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**Technical Support Document for
Proposed 1994 Revision of the MEC
Thermal Envelope Requirements**

**C. C. Conner
R. G. Lucas**

March 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

PNL-9400

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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) 1994 supplement to the 1993 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.

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.

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Summary

This report documents the analysis that underlies the proposed revision of the Council of American Building Officials' (CABO) 1993 Model Energy Code (MEC) (with "1994 amendments") building thermal envelope requirements for single-family and low-rise multifamily residences. The 1994 amendments to the 1993 MEC were established in last year's code change cycle and did not change the envelope requirements. This report is an update and revision of the Technical Support Document (TSD) for Proposed Revision of the Model Energy Code Thermal Envelope Requirements (Conner and Lucas 1993, PNL 8546). The revisions of the proposed U_o -value requirements resulted from our review and analysis of written and oral comments from opponents and supporters identified at the first and second public hearings in 1993. Many of the comments, as well as additional information obtained in meetings, phone conversations, and correspondence with the commenters after the first hearing, were relevant, persuasive, and substantiated. This information caused us to modify some of our original analysis. The net impact of these revisions lessens the proposed increase in the stringency of the ceiling, wall, and floor U_o -value requirements in comparison to the 1993 proposal. Appendix E summarizes the changes in the analysis from the 1993 DOE proposal to the 1994 proposal. Note that the original proposed code changes submitted in last year's cycle also received comments from a wide range of reviewers.

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_o -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 4 (floors over unheated spaces) in the 1993 MEC (CABO 1993, pp. 73, 74, and 76).

The approach used in developing the proposed MEC revision was a cost-benefit analysis in which the cost of the ECMs was 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 more than 800 cities in the United States.

The resulting envelope component U_o -values were then presented as a function of heating degree-days (HDD) 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. Separate parameters were identified for single-family homes (privately owned) and multifamily homes (rental property). The loan parameters selected for the single-family homes analysis were a 3.9% real interest rate (8.0% nominal, assuming an inflation rate of 3.9%) over 30 years with points and loan fees of 1.6% and 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% (8.1% nominal). The loan parameters selected for the multifamily homes analysis were a 9% nominal interest rate over 30 years with points of 2.0% and loan fees of 1.5% and a down payment of 35%. 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 predicting future energy costs. The long-term average annual fuel escalation rates (real) used were electricity, 0.2%; fuel oil, 0.5%; natural gas, 1.5%; and LPG, 0.3%.

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_o -value of 1.31 to 0.35.

Initially, homes that made use of eight specific types of heating equipment, distribution systems, 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. The natural gas and oil furnaces had either forced air or hydronic distribution systems. In most climates 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 eight 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_o -value was produced.

The 14,096 individual U_o -values (881 cities, eight HVAC/fuel types, two building types) were aggregated to U_o -value curves that can be used in the MEC. The separate optimums for each heating fuel/equipment type were combined into U_o -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_o -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_o -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 a sales-weighted average, the existing MEC required an overall single-family home U_o -value of 0.088. The standard proposed here would require a U_o -value of 0.078, a reduction of about 11%. For the multifamily prototype, the sales-weighted average proposed U_o -value is 0.101 compared to 0.117 for the 1993 MEC, a reduction of about 14%.

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 \$700 for single-family homes. The present value of the benefits of the more stringent requirements (the energy savings) was estimated at \$1100 over the life of the home. The proposed standard was estimated to increase nonenergy costs by about \$420 for single-family homes. For multifamily units, the net life-cycle benefit is \$300, the present value of the energy savings was estimated at \$510, and the nonenergy costs increased by about \$270.

Figure S.1. Proposed MEC U_o Requirement for Roof/Ceilings with Attics

Figure S.2. Proposed MEC U_o Requirement for Roof/Ceilings without Attics

Figure S.3. Proposed MEC U_o Requirement for Single-Family Walls

Figure S.4. Proposed MEC U_o Requirement for Multifamily Walls

Figure S.5. Proposed MEC U_o Requirement for Floors over Unheated Spaces

Based on the analysis documented in this report, revised U_o -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)

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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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1.0 Introduction

This report documents the development of the proposed revision of the Council of American Building Officials' (CABO) 1994 supplement to the 1993 Model Energy Code (MEC) building thermal envelope requirements for maximum component U_o -value. The 1994 amendments to the 1993 MEC were established in last year's code change cycle and did not change the envelope requirements. 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_o -values (thermal transmittances). ECMs include window types (for example, double-pane vinyl) and insulation levels (for example, R-19) for ceilings, walls, and floors.

This report is an update and revision of the Technical Support Document (TSD) for Proposed Revision of the Model Energy Code Thermal Envelope Requirements (Conner and Lucas 1993). The revisions of the proposed U_o -value requirements resulted from our review and analysis of written and oral comments from opponents and supporters identified at the first and second public hearings in 1993. Many of the comments, as well as additional information obtained in meetings, phone conversations, and correspondence with the commenters after the first hearing, were relevant, persuasive, and substantiated. This information caused us to modify some of our original analysis. The net impact of these revisions lessens the proposed increase in the stringency of the ceiling, wall, and floor U_o -value requirements in comparison to the 1993 proposal. Appendix E summarizes the changes in the analysis from the 1993 DOE proposal to the 1994 proposal. Note that the original proposed code changes submitted in last year's cycle also received comments from a wide range of reviewers.

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 4 (floors over unheated spaces) in the 1993 MEC (CABO 1993, amended pp. 73, 74, and 76).

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

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

large number of cities in the United States. The resulting envelope component U_o -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 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. Appendixes A through E 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.

$$\begin{aligned} \text{Life-cycle cost} = & \text{Energy-efficiency improvement costs} + \text{Operating costs} \\ & + \text{Maintenance costs} - \text{Resale value} \end{aligned}$$

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 minimum-cost 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. These parameters represent the costs and benefits from the home owner's perspective or, in the case of multifamily rental housing, that of the building owner/developer and the utility bill payer (may be owner or renter).

- New home mortgage parameters
 - mortgage interest rate (8.0% nominal assuming 3.9% inflation for single-family, 9% nominal for multifamily)
 - points and loan fees (1.6% of the mortgage amount for single-family, 3.5% for multifamily)
 - loan term (30 years)
 - down payment (10% for single-family, 35% for multifamily)
- Other rates and economic parameters
 - Alternate investment rate (discount rate) (4.0% real or about 8.1% nominal assuming 3.9% future inflation for single-family, 9.0% nominal for multifamily--based on the mortgage interest rate)
 - marginal federal plus state income tax rates (24% average for single-family, see Appendix D; 37% for multifamily)
 - property tax rates (1.36% average, see Appendix D)
 - period of analysis (30 years)
 - building life (50 years for single-family, 40 years for multifamily)
- Residential fuel prices by state (see Appendix A) and annual escalation rates
 - electricity (escalation: 0.2%)
 - fuel oil (escalation: 0.5%)
 - liquid petroleum gas (escalation: 0.3%)
 - natural gas (escalation: 1.5%).

In choosing the parameters for the 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 and multifamily rental financing need to be defined. The financing of owner-occupied homes differs substantially from that of multifamily rental property, so the two types were defined separately.

3.1.1 Owner-Occupied Financing

A mortgage interest rate of **3.9% real** (8.0% 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 real averages using 1963-1991 data (OTS 1991). Points and loan fees were determined from the same data to average 1.6% of the mortgaged amount; this cost was assumed to be split equally between points (tax-deductible) and loan fees (not tax-deductible). This long-term rate is also close to current real mortgage rates.

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.

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 12% for all home buyers who finance their purchase (NAR 1992). 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.

Private mortgage insurance (PMI) is normally required for loans with low down payments. Based on data provided by a mortgage company, NAHB-developed data in Profile of the New Home Buyer (NAHB 1992d), and the various types of loans and down payments commonly available, average PMI costs were calculated. PMI was included as a first-year, non-tax-deductible cost to the home buyer, fixed at 3.5% of the mortgage loan amount.

3.1.2 Multifamily Rental Financing

Rental property makes up about 74% of all multifamily housing units, according to Housing Characteristics 1990 (EIA 1992a). It was assumed that the apartment builder or developer will pass the increased costs of energy conservation measures to the renter in the form of higher rents, thereby making those costs a "real" expense to the renter. The loan costs and associated taxes are paid by the owner/developer; therefore, the cost of an increase in energy efficiency was calculated from the owner's perspective. Savings on fuel bills were calculated using average residential fuel prices as discussed later. The cost of the fuel used in a multifamily home is expected to be similar, whether

paid by the owner or occupant. Utility bills in new multifamily units are usually paid by the renter. The cost minimization methodology simply looks for the lowest total costs in multifamily units: at what point are the construction and financing costs associated with energy efficiency less the utility bill savings at their minimum?

The following synopsis of typical multifamily housing financing was developed, based primarily on input from Mr. Michael Evans, National Director of Real Estate Advisory Services for the accounting firm of Ernst and Young, San Francisco, California. Mr. Evans has considerable experience with the economics of the apartment industry.

Multifamily housing is financed by a conventional loan or, less frequently, with a government guaranteed (HUD) loan. A typical loan has a 9% interest rate (8% to 8.25% for HUD-guaranteed financing), 2 points (1 to 2 for HUD), 35% down payment (15% for HUD), and 0.5% to 0.75% in miscellaneous costs (filing fee, appraisal, title insurance, etc.). Conventional loans have a 10-year term amortized over 25 to 30 years. The difference in the term and the amortization implies a balloon payment at the 10-year point, but housing is typically sold or exchanged before then. (HUD loans have a 30- to 35-year term, amortized over the same 30 to 35 years.) A construction loan precedes the loan secured by the completed building and is converted to the secured loan after 18 to 24 months. The construction loan characteristics are approximately 2 points, 1.5% in fees, 9% interest, and 35% down.

Some multifamily housing units receive a low-income tax credit (LITC), which is a credit on taxes owed, not a tax deduction on the income of the owners. LITCs amount to 70% of the value of the low-income units for conventional mortgages and 30% of the value for federally-financed mortgages (HUD programs). Energy-efficient features, such as insulation and energy-efficient windows, qualify under the HUD and LITC programs like any other building components.

According to Mr. Evans, over the long term, about two-thirds of all apartment units will have conventional loans and no LITC and about one-sixth will have conventional loans and the tax credit. The remaining one-sixth of the units will have HUD loans equally split between those that receive the tax credit and those that do not.

By law, multifamily housing is depreciated over 27.5 years using straight-line depreciation. Depreciation is treated as a cost for tax purposes and is deducted from profits. If a building is sold, the depreciation tax deduction starts again with a new owner. If the building is sold for more than its depreciated value, the excess is subject to capital gains taxes. If the seller buys new property, the capital gains taxes do not apply. More than 50% of the investors exchange property to avoid capital gains taxes.

Marginal federal corporate taxes plus the effective state taxes (after federal deduction is taken) are about 40% for corporations and almost 36% for individuals. Roughly 80% of the owners of rental property are individuals and the rest are corporations. A reasonable overall average tax rate is 37%.

All of the above-mentioned factors were considered in developing a reasonable scenario for financing multifamily rental housing defined as follows: 9% mortgage interest rate, 35% down payment, 2 points on the mortgage loan and construction loan, 1.5% fees for the construction loan, loans transferred every 7 years with all applicable fees and points, 30-year analysis period, depreciation tax deductions, LITC on the fraction of units that receive it, and a 37% marginal tax rate.

Twenty-four percent of multifamily housing are owner-occupied condominiums. Condos are financed like single-family housing, with the exception of the down payment, which may be larger. The minimization of condominium energy-related costs resulted in cost-effective conservation levels similar to those for rental housing. Therefore, the results for rental housing analysis were used to produce the proposed code change that applies to walls for all types of multifamily housing. Our analysis indicates that equivalent nonwall envelope requirements for single-family and multifamily housing are reasonable. The separate requirements for walls are justified because multifamily housing commonly have much higher window-to-wall area ratios than do single-family housing.

3.2 Economic Parameters

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

3.2.1 Alternative Investment Rate (Discount Rate)

A cost minimization must convert costs and benefits occurring in future years into present-value dollars. To convert future dollars into present dollars, an alternate investment rate or 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 is near 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 to the home owner.) 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 5.5%,^(a) or 1.5% real accounting for the projected 3.9% inflation. Therefore, the prepayment "investment" yields between 5.5% and 8.0% nominal or between 1.5% and 4.0% 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.

(a) The maximum federal income tax rate is assumed to be 28%. The average marginal state income tax was estimated to be 3%. The 8.0% return less the tax deductions of 31% (28% federal plus 3% state), yields a 5.5% nominal return.

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 1.5% to 4.0%. 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, this 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 average rate established by prepayment of the mortgage.

For multifamily rental housing, mortgage rates are about 9%, as discussed in Section 3.1.2. The multifamily discount rate was set to equal this mortgage rate, or 4.9% in real terms.

3.2.2 Inflation Rate

The inflation rate is used to convert between nominal and real rates. An inflation rate of 3.9% was used. This projected rate is from DOE's Annual Energy Outlook 1993 (EIA 1993a) and is equal to the average forecast of four other sources (EIA 1993a). The inflation rate has little impact on this analysis, however, because all parameters were collected as real (i.e., preadjusted for inflation) values.

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 (to HUD) 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 perhaps conservative building life of 40 years was assumed for multifamily homes based on consultation with Michael Evans of Ernst and Young.

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. Data on household incomes for all purchasers of homes were obtained from the Internal Revenue Service (Statistics of Income 1989, Individual Income Tax Returns) and the NAR (1992). These data were used to estimate Federal tax deductions for the average homeowner. Approximately half of all home purchasers fell into the 28% bracket and half fell into the 15% bracket. For our revised analysis, we therefore used 21% to represent the weighted average income tax rate.

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 (SEPER) (EIA 1992b), were used in the analysis (except for electrical heating, see below). The 1990 fuel prices for each state were updated for the fuel price escalation in 1991 and 1992 (EIA 1993b).

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.

Based on the DOE Energy Information Administration (EIA 1988) publication, Typical Electric Bills, we obtained electrical heating prices that are marginal, not average. The resulting heating season marginal electric rates were approximately 14% lower (on average) than average heating season electric rates. The marginal rates include rates that are sometimes established for "all-electric" homes. Data for marginal cooling season electric rates were not available in Typical Electric Bills, so the SEPER data were used with two adjustments. The EEL publication, Typical Residential, Commercial and Industrial Bills--Investor Owned Utilities (EEI 1993) was used to obtain a 7% average-to-marginal price decrease. This same source was used to obtain annual to cooling season adjustments as shown in Appendix A.

For natural gas, NAHB (1992d) 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% to account for estimated marginal prices. 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]). The AGA Rate Service (1993) was examined, followed up by calls to the largest utility in each state. Based on this data, the average tax was estimated to be 4%; this was applied 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 the most recent data available from the EIA in its publication, Annual Energy Outlook (1993b). The EIA projects fuel escalation rates for 20 years into the future for each fuel used in this analysis. These rates were assumed for the entire 30-year analysis period. Extrapolating the rates out over years 20 to 30 is reasonable and has little effect because of discounting.

Table 3.1. Residential Fuel Price Escalation Rates (Percent, Real) 1992 through 2021

<u>Fuel</u>	<u>Escalation Rate</u>
Electricity	0.2
Fuel oil	0.5
Natural gas	1.5
Liquid petroleum gas	0.3

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_o -values in the code change proposal (all U_o -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_o -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_o -value combinations available.

It should be noted that compliance with the MEC can be based on meeting individual component U_o -value requirements, an equivalent overall building U_o -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_o -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_o -value, overall U_o -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_o -values for each ECM. Section 4.1 presents the ECM levels, costs, and U_o -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_o -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 (1993). 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_o -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_o -values in detail. The overall U_o -values for wall, floor, and ceiling assemblies were calculated assuming construction techniques currently used in

the industry. The U_o -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 1993 (Means 1993)
- 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

(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).

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/ft² 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).

Our framing lumber costs are based on 1992 data. Since about the start of 1993, lumber prices have risen and been extremely volatile. Lumber prices as reported in the trade newsletter Random Lengths were tracked until the date of the analysis. Based on data provided therein, we have assumed framing costs to have increased 25% relative to 1992 costs for those energy conservation increments dependent on framing lumber size changes.

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_o-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.

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.

Figure 4.1. Ceiling-with-Attic ECM Costs from Five Sources

Table 4.1. Ceiling-with-Attic U_o -Values and Costs

<u>Nominal R-value</u>	<u>Ceiling U_o-value</u>	<u>Cost Relative to R-11 (\$/ft²)</u>
R-11	0.0819	0.00
R-19	0.0507	0.13
R-30	0.0353	0.30
R-38	0.0300	0.44
R-38 with raised truss	0.0254	0.99
R-49	0.0259	0.59
R-49 with raised truss	0.0200	1.17

Table 4.2. Vaulted Ceiling U_o-Values and Costs

<u>Nominal R-value</u>	<u>Ceiling U_o-value</u>	<u>Cost Relative to R-11 (\$/ft²)</u>
R-11	0.0850	0.00
R-19	0.0526	0.15
R-30	0.0351	0.73
R-38	0.0282	1.51
R-30 + R-7	0.0277	1.45
R-38 + R-7	0.0231	2.23

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

- Means Residential Cost Data 1993 (Means 1993)
- 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 1993), 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/ft² of wall area for 16-in. O.C. construction and \$0.07/ft² 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 1992 National Construction Estimator. According to the NCE (Craftsman 1992), the additional cost for window and door framing in 2x6 construction is \$0.07/ft² 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. The cost of extra lumber for 2x6 walls relative to 2x4 walls was scaled up by 25% to account for recent lumber cost increases as described in Section 4.1.1.

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 22% 24-in. O.C. construction and 78% 16-in. O.C. construction for 2x6 framing. The conservative assumption of 22% 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 22% 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 (1993, 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/ft² 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 (1993) 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 (1993) 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 (1993) 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_o -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_o -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_o -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 (1993), 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/ft² for supporting netting (including installation) was 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 (1993) 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

Table 4.3. Wall U_o-Values and Costs

<u>Nominal Batt Insulation R-value</u>	<u>Rigid Insulation R-value^(a)</u>	<u>U_o-value of wall</u>	<u>Cost Relative to R-11 (\$/ft²)</u>
11	1.32	0.0796	0.00
13	1.32	0.0722	0.07
11	4	0.0649	0.03
13	4	0.0596	0.10
11	7	0.0540	0.24
19	1.32	0.0549	0.83
13	7	0.0501	0.31
19	4	0.0473	0.85
15	7	0.0469	0.48
21	4	0.0430	0.96
19	7	0.0411	1.08
21	7	0.0377	1.18

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

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/ft² 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 (1993) were averaged with each of the two NAHB (1986) sets of cost data, creating crawlspace insulation costs \$0.02/ft² more than basement ceiling costs. Figure 4.3 shows insulation costs for the Means and NAHB data for basement ceilings as a function of floor U_o-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/ft² higher. Table 4.4 shows the floor U_o-values and cost increments used in the LCC analysis.

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_o-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.

Figure 4.3. Floor ECM Costs from Two Sources

Table 4.4. Basement Ceiling and Crawlspace U_o -Values and Costs

<u>Insulation R-Value</u>	<u>U_o-value of floor</u>	<u>Basement Cost Relative to R-0 (\$/ft²)</u>	<u>Crawlspace Cost Relative to R-0 (\$/ft²)</u>
0	0.2494	0.00	0.00
11	0.0719	0.47	0.49
13	0.0648	0.56	0.58
19	0.0478	0.69	0.71
30	0.0328	0.92	0.94

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_o -values from these sources were probably more reliable than older data; particularly the U_o -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/ft² (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/ft² to \$2/ft² to the consumer. To be more conservative, we placed a price of \$2/ft² 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/ft² (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 large 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_o -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.

Clear evidence exists that vinyl windows have gained acceptance in new residential construction. Vinyl windows currently represent 8% of windows used in new residential construction; their share of the market is expected to increase to 12% during 1994. If true, this increase in the market share for vinyl windows will represent a doubling between 1991 to 1994 (AAMA 1992). Thus, the acceptance and growth of vinyl windows in new construction is well under way and is expected to continue.

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/ft². 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/ft² 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_o -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_o -values are based on testing of numerous windows for the Washington State Energy Code (WSEO 1992). A U_o -value provided by ASHRAE (1989) was used for the single-paned aluminum window. See Appendix B for more information on the window U_o -values used in this analysis.

4.1.5 Doors

Opaque door options were examined. The impact of doors on the wall U_o 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/ft². 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.

Table 4.5. Window U_o -Values and Costs

<u>Window/Sash Type</u>	<u>Window U_o-value</u>	<u>Cost Relative to Single Aluminum (\$/ft²)</u>
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

4.2 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_o -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 (1992a).

The median floor area for a new single-family home according to DOC (1992a) was 1890 ft². 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 ft²). Eight-ft-high ceilings were assumed. The ceiling area (bordering the unconditioned exterior) averaged 1418 ft². The average gross wall area was 1736 ft². A total door area of 56 ft² (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 ft² 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 Freedomia Group updated this value for us for 1992. He estimated that the average for 1992 was 430 ft² per residence. Accounting for double-paned windows, storm windows, and storm doors (AAMA 1992), we estimated an average of about 220 ft² 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 ft² 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 ft², or 16.3% of the gross wall area). This area is conservative in the sense that it raises the combined window/wall U_o-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_o-value.

The reported median floor area of new multifamily units--980 ft² (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 three-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_o-value curve that can be complied with, even if the building has large window areas. A 24-unit building was assumed. The building dimensions were assumed to be 184.0 ft by 42.6 ft. Assuming 8-ft-high ceilings, the gross exterior wall area per unit is 453.2 ft². The window area was selected by assuming that 25% of the wall area was window.^(a) This gives 113.3 ft² of window area, equivalent to 11.6% of the floor area. The door area was assumed to be 40 ft², 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.

(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.

Table 4.6. Equipment Efficiencies Used in Analyses

<u>System</u>	<u>Efficiency</u>
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.

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.

4.3.1 Distribution Systems Efficiency

We used a single distribution efficiency factor for air-duct systems 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 average values of 75% and 95% duct efficiency (i.e., 25% and 5% loss) were used for the single-family prototype and the multifamily prototype, respectively. The technical justification for these factors is 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.

$$\text{Adjusted HVAC Effic.} = \text{Equipment Effic.} \times \text{Distribution Effic.} \quad (4.1)$$

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 1988). 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 study of 24 all-electric homes in the Pacific Northwest (Olson 1993) measured heating system efficiencies. Twenty-two of the homes had ductwork located outside the conditioned space; these homes had an average system efficiency of 71%. Two of the homes had ductwork located outside the conditioned space and had an average efficiency of 98%. These 24 homes vary in age with 1983 being the average year of construction.

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 four 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 four primary sources, is 0.75. The four 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.

Hydronic systems (piped water/steam) are common heating distribution systems in the northeast. The hydronic distribution efficiency is much higher than the distribution efficiency for forced air systems. This efficiency was set at 96% for the single-family prototype (Andrews and Modera 1991) in our revised analysis.

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 ducts is higher than the efficiency of single-family ducts. We estimated the multifamily duct efficiency factor to be 0.95 or a conservatively low 5% distribution loss. Losses from hydronic systems in multifamily buildings were set to 0%.

4.4 1993 MEC Compliance

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

Table 4.7. Ducted Distribution Efficiency Factors

<u>Source</u>	<u>Location of Ducting</u>			<u>Weighted Average</u>
	<u>Unconditioned</u>	<u>Partially Conditioned</u>	<u>Conditioned</u>	
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
Olson	0.71	--	0.98	--
Average	0.73	0.74	0.99	0.75

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_o -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_o -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_o -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_o -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_o -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, eight combinations of HVAC equipment and fuel were optimized:

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

The two home prototypes (single- and multifamily) were optimized separately. The combinations of equipment/fuel types (8) and prototypes (2) resulted in 16 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.

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. As seen in Figure 5.1, selection of all 881 cities provides a high density of locations across the United States. The selection of 881 cities, 8 equipment/fuel types, and 2 prototypes resulted in the output of 14,096 cases with specific optimal

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

U_o -values for each envelope component.^(a) The results were weighted to account for new housing starts for 1992 using data from the DOC (1993). Doing so resulted in localities with high levels of construction activity (e.g., Phoenix, Arizona) having a proportionately high impact on the final results.

Some new housing in cooler climates does not have central air conditioning. The analysis was adjusted to reflect the state-by-state penetration of air conditioning as reported in a NAHB survey of new housing (NAHB 1991).

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 fuel types. The retention of separate U_o -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_o -value requirements across fuels is

(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.

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_o -values is the accuracy with which the cost-effective level can be defined. The separate requirements would have lower maximum U_o -values for the more expensive electric resistance heat and higher U_o -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 for single-family homes 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 to obtain fuel-averaged U-values for each envelope component in each of the 881 cities.

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

	<u>South</u>	<u>Northeast</u>	<u>Midwest</u>	<u>West</u>	<u>Northwest</u>
Oil/Air	0	17	0	0	0
Oil/Hydronic	0	15	0	0	0
Nat. Gas/Air	42	25	82	68	48
Nat. Gas/ hydronic	0	23	2	1	1
LPG	2	2	1	1	1
Electric Furnace	9	2	2	4	18
Heat Pump	41	9	6	12	12
Electric Baseboard	3	5	3	5	20

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

	<u>South</u>	<u>Northeast</u>	<u>Midwest</u>	<u>West</u>	<u>Northwest</u>
Oil/Air	1	3	0	0	0
Oil/Hydronic	0	3	0	0	0
Nat. Gas/Air	16	37	74	49	10
Nat. Gas/Hydronic	0	34	2	1	0
LPG	0	0	0	0	0
Electric Furnace	14	3	4	9	5
Heat Pump	63	13	13	29	85
Electric Baseboard	5	7	7	12	0

5.3 Creation of the Revised MEC U_o -Value Requirements

The proposed MEC maximum U_o -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_o -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_o -values are significantly below those required by the 1993 MEC. Figure 5.2 shows that for cities below 5000 HDD, the optimum ceiling with attic U_o -value is generally below the 1993 MEC requirement. The vaulted ceiling requirements are 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 requirements (Figure 5.6) are more stringent than the 1993 MEC requirement for locations with more than 4000 HDD. The proposed code change would require no insulation for floors for locations with less than 500 HDD. The proposed requirements are different for basements and crawlspaces for locations with 500 to 1500 HDD. Our analysis shows that floor insulation for basements is not cost-effective in these mild climates. (There are no dots shown on Figure 5.6 below 1500 HDD because the combined optimum U -values for basements and crawlspaces average above the 0.10 upper limit shown.) This is because the ground provides some natural insulation and advantageous thermal mass effects. In the cooling season, floor insulation in basements is not necessarily helpful as the insulation isolates the house from the cool basement. Crawlspaces do not have the thermal connection to the ground to the extent that basements do. R-13 insulation is cost-effective for crawlspaces in the 500 to 1500-HDD range.

The proposed revised MEC U_o -value requirements were created from the 881 city points with the results grouped into 500 HDD bins (e.g., 2000 to 2500 HDD). The weighted average for each bin was then determined using the 1992 housing start data described above. For ceilings and floors, the optimums in each HDD bin were set to the U_o -value of the nearest ECM (i.e., nominal insulation

Figure 5.2. Proposed MEC U_o Requirement for Roof/Ceilings with Attics

Figure 5.3. Proposed MEC U_o Requirement for Roof/Ceilings without Attics

Figure 5.4. Proposed MEC U_o Requirement for Single-Family Walls

Figure 5.5. Proposed MEC U_o Requirement for Multifamily Walls

Figure 5.6. Proposed MEC U_o Requirement for Floors over Unheated Spaces

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

level). For walls, the proposed requirements are a series of lines centered through the averages of the bins except at low and high HDDs, where the wall U_o -values were essentially unchanged from those of 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 (Figures 5.9, 5.11, 5.15, and 5.17), 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, with requirements generally becoming incrementally more stringent to the north. The 1993 MEC has varying requirements for wall and ceiling U_o -values for much of the United States.

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_o -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_o requirement of 0.11 (most of the northern United States 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_o -Values to Assumptions

The sensitivity of the overall building U_o -values to several of the parameters defined in Sections 3 and 4 was examined with a sensitivity analysis. The overall U_o -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_o -value optimum.

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)

Table 5.3. Examples of Single-Family Window and Wall Requirements as a Function of Window Area for the Northern United States

Window area as a % of floor area	Complying Combinations of Wall Insulation Levels and Window Types for Wall U_o Requirement of 0.11 ^(a)		
	Wall Framing	Complying Batt and Rigid Insulation	Complying Window U_o -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_o -value (excluding Alaska).

(b) See Table 4.5 for window types and typical window U -values.

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_o -value for each variation was computed as the 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

- (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 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.

determined. The fourth column gives the change in the average U_o -value going from the low value to the high value, with the change expressed as a percentage of the average U_o -value for the value selected in the analysis (column five of this table). A positive U_o -value change represents an increase in the allowed U_o -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_o -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_o -value optimum. The choice of **mortgage interest** rate also has a significant effect on the optimum U_o -value. A change in the **ECM costs** can make an important difference in the optimum U_o -values. Moving from a 1% to a 3% **property tax** would raise the optimum U_o -value by 10%. 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_o -value as the deduction of the mortgage interest from income tax greatly benefits the homeowner. The **period of analysis** has a moderately large impact on the U_o -value. Increasing the period from 7 years to the 50-year building life would result in ECM optimums that reduce the U_o -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_o -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.

Table 5.4. U_o -Value Sensitivity to Selected Parameters

<u>Parameter Varied</u>	<u>Range</u>		<u>U_o-value</u>	<u>Parameter Value Selected</u>
	<u>Low</u>	<u>High</u>	<u>% Change</u>	
Down payment	0%	20%	+0.5%	10% (35% for multifamily)
Loan term	15	40	-1.4%	30 years
Discount rate (real)	2%	6%	+9%	4% (about 8% nominal)
Mortgage rate (nominal)	6%	10%	+9%	8% (9% for multifamily)
ECM costs	-20%	+20%	+13%	costs in Section 4
Property tax rate	1%	3%	+10%	1.36% average
Income tax (deduction)	18%	36%	-7%	24% (37% for multifamily)
Analysis period, years	7	50	-9%	30 years
Fuel price annual escalation rate	0%	4%	-12%	as shown in Table 3.1
Initial fuel prices	-20%	+20%	-13%	as shown in Appendix A

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 weighted average of the proposed changes for all 881 cities was used 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 5.6 shows the cost impacts for single-family homes by heating fuel/equipment type. The cost savings are significantly higher for electric resistance because of the high price of electricity.

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 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

Table 5.5. National Average Estimated Cost Impacts of Proposed Revisions

<u>Economic Parameter</u>	<u>Cost Change Per Housing Unit</u>	
	<u>Single-Family</u>	<u>Multifamily</u>
Life-cycle cost savings	\$700	\$300
Present value of energy cost savings	\$1100	\$510
Present value of nonenergy cost increase	\$400	\$210
First cost increase	\$420	\$270
Down payment increase	\$42	\$95
Benefit to cost ratio	2.75	2.4

Table 5.6. National Average Estimated Cost Impacts by Heating Fuel/Equipment Type for Single-Family Homes

<u>Economic Parameter</u>	<u>Cost for Single-Family Homes</u>			
	<u>Nat. Gas</u>	<u>Oil</u>	<u>Heat Pump</u>	<u>Elec. Res.</u>
Life-cycle cost savings	\$600	\$670	\$800	\$1900
Present value of energy cost savings	\$1000	\$1100	\$1200	\$2400
Present value of nonenergy cost increase	\$400	\$430	\$400	\$500
First cost increase	\$420	\$420	\$420	\$420
Down payment increase	\$42	\$42	\$42	\$42
Benefit to cost ratio	2.5	2.6	3.0	4.8

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.

A simple method of looking at the costs and benefits of higher energy efficiency over time is by studying the cash flow. Figure 5.18 shows the national average cumulative cash flow for a typical first owner of a single-family home. The figure shows the cash flow for a home built to the conservation levels proposed here relative to a home built to the 1993 MEC. A 30-year mortgage and a 10% down payment are assumed. At the time of the purchase, there is a cost of about \$48 to cover the increased down payment and other up-front cost increases. As the energy cost savings easily exceed the mortgage payment increases, the net cash flow for each year is positive (excluding the first year, which has the up-front costs). The cumulative cash flow becomes positive after only 2 years and

Figure 5.18. Typical Cash Flow for the First Owner of a Single-Family Home

continues to grow in all future years. Note that if the first owner sells the house in the future, any future owner will also obtain a positive cash flow after 2 years. The cash flow from increased conservation for future owners is even more favorable than the cash flow for the first owner because depreciation causes the purchase cost to decrease and future fuel cost escalation causes energy cost savings to increase.

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. In the opinion of the authors, the strongly positive cash flow and the short time to positive cash flow argue that the change proposed herein is strongly in the interest of the homeowner.

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, \$420, producing an estimate that the energy-efficiency standards would require an additional \$142 in family income and disqualify about 0.6% of the potential new homebuyers. This calculation assumes that no credit is given in the mortgage process for reduced homeowner expenses resulting from a reduction in energy costs and that the homebuyer does not cut expenses elsewhere in the cost of the residence. In the aggregate, the 99.4% of the homebuyers who can afford the price increase would 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. 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 greatly exceed 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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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, Heating \$/kWh	Electricity, Cooling \$/kWh	Nat Gas, \$/therm	LPG, \$/gal	Fuel Oil, \$/gal
Alabama	0.055	0.070	0.60	0.87	0.85
Alaska	0.084	0.103	0.38	1.31	1.01
Arizona	0.065	0.092	0.63	1.09	0.96
Arkansas	0.055	0.086	0.48	0.85	0.98
California	0.132	0.102	0.53	0.98	0.72
Colorado	0.070	0.071	0.43	0.55	0.79
Connecticut	0.086	0.102	0.79	1.07	1.08
Delaware	0.055	0.090	0.57	1.07	0.97
Washington, D.C.	0.056	0.065	0.67	0.99	1.05
Florida	0.084	0.083	0.74	0.99	1.22
Georgia	0.060	0.080	0.63	0.80	0.85
Hawaii	0.103	0.104	1.46	1.42	0.98
Idaho	0.051	0.050	0.47	0.93	0.93
Illinois	0.046	0.106	0.47	0.62	0.93
Indiana	0.049	0.073	0.50	0.80	0.95
Iowa	0.048	0.083	0.47	0.57	0.73
Kansas	0.057	0.084	0.42	0.62	0.79
Kentucky	0.047	0.061	0.45	0.94	0.86
Louisiana	0.065	0.079	0.55	0.90	0.82
Maine	0.110	0.095	0.72	1.14	0.95
Maryland	0.059	0.077	0.60	0.99	1.07
Massachusetts	0.092	0.098	0.72	1.05	1.04
Michigan	0.073	0.084	0.46	0.90	0.96
Minnesota	0.059	0.073	0.44	0.66	0.98

Table A.1. (contd)

State	Electricity, Heating \$/kWh	Electricity, Cooling \$/kWh	Nat Gas, \$/therm	LPG, \$/gal	Fuel Oil, \$/gal
Mississippi	0.051	0.074	0.49	0.75	0.58
Missouri	0.045	0.079	0.49	0.76	0.92
Montana	0.060	0.055	0.42	0.79	0.81
Nebraska	0.037	0.066	0.44	0.62	0.86
Nevada	0.064	0.058	0.52	1.03	0.86
New Hampshire	0.104	0.105	0.69	0.94	0.94
New Jersey	0.058	0.105	0.61	1.11	1.06
New Mexico	0.081	0.091	0.51	0.73	0.82
New York	0.113	0.116	0.68	1.08	1.07
North Carolina	0.070	0.084	0.57	0.89	1.01
North Dakota	0.052	0.067	0.43	0.63	0.87
Ohio	0.059	0.086	0.48	0.95	0.94
Oklahoma	0.040	0.070	0.45	0.65	0.93
Oregon	0.048	0.048	0.58	1.10	0.89
Pennsylvania	0.062	0.094	0.60	1.02	0.99
Rhode Island	0.095	0.100	0.67	1.09	1.06
South Carolina	0.067	0.076	0.66	0.83	0.96
South Dakota	0.049	0.074	0.48	0.57	0.70
Tennessee	0.060	0.061	0.47	0.94	0.84
Texas	0.052	0.077	0.53	0.82	0.55
Utah	0.069	0.073	0.46	0.73	0.91
Vermont	0.127	0.094	0.56	1.09	1.02
Virginia	0.061	0.077	0.61	1.03	1.05
Washington	0.052	0.045	0.46	0.97	1.00
West Virginia	0.057	0.063	0.57	0.99	0.96
Wisconsin	0.066	0.071	0.54	0.79	0.90
Wyoming	0.048	0.061	0.42	0.85	0.81

(a) The costs in Table A.1 are from the EIA's report of 1990 prices (EIA 1992) and inflated to 1992 prices using the rates in Table A.2 which are from the Monthly Energy Review (EIA 1993). 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.2 shows the fuel price escalation rates used to update the 1990 fuel prices to more current 1992 prices. Table A.3 shows the seasonal electricity price adjustments to account for the higher price of electricity in the summer relative to the yearly average.

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

<u>Fuel</u>	<u>Escalation Rate (% over entire period)</u>
Fuel oil and LPG	-12.1
Natural gas	1.2
Electricity	5.1

Table A.3. Seasonal Electricity Price Variation^(a)

<u>Census Region</u>	<u>Summer Adjustment</u>
Northeast	1.00
North Central	1.05
South	1.05
West	1.00

- (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 Edison Electric Institute reports (1992, 1993). 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_o -Value Calculations

This appendix describes the assumptions and calculations used to determine thermal conductances (U_o -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_o -values are the bottom line, and that construction materials and techniques may vary from those described below but still produce similar U_o -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/ft² 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_o -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

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

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

<u>Nominal R-Value</u>	<u>Average Insulation R-Value</u>	<u>Insulation R-Value Above Joists (R_{ij})</u>	<u>U_o-Value of Ceiling Including Framing</u>
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 assumptions, the 16-in. O.C. translates to a framing fraction of 15% of the opaque wall area (ASHRAE 1989).

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

<u>Description</u>	<u>(7%) R-Value at Joists</u>	<u>(93%) R-Value at Insulation</u>
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/Ceilings (refer to Table B.3 for calculation details)

<u>Batt Insulation R-Value</u>	<u>Rigid Insulation R-Value</u>	<u>Rafter R-Value</u>	<u>U-Value of Ceiling Including Framing</u>
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

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 this split for the stud O.C. distance. 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

<u>Description</u>	<u>(12% or 15%) R-Value at Studs</u>	<u>(88% or 85%) R-Value at Insulation</u>
Outside air film	0.17	0.17
Plywood siding	0.59	0.59
Sheathing	R _s	R _s
Wood studs	R _w	--
Insulation	--	R _i
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* =	$\frac{0.15}{1.89 + R_s + R_w}$	$\frac{0.85}{1.89 + R_s + R_i}$
U _o -Value for 24-in. O.C. construction =	$\frac{0.12}{2.00 + R_s + R_w}$	$\frac{0.88}{2.00 + R_s + R_i}$

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

<u>Nominal Insulation R-Value</u>	<u>Batt R-Value (R_i)</u>	<u>Rigid Insulation (R_s)^(a)</u>	<u>Stud R-Value (R_w)</u>	<u>U_o-Value of wall</u>
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	0.0549
13	13	7	4.38	0.0501
19	17.8	4	6.88	0.0473
15	15	7	4.38	0.0469
21	21	4	6.88	0.0430
19	17.8	7	6.88	0.0411
21	21	7	6.88	0.0377

(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/hrft²°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.

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_o-values from the optimum ECMs are based on window U-values with the normal rating conditions of 15-mph wind speed for windows.

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

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_o -values for floors over unheated spaces are shown in Table B.8.

Table B.8. Floor ECM U_o -Values

<u>Batt R-Value</u>	<u>U_o-Value of Floor including framing</u>
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

2 of 2

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
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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	Cuiver 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
San Bernardino
San Jose
Santa Barbara
Santa Paula
Tracy
Visalia

Riverside
San Diego
San Luis Obispo
Santa Cruz
Santa Rosa
Tustin
Watsonville

Sacramento
San Francisco
San Rafael
Santa Maria
Stockton
Upland
Woodland

Salinas
San Gabriel
Santa Ana
Santa Monica
Torrance
Vacaville
Yorba Linda

Colorado

Boulder
Durango
Lakewood

Canon City
Fort Collins
Longmont

Colorado Springs
Grand Junction
Pueblo

Denver
Greeley
Sterling

Connecticut

Bridgeport
Hartford
Norwalk

Danbury
Meriden
Storrs

Enfield
Middletown
Waterbury

Groton
New Haven

Delaware

Dover

Newark

Wilmington

District of Columbia

Washington

Florida

Bartow
Daytona Beach
Fort Pierce
Jacksonville
Miami
Palatka
St. Petersburg
Tampa
Winter Haven

Belle Glade
Deland
Gainesville
Key West
Naples
Pensacola
Sanford
Titusville

Bradenton
Fort Lauderdale
Hialeah
Lakeland
Ocala
Plant City
Sarasota
Vero Beach

Clearwater
Fort Myers
Homestead
Melbourne
Orlando
Pompano Beach
Tallahassee
West Palm Beach

Georgia

Albany
Augusta
Covington
Fitzgerald
Milledgeville
Savannah

Americus
Brunswick
Dalton
Gainesville
Moultrie
Thomasville

Athens
Carrollton
Douglas
La Grange
Newnan
Tifton

Atlanta
Columbus
Dublin
Macon
Rome
Waycross

Hawaii

Hilo
Lahaina

Honolulu

Kahului

Kaneohe Mauka

Idaho
Boise
Moscow

Caldwell
Pocatello

Coeur d'Alene

Idaho Falls

Illinois

Alton
Carbondale
Danville
Effingham
Joliet
Monmouth
Peoria
Rantoul
Waukegan

Aurora
Champaign
Decatur
Elgin
Kewanee
Mount Vernon
Peru
Rockford
Wheaton

Belleville
Charleston
De Kalb
Galesburg
Lincoln
Ottawa
Pontiac
Springfield

Bloomington
Chicago
Dixon
Jacksonville
Mattoon
Park Forest
Quincy
Urbana

Indiana

Anderson
Elwood
Gary
Huntington
Lafayette
New Castle
South Bend
Wabash

Bloomington
Evansville
Goshen
Indianapolis
Marion
Richmond
Terre Haute
West Lafayette

Columbus
Fort Wayne
Greenfield
Kokomo
Martinsville
Seymour
Valparaiso

Crawfordsville
Frankfort
Hobart
La Porte
Muncie
Shelbyville
Vincennes

Iowa

Ames
Clinton
Fort Dodge
Marshalltown
Oskaloosa
Waterloo

Ankeny
Davenport
Indianola
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Ottumwa

Boone
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Augusta
Presque Isle

Bangor
Waterville

Lewiston

Portland

Maryland
Baltimore
Hagerstown

Cambridge
Laurel

College Park
Rockville

Cumberland
Salisbury

Massachusetts
Amherst
Fitchburg
Lowell
Taunton

Boston
Framingham
New Bedford
Worcester

Brockton
Haverhill
Pittsfield

Clinton
Lawrence
Springfield

Michigan
Adrian
Bay City
Detroit
Grand Rapids
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Mt Pleasant
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Ypsilanti

Alpena
Benton Harbor
Escanaba
Holland
Marquette
Muskegon
Saginaw

Ann Arbor
Big Rapids
Flint
Jackson
Midland
Owosso
Sault Ste Marie

Battle Creek
Cadillac
Grand Haven
Kalamazoo
Monroe
Pontiac
Traverse City

Minnesota
Albert Lea
Duluth
Marshall
St. Paul

Austin
Fairmont
Minneapolis
Virginia

Bemidji
Faribault
Rochester
Willmar

Cloquet
Fergus Falls
St. Cloud

Mississippi
Biloxi
Cleveland
Greenwood
Laurel
Tupelo

Brookhaven
Columbus
Gulfport
Meridian
Vicksburg

Canton
Corinth
Hattiesburg
Natchez
Yazoo City

Clarksdale
Greenville
Jackson
Picayune

Missouri
Carthage
Jefferson City
Mexico
St. Joseph

Columbia
Joplin
Moberly
St. Louis

Fulton
Kansas City
Poplar Bluff
Sedalia

Hannibal
Kirksville
St. Charles
Sikeston

Springfield

Warrensburg

Montana

Billings
Havre

Bozeman
Helena

Butte
Kalispell

Great Falls
Missoula

Nebraska

Beatrice
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North Platte

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Roswell

Artesia
Hobbs
Santa Fe

Carlsbad
Las Cruces

New York

Albany
Canandaigua
Fredonia
Lockport
Ogdensburg
Rochester
Syracuse

Batavia
Cortland
Geneva
Massena
Oswego
Rome
Utica

Binghamton
Dobbs Ferry
Gloversville
Mineola
Patchogue
Scarsdale
Watertown

Buffalo
Elmira
Ithaca
New York
Poughkeepsie
Schenectady

North Carolina

Albemarle
Burlington
Durham
Goldsboro
Kinston
Lumberton
Raleigh

Asheboro
Chapel Hill
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Monroe
Reidsville

Asheville
Charlotte
Fayetteville
Hickory
Lenoir
Morganton
Rocky Mount

Boone
Concord
Gastonia
High Point
Lexington
New Bern
Salisbury

Shelby
Winston-Salem

Statesville

Wilmington

Wilson

North Dakota

Bismarck
Mandan

Dickinson
Minot

Grand Forks
Williston

Jamestown

Ohio

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Bellevue
Canton
Columbus
Delaware
Greenville
Lima
Norwalk
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Wooster

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Dover
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Tiffin
Warren
Xenia

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Columbia
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Laurens

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Huron
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Mitchell
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Tennessee

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Mc Minnville
Oak Ridge
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Columbia
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Paris
Union City

Texas

Abilene
Austin
Big Spring
Brownwood
College Station
Del Rio
Fort Worth
Harlingen
Huntsville
Laredo
Midland
Palestine
Port Lavaca
Snyder
Tyler
Waco
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Alice
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Borger
Bryan
Corpus Christi
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Racine
Two Rivers
West Allis

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Rock Springs

Gillette
Sheridan

Green River

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

<u>State</u>	<u>Property Tax (%)</u>	<u>State Tax (%)</u>
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

Table D.1. (contd)

<u>State</u>	<u>Property Tax (%)</u>	<u>State Tax (%)</u>
Massachusetts	1.4	5.0
Michigan	2.3	3.8
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

Appendix E

Summary of Changes from 1993 Proposal

Appendix E

Summary of Changes from 1993 Proposal

The proposed code changes to 1994 roof/ceiling, wall, and floor U-value requirements documented in this report are similar to changes proposed in 1993. The report Technical Support Document for Proposed Revision of the Model Energy Code Thermal Envelope Requirements (Conner and Lucas 1993) documents the technical analysis underlying the 1993 proposal. All major aspects of the methodology to determine the minimum life-cycle cost conservation levels that form the proposed requirements are the same as in last year's proposal. However, numerous changes and improvements have been made to inputs to the technical analysis between the code changes proposed in 1993 and 1994. This revised report documents the updated analysis for the 1994 submittals.

Some readers may be familiar with the analysis for the original 1993 proposal (presented in March 1993) and may want to know specifically what changes were made for the 1994 proposal without reading this entire document. This appendix briefly summarizes these changes. Refer to the section numbers shown in parentheses below for more information on the specific assumptions and methods used in the analysis to produce the 1994 proposed code changes.

- For the multifamily analysis, a completely new set of financial parameters was determined to better reflect the economics of rental property (Section 3.1.2).
- For the single-family analysis, mortgage points and loan fees are included as up-front costs, whereas, in the original analysis, points and loan fees were factored in the mortgage interest rate (Section 3.1.1).
- A mortgage insurance rate equivalent to an up-front cost of 3.5% of the mortgaged amount was assumed for single-family homes. The original analysis implicitly assumed no mortgage insurance (Section 3.1.1).
- The marginal federal income tax rate was lowered from 28% to 21% to account for the segment of home owners who deduct mortgage interest payments at the 15% marginal rate (Section 3.2.5).
- Fuel prices were updated slightly with the most current data available. Electricity heating prices were changed to more accurately reflect marginal electricity rates. The variation between annual and cooling season electricity rates is now accounted for using Edison Electric Institute data (Section 3.3.1, Appendix A).

- Fuel price escalation rates for the future are from DOE's 1993 Annual Energy Outlook (Section 3.3.2).
- Walls requiring 2x6 lumber are assumed to have 22% of the studs spaced 24 in. apart and 78% of the studs spaced at 16 in. (Section 4.1.2).
- Local construction cost multipliers applied to national average data for each state were raised by 5% to account for an apparent discrepancy in the source (Means Residential Cost Data) (Section 4.1).
- Construction cost data were updated using the 1993 Means Residential Cost Data in place of 1992 Means data (Section 4.1).
- Lumber prices were raised by 25% to reflect the increase in cost of lumber from the original analysis done in late 1992. This affects the cost of increases in insulation levels in some cases, such as R-19 insulation in walls, which require 2x6 studs instead of 2x4 studs (Section 4.1.1).
- The original analysis assumed that each of the 881 U.S. cities analyzed receive equal weighting in determining average U_o -values. No adjustments were made for relative population and/or number of recent housing starts. The results presented here are based on new home start data from the U.S. Department of Commerce's Housing Units Authorized by Building Permits; December 1992 (Section 5.1).
- The penetration of central air conditioners in new single-family homes was accounted for on a state-by-state basis using NAHB data. The original analysis assumed all homes have direct expansion air conditioning (Section 5.2).
- The use of hydronic systems for distributing space heating in new housing was accounted for. The original analysis assumed all fossil fuel heating system had ducted air distribution. Hydronic systems have a much lower distribution loss of 4% (Section 4.3.1, Section 5.2).
- Distribution losses for multifamily buildings were lowered to 5% for ducted systems and 0% for hydronic systems (Section 4.3.1).
- No requirements for any insulation over unheated spaces is proposed in climates with less than 500 HDD because insulation is generally not cost-effective in these very mild climates. The requirements for unheated basements and crawlspaces were split for climates with 500 to 1500 HDD, as insulation is not generally cost-effective for basements while insulation for crawlspaces is cost-effective (Section 5.3).

Reference

Conner, C. C., and R. G. Lucas. 1993. Technical Support Document for Proposed Revision of the Model Energy Code Thermal Envelope Requirements. PNL-8546. Pacific Northwest Laboratory, Richland, Washington.

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