Better Building Codes for Energy Efficiency

B.D. Howard
Member ASHRAE

M. McBride, Ph.D.
Member ASHRAE

ABSTRACT

This paper discusses the energy, fuel, and dollar savings, life-cycle economics, consumer affordability, and environmental benefits that could be gained from the rapid adoption of the 1990 version of the Council of American Building Officials' Model Energy Code (MEC) for new residential buildings. The 1990 MEC is the 1989 Model Energy Code plus 1990 amendments. Technically supportable, calculable, and replicable savings and benefits resulting from the adoption of more stringent thermal envelope standards in state building codes are reviewed, and the methodologies used are discussed.

The analytical approach used and the information contained in this report is entirely new. It is based on extensive research on actual housing characteristics, installed mechanical equipment, and space-conditioning fuels consumed in a large sample of U.S. housing starts. It is representative of more than half of 1991 U.S. residential construction, including both single-family and multi-family homes.

Significant energy savings, reductions in fuel use, and economic and environmental benefits could accrue through adoption of the MEC in states with less stringent residential energy codes. The Alliance to Save Energy determined that immediate adoption of the MEC in 34 states would, in the first year alone,

- *save 7.2 trillion Btu (7.6 quadrillion joules) of energy in each year's new home production—equivalent to the heating and cooling energy for nearly 70,000 single-family homes for a year;*
- *eliminate 565,000 tons (510 million kg) of energy-related air pollution from power plant and on-site fuel combustion emissions; and*
- *reduce the home buyers' heating and cooling bills by \$76 million, saving average owners about \$130 in the first year per housing unit (\$160 for single-family homes).*

Over the assumed life of a 30-year mortgage, adopting the MEC would provide a benefit-cost ratio of 3.0 and a net present value (energy savings) of \$687 million for a moderate \$511 million added first cost for the energy-efficient enhancements.

Using the MEC in state building codes would lead to significant reductions in air pollution, lowering the environmental externality costs of energy utilization in new residential buildings due to the resulting lower energy use in the nearly 600,000 annual housing starts affected. Thus, not only consumers of these new homes benefit, but society stands to gain significant benefits as a result of MEC adoption.

INTRODUCTION

The energy-efficiency provisions of building codes, administered chiefly by state and local governments in more than 8,000 jurisdictions, have a major effect on the energy consumption and environmental impacts of new housing. The Alliance to Save Energy (the Alliance) conducted a detailed technical review of the recently revised Council of American Building Officials' (CABO) 1989 Model Energy Code (MEC), including its 1990 revisions, to determine the economic, environmental, and housing affordability benefits of increased levels of building envelope energy efficiency in the state codes that it could provide.

Our findings generally support conclusions developed in recent studies by other agencies, such as Lee et al. (1990), that the MEC represents a practical and cost-effective set of residential energy-efficiency criteria for state and local building officials to reference as they upgrade their 10- to 15-year-old energy standards. Because the MEC is in a very similar format to the *ANSI/ASHRAE/IES 90A-1980* standard but is more efficient thermally and uses familiar means to establish compliance, there is little administrative burden in its local adoption. The CABO consensus process provides unique opportunities to accelerate the transfer of technically advanced, cost-effective, and affordable designs, systems, materials, components, and products into practical use in U.S. housing.

Significance of Energy Efficiency

Our buildings use about 36% of the primary energy consumed in the United States (DOE-EIA 1987). According to the Office of Technology Assessment (OTA 1992), the energy consumption of U.S. buildings was 30 quads (quad = 10^{15} British thermal units) in 1989, out of nearly 80 quads—the total U.S. primary energy consumption. This prodigious amount is almost equal to the total industrial energy use of the United States. The U.S. Department of Energy (DOE) has calculated that about 30% of the anticipated building energy consumption could be cheaply saved

Bion D. Howard is program manager at the Alliance to Save Energy, Washington, DC. **Merle McBride** is a research associate at the Owens-Corning Fiberglas Technical Center, Gransville, OH.

Foundation thermal criteria data and methods were provided by a national laboratory. Researchers, questioning the limited accuracy of the DOE2.1 foundation heat transfer algorithms, developed the 90.2 slab, crawl space, and basement thermal performance data and system utilization information for representative building foundations. The analytical approach they used is described in the *Building Foundation Handbook* (ORNL 1987).

Following calculation of the difference in thermal energy use, for both the heating and cooling loads, between the existing energy code and the MEC, another set of calculations is performed to determine whether the mechanical equipment for heating and cooling could be downsized according to standard engineering practice. Increments of downsizing used were based on the mechanical system's utilization and cost data (NAHB Research Center 1986). If a less costly mechanical plant could be used according to the calculation, this cost result was preserved and credited against the gross cost of additional energy-efficiency (thermal protection) required by upgrading from the building envelope energy-efficiency levels of the existing building code to the more energy-efficient MEC efficiency levels.

Conversion to fuel savings was made using mechanical system efficiencies listed in ASHRAE 90A-80 and the 1990 marginal fuel prices for oil and natural gas space heating and electric heat and air conditioning developed from reference sources. The marginal fuel price is the price of the next increment of delivered utility commodity (fossil fuels or electricity) to provide useful comfort conditioning after the base demand is met at the house. The base demand is composed of water heating, illumination, cooking, etc. Utility data analysis shows the marginal fuel price for space conditioning is almost never the same as the average billing price.

The least costly set of building envelope thermal protection options was selected from a large data base of cost information derived from several sources, including a report to the ASHRAE 90.2 committee (NAHB Research Center 1986). These cost data were updated to 1990 dollars by discrete cost escalation (inflation) multipliers for each class of material (wall framing, insulation, mechanical equipment, labor, etc.) described in the data base. The construction cost inflation data were derived from NAHB *Housing Economics*, the *Engineering News Record*, and the U.S. Department of Census *Statistical Abstracts—1990*.

Analytical Program Structure

The analyses conducted for this project were completed using a specialized computer program developed specifically for this project. It consists of a main source program and three major subroutines. All of the code was written in Fortran and runs on a mainframe computer. A brief overview of the computer model's structure is provided in this section.

The main source program, ASE, was structured to read in all of the data, perform calculations, call the subroutines, accumulate the data, calculate averages, and print the tables of energy and economic results. The main program structure consists of three nested loops: first the city (1-259), next the house (1-33) (within the "house" loop both codes are analyzed, state and MEC), and finally the HVAC loop (1-11). The results of each individual calculational case are accumulated. The main program calculates the heating and cooling load savings using the envelope load factors presented in ASHRAE Standard 90.2P (McBride 1991). The load savings are then converted into energy savings using distribution loss factors and the HVAC equipment efficiencies. The energy savings are converted into annual cost savings using marginal fuel price data. The main source program also calculates the first costs associated with compliance to the state code and to the MEC.

The WALCOMP subroutine searches for the lowest first cost wall assembly option that meets the wall Uo criteria. This is necessary because the individual requirements for the opaque wall, fenestration, and doors are all combined into one overall thermal transmittance (Uo) value. The searching routine checks 21,440 combinations for compliance, which consist of 67 opaque wall options (sheathing and cavity insulation options with 2×4 and 2×6 framing options), 20 glazing options, four front door options, and four rear door options. Determining wall compliance through this search technique is a significant feature of the program because it ensures a consistent and unbiased compliance option to meet a specific Uo value requirement.

Another key feature of the main source program is the weighting of results by various statistical saturations. All of the data on thermal load savings, fuel savings, and economic variables are statistically weighted by housing starts, saturation of house type, saturation of foundation type, saturation of HVAC type, and saturation of fuel type.

The incremental savings associated with any downsizing of the HVAC equipment that occurs due to improvements in thermal envelope efficiency is included in calculating the first costs of MEC compliance. This DESIGN subroutine calls a file containing the HVAC system saturations by state or census region as a function of building type including 11 categories:

- gas furnace,
- electric furnace,
- oil furnace,
- gas boiler,
- electric boiler,
- oil boiler,
- heat pump,
- electric baseboard,
- gas furnace with central air conditioning,
- electric furnace with central air conditioning, and
- oil furnace with central air conditioning.

in buildings through "the application of cost-effective energy efficient technology" commercially available today. These energy savings could equal $77 billion by 2010 (DOE 1990).

Housing energy use accounts for nearly 60% of the building sector's energy demand, and our residential building stock currently consumes more than 30% more energy than our commercial building stock. Housing has a larger square footage—157 billion ft^2 (14.6 billion m^2) according to EPRI estimates—than does our commercial building space. More than 70% of the nation's households occupy one- and two-family dwellings, while slightly less than 30% occupy multi-family dwellings. One- and two-family homes represent about 85% of the residential floor space and thus consume the major portion of this sector's energy.

Establishing a nationwide technically supportable, economically reasonable, environmentally responsible, and up-to-date set of residential building thermal criteria is overdue. The adoption of more stringent building energy standards in the model codes and by states has lagged in recent years due to apathy about energy issues and the lack of clear federal leadership on energy policy. Housing today is nearly 35% to 40% more energy efficient than in 1970, but continued gains are needed in view of the increasing U.S. oil vulnerability and serious environmental consequences of energy use, such as potential global climatic change, acid rain, strip-mining damage, oil-spill water pollution, and nuclear waste management. Adopting new standards may save more than 50% of the anticipated building energy requirements for space conditioning while helping the environment, according to the U.S. Environmental Protection Agency. Work by others indicates 90% savings may be technically feasible.

ANALYTICAL PLAN AND METHODOLOGIES

This analysis was designed to evaluate the residential thermal envelope energy criteria in the MEC compared to current provisions in state building codes. The project work plan had six parts:

- the creation of the detailed plan of analysis;
- a data-gathering phase;
- an input development phase;
- computer analysis program development;
- calculation of the thermal, fuel savings, economics, and affordability results; and
- the accurate reporting of the findings in a detailed technical report.

The fundamental approach taken was to calculate incremental energy, fuel, and dollar savings at the housing-unit level for 259 cities nationwide. This was done using 33 housing prototypes and 11 possible mechanical system combinations, verified by statistical data on the actual frequency of construction of specific housing types, installed mechanical system configurations, and heating and cooling fuels used. Cost information on the differences between current state code and MEC thermal efficiency levels representing incremental first cost of construction was determined using a sorting routine that selects the most economical residential construction arrangement meeting the thermal requirement imposed by the code requirements comparison data base.

Marginal utility and fuel prices were used, along with representative climatic data developed by ASHRAE. Aspects of the thermal analysis and economic assessment are similar to those described by McBride (1991). Reference statistical information, including fuel utilization frequency, mechanical systems type and efficiency, local housing types, foundations and their insulation systems, and other information indicative of actual housing characteristics, was used to make the results as representative as possible. Also, where the MEC's better thermal protection levels permitted downsizing of the mechanical system according to standard engineering practice, credit was given in the net construction cost accounting.

Following the detailed calculation of the city-level energy efficiency, fuel savings, and economic parameters, sets of accumulated and averaged results were generated for states, regional model code jurisdictions, and the nation as a whole. Environmental benefits of reductions in air pollution emissions and their estimated externality dollar value were then calculated from the state results to complete the investigation.

Energy Saving Calculations

The calculation approach to determine energy savings comparing the more stringent MEC levels with current state energy code levels is based on methods used by the ASHRAE 90.2 Standards Project Committee, Thermal Envelope Panel. This approach uses the envelope thermal loads correlation data developed in the Affordable Housing through Energy Conservation project. Thousands of hourly DOE2.1 computer simulation runs, along with detailed sensitivity studies checking numerous housing attributes and extensive correlation analysis, form an extensive data base of incremental energy-efficiency load factors describing above-grade thermal envelope construction typical of U.S. housing (McBride 1991; DOE 1989; ASHRAE 1988; Huang et al. 1987).

Building envelope energy calculations were made for each residential prototype building in the computer analysis program. Calculations use the thermal differences between the existing building code criteria construction data set based on compliance data in the *Energy Directory* (NCSBCS 1989) and the 1989 MEC thermal envelope criteria, using the same prototype building description. A difference in thermal energy use is then calculated for each prototype building in each city.

The HVAC saturation data were assumed to be uniform across the states or regions, but the data format allowed for alternative subsystem saturations when substantiating data were identified. The subroutine calculates the heating and cooling design loads for sizing the HVAC equipment. DESIGN directly follows standard procedures presented in an ASHRAE technical paper (McQuiston 1984). Data from this calculation are used to detect differences and credit load decrement costs against gross thermal protection costs. If the decrement in loads from adopting the MEC thermal criteria is enough to allow installation of the next smaller HVAC plant, a cost credit is taken against the gross cost of energy improvements for the building(s), much like a builder trading off component first costs.

The final subroutine, ECON, calculates economic variables, specifically, the benefit-to-cost ratio (BCR), the net present value (NPV), and the years to positive cash flow (YPCF), developed to address affordability in terms of how long it takes for energy savings to provide positive cash flow. However, errors in using the accumulated data ultimately lead to making the YPCF calculations separately, using the state, code-region, and national energy saving and cost results provided from the main program.

Economics and Financial Analysis

A vital part of any complete analysis comparing current to proposed thermal envelope energy-efficiency criteria is the calculation of economic parameters to communicate the relative cost-effectiveness of the proposed changes. The methods used to assess the economic and financial impact of the MEC were net present value, benefit cost ratio, and a cash-flow "affordability" test. Standard economic measures were used to describe these terms numerically. However, there currently is no standard measure of consumer affordability. We elected to report the results of the affordability cash-flow test expressed as years, similar to a payback result, rather than in absolute dollars. A cash-flow approach to determining affordability has been advocated by NAHB for ten years. A home has been termed by NAHB as affordable if the energy investments enter into positive cash flow no later than the end of the second year following purchase (Johnson and Johnson 1982).

Three methods were used for evaluating the relative cost-effectiveness of the MEC provisions compared to existing codes for specific cities. Two of these calculations were life-cycle-cost net present value (NPV), and a benefit-to-cost ratio (BCR) calculation. We avoided specific calculation of simple payback since prominent energy economists have indicated using it is inherently misleading (Ruegg 1990) since it cannot account for the time value of money or for fuel cost escalation.

Life-cycle cost benefit analysis was performed using methods described in standard practices of the American Society for Testing and Materials and listed together in a recent compendium (ASTM 1992). The methods are identical to those used by the Federal Energy Management Program (Ruegg 1990). The life span analyzed for the LCC calculations was set to 30 years, typical of a fixed-rate residential mortgage. We used two discount rates in the calculations, 7% and 10%, based on consumer economics information from the National Institute for Standards and Technology, ASHRAE 90.2, and other sources.

Three other discount rate scenarios were studied for sensitivity. Some evidence exists that for lower-income buyers, in a disinflationary economy, 7% to 10% discount rates are conservative (numerically higher return than their competing investment choices) and rates as low as 4% to 5% could be appropriate and justified (Peterson 1981).

The net present value (NPV) of the savings resulting from more energy-efficient MEC thermal protection measures is calculated using the present value of the energy savings over a 30-year useful building life cycle, minus the present value of net incremental costs, to yield the result. Table 1 contains data on general economic parameters and reference correction factors used in the detailed economic calculations.

The benefit-cost ratio (BCR) uses the present value of energy savings (MEC versus current state code) calculated using the discount and escalation rates specified in Table 1, divided by the incremental cost, in 1990 dollars, of the additional thermal protection required to meet the MEC. This result is then expressed as a decimal, e.g., 1.5, 3.2, etc., with numbers significantly greater than 1.0 indicating cost effectiveness (Ruegg 1990; Ternes et al. 1991).

The affordability test (YPCF) was made to determine the financial impacts on home buyers of the energy-efficiency improvements in the MEC criteria. During preliminary analysis, two different assumptions were made about how energy improvements are financed. The first set of assumptions considers that the entire cost of the building energy

TABLE 1
Economic Parameters for Comparison of the MEC to State Energy Codes

(Parameter)		(Factor)
Inflation - Base rate		4.5%
Cost of Construction Materials (Escalation Rates)		
Insulation		1.0202
Wood Framing		1.1650
HVAC Equipment		1.1260
Labor Costs		1.2530
Update energy prices to 1990 dollars:		
Heating, Electrical		1.0200
Cooling, Electrical		1.0000
Natural Gas		1.0290
Fuel oil		1.1070(1)
Mortgage term		30 years
Mortgage rate		9.50%
Origination/disc. fee		2.3%
Federal income tax rates		28.0%
Local property tax rate		2.0%
State Income tax		(n.a.)
NIST "real" discount, + inflation	(Low)	7.00% (2)
	(High)	10.00%

NOTES: 1. Does not include the "blip" of Iraq war. 2. Sensitivity studies were performed at five discount rates. n.a. – denotes not applicable improvements is financed in the mortgage. The second set assumed the buyer makes an additional down payment at 16.7% (the NAHB-calculated average down payment as of April 1990) to cover the improvements and finances the balance of the improvements.

The first scenario is more probable in the case where the MEC becomes the reference statewide building code. Since all builders would add the cost of increased energy efficiency into the overall price of homes, it is likely the energy-efficiency costs would be considered a normal portion of the overall cost of the home. In addition, housing finance data from the federal government suggest there are relatively few home buyers who are so marginally qualified that an additional small ($25 to $145) down payment would be problematic.

DATA SOURCES

The data sources used were intended to allow for repeatability and ease of future updates and provide the most up-to-date information available through September 1991. These included gathering housing characteristic and economic data from the National Association of Home Builders (NAHB) and other credible sources to develop the data base.

Other data sources include the American Gas Association (AGA); the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); the U.S. Department of Energy (DOE); the Energy Information Agency (EIA); Lawrence Berkeley Laboratory (LBL); the National Association of Regulatory Utility Commissioners (NARUC); the National Conference of States on Building Codes and Standards (NCSBCS); the National Institute for Standards and Technology (NIST, formerly the Bureau of Standards); the U.S. Departments of the Census and of Commerce; and the WEFA Group (tracks housing starts and permits nationwide).

Energy-Efficiency Construction Costs

The cost data for energy-efficient construction options was derived from a report (NAHB Research Center 1986) used by the ASHRAE Standard 90.2 committee on Energy Efficient Design of New Low-Rise Residential Buildings. The incremental construction cost data on added insulation, changes to framing to accommodate additional insulation, as well as the mechanical system sizing and efficiency information was coded into a data base. The data were corrected to current dollars using the escalation factors from finance and economics journals and other reference literature. Foundation insulation costs identical to those used by ASHRAE are also included in the construction cost data base.

Insulation The insulation cost data are directly traceable to the ASHRAE 90.2 cost data base. Data for insulation systems consist of generic incremental costs per square foot of installed product in typical structural configurations. Data on foam plastic board insulation used for sheathing, built-up roofs, and foundations were also included. Corrections for cost escalation (described in Table 1) were applied to bring the construction cost data up to date.

Framing Changes Any wall, ceiling, or roof framing changes required to accommodate code-required increased thermal protection were considered and accounted for in the analysis. The incremental costs of structural changes needed to accommodate better insulation were added to the gross cost of the thermal protection system. These costs were added in cases where structural framing had to be thickened in order to accommodate insulation and where no less costly options were available. The gross cost of added thermal protection is the sum of the applicable insulation, framing, and labor costs to boost the building's thermal envelope up to the more stringent MEC levels.

Analysis of Windows The requirements for thermal protection of walls in this analysis uses the Uo approach for fenestration described in the *1989 ASHRAE Handbook—Fundamentals* (ASHRAE 1989). To simulate a builder's decisionmaking, the model included 20 window types that were sorted in the cost optimization process to provide the necessary overall U-value at least cost. Within the wall cost data base, the package with the lowest cost that meets the steady-state requirement is automatically selected when both the MEC and the existing code requirements are translated into thermal values.

MECHANICAL SYSTEMS AND DISTRIBUTION EFFICIENCY

Mechanical efficiency and distribution effectiveness assumptions are necessary in any energy analysis that uses differential thermal load data to process resultant economic valuation of energy savings as their fuel equivalent (Btu to therms, gallons, or kWh). Both current efficiency levels for mechanical equipment and typical distribution loss assumptions for forced-air systems must be accounted for.

We used the same approach to distribution losses as the ASHRAE 90.2 alternate compliance path, where different inefficiencies are assigned by house and equipment type (ASHRAE 1991). These data are traceable to California Energy Commission studies used by the ASHRAE 90.2 committee. The so-called current ASHRAE 90.2 requirements for mechanical system efficiency were used for the purposes of this analysis. These efficiency levels, shown in Table 2, have, in effect, been standard practice since late 1984 in numerous state and local building codes, in the MEC, and were in effect at the time this study was done.

As of 1992, new federally mandated efficiency levels for mechanical space conditioning are in effect due to the National Appliance Energy Conservation Act (NAECA) of 1987. A separate output using NAECA 1987 equipment

TABLE 2
Mechanical Equipment Efficiency Levels Used

Equipment Description	Efficiency	Factor
Gas-fired warm-air furnace < 225,000 Btu/h	66	AFUE (1)
Oil-fired warm-air furnace < 225,000 Btu/h	69	AFUE
Gas-fired hydronic boilers	66	AFUE
Oil-fired hydronic boilers	69	AFUE
Unitary air-source heat-pump	8.5	SEER
	6.4	HSPF
Unitary air-cooled A/C	8.5	SEER

Notes: From DOE Test Procedure. 10 CFR 430, Test Procedures for Consumer Products.
AFUE: Annual fuel utilization factor.
SEER: Seasonal energy-efficiency ratio.
HSPF: Heating seasonal performance factor.

standards produced unpublished results that show the upgraded MEC thermal envelope increment compared to existing levels in codes are still generally cost-effective even when more efficient mechanical systems are considered (McBride and Braun 1991).

ENVIRONMENTAL BENEFITS

Conversion data from the literature were used for calculation of the amounts of carbon dioxide (CO_2), sulfur dioxide (SO_2), oxides of nitrogen as NO_2, and particulate matter avoided by the adoption of the MEC thermal envelope criteria. Using data from the National Association of Regulatory Utility Commissioners (NARUC) and ASHRAE (1989), we were able to estimate air pollution avoidance due to the improved energy efficiency of the MEC compared to current codes. The project analysis plan facilitated this further study since energy savings results were already segregated by actual fuels conserved and electric power saved by meeting the MEC. The environmental benefits were calculated directly from the fuel-saving results of the study as estimates of avoided pollution tonnage and to provide a range of dollar values of the environmental externality cost reductions.

Summary of Assumptions Used

Accurate estimates of pollution emission quantities due to various energy utilization activities are vital for this type of analysis. We reviewed the environmental engineering literature and found a substantial amount of data exists concerning the weight of various air pollution emission constituents resulting from fuel utilization. Using primarily ASHRAE, ORNL, and Harvard University data, we developed a set of conversion factors (i.e., kg of CO_2 per kWh, etc.).

NARUC service-area data on utility fuel mix were reduced to state-by-state breakdowns by energy type: coal, gas, hydro, nuclear, oil, purchased, and other. The step allowed a more accurate accounting of avoided air pollution emissions because the fuel mix for electric utilities varies considerably from state to state.

The resulting conversion factors were used to determine the pollutants avoided, resulting from the calculated fuel savings delivered by adopting the MEC. Significant quantities of three other regulated air pollutants can be achieved, despite much smaller unit rates of emission, according to the data. Using the state-average NARUC electric generation fuel-mix data allows each state's MEC-based emissions reduction due to electric power savings to be calculated more accurately (Howard and Prindle 1991).

Externality Value of Avoided Emissions

Environmental analysis is frequently concerned with estimating the costs to society due to actions not accounted for in the hard cost or consumer "price" of goods and services. The emission of air pollution related to home energy use also creates externality costs. A home's furnace, for example, has relatively small and difficult to regulate direct and indirect levels of air pollution and other waste products that are not now accurately reflected in the price of operation and maintenance.

Millions of homes using excess electric power or on-site fuel combustion, due to inefficient thermal envelopes or poor mechanical systems, inexorably boost the levels of atmospheric CO_2, acid rain, smog precursors like SO_2, NO_x, and particulates. However, it is much easier to regulate large power plants and industrial point sources than millions of homes, vehicles, and other nonpoint sources. The environmental impact of myriad small sources is accumulated in unresolved environmental degradation on a massive and pervasive scale, particularly in urbanized areas.

A set of estimates for the externality costs of energy utilization emissions was found in the recent literature (Ottinger 1990) and used to calculate representative dollar values of air pollutants for both heating and cooling electric power production and on-site combustion of fossil fuels in typical residential space-heating systems. Pollutant emissions were estimated from the fuel savings and electric power savings results. These energy-savings-related weights are used to estimate the present dollar value of the avoided pollution.

Two scenarios were used for calculating the externality cost of CO_2 because a range of "carbon tax" rates per ton have been proposed in draft federal legislation, reflecting different levels of ambition in CO_2 control. They represent a wide range from the literature in which actual CO_2 emission tax options ("carbon taxes") may be exercised in the future. While the energy savings calculations are based on energy delivered to the site, the pollutants avoided by electric power conservation are based on source energy, including transmission and generation losses. On-site combustion of fuel oil and natural gas also produces air pollution, and the estimates for its avoidance accurately account for mechanical and distribution system inefficiency because fuel savings results are directly used as input to all environmental calculations.

RESULTS AND DISCUSSION

National energy, fuel, and pollution savings results are presented for nearly 600,000 housing starts for 1991. Of this total, single-family homes in the sample represent about 450,000 starts out of more than 700,000 single-family starts for 1991, according to the NAHB. The data indicate the MEC is cost-effective on a national level for adoption in those states currently using less stringent energy codes. Consumers of MEC-compliant housing would save $76 million in year one in housing that had an incremental cost of $511 million for energy-efficient construction upgrades.

Table 3 contains a national summary of results including all relevant data on energy savings, fuel savings, economic and affordability results, and pollution avoidance. A total of 7.2 trillion Btu (7.6 quadrillion J) can be saved by MEC adoption in 34 states. This translates into considerable fuel savings. On the basis of the specific fuels conserved, 500 million kWh, 5.2 billion ft^3 (147 million m^3) of natural gas, and 740,000 gallons (2.8 million L) of number-2 fuel oil would be saved in the first year following comprehensive MEC adoption, compared to "business as usual."

National Economic Benefits

The MEC thermal envelope upgrades produce a net present value of $687 million at the 10% discount rate assumed. The benefit-to-cost ratio (BCR) that would accrue from MEC adoption is quite high—at least 3.0 for a 10% discount rate. For comparison, a U.S. DOE-funded advanced weatherization assessment project looking at improving energy conservation audit tools used a 1.2 BCR threshold to gauge "cost-effectiveness" (Ternes et al. 1991).

The energy-efficiency investment costs are generally affordable to home buyers, according to the Alliance analysis of consumer cash flows. Less than one year (average 0.79 years) would be required for the average MEC home buyer to obtain positive cash flow. In areas with high fuel and electric prices, these returns are even more rapid.

Housing affordability is enhanced by adopting the MEC. The MEC should reduce homebuyers' heating and cooling bills by $76 million in the first year, with savings for average homeowners of $130 per housing unit ($161 per single-family house). In some states, such as Maine, single-family homeowners could obtain up to $600 savings in year one.

TABLE 3
National Summary of Results—Benefits of Adopting the CABO Model Energy Code

	Housing Starts 1991	Total Savings (Billion Btu)	Savings by Energy Type: Electric (Million kWh)	Nat. Gas (Million CF)	#2 Fuel Oil (Gallons)
National Total	584,595	7,240	498.4	5,183	739,858
Single-family	449,796	7009	469.0	5,058	739,200
Multi-family	134,798	231	29.4	125	658

Economic Benefits of Adopting the CABO Model Energy Code

	First Cost of MEC ($)	First Year Energy Savings ($)	Benefit/Cost Ratio (10% disc. rate)	Net Present Value (10% disc. rate)	Consumer Affordability (Yrs./ +Cashflow)
Average Unit	874	130	3.0	1,176	0.79
Single-family	1,085	161	3.4	1,470	0.79
Multi-family	173	24	1.7	196	0.81
Total (Million)	511	75.7	--	687	--
Single-family	488	72.5	--	611	--
Multi-family	23.3	3.25	--	26.4	--

Environmental Benefits of Adopting CABO Model Energy Code
Tons of Air Pollution Avoided (Year 1)

	Total	Carbon Dioxide	Sulfur Dioxide	Nitrogen Dioxide	Particulate
Housing Sample	564,876	557,082	4,728	2,037	1,031
Single-family	533,437	526,007	4,512	1,931	988
Multi-family	31,439	31,075	216	106	43

National Pollution Reductions

Considerable air pollution can be avoided by adopting the MEC where current building codes have weaker criteria. A total of 565,000 tons (510 million kg) per year of air pollutants could be avoided. The biggest contributor to this figure is CO_2, a combustion byproduct gas implicated in global climatic change. Also, considerable SO_2 reduction is provided. SO_2 is a key constituent in the process of precipitation acidification (as a precursor to acid rain), implicated in acidification of lakes and damaging forests in many areas of the world. More than 4,700 tons of SO_2 would be avoided in the first year alone by rapid MEC adoption.

The results indicate prodigious long-term quantities of energy savings and air-pollution reductions can be obtained at relatively high benefit-to-cost ratios. For the 50- to 75-year useful life of a new home, considering 10 years' housing production (10 years approximates the historical gestation of major energy standard advances), about 3.6 quad to 5.4 quad (quad = 10^{15} Btu) (3.8 to 5.7 terra-J) could be saved, about 2.7 to 3.8 million barrels of oil (445 to 626 million L) not imported, and up to 430 million tons (388 billion kg) of pollution not emitted into the atmosphere. These results should be considered carefully, as they represent significant added benefits to the energy savings produced.

The calculated dollar value of the avoided air pollution is \$20 to \$50 million in the first year alone. These savings are of the same order of magnitude as the dollar value of the first year's total consumer energy savings (\$76 million). The dollar value of avoided pollution depends directly on the externality cost used for the avoided CO_2 emissions; we used \$17 and \$80 per ton as a range. Proper cost accounting of these avoided externalities in addition to the "hard" fuel savings may eventually enter into setting new levels of energy efficiency for environmental protection. When hard dollar energy savings and pollution avoidance "externality value" are added up for year one, the total societal value of the adoption of MEC residential thermal criteria could reach \$126 million. In addition, the acceptance of an "externality value" for the avoided pollution significantly leverages the energy savings by reducing the length of time to recoup investment.

Model Code Regions Results

Building codes are promulgated through three major model code groups in the U.S. Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and Southern Building Code Congress International (SBCCI) all have "territories" where they have obtained major influence over locally adopted building codes. BOCA, ICBO, and SBCCI are all members of the Council of American Building Officials (CABO), which publishes the *Model Energy Code*. They rotate their responsibility for acting as the CABO secretariat and managing the MEC code-change annual review process.

In the BOCA region, largely composed of eastern and midwestern areas, our analysis indicates that the MEC would be quite cost-effective. This is indicated by high BCR values, averaging 2.0 to 2.9 depending on the discount rate. The first cost per unit for the required energy-efficiency provisions is about 38% higher in the BOCA region than the total sample average. This is offset by a 28.5% higher first-year saving. More than 60% of the total national accrual of net present value of savings is obtained in the BOCA region.

In the SBCCI region, composed of South Atlantic and Gulf Coast states, the MEC represents a significant improvement from existing standards. The proportional energy savings data and economics results indicate the MEC levels are significantly less stringent in the South than the optimal levels. More improvement to the MEC is needed here, since this region is dominated by air conditioning and the consumer cost and environmental implications of inefficient electric use are considerable. The BCR averages 4.4 to 6.4 depending on the discount rate selected. This indicates not only that current energy code stringency is inadequate but that the MEC levels could be tightened further. The first cost per unit is about 37.5% lower than the total sample average for the required energy-efficiency provisions in the SBCCI region.

In the ICBO region, composed of western and some midwestern states, the MEC would be cost-effective according to standard life-cycle economics but potentially somewhat less affordable than elsewhere for multi-family buildings. The ICBO region is dominated by states and utility regions that have changed their building codes to more stringent energy code criteria or have adopted very energy-efficient standards.

Three West Coast states already have more stringent criteria. These states harbor considerable housing activity that acted to compress the ICBO region's relative sample size. Our analysis still indicates that the MEC would be cost-effective for single-family homes in the ICBO region in those states that have not yet improved their energy codes. This is indicated by the high BCR values in single-family homes—from 3.2 to 4.7 depending on the discount rate selected.

State Energy, Economic, and Environmental Results

Of the 34 states in which the MEC was found to be more stringent than existing residential building energy codes, 10 had per-housing-unit energy savings exceeding 20 million Btu. The highest thermal energy savings for the average housing units were obtained in heating-dominated Maine, Colorado, and Nebraska. The lowest thermal energy savings found per housing unit were in Arizona, Louisiana,

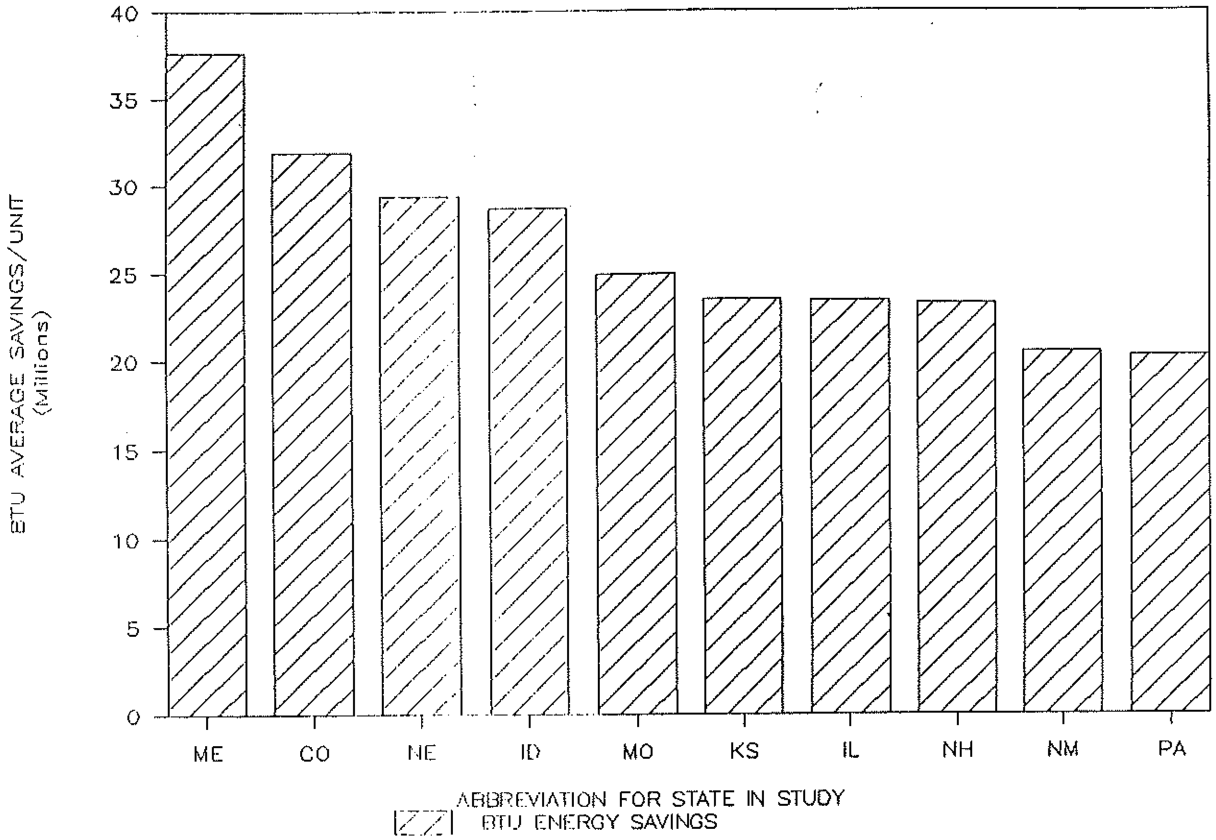

Figure 1 Top-10 unit thermal energy savings rankings by state.

and Mississippi, all dominated by air-conditioning loads. Figure 1 illustrates the rank order of per-unit thermal savings in the top 10 states.

This ranking differs from the state's ranking for total energy savings, shown in Table 4. By total energy savings, the top three are Ohio, the DC metropolitan region (includes suburban Maryland, northern Virginia counties, and the District of Columbia), and Illinois. Missouri is a close fourth, followed by Michigan and Nevada. In these three states, residential energy use is dominated by natural gas. Table 4 also contains economics and finance data on these top 10 states. Note that the greatest length of time to positive cash flow is less than two years, and five states have positive cash flows in one-half year or less.

A ranking of the 34 states by per-housing unit electrical energy savings (Figure 2) indicates Maine is again in the lead in terms of potential benefits from adoption of the MEC, followed by Pennsylvania and the DC metropolitan region. Maryland, West Virginia, Virginia, and Delaware are also closely grouped in the top 10 states for per-housing-unit electrical savings. Consumers in the mid-Atlantic states would be well served by increased residential energy efficiency, since much of their space-conditioning energy use is from electric power.

Additional state-by-state analysis data is presented in Table 5, Economics and Finance Data, and Table 6, Pollution Avoided through Energy Efficiency. These data are presented as an alphabetized listing by state of the important findings of the study on a per-housing-unit average. Additional details can be found in the original report available from the Alliance or NAIMA (Howard and Prindle 1991).

CONCLUSIONS AND RECOMMENDATIONS

On the basis of very favorable overall energy savings, pollution avoidance, and economic assessment results, we

TABLE 4
Total Energy Savings—
Top Ten Ranking States in Study

STATE	— YEAR ONE SAVINGS — BTU (E9)	N-GAS (E6)	ELEC (E6)	— OIL (E3)	FCD($) (E6)	(AT 10% DISC.) FYS($) (E6)	NPV ($E6)	BCR (dim)	YPCF (yrs)
OH	693.3	527.4	41.0	0.0	62.8	6.6	44.4	1.5	0.95
DC	628.3	267.5	101.9	0.0	44.6	10.6	119.6	3.1	0.42
IL	597.8	556.7	4.1	0.0	40.2	3.4	19.2	1.3	1.92
MO	584.2	477.7	24.3	0.0	31.2	4.6	36.1	1.9	0.67
MI	544.1	491.5	5.4	73	40.5	3.4	20.9	1.5	1.93
NV	440.2	405.2	4.1	0.0	36.8	3.4	25.2	1.4	1.84
GA	410.5	323.8	20.8	0.0	16.6	4.9	57.8	4.4	0.34
VA	352.7	186.5	46.0	0.0	20.6	4.5	61.2	3.5	0.38
TN	330.1	235.8	21.9	56.3	15.1	2.9	31.2	3.1	0.51
TX	312.6	219.9	24.0	0.0	7.9	3.6	43.9	6.0	0.22

NOTE: Due to the large quantities involved, scientific notation has been used. 1000 = "1E+03" 1,000,000 = "1E+06" 1,000,000,000 = "1E+09" etc. 1 Quad is 1E+15; or a million billions.

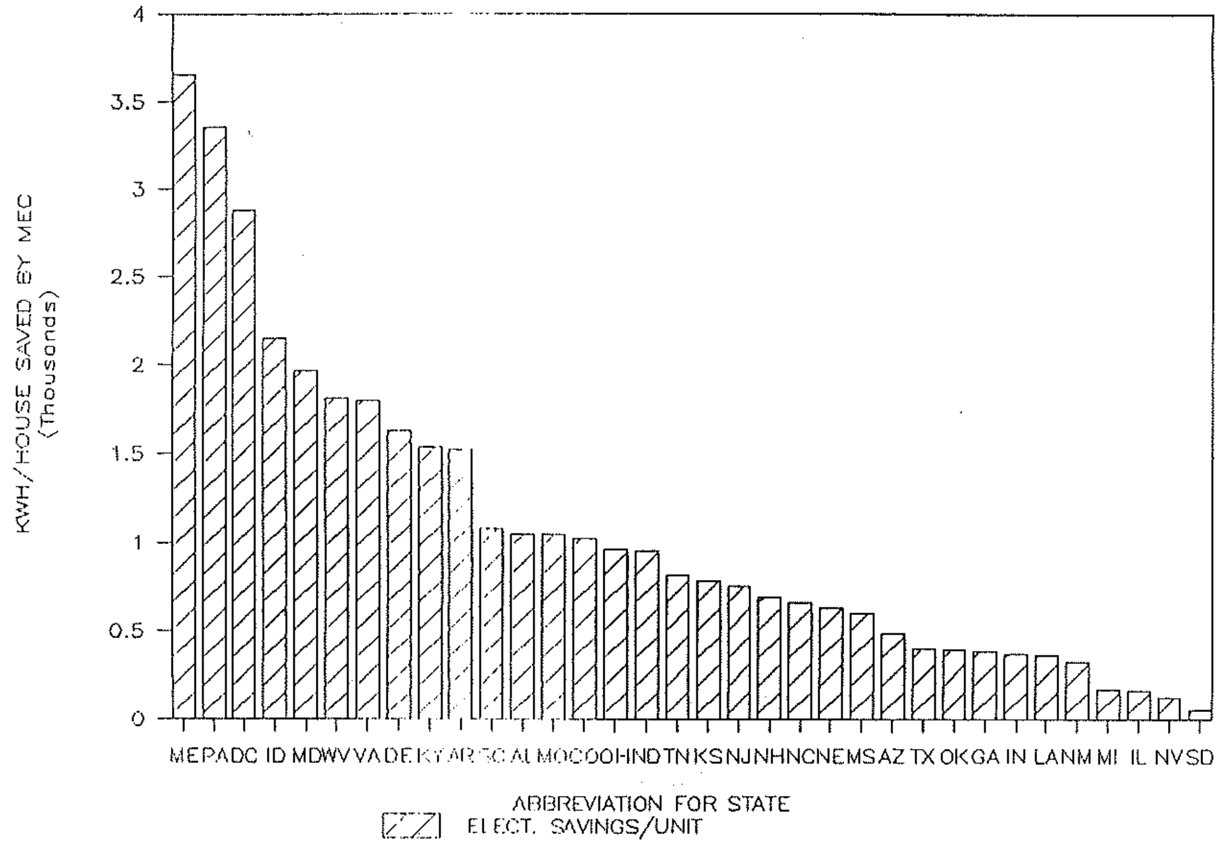

Figure 2 *Electric savings rankings by state.*

believe sufficient justification exists for the rapid but selective adoption of the more energy-efficient standards represented by the MEC. We found that significant energy, economic, and environmental benefits would accrue through immediate adoption of the MEC. Building officials now have better information that supports moving ahead with the promulgation of the MEC or even more stringent standards.

Adjusting Ineffective Housing Energy Policy

- States should review their existing energy standards criteria in building codes. The MEC can be used as a model for adoption of up-to-date criteria. States should also review the ASHRAE 90.2 residential standard when it is issued.
- The MEC should be strengthened in the air-conditioning-dominated southern states and should be revised to reference the National Appliance Energy Efficiency Act of 1987.
- The MEC multi-family dwelling thermal standards should be upgraded, recognizing the cost-effective criteria contained in ASHRAE's proposed standard 90.2.
- The federal government, through the U.S. Department of Energy, should help states to upgrade their energy standards and codes by providing technical assistance and training on advanced standards.
- States must also evaluate and improve their energy code enforcement efforts, since there is evidence that lax enforcement can retard energy efficiency to the same degree as obsolete technical criteria.

ACKNOWLEDGMENTS

This report is a result of research funded primarily under an R&D contract from the North American Insulation Manufacturers Association (NAIMA). Considerable in-kind support was provided by the Owens-Corning Fiberglas Corporation (O-CF). The Alliance to Save Energy provided additional funding for this project through its unrestricted programs on Housing Affordability and Building Technology.

REFERENCES

ASHRAE. 1988. Commentary on background and development of ASHRAE Standard 90.2. Committee Print.

TABLE 5
State Economics and Finance Data
Average Values/Full Sample

STATE	HOUSING STARTS	FCD ($)	FYS ($)	--DISC RATE 10%-- BCR	NPV ($)	--DISC RATE 7%-- BCR	NPV ($)	YEARS TO POSITIVE CASH FLOW (YPCF)
AL	20000	399	91	3.90	942.70	5.70	1546.00	0.44
AR	3400	487	144	4.20	1633.00	6.00	2569.00	0.34
AZ	17500	97	71	9.60	956.10	13.80	1426.00	0.14
CO	9700	1899	220	1.80	1854.00	2.70	3633.00	0.86
DC	35400	1259	299	3.10	3378.00	4.40	5465.00	0.42
DE	6200	1267	133	1.50	777.10	2.20	1700.00	0.95
GA	54200	306	90	4.40	1067.00	6.40	1713.00	0.34
ID	1400	1688	245	2.00	2420.00	2.90	4358.00	0.68
IL	25500	1576	134	1.30	751.70	1.90	1896.00	1.92
IN	14400	1620	125	1.30	579.10	2.00	1651.00	2.95
KS	2900	1312	174	1.90	1325.00	2.80	2563.00	0.75
KY	8300	1003	141	2.20	1201.00	3.20	2211.00	0.71
LA	5100	116	50	6.00	578.40	8.80	896.60	0.23
MD	15000	1175	188	2.10	1645.00	3.00	2903.00	0.62
ME	3000	2123	500	3.30	6255.00	4.80	10070.00	0.42
MI	31400	1291	108	1.50	668.40	2.20	1628.00	1.93
MO	23400	1332	198	1.90	1539.00	2.80	2894.00	0.67
MS	2900	184	65	5.70	758.70	8.20	1181.00	0.28
NC	26100	630	86	2.20	677.80	3.20	1273.00	0.73
ND	1000	920	127	1.70	1198.00	2.50	2192.00	0.72
NE	2600	1552	192	1.40	1435.00	2.10	2881.00	0.80
NH	2100	1241	221	2.80	2638.00	4.00	4465.00	0.56
NJ	24500	1073	137	1.80	1081.00	2.60	2073.00	0.78
NM	3000	792	158	3.20	1822.00	4.70	3082.00	0.50
NV	36600	1005	93	1.40	687.20	2.10	1515.00	1.84
OH	42700	1471	154	1.50	1039.00	2.10	2212.00	0.95
OK	5600	554	132	3.30	1385.00	4.90	2312.00	0.42
PA	35900	919	78	1.20	296.60	4.40	837.30	1.92
SC	11300	441	93	3.60	949.90	5.20	1561.00	0.47
SD	400	169	26	0.80	247.20	1.20	450.00	0.65
TN	26900	562	109	3.10	1158.00	4.50	1959.00	0.51
TX	60000	132	60	6.00	732.00	8.80	1132.00	0.22
VA	25600	806	210	3.50	2390.00	5.10	3839.00	0.38
WV	600	921	130	2.10	1078.00	3.00	1963.00	0.70

July. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1989. *1989 handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1991. Final draft, Standard 90.2, Energy efficient design of low-rise residential buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASTM. Special publication, *Building economics methods*. Philadelphia: American Society for Testing and Materials. (Contains relevant energy economics standards of ASTM.)

CABO. 1990. Model energy code. Falls Church, VA: Council of American Builder Officials.

DOE. Test Proc. CF: 10 CFR 430, Test procedures for consumer products. Washington, DC: U.S. Department of Energy.

DOE. 1989. Affordable housing through energy conservation—Technical documentation. Washington, DC: U.S. Department of Energy.

DOE. 1990. Interim national energy strategy. Washington, DC: U.S. Department of Energy.

DOE-EIA. 1987. Annual energy review. Washington, DC: U.S. Department of Energy-Energy Information Agency.

Howard, B.D., and W.R. Prindle. 1991. Better building codes for energy efficiency. Washington, DC: Alliance to Save Energy.

Huang, Y.J., et al. 1987. Methodology and assumptions for evaluating heating and cooling energy requirements in new single-family residential buildings (technical support document for the PEAR Microcomputer Program). Berkeley, CA: Lawrence Berkeley Laboratory.

Johnson, A.W., and R.J. Johnson. 1982. NAHB thermal performance guidelines: 1982 methodology update.

TABLE 6
State Air Pollution Avoidance Values
Averages/Full Sample

STATE	HSNG STARTS	FCD ($)	FYS ($)	MEC SAVINGS RELATIVE TO STATE CODE BTU	GAS(FT3)	ELE(KWH)	OIL(GAL)	-- POLLUTION AVOIDANCE IN TONS/YEAR-1 -- CO2	SO2	NOx	PARTIC	TOTAL
AL	20000	399	91	6.947E+06	3224	1044	0.00	0.749	0.005	0.003	0.001	0.758
AR	3400	487	144	7.907E+06	2595	1519	0.00	1.338	0.008	0.004	0.002	1.352
AZ	17500	97	71	2.162E+06	481	486	0.00	0.566	0.003	0.002	0.001	0.572
CO	9700	1899	220	3.190E+07	27080	1022	0.00	1.546	0.017	0.006	0.004	1.573
DC	35400	1259	299	1.775E+07	7556	2878	0.00	3.140	0.020	0.010	0.004	3.174
DE	6200	1267	133	1.010E+07	4341	1626	0.00	1.670	0.011	0.006	0.002	1.689
GA	54200	306	90	7.574E+06	5974	383	0.00	0.513	0.005	0.002	0.001	0.521
ID	1400	1688	245	2.871E+07	20380	2148	0.00	1.988	0.017	0.007	0.004	2.016
IL	25500	1576	134	2.344E+07	21830	159	0.00	0.505	0.009	0.003	0.002	0.519
IN	14400	1620	125	1.942E+07	17120	372	1.42	0.686	0.009	0.003	0.002	0.700
KS	2900	1312	174	2.346E+07	19810	785	0.00	1.074	0.012	0.004	0.003	1.094
KY	8300	1003	141	1.544E+07	9714	1538	0.00	1.921	0.014	0.007	0.003	1.944
LA	5100	116	50	3.577E+06	2226	364	0.00	0.310	0.002	0.001	0.001	0.314
MD	15000	1175	188	1.171E+07	4770	1964	0.00	1.776	0.012	0.006	0.002	1.796
ME	3000	2123	500	3.761E+07	12380	3655	87.16	3.271	0.022	0.010	0.005	3.307
MI	31400	1291	108	1.733E+07	15650	171	2.32	0.457	0.007	0.002	0.002	0.468
MO	23400	1332	198	2.497E+07	20420	1040	0.00	1.317	0.013	0.005	0.003	1.339
MS	2900	184	65	3.904E+06	1777	598	0.00	0.640	0.004	0.002	0.001	0.647
NC	26100	630	86	6.034E+06	3602	661	0.00	0.438	0.004	0.002	0.001	0.444
ND	1000	920	127	1.552E+07	11700	953	0.00	0.799	0.008	0.003	0.002	0.812
NE	2600	1552	192	2.934E+07	25940	626	0.00	0.991	0.013	0.004	0.003	1.012
NH	2100	1241	221	2.326E+07	9893	690	75.51	1.578	0.011	0.004	0.003	1.597
NJ	24500	1073	137	1.086E+07	7299	752	4.58	0.682	0.006	0.002	0.001	0.692
NM	3000	792	158	2.049E+07	18480	324	0.00	0.603	0.009	0.003	0.002	0.617
NV	36600	1005	93	1.203E+07	11070	121	0.00	0.310	0.005	0.002	0.001	0.318
OH	42700	1471	154	1.624E+07	12350	961	0.00	1.181	0.010	0.004	0.002	1.198
OK	5600	554	132	1.653E+07	14470	394	0.00	0.590	0.008	0.003	0.002	0.602
PA	35900	919	78	4.478E+06	1653	738	1.62	0.689	0.004	0.002	0.001	0.696
SC	11300	441	93	4.516E+06	817	1072	0.00	0.698	0.004	0.002	0.001	0.705
SD	400	169	26	3.989E+06	3632	53	0.00	0.109	0.002	0.001	0.000	0.112
TN	26900	562	109	1.227E+07	8765	816	2.09	0.711	0.007	0.003	0.001	0.722
TX	60000	132	60	5.210E+06	3665	400	0.00	0.428	0.004	0.002	0.001	0.434
VA	25600	806	210	1.378E+07	7285	1798	0.00	2.044	0.014	0.007	0.003	2.067
WV	600	921	130	8.772E+06	2468	1812	0.00	2.030	0.012	0.007	0.002	2.051

NOTE: Due to the large quantities involved, scientific notation has been used.
1000 = "1E+03" 1,000,000 = "1E+06" 1,000,000,000 = "1E+09" etc.
1 Quad is 1E+15; or a million billions.

ASHRAE Thermal Envelope Conference II, Las Vegas, NV. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Lee, A.D., R.G. Lucas, and C.C. Conner. 1990. Comparison of the economic effects of three residential energy codes on home buyers. Richland, WA: Battelle-Pacific Northwest Laboratory.

Lippiatt, B.C., and R.T. Ruegg. 1990. Energy prices and discount factors for life-cycle cost analysis 1990. NISTIR-85-3273-2 (Rev. 5/1990). Gaithersburg, MD: National Institute for Standards and Technology.

McBride, M. 1991. ASHRAE Standard 90.2 envelope criteria optimization technique. *ASHRAE Transactions* 97(1). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

McBride, M., and S. Braun. 1991. Results from unofficial run of ASE program using the NAECA equipment efficiency levels indicated a 7% to 10% difference in some cities, but no change in conclusions.

McQuiston, F.C. 1984. A study and review of existing data to develop a standard methodology for residential heating and cooling load calculations, RP-342. Final Report. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

NAHB Research Center. 1986. An economic data base on costs of residential energy, thermal envelope and HVAC equipment. Upper Marlboro, MD: National Association of Home Builders Research Center.

NCSBCS 1989. *The energy directory*. Herndon, VA: National Conference of States on Building Codes and Standards.

Norberg-Bohm, V. 1990. Potential for carbon dioxide emission reduction in buildings. Harvard Global Environmental Policy Project G-90-04. Cambridge, MA: J.F.K. School of Government.

ORNL. 1987. *Building foundation handbook*. Oak Ridge, TN: Oak Ridge National Laboratory.

ORNL. 1991. Global warming program. Oak Ridge, TN: Oak Ridge National Laboratory.

OTA. 1992. *Building energy efficiency*. Washington, DC: Office of Technology Assessment.

Ottinger, D. 1990. Environmental cost of electricity generation. Pace University Center for Environmental Legal Studies.

Peterson, S.R. 1981. Economics and energy conservation in the design of new single-family housing. NISTIR 81-2380. Gaithersburg, MD: National Institute for Standards and Technology.

Ruegg, R.T. 1990 (revised). *Life-cycle costing manual for the federal energy management program*. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology.

Ternes, M.P., P.S. Hu, L.S. Williams, and P. Goewey. 1991. The national fuel end-use efficiency field test: Energy savings and performance of an improved energy conservation measure selection technique. ORNL/CON-303. Oak Ridge, TN: Oak Ridge National Laboratory.

U.S. Departments of Commerce, Housing and Urban Development, and Census. 1987. Characteristics of new housing: 1987. Washington, DC: U.S. Government Printing Office.

WEFA Group. 1990. Real estate and construction service —Long-term MSA tables. Bala Cynwyd, PA: The WEFA Group.