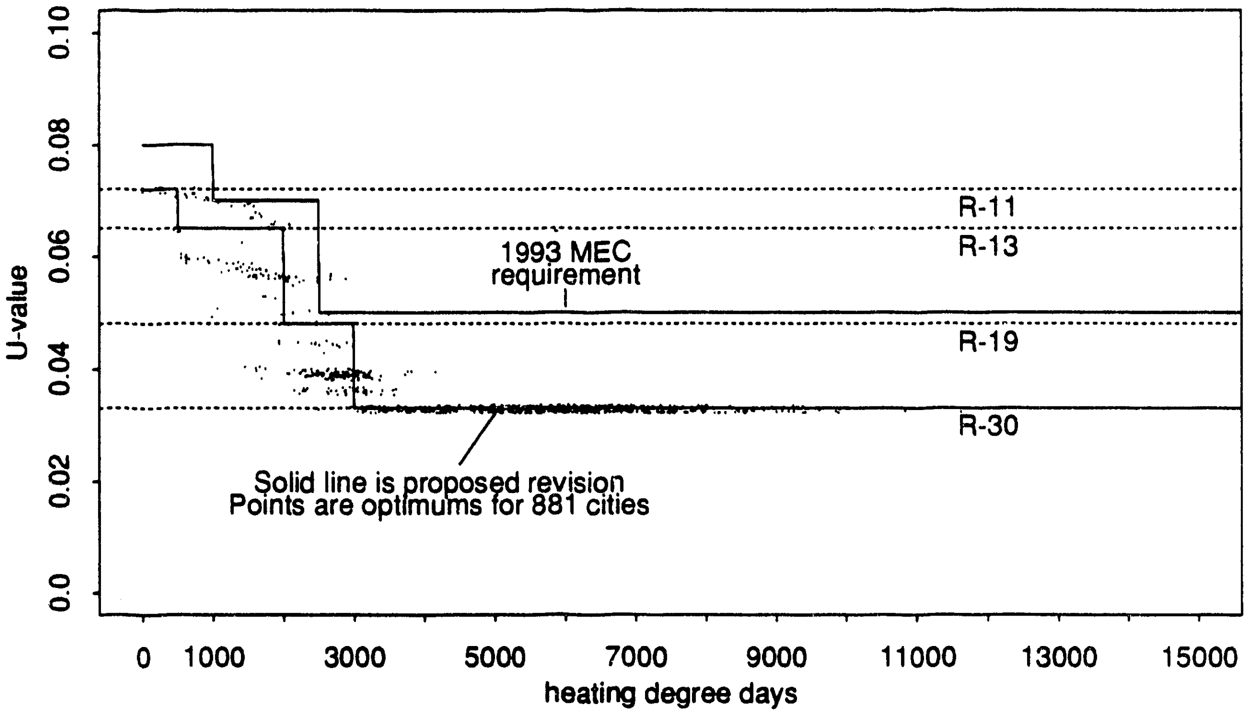

FIGURE 5.6. Proposed MEC U_0 Requirement for Floors over Unheated Spaces

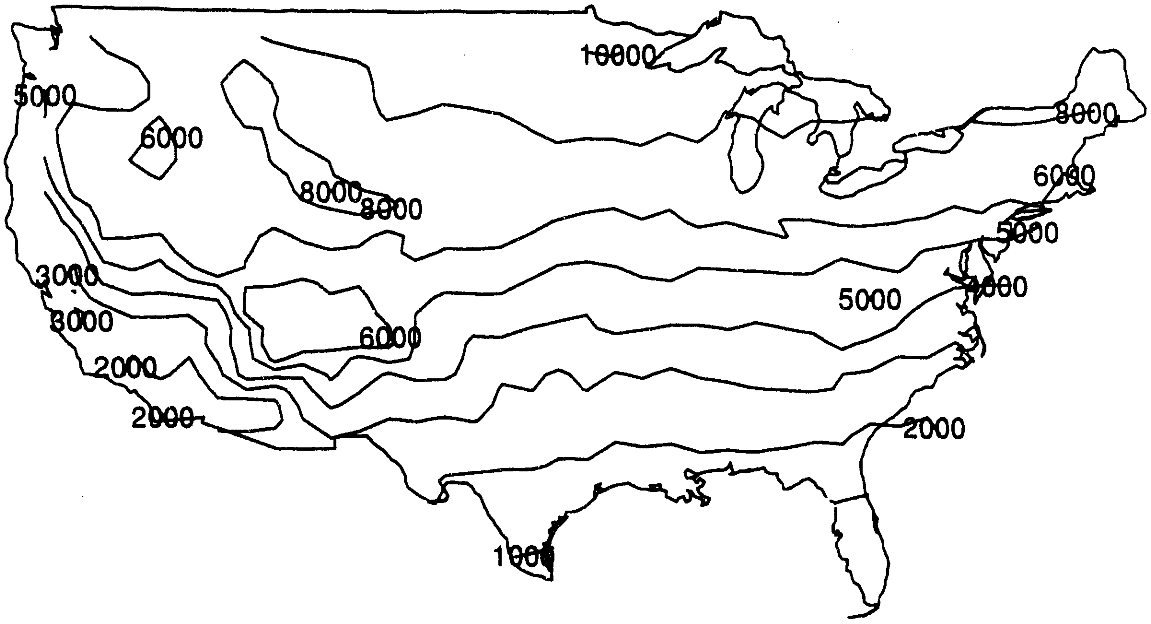

FIGURE 5.7. Heating Degree-Days (Base 65°F)

the optimum ceiling with attic U_o-value is below the 1993 MEC requirement. The vaulted ceiling requirements are generally not as stringent as the 1993 MEC requirements (Figure 5.3). We are proposing this separate, less stringent, set of requirements for vaulted ceilings, which result from the much higher cost of putting in high insulation levels for vaulted ceilings. Figure 5.4 shows the optimum single-family wall U_o-values are less than the 1993 MEC requirement, except in the very mild and the cold climates. In Figure 5.5, the optimum multifamily wall U_o-value is less than the MEC requirement except in mild climates. The MEC U_o-value requirements were not adjusted to be above the 1993 MEC requirements at low HDDs because the optimums shown in Figure 5.5 are based on above average glazing area of 25% of the wall area (this large area allows architectural freedom for the more stringent requirements in colder climates). The optimum floor U_o-value (Figure 5.6) is less than the 1993 MEC requirement in nearly all cities.

The proposed revised MEC U_o-value requirements were created from the 881 city points. For ceilings and floors, the optimums in small ranges of HDD were averaged together and then set to the U_o-value of the nearest ECM (i.e., nominal insulation level). For walls, the proposed requirements are a series of lines centered through the optimum points except at low and high HDDs, where the wall U_o-values were not changed from the 1993 MEC.

The MEC envelope U_o-value curves present requirements as a function of heating degree-days, as shown in Figures 5.2 through 5.6. To help readers visualize how the proposed MEC envelope U_o-value changes may affect any given state, examples of insulation levels and window types that comply with the proposed revisions and the 1993 MEC are shown in Figures 5.8 through 5.17. Approximate levels complying with the proposed revisions are shown in the maps on the top of the pages; levels complying with the 1993 MEC are shown in the maps at the bottom of the pages. These figures show the proposed requirements and the 1993 MEC requirements by geographical region.

For regions where U_o-value requirements are not constant over ranges of heating degree-days, the ECMs are shown by dotted lines and represent the location at which one of our ECMs would exactly meet the code. Intermediate levels vary. This is the case for 1993 MEC wall and ceiling requirements.

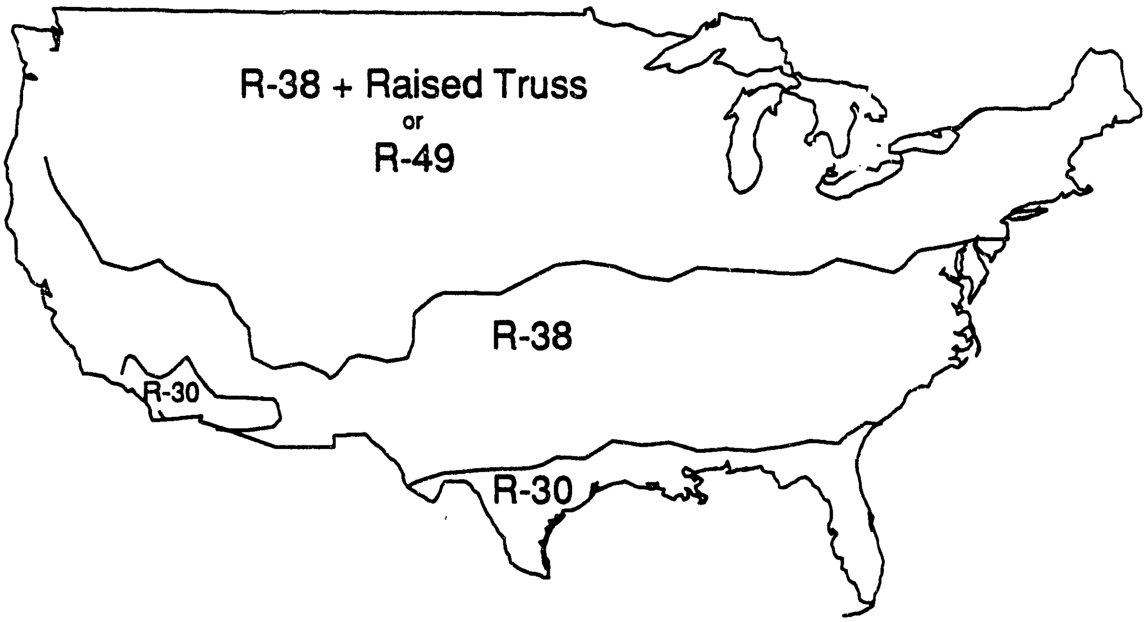

FIGURE 5.8. Ceiling-with-Attic Insulation R-value by Region Complying with the Proposed MEC Change

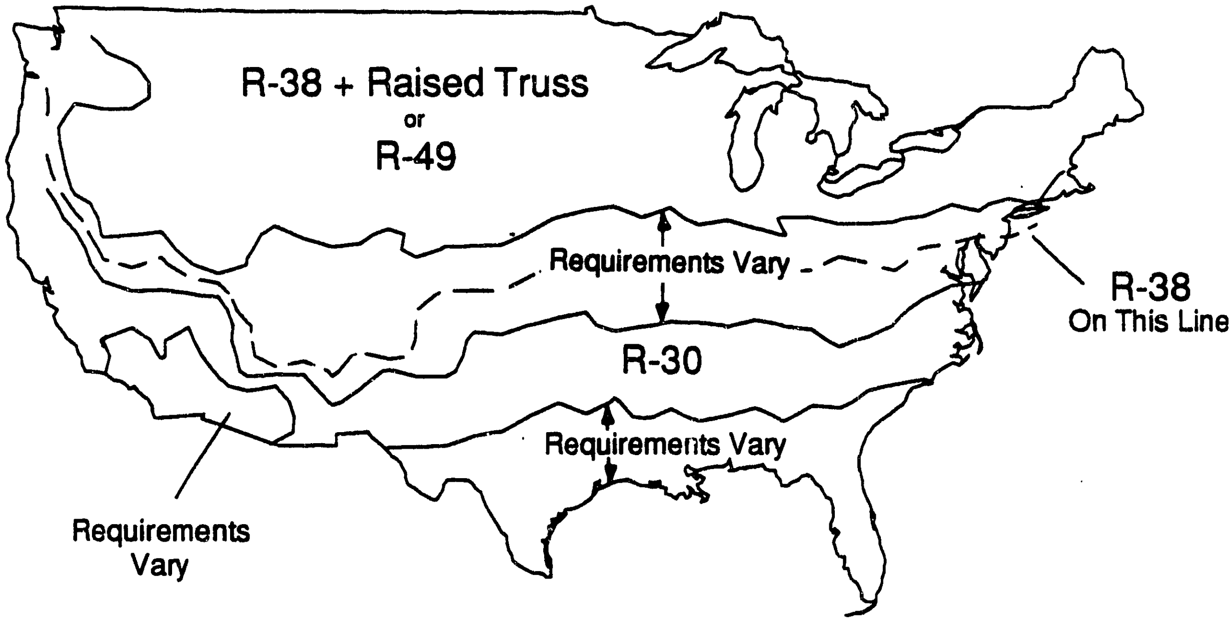

FIGURE 5.9. Ceiling-with-Attic Insulation R-value by Region Complying with the 1993 MEC

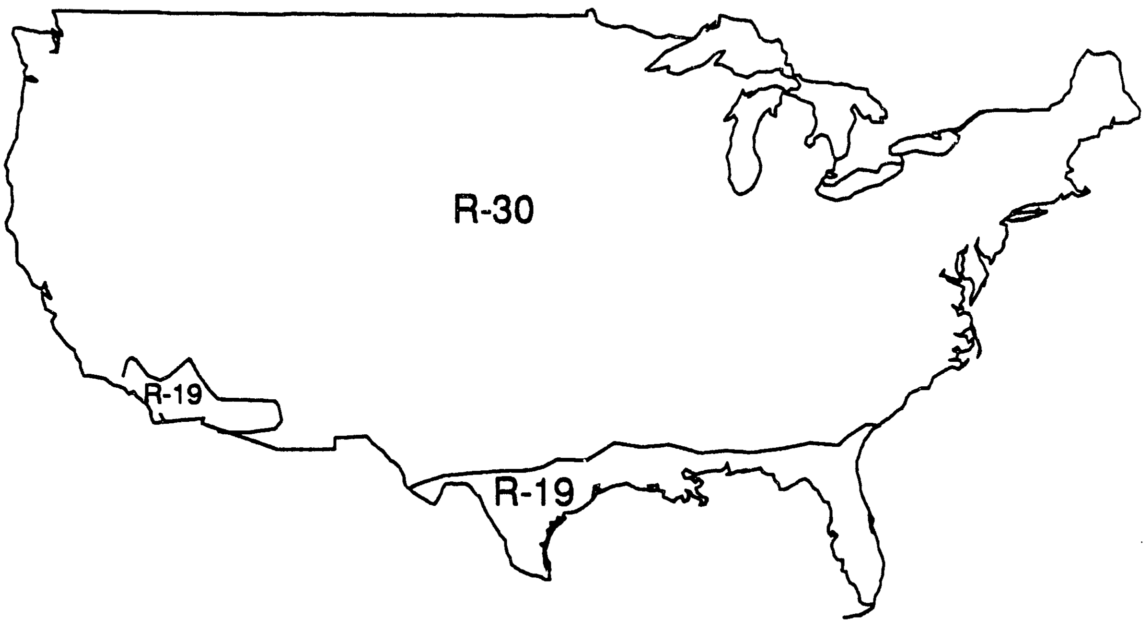

FIGURE 5.10. Ceiling without Attics Insulation R-value by Region Complying with the Proposed MEC Change

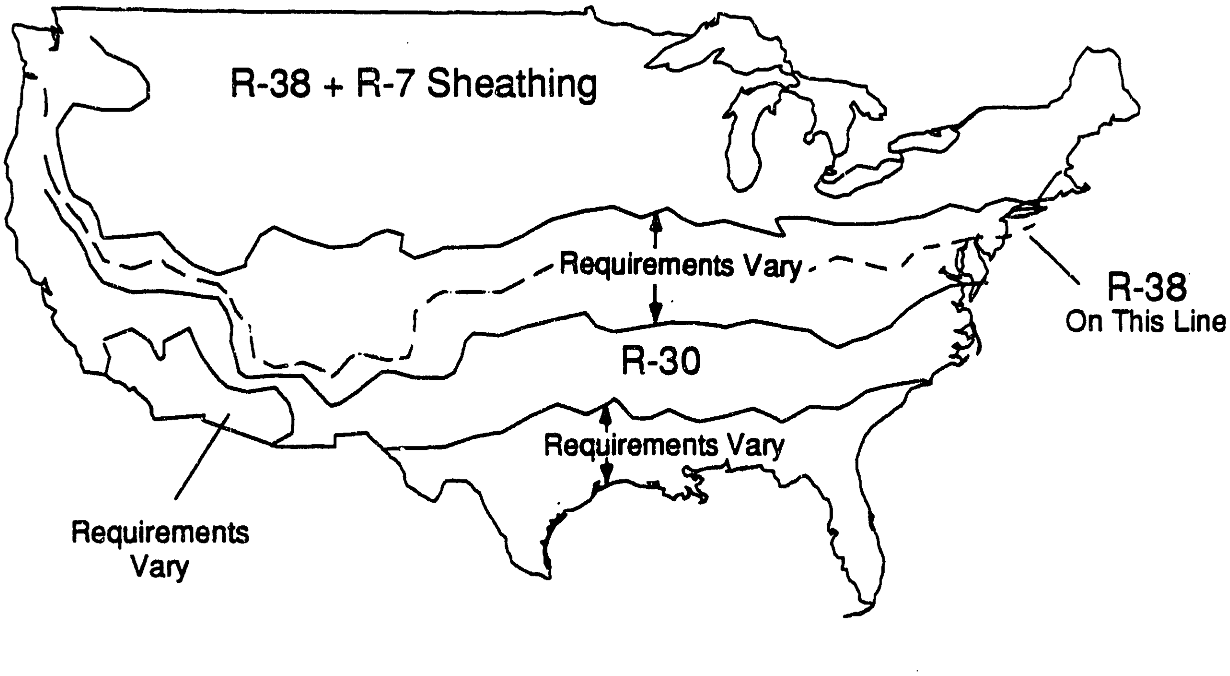

FIGURE 5.11. Ceilings without Attics Insulation R-value by Region Complying with the 1993 MEC

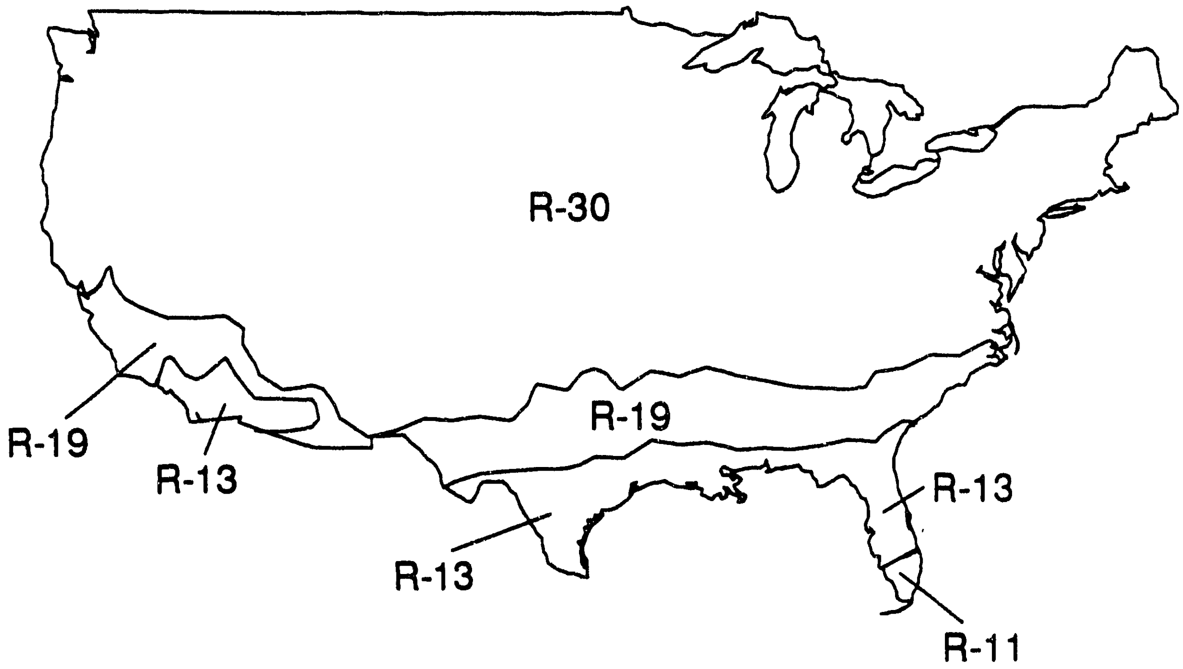

FIGURE 5.12. Floor over Unheated Spaces Insulation R-value by Region Complying with the Proposed MEC Change

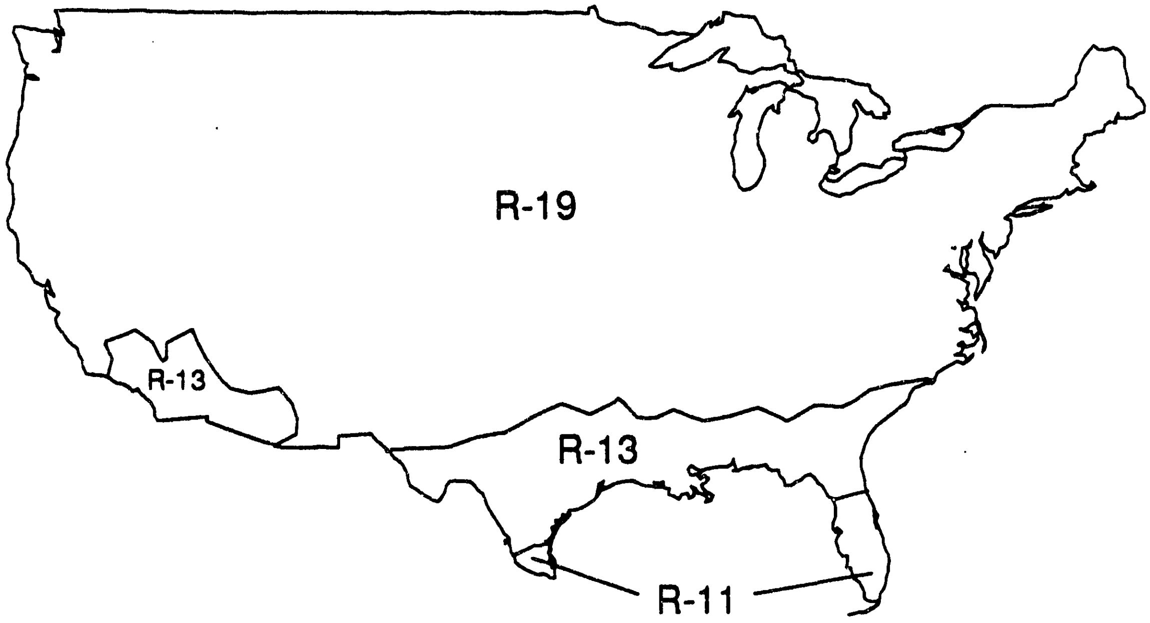

FIGURE 5.13. Floor over Unheated Spaces Insulation R-value by Region Complying with the 1993 MEC

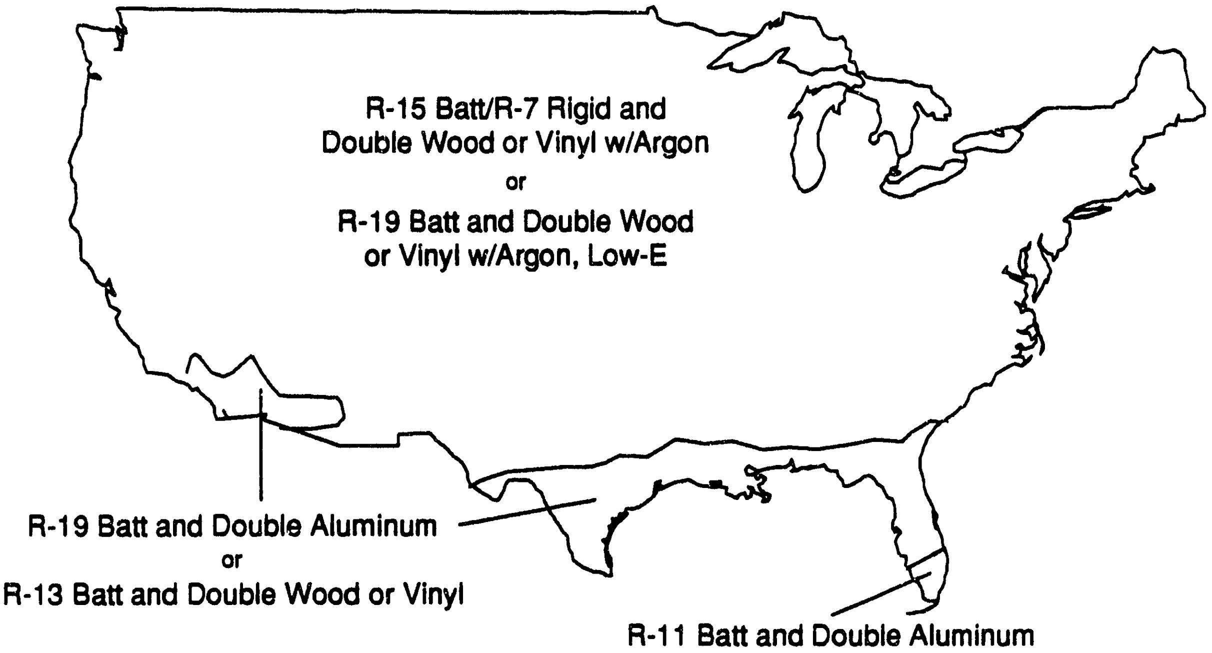

FIGURE 5.14. Possible Single-Family Wall Insulation R-values and Window Types by Region Complying with the Proposed MEC Change (assuming an above average window area equal to 15% of floor area)

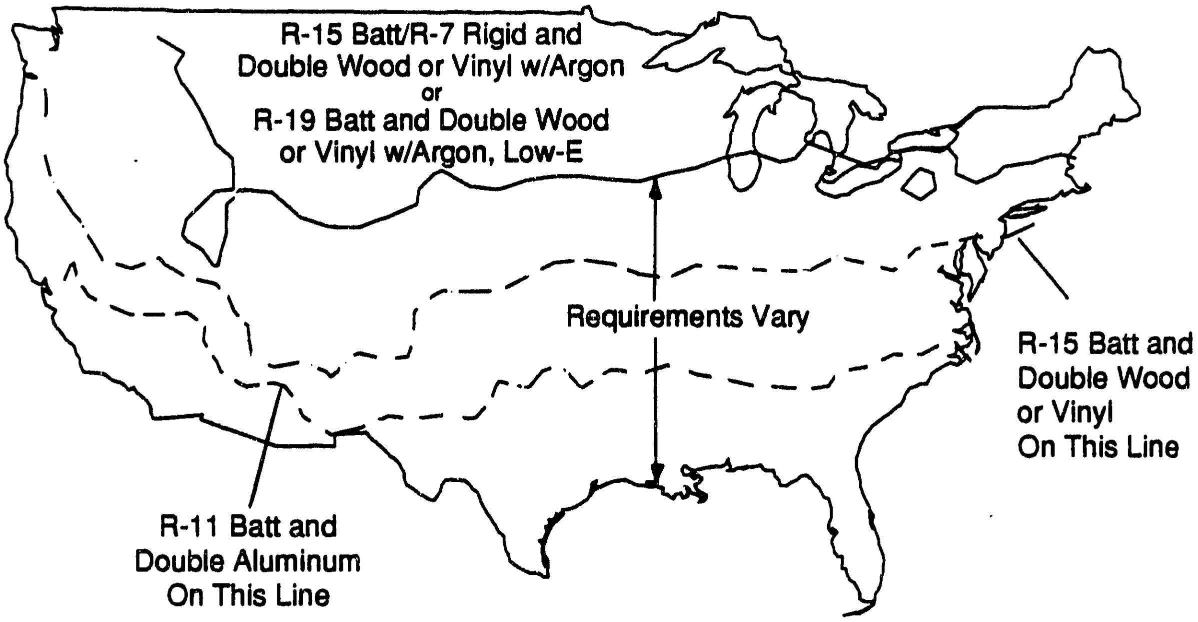

FIGURE 5.15. Possible Single-Family Wall Insulation R-values and Window Types by Region Complying with the 1993 MEC (assuming an above average window area equal to 15% of the floor area)

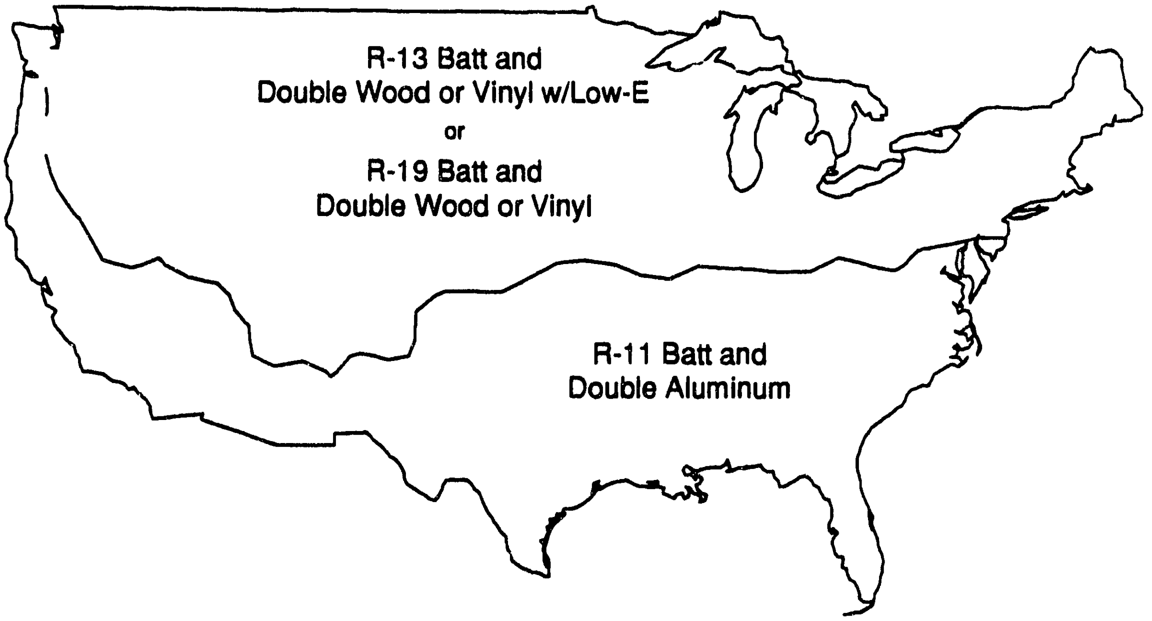

FIGURE 5.16. Possible Multifamily Wall Insulation R-values and Window Types by Region Complying with the Proposed MEC Change (assuming a window area equal to 20% of wall area)

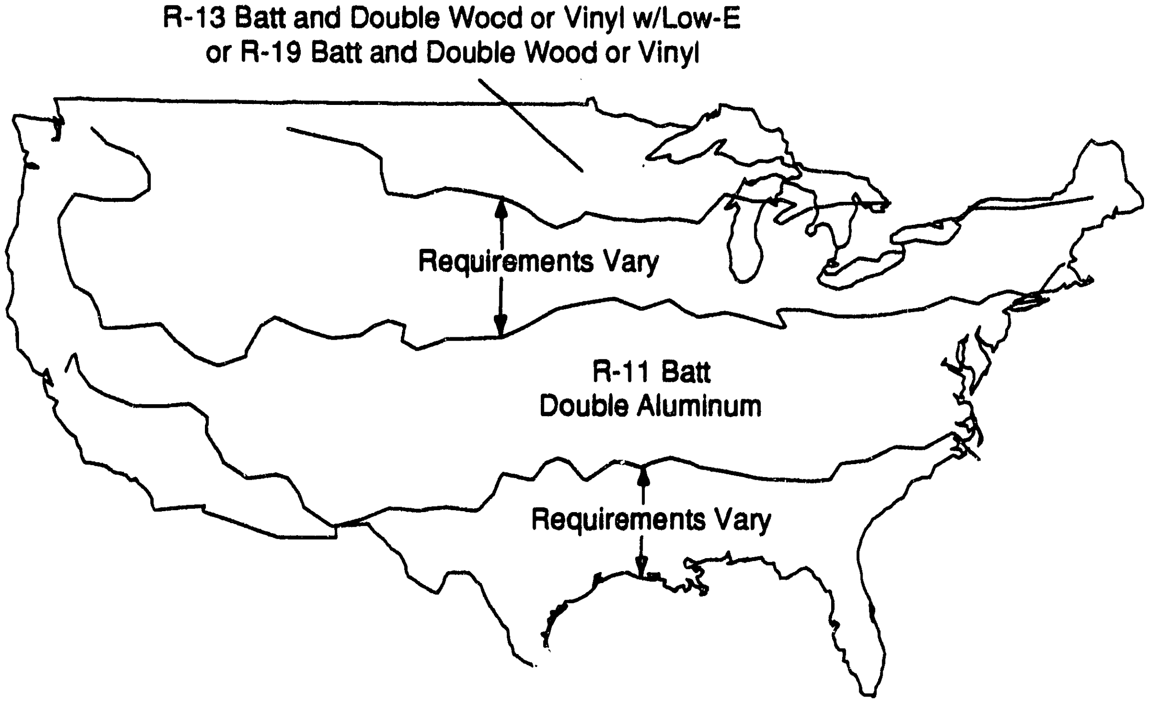

FIGURE 5.17. Possible Multifamily Wall Insulation R-values and Window Types by Region Complying with the 1993 MEC (assuming a window area equal to 20% of the wall area)

Because the construction details of envelope components may vary, buildings actually built with the insulation R-values and window types shown in this section either may fail to comply with or may exceed the actual U_0-value requirements in many cases. For example, use of a single-family window area greater than 15% of the floor area (the value assumed in Figures 5.14 and 5.15) will often require more wall insulation and/or lower window U-values. The glazing of most single-family residences is less than 15% of the floor area. Note that the complying ECMs for multifamily wall (Figures 5.16 and 5.17) are based on a window area that is 20% of the wall area, which is our estimated average window area for multifamily residences.

Table 5.3 shows examples of wall and window measures complying for a single-family wall U_0 requirement of 0.11 (most of the U.S. for the proposed changes) as the window area varies from 12% to 20% of the floor area of the prototype described in Section 4.2. Similar changes in complying wall and window measures occur with changing window areas in multifamily buildings.

5.4 SENSITIVITY OF OPTIMUM U_0-VALUES TO ASSUMPTIONS

The sensitivity of the overall building U_0-values to several of the parameters defined in Sections 3 and 4 was examined with a sensitivity analysis. The overall U_0-value was used to illustrate the change in the average thermal efficiency of the building envelope. A sensitivity analysis varies key input parameters and assesses the impact of each. Each parameter was varied separately to determine that parameter's effect on the final U_0-value optimum.

The sensitivity analysis was done with ARES using the single-family prototype for each of the 6 fuel/equipment types in each of 10 representative cities.(a) The average U_0-value for each variation was computed as the

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(a) The cities used in the sensitivity analysis were Key West, Florida; Brownsville, Texas; San Diego, California; San Francisco, California; New Orleans, Louisiana; Nashville, Tennessee; Oklahoma City, Oklahoma; Seattle, Washington; Buffalo, New York; and Duluth, Minnesota. These cities were selected based on a hierarchical clustering technique to represent the variations in U.S. climate. Clustering was done on six parameters: heating degree-days, cooling degree-days (CDDs) and state

TABLE 5.3. Examples of Single-Family Window and Wall Requirements as a Function of Window Area for the Northern U.S.

	Complying Combinations of Wall Insulation Levels and Window Types for Wall U_0 Requirement of 0.11[a]		
Window area as a % of floor area	Wall Framing	Complying Batt and Rigid Insulation	Complying Window U_0-values[b]
12	2x4	R-13	0.34
	2x4	R-11 + R-7	0.46
	2x6	R-19	0.46
14	2x4	R-13	0.30
	2x4	R-11 + R-7	0.40
	2x6	R-19	0.40
16	2x4	R-15 + R-7	0.40
	2x6	R-19 + R-4	0.38
18	2x4	R-15 + R-7	0.36
	2x6	R-21 + R-7	0.40
20	2x4	R-15 + R-7	0.32
	2x6	R-21 + R-7	0.36
	2x6	R-21	0.32

(a) This is the most stringent proposed U_0-value (excluding Alaska).
(b) See Table 4.5 for window types and typical window U-values.

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fuel prices for oil, gas, LPG, and electricity. HDDs and CDDs were weighted 25% each, and each fuel price was weighted 12.5%. Ten clusters were formed containing all 881 cities, and representative cities were selected from each cluster.

unweighted average of each of the 60 cases. The first column in Table 5.4 identifies the parameter tested. The next two columns show the two values for which a change was determined. The fourth column gives the change in the average U_0-value going from the low value to the high value, with the change expressed as a percentage of the average U_0-value for the value selected in the analysis (column five of this table). A positive U_0-value change represents an increase in the allowed U_0-value of the building. The significance of the parameter selections can be seen from Table 5.4. The **down payment** and **loan term** have small effects on the ultimate U_0-values because the discount rate is close to the mortgage rate and, therefore, the owner is relatively indifferent to when the cost is incurred. The **discount rate**, which is a measure of the value placed on future cash flows, has a major effect on the U_0-value optimum. The choice of **mortgage interest** rate also has a significant effect on the optimum U_0-value. A change in the **ECM costs** can make an important difference in the optimum U_0-values. Moving from a 1% to a 3% **property tax** would raise the optimum U_0-value by 8%. Note that the property tax differs from some of the other rates in that it is paid annually. The **income tax rate** can make a large difference in the optimum U_0-value as the deduction of the mortgage interest from income tax greatly benefits the homeowner.

TABLE 5.4. U_0-value Sensitivity to Selected Parameters

Parameter Varied	Range Low	Range High	U_0-value % Change	Parameter Value Selected
Down payment	0%	20%	+3%	10% (30% for multifamily)
Loan term	10	40	-6%	30 years
Discount rate (real)	2%	6%	+11%	4% (about 8% nominal)
Mortgage rate (nominal)	6%	12%	+14%	8.3% (10% for multifamily)
ECM costs	-20%	+20%	+12%	costs in Section 4
Property tax rate	1%	3%	+8%	1.36% average
Income tax (deduction)	0%	43%	-32%	31% average
Analysis period, years	7	50	-9%	30 years
Fuel price annual escalation rate	0%	5%	-16%	as shown in Table 3.1
Initial fuel prices	-20%	+20%	-13%	as shown in Appendix A

The **period of analysis** has a moderately large impact on the U_0-value. Increasing the period from 7 years to the 50-year building life would result in ECM optimums that reduce the U_0-value by 9%. Because fuel savings are the major benefit of any investment in conservation, changes in **fuel price escalation rates** or **initial fuel prices** have important impacts on the optimum U_0-value.

The sensitivity results reported in Table 5.4 can be used to estimate the impact of other levels or combinations of changes in parameters. Although the sensitivity is not linear with most of the parameters listed in Table 5.4, it can usually be assumed to be linear for purposes of estimating the impact of a small change.

5.5 LIFE-CYCLE COSTS, FIRST COSTS, MORTGAGE COSTS, AND ENERGY COSTS

This section compares the estimated costs and benefits from the consumer's perspective of the proposed revisions relative to the 1993 MEC requirements. Table 5.5 compares the proposed revisions of the 1993 MEC in terms of LCC, energy costs, nonenergy costs, first costs (assuming no mortgage), downpayment costs, and a simple benefit to cost ratio for the single-family and multifamily prototypes. The proposed code changes will increase construction costs and decrease energy costs by saving energy. The net present value of nonenergy costs from the consumer's perspective includes the down payment, mortgage costs, and taxes. Note that the energy cost savings less the first cost increase is lower than the LCC savings primarily because of the tax benefits of the mortgage and the discounting of future costs. The various cost impacts for the multifamily prototype are much lower than the corresponding impacts for the single-family prototype primarily because of the much smaller envelope area of the multifamily prototype. The proposed changes for all 881 cities are averaged to produce Table 5.5. The costs and benefits of the proposed revisions relative to the 1993 MEC will vary with location and climate.

TABLE 5.5. National Average Estimated Cost Impacts of Proposed Revisions

Economic Parameter	Cost Change Per Housing Unit	
	Single-family	Multifamily
Life-cycle cost savings	$1200	$300
Present value of energy cost savings	$2000	$550
Present value of nonenergy cost increase	$800	$250
First cost increase	$1100	$230
Down payment increase	$110	$69
Benefit to cost ratio	2.5	2.2

5.6 HOUSING AFFORDABILITY

Many organizations and individuals are concerned about housing affordability. The nature of this concern varies, although there are two general aspects of the affordability issue. The first emphasizes either low first cost for residences by keeping costs down so that buyers are able to qualify for loans to purchase homes; or adjusting existing lending practices so that decreased energy costs from energy-efficient homes are reflected in the purchasers' ability to qualify for a larger loan. The biggest concern is often with the first (new home) buyer and how the additional first cost for higher energy efficiency will eliminate some prospective buyers from qualifying for loans. There is also some concern that the first buyer will not receive a fair return on the energy-efficiency investment on resale.

The second aspect of the affordability issue emphasizes minimizing total costs, including purchase costs and operating costs. The objective is to minimize the sum of the costs of owning the home, including both energy costs and mortgage costs for energy-efficiency improvements. This longer-term focus captures the full benefits of energy efficiency over the home's lifetime. Nonmarket costs or impacts of energy consumption, such as environmental externalities, are sometimes included as costs.

It is our opinion that both concerns can and should be addressed. The methodology used here inherently minimizes total costs of owning and operating a home over most of its life. Some might suggest alternative assumptions--discount rates, feasible constructions, and so on--but the methodology remains the same. Some might also want to add market "externalities" by including social costs of fuel consumption not reflected in the market; for example, including the impact of increased fuel use on the environment, reflecting marginal costs of new power sources, reflecting the higher than average capacity charge associated with HVAC loads, and/or adding national balance of payments cost.

The concern that homeowners will be eliminated by higher first costs associated with higher levels of energy-efficiency must be addressed by reflecting the increased financial viability of the homeowner in the mortgage process. In cases where the cost of energy improvements themselves may disqualify buyers from home loans, lenders need to use a mortgage qualification criterion that takes into account the fact that the owner is actually financially stronger from a more energy-efficient home and therefore better able to pay the energy-efficient home mortgage than the non-energy-efficient home mortgage. Although energy-efficient mortgages have been around in some form for a long time, they are seldom used. Therefore, an effort should be made to introduce viable methods of reflecting the homeowner's stronger financial situation in energy-efficient lending criteria. We believe that the best way to address the effects of energy-efficiency improvements on the price of a home is to adjust the lending criteria rather than to reduce the purchase price by backing off the energy-efficiency levels.

A similar situation exists in the rental market. This is especially true when prices are fixed by governmental agencies, such that the building investor/owner/manager is not able to pass the additional cost of energy efficiency to the occupant (assuming the occupant gets the benefits of lower energy bills). Builders and owners of multifamily housing should be allowed to profit on the construction and management of energy-efficient housing.

The number of buyers impacted by the increased first cost can be estimated. The NAHB estimated that a home cost increase of $1,680 required an additional $570/year in buyer income (at 10% down) and disqualified 2.5% of the potential homebuyers (Consumers' Research 1991). This was scaled back to our estimated increase in first cost, $1100, producing an estimate that the energy-efficiency standards would require an additional $370 in family income and disqualify about 1.6% of the potential new homebuyers. This calculation assumes that no credit is given in the mortgage process for reduced homeowner expenses and that the homebuyer does not cut expenses elsewhere in the cost of the residence. In the aggregate, the 98.4% of the homebuyers who can afford the price increase should be better off.

It should be noted that no one is advocating minimizing the first cost of energy conservation features in homes to maximize the number of prospective homebuyers who qualify for loans. For energy-efficiency, minimum first costs would be achieved by leaving out insulation. Clearly, no insulation in the home would be accompanied by very high energy bills, which would swamp the savings in first costs.

The NAHB's definition of "affordable" energy-efficiency standards offers a goal for changing lending practices to eliminate the impact of increased energy-efficiency requirements on the ability to qualify for a mortgage. In its resolution, NAHB (1992b) defines increases in thermal performance standards to be affordable if "A buyer of a home who qualifies to purchase the home before the addition of the thermal performance standards would still qualify to purchase the same home after the additional cost of the energy-savings construction features ...".

Because the homeowner's total expenses are less under the proposed thermal standard, the homeowner has a stronger financial position. In the absence of a procedure that considers the benefit of the energy-efficiency in the mortgage qualification process, we acknowledge that some buyers may be forced to accept a slight downgrade or, at the extreme, may not be able to afford a new home. The number of buyers impacted should be small. Additionally, the lending industry is moving in the direction that will give credit to energy conservation investments. Further work is needed to make energy-efficiency mortgages a reality for those who might be disqualified from a loan based on the added cost of energy-efficiency.

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PNL-4870-16.	Part 3: Life-Cycle Cost Results.
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APPENDIX A

FUEL PRICES AND EQUIPMENT/FUEL TYPES BY STATE

APPENDIX A

FUEL PRICES AND EQUIPMENT/FUEL TYPES BY STATE

This appendix presents information on the residential fuel price used in the analysis.

TABLE A.1. 1992 Residential Fuel Prices by State[a]

State	Electricity, $/kWh	Nat Gas, $/therm	LPG, $/gal	Fuel Oil, $/gal
Alabama	0.066	0.63	0.86	0.84
Alaska	0.101	0.40	1.30	0.99
Arizona	0.090	0.66	1.07	0.95
Arkansas	0.080	0.50	0.84	0.96
California	0.099	0.56	0.97	0.71
Colorado	0.070	0.45	0.55	0.77
Connecticut	0.100	0.83	1.06	1.07
Delaware	0.084	0.60	1.05	0.95
Washington, D.C.	0.061	0.71	0.98	1.03
Florida	0.077	0.77	0.98	1.20
Georgia	0.074	0.66	0.79	0.84
Hawaii	0.102	1.53	1.40	0.96
Idaho	0.049	0.49	0.91	0.92
Illinois	0.099	0.49	0.61	0.92
Indiana	0.068	0.52	0.79	0.94
Iowa	0.078	0.49	0.56	0.72
Kansas	0.078	0.45	0.61	0.78
Kentucky	0.057	0.47	0.92	0.85

(a) The costs in Table A.1 are from the EIA's report of 1990 prices (EIA 1992b) and inflated to 1992 prices (price indices from June 1991 through May 1992 were used to obtain a full year average) using the rates in Table A.2 which are from the Monthly Energy Review (EIA 1992a). The seasonal variation in electrical prices is shown in Table A.3. Cost adjustments for natural gas and electricity were made to use marginal, not average, fuel prices. All fuel prices were increased by 4% to account for estimated point-of-use taxes. See Section 3.3 for more details.

TABLE A.1. (contd)

State	Electricity, $/kWh	Nat Gas, $/therm	LPG, $/gal	Fuel Oil, $/gal
Louisiana	0.074	0.58	0.89	0.81
Maine	0.093	0.75	1.12	0.94
Maryland	0.072	0.62	0.98	1.06
Massachusetts	0.096	0.75	1.04	1.03
Michigan	0.078	0.48	0.89	0.95
Minnesota	0.068	0.46	0.65	0.97
Mississippi	0.069	0.51	0.74	0.57
Missouri	0.073	0.51	0.75	0.91
Montana	0.054	0.44	0.78	0.80
Nebraska	0.062	0.46	0.61	0.84
Nevada	0.057	0.55	1.02	0.85
New Hampshire	0.103	0.73	0.93	0.93
New Jersey	0.103	0.64	1.10	1.05
New Mexico	0.089	0.53	0.72	0.81
New York	0.114	0.71	1.06	1.06
North Carolina	0.078	0.59	0.87	0.99
North Dakota	0.062	0.45	0.62	0.86
Ohio	0.080	0.51	0.94	0.93
Oklahoma	0.066	0.47	0.64	0.92
Oregon	0.047	0.61	1.08	0.87
Pennsylvania	0.092	0.63	1.01	0.98
Rhode Island	0.098	0.70	1.08	1.05
South Carolina	0.071	0.69	0.82	0.95
South Dakota	0.069	0.50	0.56	0.69
Tennessee	0.057	0.49	0.93	0.82
Texas	0.072	0.55	0.81	0.54
Utah	0.071	0.48	0.72	0.90
Vermont	0.093	0.58	1.07	1.00
Virginia	0.072	0.64	1.01	1.03
Washington	0.044	0.48	0.96	0.99
West Virginia	0.059	0.60	0.97	0.95
Wisconsin	0.066	0.57	0.78	0.89
Wyoming	0.060	0.44	0.83	0.79

Table A.2 shows the fuel price escalation rates used to update the 1990 fuel prices to more current 1992 prices. (Because 1992 was not yet over, early 1992 prices were supplemented by late 1991 prices to obtain an estimated 1992 escalation rate.) Table A.3 shows the seasonal electricity price adjustments to account for the higher price of electricity in the summer relative to the winter.

TABLE A.2. Nominal Fuel Escalation Rates, 1990 to 1992

Fuel	Escalation Rate (% over entire period)
Fuel oil and LPG	-13.3
Natural gas	6.2
Electricity	4.1

TABLE A.3. Seasonal Electricity Price Variation[(a)]

Census Region	Winter / Summer Adjustment
Northeast	0.94 / 1.06
North Central	0.94 / 1.06
South	0.90 / 1.10
West	1.00 / 1.00 (constant prices)

(a) These adjustments are multipliers to the annual electricity prices shown in Table A.1. The seasonal electricity variation in price by region was estimated from a Gas Research Institute report (1986, p. 11). Prices were taken from the residential, 1000 kWh/month category. The price variations for Washington, Oregon, Idaho, and Montana were verified from rates supplied by the Northwest Public Power Association, Portland, Oregon. The estimated variation for each region was the mean of the locations reported. The ratios, used as multipliers on the annual prices, were computed as the summer or winter price divided by the mean of the summer plus winter prices. No seasonal adjustment for other fuels was done.

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APPENDIX B

ENERGY CONSERVATION MEASURE U_o-VALUE CALCULATIONS

APPENDIX B

ENERGY CONSERVATION MEASURE U_0-VALUE CALCULATIONS

This appendix describes the assumptions and calculations used to determine thermal conductances (U_0-values) of ECMs for roof/ceilings, walls, windows, and floors over unheated spaces. The ECMs are discussed in Section 4. It is important to stress that the component U_0-values are the bottom line, and that construction materials and techniques may vary from those described below but still produce similar U_0-values.

B.1 ROOFS AND CEILINGS

Two types of ceilings/roofs were analyzed: ceilings and roofs separated by an attic space and ceiling/roofs without attics (vaulted or cathedral ceilings/roofs). Ceiling joists or rafters were assumed to be at 24-in on center (O.C.) occupying 7% of the ceiling area (ASHRAE 1989). For ceilings with attics, the calculation of the integrated effective insulation R-values accounts for the limited space for insulation at the eaves. For ceilings with attics, we included the option of raising trusses 12 in. for R-38 and R-49 insulation to allow increased space near the eaves for the thicker insulation level. The increased construction cost for the raised truss, including additional wall siding and sheathing, was accounted for.

Our analysis assumed installation of blown fiberglass insulation in ceilings with attics, although batt insulation in ceilings is also common. Blown insulation has less insulating value per inch than batt insulation (ASHRAE 1989), but is generally less expensive (see Section 4.1). Blown insulation was assumed to cover the ceiling joists such that "voids" were negligible. Batt insulation was assumed for vaulted ceilings, as vaulted ceilings typically have inadequate space for blown insulation.

ASHRAE recommends an attic ventilation rate of 0.5 cfm/ft^2 of ceiling area to control moisture (ASHRAE 1989). We assumed a fully vented attic, with a still air film resistance above the insulation and a 1-in. space between the insulation and the roof near the eaves for ventilation. For ceilings with attics, a prefabricated truss system was assumed, as these systems are most common in new residential construction (Anderson and McKeever 1991). For the truss members, 2x4 framing was assumed (DeCristoforo 1987); a roof slope of 4/12 was assumed. Table B.1 gives the heat flow paths, and Table B.2 shows the U_0-values for the ceiling with attic construction.

The vaulted ceiling was assumed to be fully vented, with a still air film resistance above the insulation. The vaulted ceiling rafters were modeled as 2x8, 2x10, and 2x12 studs 24-in. O.C. (as discussed in Section 4); however, the effective thickness of the rafters was set equal to the thickness

TABLE B.1. Heat Flow Paths for Roof/Ceilings with Attics

Description		(7%) R-Value at Joists		(93%) R-Value at Insulation
Attic air film		0.61		0.61
Insulation		Ri_j		Ri
Joists		4.38		--
1/2-in. drywall		0.45		0.45
Inside air film		0.61		0.61
U_0-value for Ceiling/Roof	=	$\frac{0.07}{6.05 + Ri_j}$	+	$\frac{0.93}{1.67 + Ri}$

TABLE B.2. ECM U_0-Values for Roof/Ceilings with Attics (refer to Table B.1 for calculation details)

Nominal R-Value	Average Insulation R-Value	Insulation R-Value Above Joists (Ri_j)	U_0-Value of Ceiling Including Framing
11	11	2.2	0.082
19	18.5	9.2	0.051
30	27.3	15.9	0.035
38	32.5	19.1	0.030
38 + raised truss	38.0	29.2	0.025
49	38.0	22.2	0.026
49 + raised truss	48.6	39.9	0.020

of the insulation. This was done because heat flows directly out the side of the wood beyond the depth of the insulation. Tables B.3 and B.4 show the heat flow paths and U_o-values, respectively, for vaulted ceilings.

B.2 WALLS

Wall materials for all ECMs consisted of plywood siding, fiberboard or foam insulation sheathing on the exterior, batt insulation and framing, and 1/2-in. or 5/8-in. gypboard. As discussed in Section 4.1.2, walls without fiberboard (i.e., walls with rigid foam insulation) were assumed to have corner braces for structural support. Walls with insulation R-values less than R-19 were modeled as having 2x4 studs at 16-in. O.C. Based on ASHRAE

TABLE B.3. Heat Flow Paths for Vaulted Roof/Ceilings

Description	(7%) R-Value at Joists	(93%) R-Value at Insulation
Ceiling air film	0.61	0.61
Insulation	--	Ri
Rafters	Rr	--
1/2-in. drywall	0.45	0.45
Inside air film	0.61	0.61
U_o-value for Ceiling/Roof =	$\frac{0.07}{1.67 + Rr}$	+ $\frac{0.93}{1.67 + Ri}$

TABLE B.4. ECM U-Values for Vaulted Roof/Ceiling (refer to Table B.3 for calculation details)

Batt Insulation R-Value	Rigid Insulation R-Value	Rafter R-Value	U-Value of Ceiling Including Framing
11	--	4.38	0.0850
19	--	7.50	0.0526
30	--	10.63	0.0351
30	7	10.63	0.0277
38	7	13.12	0.0231

assumptions, the 16-in. O.C. translates to a framing fraction of 15% of the opaque wall area (ASHRAE 1989).

Walls of R-19 or R-21 batt insulation were assumed to have 2x6 studs with an average of 50% at 16-in. O.C. and 50% at 24-in. O.C. One source indicated that 22% of 2x6 walls are built at 24-in. O.C. (Anderson and McKeever 1991). We assumed the 50/50 split for the stud O.C. distance because walls with studs at 24-in. O.C. are clearly feasible in most cases, yet builders still commonly use 16-in. O.C. construction. Walls with 24-in. O.C. studs were assumed to have a framing fraction of 12% of the opaque wall area (ASHRAE 1989) and 5/8-in. gypboard. Walls with R-19 have an effective insulation R-value of 17.8 because of compression of an assumed 6-in. batt into the 5.5-in. space of the stud cavity. Rigid sheathing insulation levels of R-4 and R-7 (in addition to the option of no rigid sheathing) were assumed. Wall construction heat flow paths and U_o-values are shown in Tables B.5 and B.6, respectively.

TABLE B.5. Wall Heat Flow Paths

Description		(12% or 15%) R-Value at Studs		(88% or 85%) R-Value at Insulation
Outside air film		0.17		0.17
Plywood siding		0.59		0.59
Sheathing		Rs		Rs
Wood studs		Rw		--
Insulation		--		Ri
1/2-in. or 5/8-in. gypboard		0.45, 0.56		0.45, 0.56
Inside air film		0.68		0.68
U_o-Value for 16-in. O.C. construction	=	$\frac{0.15}{1.89 + Rs + Rw}$	+	$\frac{0.85}{1.89 + Rs + Ri}$
U_o-Value for 24-in. O.C. construction	=	$\frac{0.12}{2.00 + Rs + Rw}$	+	$\frac{0.88}{2.00 + Rs + Ri}$

TABLE B.6. Wall ECM U_0-Values (refer to Table B.5 for calculation details)

Nominal Insulation R-Value	Batt R-Value (Ri)	Rigid Insulation (Rs)[a]	Stud R-Value (Rw)	U_0-Value of wall
11	11	1.32	4.38	0.0796
13	13	1.32	4.38	0.0722
11	11	4	4.38	0.0649
13	13	4	4.38	0.0596
11	11	7	4.38	0.0540
19	17.8	1.32	6.88	0.0544
13	13	7	4.38	0.0501
19	17.8	4	6.88	0.0470
15	15	7	4.38	0.0469
21	21	4	6.88	0.0426
19	17.8	7	6.88	0.0409
21	21	7	6.88	0.0374

(a) The R-value of 1.32 corresponds to 1/2-in. fiberboard.

B.3 WINDOWS

Window thermal transmittance values for the window types included in the analysis are shown in Table B.7, along with the number of tested windows on which the U-value is based. The selection of window types is discussed in Section 4.1.4. Each of the U-values for the window types (except single-pane and wood windows with argon) was the average of tested U-values (AMMA 1503.1 or ASTM C236/C976) for the window type as reported by the Washington State Energy Office (WSEO 1992). The single-pane U-value was not available from the WSEO database and was taken from ASHRAE (1989). U-values for wood windows with argon, also not available from the WSEO database, were estimated from the U-values for vinyl windows with argon. All multipane windows are assumed to have a 1/2-in. air space. Low-E indicates a low-emissivity coating.

The WSEO-tested U-value data indicated the insertion of argon into spaces between the panes for double-pane windows makes a thermal improvement of 0.09 Btu/hr·ft^2·°F. If the argon leaks, part or all of this improvement will be lost. However, an article in Energy Design Update (1991) suggests that argon leakage from well-built windows is not a concern.

TABLE B.7. Window ECM U-values

Window/Sash Type	Window U-value	Number of Tested Windows
Single Aluminum	1.31	0
Double Aluminum	0.61	40
Double Aluminum/Thermal Break	0.54	36
Double Wood	0.52	17
Double Vinyl	0.49	92
Double Wood with Argon	0.43	--
Double Wood with Low-E	0.42	10
Double Vinyl with Argon	0.40	52
Double Vinyl with Low-E	0.39	74
Double Wood with Argon, Low-E	0.37	--
Double Vinyl with Argon, Low-E	0.35	52

The tested U-values shown in Table B.7 were for design conditions, which assume a 15-mph outdoor wind speed. In reality, average wind speeds are well below 15 mph. Therefore, the window U-values were adjusted in the energy analysis to determine optimum ECMs for a more reasonable 7.5-mph wind speed (ASHRAE 1985), which improves (lowers) all the window U-values, particularly for single-pane windows. The ultimate generation of the proposed MEC U_0-values from the optimum ECMs are based on window U-values with the normal rating conditions of 15-mph wind speed for windows.

B.4 FLOORS OVER UNHEATED SPACES

At the national level, foundations in new housing (in 1991) are 40% slab, 38% full or partial basement, and 22% crawlspace (U.S. Department of Commerce [DOC] 1992). Slabs are the predominant foundation type in the South, crawlspaces are predominant in the Pacific Northwest, and basements are predominant everywhere else (Christian 1988). This MEC code change proposal is for only floors over unheated spaces, which can be either basements or crawlspaces. The floor is assumed to have the same construction regardless of foundation type.

Floors over unheated spaces were assumed to be constructed of insulation and framing, 3/4-in. wood subfloor, and carpet with a rubber pad. The floor joists were modeled as 2x10 studs 16-in. O.C. (DeCristoforo 1987) occupying 10% of the floor area. The effective thickness of the joists for the thermal calculation was set equal to the thickness of the insulation when the insulation was less than 10 in. thick. This was done because heat flows directly out of sides of the joists beyond the depth of the insulation. The construction U_0-values for floors over unheated spaces are shown in Table B.8.

TABLE B.8. Floor ECM U_0-Values

Batt R-Value	U_0-Value of Floor including framing
0	0.2494
11	0.0719
13	0.0648
19	0.0478
30	0.0328

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APPENDIX C

CITIES USED IN U_o-VALUE OPTIMIZATION

APPENDIX C

CITIES USED IN U_o-VALUE OPTIMIZATION

The U_o-value optimums were generated for the following 881 cities using ARES. (ARES is described in Section 2.) This list includes all the cities in the ARES database. For each city, six different equipment and fuel types were analyzed for both single- and multifamily homes.

Alabama
Andalusia
Anniston
Auburn
Birmingham
Dothan
Eufaula
Gadsden
Huntsville
Mobile
Montgomery
Ozark
Scottsboro
Selma
Talladega
Tuscaloosa

Alaska
Anchorage
Fairbanks
Juneau
Kenai

Arizona
Casa Grande
Douglas
Flagstaff
Mesa
Nogales
Phoenix
Prescott
Tempe
Tucson
Yuma

Arkansas
Arkadelphia
Benton
Blytheville
Camden
Conway
El Dorado
Fayetteville
Fort Smith
Hope
Hot Springs
Jonesboro
Little Rock
Magnolia
Malvern
No. Little Rock
Paragould
Pine Bluff
Russellville
Searcy
Stuttgart
Texarkana

California
Antioch
Bakersfield
Barstow
Berkeley
Burbank
Chico
Chula Vista
Claremont
Concord
Corona
Culver City
Davis
El Centro
Escondido
Eureka
Fairfield
Fontana
Fresno
Hanford
Indio
Laguna Beach
La Mesa
Lancaster
Livermore
Lodi
Lompoc
Long Beach
Los Angeles
Los Banos
Los Gatos
Madera
Merced
Modesto
Monterey
Napa
Newport Beach
Oakland
Oceanside
Oxnard
Palm Springs
Palo Alto
Pasadena
Petaluma
Pomona
Porterville
Redding
Redlands
Redwood City
Richmond
Riverside
Sacramento
Salinas
San Bernardino
San Diego
San Francisco
San Gabriel
San Jose
San Luis Obispo
San Rafael
Santa Ana

Santa Barbara
Santa Cruz
Santa Maria
Santa Monica
Santa Paula
Santa Rosa
Stockton
Torrance
Tracy
Tustin
Upland
Vacaville
Visalia
Watsonville
Woodland
Yorba Linda

Colorado

Boulder
Canon City
Colorado Springs
Denver
Durango
Fort Collins
Grand Junction
Greeley
Lakewood
Longmont
Pueblo
Sterling

Connecticut

Bridgeport
Danbury
Enfield
Groton
Hartford
Meriden
Middletown
New Haven
Norwalk
Storrs
Waterbury

Delaware

Dover
Newark
Wilmington

District of Columbia

Washington

Florida

Bartow
Belle Glade
Bradenton
Clearwater
Daytona Beach
Deland
Fort Lauderdale
Fort Myers
Fort Pierce
Gainesville
Hialeah
Homestead
Jacksonville
Key West
Lakeland
Melbourne
Miami
Naples
Ocala
Orlando
Palatka
Pensacola
Plant City
Pompano Beach
St. Petersburg
Sanford
Sarasota
Tallahassee
Tampa
Titusville
Vero Beach
West Palm Beach
Winter Haven

Georgia

Albany
Americus
Athens
Atlanta
Augusta
Brunswick
Carrollton
Columbus
Covington
Dalton
Douglas
Dublin
Fitzgerald
Gainesville
La Grange
Macon
Milledgeville
Moultrie
Newnan
Rome
Savannah
Thomasville
Tifton
Waycross

Hawaii

Hilo
Honolulu
Kahului
Kaneohe Mauka
Lahaina

Idaho

Boise
Caldwell
Coeur d'Alene
Idaho Falls
Moscow
Pocatello

Illinois

Alton
Aurora
Belleville
Bloomington
Carbondale
Champaign
Charleston
Chicago
Danville
Decatur
De Kalb
Dixon

Effingham
Elgin
Galesburg
Jacksonville
Joliet
Kewanee
Lincoln
Mattoon
Monmouth
Mount Vernon
Ottawa
Park Forest
Peoria
Peru
Pontiac
Quincy
Rantoul
Rockford
Springfield
Urbana
Waukegan
Wheaton

Indiana

Anderson
Bloomington
Columbus
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Elwood
Evansville
Fort Wayne
Frankfort
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Greenfield
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Huntington
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La Porte
Lafayette
Marion
Martinsville
Muncie
New Castle
Richmond
Seymour
Shelbyville
South Bend
Terre Haute
Valparaiso
Vincennes
Wabash
West Lafayette

Iowa

Ames
Ankeny
Boone
Cedar Rapids
Clinton
Davenport
Des Moines
Dubuque
Fort Dodge
Indianola
Iowa City
Keokuk
Marshalltown
Mason City
Muscatine
Newton
Oskaloosa
Ottumwa
Sioux City
Spencer
Waterloo

Kansas

Hutchinson
Manhattan
McPherson
Newton
Olathe
Ottawa
Parsons
Salina
Topeka
Wichita
Winfield

Kentucky

Ashland
Bowling Green
Covington
Frankfort
Henderson
Hopkinsville
Lexington
Louisville
Madisonville
Mayfield
Middlesboro
Murray
Owensboro
Paducah
Somerset

Louisiana

Alexandria
Bastrop
Baton Rouge
Bogalusa
Hammond
Houma
Jennings
Lafayette
Lake Charles
Minden
Monroe
Morgan City
Natchitoches
New Iberia
New Orleans
Ruston
Shreveport
Tallulah

Maine

Augusta
Bangor
Lewiston
Portland
Presque Isle
Waterville

Maryland

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Cambridge
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Cumberland
Hagerstown
Laurel
Rockville
Salisbury

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New Bedford
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Big Rapids
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Detroit
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Grand Haven
Grand Rapids
Holland
Jackson
Kalamazoo
Lansing
Marquette
Midland
Monroe
Mt Pleasant
Muskegon
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Pontiac
Port Huron
Saginaw
Sault Ste Marie
Traverse City
Ypsilanti

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Faribault
Fergus Falls
Marshall
Minneapolis
Rochester
St. Cloud
St. Paul
Virginia
Willmar

Mississippi

Biloxi
Brookhaven
Canton
Clarksdale
Cleveland
Columbus
Corinth
Greenville
Greenwood
Gulfport
Hattiesburg
Jackson
Laurel
Meridian
Natchez
Picayune
Tupelo
Vicksburg
Yazoo City

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Hannibal
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Joplin
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Mexico
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St. Joseph
St. Louis
Sedalia
Sikeston
Springfield
Warrensburg

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Bozeman
Butte
Great Falls
Havre
Helena
Kalispell
Missoula

Nebraska

Beatrice
Columbus
Fremont
Grand Island
Hastings
Kearney
Lincoln
Norfolk
North Platte
Omaha
Scottsbluff

Nevada

Carson City
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Reno
Sunrise Manr
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Newark
New Brunswick
Paterson
Plainfield
Somerville
Trenton
Vineland

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Carlsbad
Clovis
Gallup
Hobbs
Las Cruces
Los Alamos
Roswell
Santa Fe

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Patchogue
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Warren
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Columbia
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Greenville
Greenwood
Laurens
Orangeburg
Sumter
Union

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Sheboygan
Stevens Point
Superior
Two Rivers
Watertown
Waukesha
Wausau
West Allis
Whitewater
Wisconsin Rapids

Wyoming

Casper
Cheyenne
Gillette
Green River
Laramie
Rock Springs
Sheridan

APPENDIX D

PROPERTY AND STATE INCOME TAXES BY STATE

APPENDIX D

PROPERTY AND STATE INCOME TAXES BY STATE

This appendix presents the average property and state income taxes for each state. These values were used in the life-cycle cost analysis. See Sections 3.2.4 and 3.2.5 for details on how these rates were determined.

TABLE D.1. Property and State Income Taxes by State

State	Property Tax (%)	State Tax (%)
Alabama	0.4	3.8
Alaska	0.9	0.0
Arizona	1.2	2.8
Arkansas	0.7	4.5
California	0.7	2.4
Colorado	1.1	3.4
Connecticut	1.5	0.7
Delaware	0.8	3.7
Washington, D.C.	1.0	5.5
Florida	1.5	0.0
Georgia	1.2	3.8
Hawaii	0.3	4.8
Idaho	1.3	4.7
Illinois	1.5	2.7
Indiana	1.5	3.1
Iowa	1.9	4.5
Kansas	1.5	2.5
Kentucky	1.0	4.2
Louisiana	0.8	2.1
Maine	2.1	3.9
Maryland	1.1	6.2
Massachusetts	1.4	5.0
Michigan	2.3	3.8

TABLE D.1. (contd)

State	Property Tax (%)	State Tax (%)
Minnesota	1.6	4.7
Mississippi	1.4	2.5
Missouri	0.9	3.2
Montana	1.7	4.4
Nebraska	2.3	3.0
Nevada	0.7	0.0
New Hampshire	2.8	0.0
New Jersey	1.7	2.0
New Mexico	0.9	3.0
New York	1.6	4.5
North Carolina	0.9	4.5
North Dakota	1.7	1.4
Ohio	1.2	3.5
Oklahoma	0.9	4.0
Oregon	2.1	6.7
Pennsylvania	1.7	2.6
Rhode Island	1.9	2.9
South Carolina	1.0	4.2
South Dakota	2.3	0.0
Tennessee	0.9	0.0
Texas	1.6	0.0
Utah	1.1	4.5
Vermont	1.7	2.9
Virginia	1.1	4.1
Washington	1.0	0.0
West Virginia	0.6	3.4
Wisconsin	2.6	4.9
Wyoming	1.4	0.0

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