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An Estimate of Consumer Discount Rates Implicit in Single-Family-Housing Construction Practices

Dennis L. O'Neal
Kenton R. Corum
Judy L. Jones

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04 Microfiche A01

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Contract No. W-7405-eng-26

AN ESTIMATE OF CONSUMER DISCOUNT RATES IMPLICIT IN SINGLE-FAMILY-HOUSING CONSTRUCTION PRACTICES*

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*Research sponsored by the Office of Conservation and Solar Energy and the Energy Information Administration, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

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ABSTRACT

An important aspect of consumer behavior with respect to energy use is the willingness of consumers to make investments which increase the efficiency of energy use in their residences. These investments may take a variety of forms: increased levels of insulation, storm windows, high efficiency air conditioners, etc. In each case, the investment decision involves the evaluation of a first cost and a stream of expected future energy and monetary savings resulting from the investment.

Essential to the comparison of the initial costs of the investment and expected future benefits is the concept of a discount rate. While individuals may not consciously employ this concept, their investment behavior can be characterized as though they did. This provides a means of analyzing some important influences on their behavior and prediction of chosen levels of efficiency in future years.

While the discount rate used by consumers to evaluate investments in energy efficiency is related to the rate of interest (i) they pay for loans, and the rate of return (r) they could get from alternative investments, recent evidence indicates that the discount rate is considerably higher than i or r. While this difference can be attributed to such factors as a lack of knowledge about the future performance of conservation investments and future energy prices, we are left without a simple analytical means of estimating the discount rate based on i or r.

This report describes the calculation of consumer discount rates implied by purchases of energy conservation options in new residences. The results are based on single-family residential construction practices in 1976, together with engineering evaluation of cost and energy use effects of available energy-conserving construction practices. The discount rate is estimated for ten cities and three heating fuels (gas, oil, and electricity). Sensitivity of the results to assumptions regarding financing arrangements and expected energy prices is also analyzed.

The discount rates resulting from this analysis are substantially higher than market rates of interest. They vary with heating fuel choice, location and price and financing assumptions, but the two cases we regard as most realistic (Case 3 and Case 4) result in discount rates (real, net of inflation) which range from a minimum of 14% to over 100%.

1. INTRODUCTION

Any attempt to influence energy conservation must take into account a number of technological and behavioral factors, including the availability of technological options (e.g., more efficient furnaces or solar collectors), the willingness of individuals to trade amenity for energy savings (e.g., lowered heating thermostat settings) and their willingness to invest in more energy-efficient buildings and equipment. The neglect of any of these factors can result in inaccurate projections of energy demand or conservation impacts, with the result that suboptimal conservation policies may be selected and pursued. This report describes the estimation of one of the crucial parameters of the investment decision, the discount rate, based on investment behavior in the residential construction industry.

If the market for new homes were perfectly competitive (free entry to the homebuilding industry, perfect information for buyers and sellers, and no externalities) homes would be built to match buyers' preferences, including those preferences which affect the energy-efficiency of the home (principally determined by the levels of insulation in attic, walls and floor and the number of layers of glass in the windows and doors). With perfect information about the effectiveness of insulation and glazing in reducing energy bills and access to funds in a perfectly functioning capital market, the homebuyer would rationally invest in increased levels of insulation and glazing until the discounted value of future energy savings from the last dollar's worth of insulation and glazing is equal to one dollar. Stated another way, the homebuyer would minimize the life-cycle costs of energy use and energy-related capital costs of the house. The appropriate discount rate in this situation would be equal to the opportunity cost of capital, or the observed market interest rate.

In the real world, of course, the markets for homes and capital are imperfect; in particular, both builders and buyers have imperfect information about a variety of matters which influence their investment behavior. For example: (1) Homebuyers are uncertain about future energy savings resulting from an investment in increased levels of insulation and glazing. (2) Homebuilders are uncertain about buyers' willingness to pay for more expensive and energy-efficient houses. (3) Both groups are uncertain about the levels of future fuel costs. (4) Both groups are uncertain about future government policies such as tax credits for conservation investments. (5) Buyers are uncertain about how long they will own the house, and what the resale value of an energy-efficient house is likely to be.

In addition to uncertainty, institutional constraints may also influence conservation investments: (6) Lending institutions fix the amount they will lend on a house based on an appraisal which may ignore the value the housing market may put on energy efficiency. (7) Lending institutions have commonly fixed the maximum amount of a mortgage loan to an individual based on a fixed estimate of monthly utility bills, rather than allowing a larger mortgage loan to be made when evidence indicates the higher mortgage payment will be offset by lower utility bills.

Most of the examples of market imperfections listed above would seem to make conservation investments less likely, though in the case of (3) it is easy to imagine a risk-averse individual making conservation investments in his house as a form of insurance against higher-than-expected fuel costs in the future. We cannot, however, predict with confidence the magnitude or even the direction of the effects of any of these imperfections without more evidence and considerable analysis.

Fortunately, it is possible to take the net effect of market imperfections into account in predicting future levels of conservation investment, without listing and analyzing each case and its influence on decisions. Instead, we can take an approach similar to Hausman's analysis of purchases of room air conditioners;[1] we can think of the construction practices of the homebuilder as being led by market forces to reflect informed homebuyers' preferences for minimum life-cycle costs of the house and its energy use, with the discount rate departing from the market rate of interest to reflect the net effect of all market imperfections. To estimate the value of this discount rate, we can compare the first costs and the future energy costs of the observed investment decisions to those of the available alternative levels of conservation investment, and ask: "What discount rate would make the observed decision the lowest life-cycle cost alternative?" This approach is taken in this analysis.

2. METHODOLOGY

This section describes the methodology used to estimate consumer discount rates implied by construction practice in new residences. Appropriate equations are derived which relate the discount rate to engineering and cost variables associated with conservation in these residences.

Recent studies have demonstrated that the energy efficiency of homes and applicances can be increased if consumers are willing to pay more for the home or appliance.[2-6] The tradeoff between energy use and capital cost can be plotted in a form similar to Fig. 1. The estimation of such a tradeoff curve is accomplished as follows: starting with a prototypical house or appliance, engineering analysis is done to evaluate the energy savings of technical conservation options or designs that can be implemented on the prototype. The initial costs of these designs to the consumer are then estimated. The options are assumed to be implemented in order of decreasing benefit to cost ratio. The benefit is the present worth of the sum of the fuel bill savings of the conservation option relative to the baseline design. The cost is the present worth of the extra costs associated with the option (capital and maintenance). Applying the conservation options in this manner allows for the most cost-effective ordering of the options.

One expression relating annual heating energy use, E_h and capital cost of thermal improvements to a home is:

$$E_h = E_\infty + (E_0 - E_\infty)e^{-\alpha C} \quad , \qquad (1)$$

where

C = capital cost of thermal integrity improvement (equals zero for no improvement)

α, E_∞ = constants in the equation. E_∞ is the asymptotic limit on heating energy use due to improvements in the thermal integrity of the house

E_0 = annual heating energy use of the prototypical or base house

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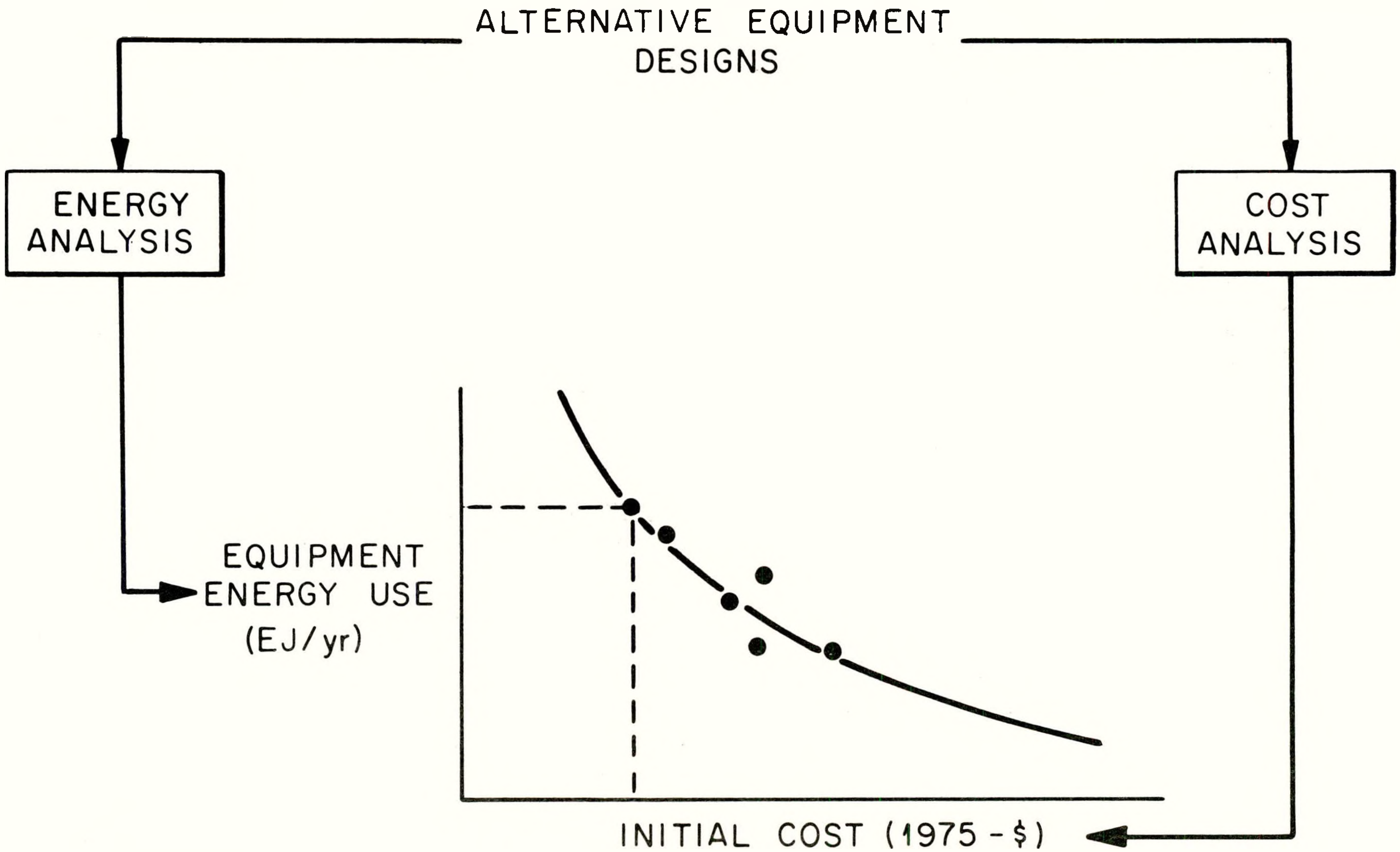

Figure 1. Typical energy use/capital cost curve.

Equation (1) has been used in the Oak Ridge National Laboratory (ORNL) residential energy use model.[7] This curve is a continuous approximation of the set of discrete points corresponding to conservation measures applicable to a home.

The life-cycle costs (LCC) of a home include its operating and capital costs discounted over the life of the home.* If only the fuel costs are included in the operating costs (i.e., no maintenance costs), then the LCC for a home is:

$$LCC = E_h FP_h \sum_{m=1}^{n} \left(\frac{1 + \varepsilon_h}{1 + d}\right)^m + E_K FP_K \sum_{m=1}^{n} \left(\frac{1 + \varepsilon_K}{1 + d}\right)^m + C$$

$$+ B - S\left(\frac{1}{1 + d}\right)^n \quad , \tag{2}$$

where

FP_h = present heating fuel price
FP_K = present cooling fuel price
ε_h = annual real fuel price escalation rate for heating fuel
ε_K = annual real fuel price escalation rate for cooling fuel
E_K = total annual cooling energy use
n = lifetime of investment
d = discount rate
B = capital cost of base house
$S\left(\frac{1}{1 + d}\right)^n$ = present value of sale price of the base house after n years.

The quantities in the summations can be reduced to:

---

*Because the conservation measures we use are passive, it is assumed that their lifetimes are the same as that of the house. We use 25 years as the lifetime in our calculations. This figure matches common mortgage terms, but is shorter than the actual expected life of most homes. Use of $n > 25$ in our calculations would result in slightly higher discount rates.

$$\sigma = \frac{(1 + \varepsilon)}{(d - \varepsilon)}\left[1 - \left(\frac{1 + \varepsilon}{1 + d}\right)^n\right] = \sum_{m=1}^{n} \left(\frac{1 + \varepsilon}{1 + d}\right)^m \ . \tag{3}$$

Thus, Eq. (2) can be rewritten as:

$$LCC = E_h FP_h \sigma_h + E_K FP_K \sigma_K + C + B - S\left(\frac{1}{1 + d}\right)^n \ . \tag{4}$$

For this analysis, we assume that consumers will minimize the life-cycle costs of providing a fixed level of amenity in the house. If we assume that the sale price of the house after n years is not affected by C,* the necessary condition for minimized LCC is:

$$\frac{\partial LCC}{\partial C} = FP_h \sigma_h \frac{\partial E_h}{\partial C} + FP_K \sigma_K \frac{\partial E_K}{\partial C} + 1 = 0 \ . \tag{5}$$

As Eq. (5) indicates, a single investment in conservation measures which improve the thermal integrity of a residence saves both heating and cooling energy use. Results from references 3 and 4 indicate that, for mobile homes and single-family residences, the percentage energy saved in cooling from implementing such conservation measures as insulation, window glazing level, and storm doors, can be related to the percentage energy saved in heating by a constant, μ. Thus, if a set of conservation measures saves 20% in heating, then the expected cooling energy saving is μ times 20%, where $\mu \leqslant 1$. Thus:

---

*Though it might be reasonable to expect a house with thermal integrity improvements to have a higher real value after n years than the base house, there are currently no data to fix the strength of this effect. Therefore we chose to let $\partial S/\partial C = 0$. If $\partial S/\partial C > 0$, then the net present value of the benefits increase with an increase in C. When that increase in the benefits is discounted over 25 years using discount rates in the range calculated in Sect. 5, however, the present value is quite small. The final result of a change in assumptions would be a slight increase in the estimates of the discount rate.

$$\frac{1}{E_K} dE_K = \frac{\mu}{E_h} dE_h \quad , \tag{6}$$

where

dE_K = change in cooling energy consumption by implementing a conservation measure

dE_h = change in heating energy consumption by implementing conservation measure

μ = constant

Equation (6) can also be rewritten as:

$$\frac{1}{E_K} \frac{\partial E_K}{\partial C} = \frac{\mu}{E_h} \frac{\partial E_h}{\partial C} \quad . \tag{7}$$

If Eq. (7) is solved for $\partial E_K/\partial C$ and substituted into Eq. (5), then:

$$FP_h \sigma_h \frac{\partial E_h}{\partial C} + FP_K \sigma_K \frac{E_K}{E_h} \mu \frac{\partial E_h}{\partial C} = -1 \quad . \tag{8}$$

In words, Eq. (8) states that to minimize LCC, the present value of the heating and cooling fuel saved by the last dollar of conservation investment must equal \$1.00. The differential, $\partial E_h/\partial C$, in Eq. (8) is calculated by differentiating Eq. (1) with respect to capital cost:

$$\frac{\partial E_h}{\partial C} = -\alpha(E_o - E_\infty)e^{-\alpha C} \quad . \tag{9}$$

Using Eq. (1), Eq. (9) can be rewritten as:

$$\frac{\partial E_h}{\partial C} = -\alpha(E_h - E_\infty) \quad . \tag{9a}$$

Then, substituting Eq. (9a) into Eq. (8) yields:

$$FP_h\sigma_h + \frac{E_K}{E_h}\mu\, FP_K\sigma_K = \frac{1}{\alpha(E_h - E_\infty)} \quad . \tag{10}$$

Equation (10) can be used to solve for the discount rate. It does not provide a closed form solution, but requires iteration of estimates of the discount rate until convergence to the solution is attained.

We also consider two important variations of Eq. (10). The first is where the fuel price escalation rates are zero ($\varepsilon_h = \varepsilon_K = 0$). For this case, Eq. (10) becomes:

$$\left[FP_h + \frac{E_K}{E_h}\mu\, FP_K\right]\left[\frac{(1 + d)^n - 1}{d(1 + d)^n}\right] = \frac{1}{\alpha(E_h - E_\infty)} \quad . \tag{10a}$$

Another special case relates to the financing arrangements made for many new homes. When buying a home (and the conservation measures in it), consumers usually pay a small down payment (5 to 20% of the total cost of the home) and then borrow the rest at some interest rate. Thus, the total cost of the house and the conservation measures in it are spread over the lifetime of the loan. For this situtation, Eq. (10) becomes:

$$FP_h\sigma_h + \frac{E_K}{E_h}\mu\, FP_K\sigma_K = \frac{n + (1 - n)\rho}{\alpha(E_h - E_\infty)} \quad , \tag{10b}$$

where

$$\rho = \sum_{i=1}^{n} \frac{AP}{(1 + d)^n} = AP\left[\frac{(1 + d)^n - 1}{d(1 + d)^n}\right]$$

$$AP = \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

i = interest rate of the loan

η = fraction down payment

Equation (10b) shows that to minimize LCC when mortgage financing is available, the present value of the marginal saving of heating and cooling fuel costs must equal the down payment on the marginal conservation measure plus the present value of its added annual mortgate payments. This equation assumes that the lifetime of the loan is equal to the lifetime of the investment.

Another set of assumptions to be analyzed combines $\varepsilon_h = \varepsilon_K = 0$ and mortgaging financing of conservation measures. To reflect these assumptions, the appropriate equation is

$$\left[FP_h + \frac{E_K}{E_h} \mu \; FP_K\right]\left[\frac{(1 + d)^n - 1}{d(1 + d)^n}\right] = \frac{\eta + (1 - \eta)P}{\alpha(E_h - E_\infty)} \; . \qquad (10c)$$

The discount rates estimated from Eqs. (10a), (10b), and (10c) will be different than those estimated from Eq. (10). Equation (10a) reflects a situation in which consumers expect current fuel prices to continue for the life of the investment. In Eq. (10b), we consider the case where not only future benefits of the conservation measure are discounted, but also the cost of the conservation measure. Equation (10b) also reflects the most typical financial arrangements in purchasing new residences. Equation (10c) reflects constant fuel price expectations <u>and</u> mortgage financing of conservation measures.

3. ENGINEERING ANALYSIS

This section describes the engineering-economic analysis used to develop the energy use versus capital cost tradeoff curves for improving single-family residences.

The thermal (both heating and cooling) performance of a new home can be improved by adding insulation to the walls, ceiling, or floor, installing insulated or storm windows, or by adding storm doors. Though this list doesn't exhaust the possibilities for improving the thermal performance of a home, it includes the most commonly used conservation measures used by home builders in 1975 and 1976.

Previous studies have evaluated the tradeoffs between heating (or cooling) energy use and added capital investment in new single-family homes. Hutchins and Hirst (ref. 3) utilized data developed by Petersen (ref. 8) to estimate the tradeoffs for nine cities. Petersen's data included fourteen cities. A description of their methodology and assumptions used to establish the tradeoffs is given in Appendix A.

We utilized data from ten of the cities evaluated by Petersen. The cities include a wide variation in heating and cooling degree days (see Table 1).

Figure 2 shows an example of a heating load versus capital cost tradeoff curve for a home in Kansas City. The conservation measures corresponding to the numbers on Fig. 2 are listed in Table 2. The energy use with each conservation measure is calculated by dividing the heating load by the efficiency of the heating system. Table 3 lists the efficiencies we used for gas, oil, and electric heating systems. The base annual heating energy uses, E_0, for the home in Kansas City are 146.4, 135.2, and 87.9 GJ for gas, oil, and electric heating, respectively. The baseline heating energy use for each of the cities is listed in Table 4.

Estimating the parameters in Eq. (1) requires rearranging the terms so that it takes the form:

$$A = e^{-\alpha C} \quad , \tag{11}$$

Table 1. Cities chosen for this study

City	Heating degree days[a]	Cooling degree days[a]
Minneapolis	4620	511
Chicago	3406	517
Boston	3212	371
Seattle	3090	79
Kansas City	2810	825
Washington, D.C.	2312	823
Atlanta	1644	755
Fort Worth	1318	1386
Phoenix	873	1908
Miami	72	2320

[a]Based on 18°C.

where

$$A = \frac{E_h/E_0 - E_\infty/E_0}{1 - E_\infty/E_0} \quad .$$

Both sides of Eq. (11) are divided by E_0, the base energy use, to normalize heating energy use to the base. The percentage change in energy use for a given fuel type is the same regardless of the heating fuel because only changes in the thermal integrity of the shell of the house are considered and not the efficiency of equipment. To estimate the parameters E_∞/E_0 and α, Eq. (1) is first transformed to a linear form:

$$A' = -\alpha C \quad , \qquad (12)$$

where

$$A' = \ln \frac{E_h/E_0 - E_\infty/E_0}{1 - E_\infty/E_0} \quad .$$

Iterative estimates of E_∞/E_0 are made and the correlation coefficient, r^2, calculated. When r^2 reached a maximum, the best fit was obtained.

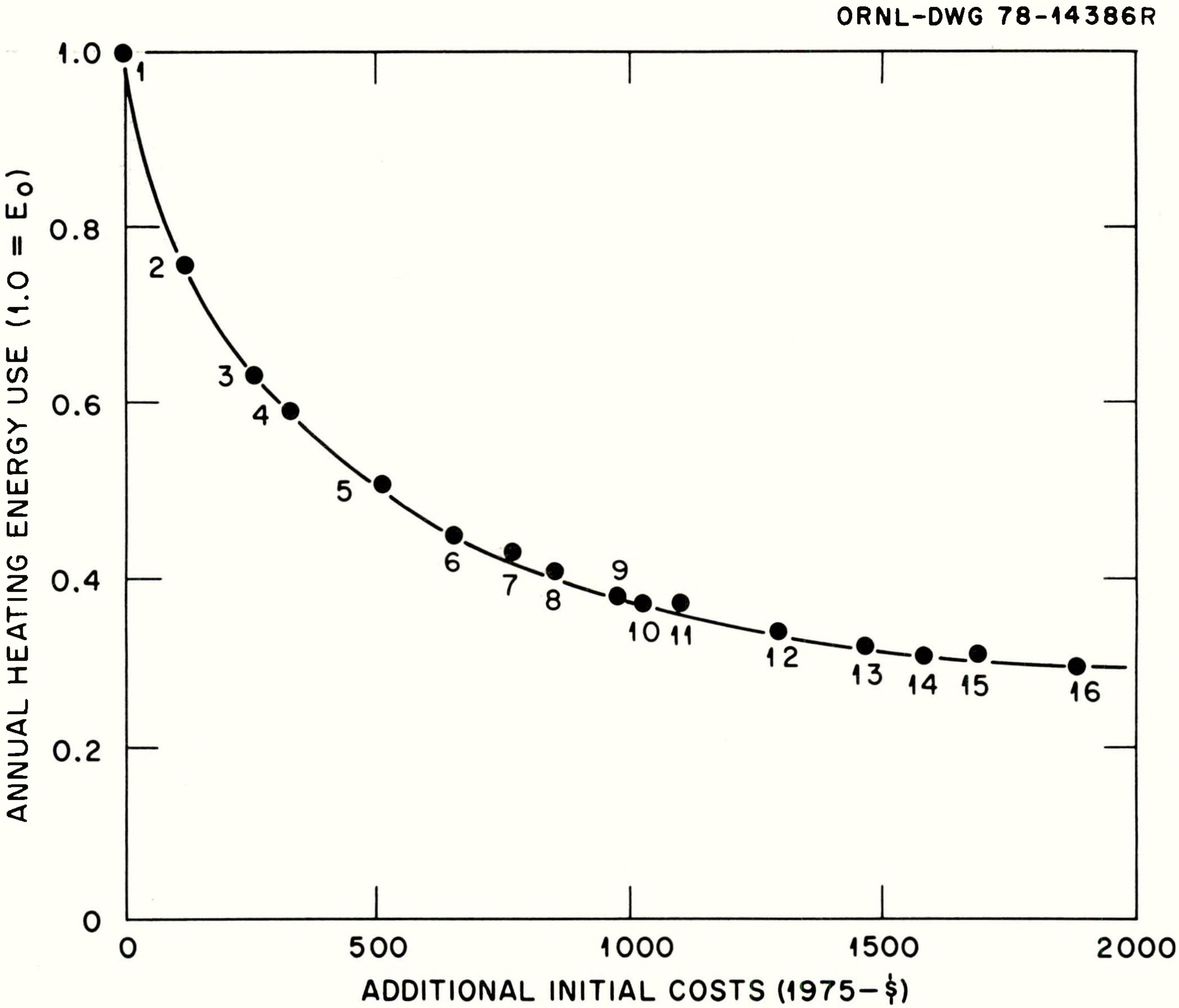

Figure 2. Heating load versus capital cost (single-family residence, Kansas City).

Table 2. Conservation measures used to improve the thermal integrity of a new single-family home

Number	Conservation measure
1	Baseline
2	1.94 m^2°C/W (R-11) attic insulation
3	1.94 m^2°C/W (R-11) wall insulation
4	3.35 m^2°C/W (R-19) attic insulation
5	1.94 m^2°C/W (R-11) floor insulation
6	Storm windows
7	5.29 m^2°C/W (R-30) attic insulation
8	3.35 m^2°C/W (R-19) floor insulation
9	Double glazed sliding glass door (SGD)
10	2.29 m^2°C/W (R-13) wall insulation
11	6.70 m^2°C/W (R-38) attic insulation
12	3.35 m^2°C/W (R-19) wall insulation
13	Triple pane windows
14	8.64 m^2°C/W (R-49) attic insulation
15	Storm door
16	4.06 m^2°C/W (R-23) wall insulation (using styrofoam)

Table 3. Heating equipment efficiencies by fuel type

Fuel	Efficiency
Gas	0.60
Oil	0.60
Electricity	1.00

Table 4. Baseline heating energy use, E_0 in each city by fuel type for an uninsulated single-family home

City	Heating energy use (GJ/yr) by fuel type	
	Gas/Oil	Electricity
Minneapolis	252.3	151.4
Chicago	168.6	101.2
Boston	173.7	104.3
Seattle	160.2	96.1
Kansas City	416.5	87.9
Washington, D.C.	116.6	69.9
Atlanta	80.5	48.3
Fort Worth	62.2	37.3
Phoenix	51.0	30.6
Miami	4.6	2.7

The values for E_∞/E_0, α, and r^2 are shown in Table 5. The correlation coefficients are extremely high (above 0.98 in all cases), indicating very good fit for the energy use and capital cost curves.

Figure 3 shows the relationship between the percentage cooling energy saving and percentage heating energy saving for implementing conservation measures in a home in Kansas City. The constant, μ, is estimated from data in ref. 3 which give the reduction in heating and cooling energy for each of the conservation measures in Table 2. For Kansas City, μ is 0.417, which means for every percent savings in heating energy resulting from a conservation measure, a corresponding 0.417 percent reduction in cooling energy use is expected.

The relationship between heating and cooling energy savings is shown in Table 6 for each. The lowest correlation coefficient is 0.949 (Boston), indicating very good correlation between percent heating and cooling energy savings.

Table 5. Values of constants for energy use versus capital cost tradeoff curves and correlation coefficient

City	E_∞/E_0	α	r^2
Minneapolis	0.340	0.00176	0.997
Chicago	0.276	0.00186	0.996
Boston	0.278	0.00179	0.996
Seattle	0.192	0.00182	0.997
Kansas City	0.278	0.00187	0.996
Washington, D.C.	0.210	0.00179	0.997
Atlanta	0.184	0.00186	0.996
Fort Worth	0.184	0.00194	0.994
Phoenix	0.091	0.00217	0.981
Miami	0.065	0.00234	0.981

Table 6. Calculated μ and r^2 for each city

City	μ	r^2
Minneapolis	0.509	0.968
Chicago	0.503	0.972
Boston	0.380	0.949
Seattle	0.499	0.965
Kansas City	0.417	0.980
Washington, D.C.	0.438	0.980
Atlanta	0.498	0.989
Fort Worth	0.449	0.996
Phoenix	0.450	0.997
Miami	0.207	0.994

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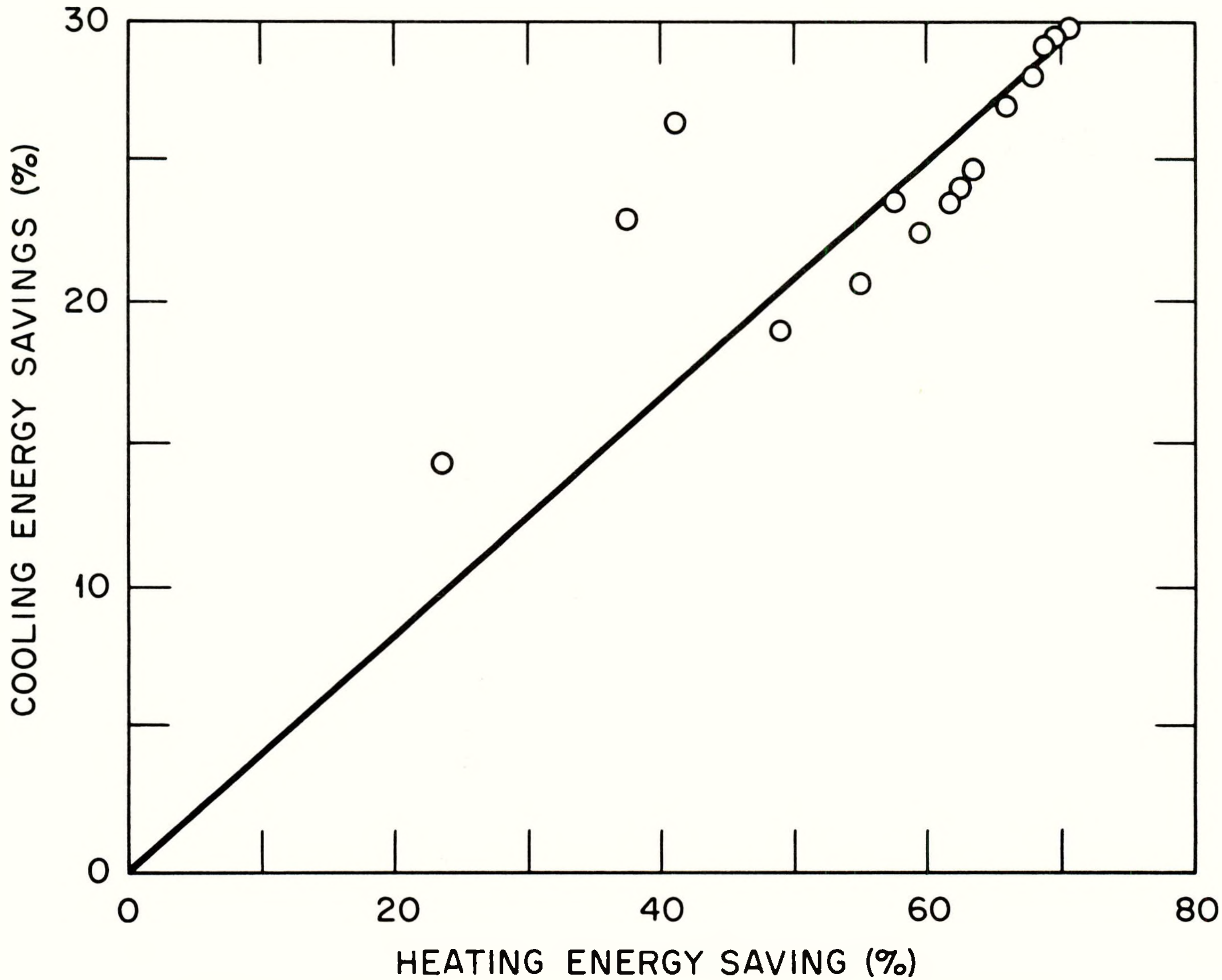

Figure 3. Heating energy savings versus cooling energy savings (single-family residences).

4. THE HOUSING DATA

This section discusses the data used to characterize the level of energy use and conservation investment in homes built in 1975 and 1976. Problems with the data and possible limitations of its use to this study are discussed.

The National Association of Home Builders (NAHB) conducted a survey of home builders to characterize newly constructed residences built in the last half of 1975 and the first half of 1976.[9,10] The survey included questions on general characteristics (house size, price, etc.) and thermal characteristics (i.e., insulation levels, storm windows, etc.) of residences. Residences were split into four categories: single-family detached, single-family attached, low-rise multi-family, and mobile homes. The total number of single-family detached homes in the survey was 112,942, approximately 10% of all single-family homes constructed during this time period.

The data was available by either the nine census regions (see Fig. 4), or seven climate zones (see Fig. 5). The data for the nine census regions was not disaggregated by fuel type, but did include thermal characteristics of crawl spaces and doors. The data for the seven climate zones included a breakdown of thermal characteristics by fuel type, but did not include information on insulation in crawl spaces or storm doors. To be able to use the latter data, we had to assume that all homes had an equivalent of R-11 insulation in the crawl space. Because we did not have a breakdown of insulation or storm (or insulated) doors in homes by heating fuel type, we assumed that if the data indicated that standard construction practice in a census region included storm doors, then all houses, regardless of heating fuel, had storm doors. Both of these assumptions lower the estimated annual fuel uses of the residences, and thus, lower the implied discount rate of the observed construction practices.

Data was not available by individual cities. We assumed that construction characteristics of residences in an individual city are the same as the construction characteristics of homes within the region the

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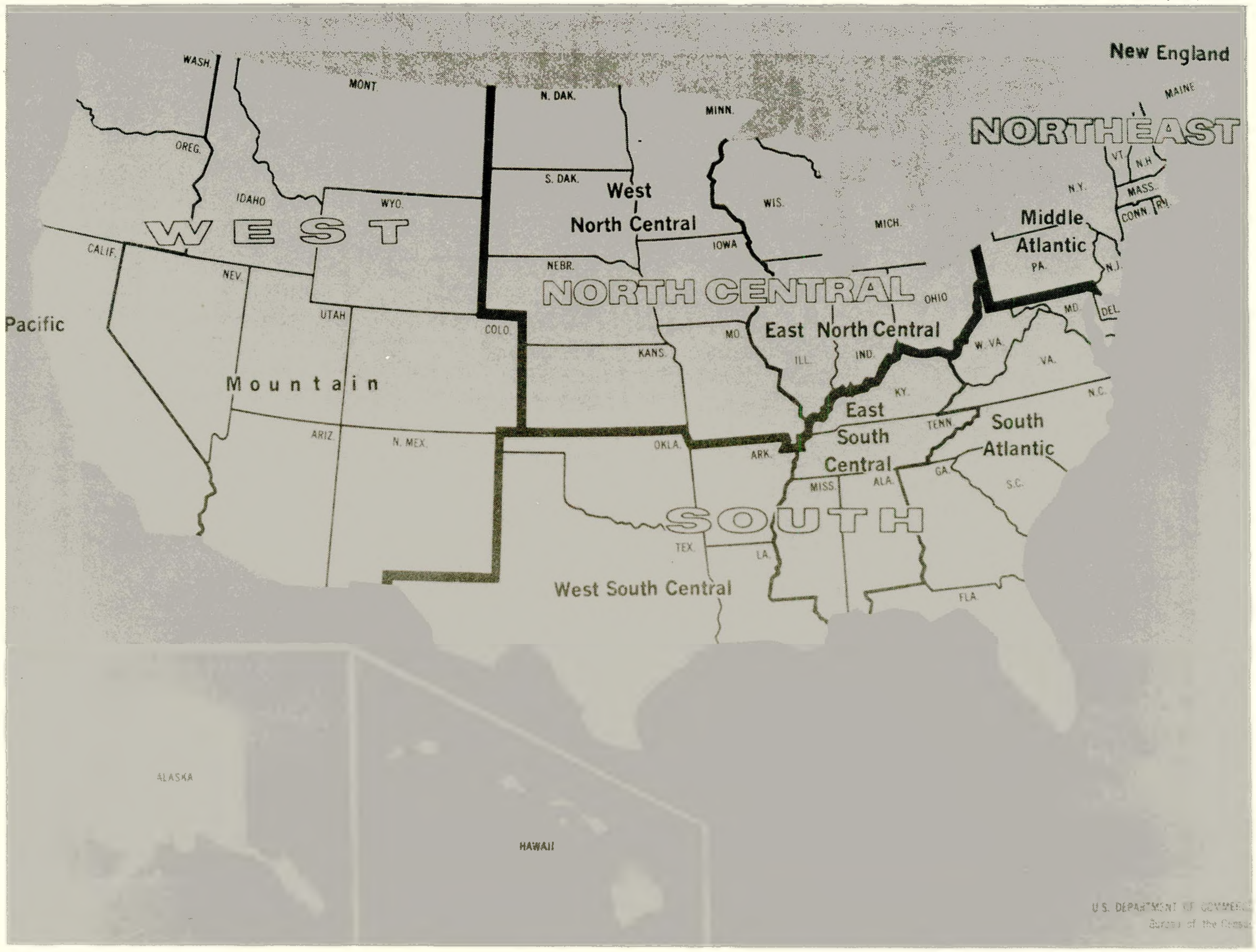

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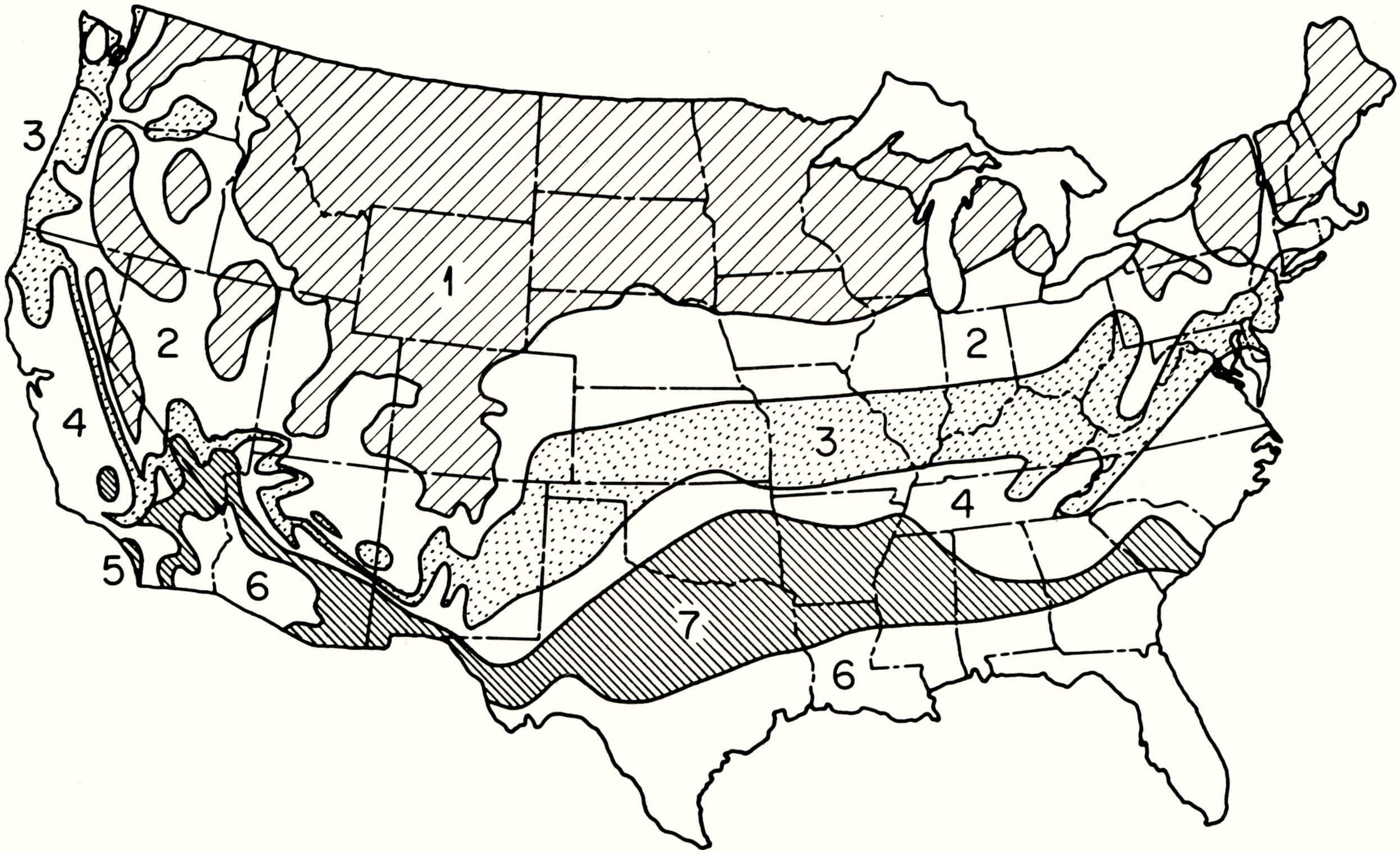

Figure 5. The seven climate zones of the U.S.

city is located. This could misrepresent reality because the characteristics of new homes in a city may vary for different cities within a region. However, because of the small variation in thermal characteristics of homes among regions (see following discussion) and the lack of more detailed data it seems the most reasonable assumption.

The thermal characteristics of homes in each city are given in Tables 7 through 9. An important observation from these tables is the uniformity of thermal characteristics in new residences across the country in this time period. For instance, a gas heated home built in Minneapolis has the same insulation levels in the ceilings, floors, and walls as a home built in Miami. In general, the thermal characteristics of electric and oil heated homes are slightly better in the Northern cities compared to the Southern cities. Because there is such uniformity in the thermal characteristics between regions of the country, the assumption that the thermal characteristics of homes in a city being the same as those of homes within its region may not be unreasonable.

The annual heating and cooling energy uses for these homes is shown in Tables 10 and 11, respectively. The thermal characteristics of Tables 7 through 9 are translated into the annual heating and cooling energy use of Tables 10 and 11 by picking the heating and cooling energy uses that correspond to the thermal characteristics from the appendix of ref. 3 and ref. 8. In the cities of Minneapolis, Chicago, Boston, and Washington, it is assumed that no air conditioners are installed in the homes. We made this assumption because, in the regions of the country where those cities are located, less than half of new homes had air conditioners installed in 1975 and 1976.[9,10]

One other potential problem with the data is knowing how representative they are of all single-family homes. Even though there were a large number of homes included in the survey, the builders who were surveyed are all members of the NAHB. Because these builders are a part of the national organization, their knowledge of building practices relating to energy conservation may be much better than those who are not. The net result is that the thermal integrity level of the homes in the survey may be better than the average of all new homes built during the 1975 and 1976 time period. Unfortunately no data is available to indicate whether NAHB members build better homes than non-NAHB members.

Table 7. Thermal characteristics of new electrically heated single-family homes

City	Thermal resistance (m^2 °C/W)			Window glazing level	Storm door
	Wall	Ceiling	Floor		
Minneapolis	2.29 (R-13)	5.29 (R-30)	1.94 (R-11)	2	yes
Chicago	2.29	5.29	1.94	2	yes
Boston	2.29	3.88 (R-22)	1.94	2	yes
Seattle	1.94 (R-11)	3.35 (R-19)	1.94	2	no
Kansas City	1.94	3.35	1.94	2	yes
Washington, D.C.	1.94	3.35	1.94	2	no
Atlanta	2.29 (R-13)	3.35	1.94	2	no
Fort Worth	1.94	3.35	1.94	1	no
Phoenix	1.94	3.35	1.94	1	no
Miami	1.94	3.35	1.94	1	no

Table 8. Thermal characteristics of new gas heated single-family homes

City	Thermal resistance (m^2 °C/W)			Window glazing level	Storm door
	Wall	Ceiling	Floor		
Minneapolis	1.94 (R-11)	3.35 (R-19)	1.94 (R-11)	2	yes
Chicago	1.94	3.35	1.94	2	yes
Boston	1.94	3.35	1.94	2	yes
Seattle	1.94	3.35	1.94	2	no
Kansas City	1.94	3.35	1.94	2	yes
Washington, D.C.	1.94	3.35	1.94	2	no
Atlanta	1.94	3.35	1.94	1	no
Fort Worth	1.94	3.35	1.94	1	no
Phoenix	1.94	3.35	1.94	1	no
Miami	1.94	3.35	1.94	1	no

Table 9. Thermal characteristics of new oil heated single-family homes

City	Thermal resistance (m^2 °C/W) Wall	Ceiling	Floor	Window glazing level	Storm door
Minneapolis	2.29 (R-13)	3.88 (R-22)	1.94 (R-11)	2	yes
Chicago	2.29	3.88	1.94	2	yes
Boston	1.94 (R-11)	3.35 (R-19)	1.94	2	yes
Seattle	1.94	3.35	1.94	1	no
Kansas City	1.94	3.35	1.94	1	yes
Washington, D.C.	1.94	3.35	1.94	1	no
Atlanta	1.94	3.35	1.94	2	no
Fort Worth	1.94	3.35	1.94	1	no
Phoenix	1.94	3.35	1.94	1	no
Miami	1.94	3.35	1.94	1	no

Table 10. Heating energy levels (E_h) of homes built in 1976

City	Annual heating energy use (GJ) by fuel type		
	Gas	Oil	Electricity
Minneapolis	127.1	123.6	71.6
Chicago	76.1	76.1	45.7
Boston	77.9	77.9	44.7
Seattle	61.7	72.4	33.3
Kansas City	65.4	74.2	39.2
Washington, D.C.	46.6	53.8	28.0
Atlanta	35.0	29.7	17.5
Fort Worth	25.5	25.5	15.3
Phoenix	16.0	16.0	9.6
Miami	1.2	1.2	0.7

Table 11. Cooling energy levels, E_K of homes built in 1976

City	Annual cooling energy use (GJ) by heating fuel type		
	Gas	Oil	Electricity
Minneapolis	0.0	0.0	0.0
Chicago	0.0	0.0	0.0
Boston	0.0	0.0	0.0
Seattle	0.7	0.7	0.7
Kansas City	7.3	7.5	7.3
Washington, D.C.	0.0	0.0	0.0
Atlanta	5.6	5.4	5.3
Fort Worth	11.1	11.1	11.1
Phoenix	19.4	19.4	19.4
Miami	20.9	20.9	20.9

5. RESULTS

In this section, we combine data from Sects. 2 and 3 to estimate the implied discount rate for consumers purchasing energy conservation measures in new residences. Results are given in four cases. The first case assumes that consumers expect rising fuel prices and they pay the entire cost of the conservation measures when purchasing the residence. The second case differs from the first in that we assume consumers expect fuel prices to have no real increase in future years. The third case differs from the second in that we assume the cost of conservation options are financed under the same conditions as the home. We assume a 25 year loan with a 20% down payment. Case 4 assumes mortgage financing plus rising fuel prices expectations.

Table 12 lists the 1975 fuel prices for gas, oil, electricity, and block electricity used for each city. The gas, oil, and electric prices are average prices for the state in which the city is located.[11-14] The block electric rate is the incremental cost to the consumer of the next kWh when purchasing more than 750 kWh/month. Because electric space heating customers usually consume a large amount of electricity each month during the heating season, the amount of savings on the fuel bills might be better reflected with the block rate rather than the average price.

Case 1

In this case, we assume consumers' expectations of future fuel prices are the same as the estimated fuel price projections for the Department of Energy's (DOE), Energy Information Administration (EIA). EIA publishes fuel price projections to 1995 for gas, oil, and electricity for each of the ten Federal regions. We used the 1979 series B forecasts to estimate real price escalations for each DOE region.[15] Then we applied the regional escalations to the cities within each region (see Table 13). The escalation rate for block electricity prices was assumed the same as that for the average price of electricity.

Table 12. Fuel prices for each city

City	Fuel prices (1975 $/GJ)			
	Gas[a]	Oil[b]	Electricity[c]	Block electricity[d]
Minneapolis	1.59	2.63	9.91	6.08
Chicago	1.58	2.77	8.19	8.68
Boston	3.20	2.94	12.03	10.62
Seattle	2.12	2.75	2.85	2.52
Kansas City	1.45	2.69	9.44	8.18
Washington, D.C.	2.40	2.81	10.06	9.79
Atlanta	1.75	2.77	8.27	7.95
Fort Worth	1.47	2.58	5.87	5.52
Phoenix	1.83	2.85	9.10	7.32
Miami	2.78	2.97	9.27	8.11

[a]Reference 11.

[b]Reference 12.

[c]Reference 13.

[d]Reference 14.

Table 13. Estimated real fuel price escalations

City	Annual fuel price escalations (%/yr)		
	Gas	Oil	Electricity
Minneapolis	4.79	3.70	1.76
Chicago	4.79	3.70	1.76
Boston	2.62	2.94	0.80
Seattle	4.54	3.75	1.84
Kansas City	5.88	3.56	1.32
Washington, D.C.	3.88	3.77	1.19
Atlanta	4.52	3.82	1.90
Fort Worth	5.94	3.68	3.35
Phoenix	4.72	3.65	1.72
Miami	4.52	3.82	1.90

In this case, we also assume that consumers pay for the whole cost of improving the thermal integrity of a residence when the residence is purchased. We therefore use Eq. (10) to estimate the discount rate. Table 14 lists the discount rates estimated for each city by fuel type.

There is a wide variation in the estimated discount rates, both between fuel types and cities. Chicago has the largest variation between fuel types: 12% for gas to 36% for electricity. Miami has no variation between fuels.

An unweighted average of the discount rates by fuel types yields 14% for gas, 18% for oil, 23% for electricity, and 21% for block electricity. These values are amazingly close to the 15% and 24% calculated by Hausman for consumer discount rate when purchasing efficiency improvements in room air conditioners.[1]

The discount rates do not seem to show any relationship with climate. For instance, the only two cities where the gas heating discount rate goes above 20% are in Phoenix and Boston. Phoenix is in the desert Southwest with 873 HDD, while Boston is in the Northeast with 3212 HDD.

Case 2

For the second case we assume that consumers expect future fuel prices to increase at the same rate as inflation (i.e., $\varepsilon_h = \varepsilon_K = 0$). To reflect this assumption we use Eq. (10a) to estimate discount rates. The results are shown in Table 15. As expected the discount rates are lower than those in the first case. With consumer expectations of future constant real fuel prices, the expected benefit of the conservation measures in reducing future fuel bills is smaller than with escalating fuel prices. Therefore, the discount rate implied by the observed investment decision is smaller.

Case 3

The third case considers the financing arrangements that homeowners have when purchasing a new home. When added conservation measures are built into a new home, their cost can be folded into the total cost of the new home. Most homebuyers finance the cost of a home with a loan

Table 14. Calculated discount rates for Case 1

City	Discount rates (%) by fuel			
	Gas	Oil	Electricity	Block electricity
Minneapolis	15	21	36	23
Chicago	12	19	29	30
Boston	20	19	36	31
Seattle	16	25	10	9
Kansas City	12	22	29	25
Washington, D.C.	12	19	25	24
Atlanta	12	12	17	16
Fort Worth	12	15	17	16
Phoenix	21	23	27	26
Miami	9	9	8	8
Average	14	18	23	21

Table 15. Calculated discount rates for Case 2

City	Discount rates (%) by fuel			
	Gas	Oil	Electricity	Block electricity
Minneapolis	10	17	34	21
Chicago	7	14	26	28
Boston	17	15	34	30
Seattle	11	20	8	7
Kansas City	7	18	27	24
Washington, D.C.	8	14	24	23
Atlanta	7	8	14	14
Fort Worth	7	11	13	12
Phoenix	18	21	25	24
Miami	6	6	6	6
Average	10	14	21	19

that ranges from 20 to 30 years. Thus, the cost of the house and the added conservation measures are spread out over the life of the loan. The interest rate paid on mortgages varies, but historically has been a few percent above inflation. We chose a three percent real interest rate because this value is close to the borrowing rate in 1976. We also assume a 25 year loan with 20% down payment. If consumers' discount rates are higher than the interest rate on mortgages, then the present value of the cost of the conservation measure is less than if they had paid its full cost when purchasing the home. When the assumption of mortgage financing is combined with the assumption that consumers expect fuel prices to continue at their current levels [i.e., Eq. (10c)] the resulting discount rates are generally higher than in Case 2, as demonstrated in Table 16.

Case 4

This case assumes mortgage financing together with the expectation of escalating fuel prices from Table 13 [i.e., Eq. (10b)]. The calculated discount rates for this case are shown in Table 17.

Table 16. Calculated discount rates for Case 3

City	Discount rates (%) by fuel			
	Gas	Oil	Electricity	Block electricity
Minneapolis	33	62	147	81
Chicago	19	51	109	117
Boston	63	56	149	129
Seattle	36	80	25	19
Kansas City	19	70	113	96
Washington, D.C.	24	51	96	93
Atlanta	21	25	52	49
Fort Worth	15	31	45	42
Phoenix	59	71	104	95
Miami	14	14	17	74
Average	30	51	86	74

Table 17. Calculated discount rates for Case 4

City	Discount rates (%) by fuel			
	Gas	Oil	Electricity	Block electricity
Minneapolis	43	70	153	85
Chicago	30	60	113	121
Boston	69	62	150	131
Seattle	46	89	29	23
Kansas City	30	78	116	100
Washington, D.C.	33	59	99	96
Atlanta	29	32	56	53
Fort Worth	31	45	52	49
Phoenix	74	86	108	99
Miami	22	22	22	21
Average	41	60	90	78

6. CONCLUSIONS

The research described in this report, like much research, raises as many questions as it answers. Let's first examine some of the conclusions which can be drawn from the study, then discuss topics for future research.

There is a significant gap between the discount rates imputed from investment choices in energy conserving measures in new homes in 1975-1976 and the market rate of interest. The reasons for this gap are not explained by the work described here, though it seems likely that it is due in part to market imperfections of the sort mentioned in the introduction.

Except in the case of Seattle, with the lowest electricity prices of the cities represented, and Miami, with the lowest heating requirements, imputed discount rates were markedly higher for electrically-heated homes than for homes heated by oil or gas. Similarly, with the exception of Boston, where oil costs were lower than gas, and Miami, the imputed discount rates for oil-heated homes are higher than homes heated by gas. A general pattern emerges in which homes heated by more expensive fuels incorporate energy conservation features which imply higher discount rates. For example, relative to gas-heated homes, electrically heated homes are not built to be as energy-efficient as their higher fuel costs would seem to justify, and similar relationships generally hold between gas vs. oil and oil vs. electrically heated homes. One possible explanation is that low first costs of electrical resistance heating systems means they tend to be chosen where the builder's general orientation is towards low first cost (i.e., high discount rate). However, this does not explain the discrepancy between the discount rates of oil and gas heated homes, because first costs of oil heating systems tend to be higher than those for gas heating systems. Another explanation, perhaps more plausible, is that building practices are in many cases a matter of convention rather than cost/benefit analysis — "a good" house has certain features, including insulation and glazing, and the definition of this "good" house is independent of the heating fuel. Yet another possible explanation is that the decisions which affect thermal integrity may not be made by the same person who chooses the heating fuel.

The imputed discount rates are sensitive to varying assumptions regarding consumers' price expectations and financing arrangements. Case 3 (mortgage financing with constant real fuel prices) and Case 4 (mortgage financing with escalating fuel prices) probably bracket the actual state of mind of most homebuyers, with Case 3 perhaps being more representative of their expectations in 1976 than in 1980. As we might expect, Case 4 results in higher imputed discount rates since (compared to Case 3) the higher fuel prices lead to higher marginal savings in the future, which must be discounted more heavily to lead to the observed investment levels. Case 2 is of interest to us, not because we regard its assumptions as necessarily the most realistic of all the cases, but because they match the assumptions of the energy efficiency investment submodel of the ORNL residential energy use model. While these assumptions are simplistic, they do give realistic simulation results when combined with the appropriate discount rates.

Choosing among the cases presented here for the one which best represents the investment decision process as it occurs in the typical homebuyers' mind is impossible on the basis of the data we have now. Resolution of this issue requires understanding of institutional constraints affecting mortgage financing of extra costs of energy-efficient houses, homebuyers' expectations regarding future fuel prices, and the efficiency of the residential housing market in capitalizing future operating costs (energy and non-energy) of houses. For the purposes of predicting the energy-efficiency of houses built in the 1980's, however, it may be more rewarding to obtain and analyze construction-practices data for years after 1975-1976 to learn whether implicit discount rates (given equivalent assumptions, e.g., Case 3) have changed with the passage of time, the increase of fuel prices, and a presumable increase in interest and information about energy efficient measures in houses. This course would leave open the question of the validity of Case 3 assumptions vs Case 4 assumptions, but may give us confidence that we can reliably predict future investment behavior using either set of assumptions, as long as it is combined with the equivalent discount rate. The development and analysis of data on construction practices for more recent years deserves high priority among extensions of this work.

Other questions not dealt with here which deserve treatment in extensions of this work include:

1. The effect of making the time horizon of the buyer, rather than the lifetime of the investment, the focus of the analysis. This would involve evaluation of costs over the period of expected ownership of the house together with the effect, excluded from this analysis, of energy efficiency on resale value.
2. The sensitivity of results of the analysis to the marginal income tax rate of the buyer. This tax rate affects the real rate of interest that the buyer pays, and with inflation pushing the average buyer into higher tax brackets the effect on levels of conservation investment could be significant.

To summarize, construction practices in 1975-1976 imply discount rates which are high relative to historical real interest rates and which vary substantially with the heating fuel, location, and assumptions regarding financing arrangements and fuel price expectations. The data are inadequate to support conclusions regarding the relative importance of hypothesized causes for the implicit discount rates calculated, but the results suggest great potential for energy savings if appropriate government programs could be designed to close the gap between the marginal rate of return to investment in thermal integrity in houses and the market rate of interest. Which programs are most appropriate depends on the relative importance of the various sources of market imperfections; some areas for future research are suggested.

ACKNOWLEDGMENTS

The authors would like to express special appreciation to David Kaserman, Mark Levine, Eric Hirst, Bill Mixon, and Jerry Hausman for their many helpful comments and suggestions on earlier drafts of this report, and Miriam Stanford for mostly cheerful assistance in typing and correcting the several versions through which the report has passed.

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Appendix A
PROTOTYPICAL HOUSE

This appendix describes the engineering analysis and costs of the prototypical house used in this study. The prototypical house was one studied by S. Petersen at the National Bureau of Standards (NBS).[8] It is a 122 m^2 single-story rancher over a vented crawlspace. The basic dimensions of the house (length to width ratio and fraction glass area) were chosen to be representative of new housing construction. The house is smaller than average new single-story construction in residences. Recent studies indicate the energy use per square meter of a single-story home shows very little dependence on house size between 100 and 300 m^2.[6] Thus, the use of a smaller than average house should not adversely affect the results of this study. Details of the house are given in Table A.1.

The thermal properties of the house described in Table 1 are considered "base case." Wall construction is 185 x 371 mm studs on 61 cm centers with no insulation. All windows are single-pane. The ceiling and crawlspace contain no insulation. The house is oriented so that its front faces due south. The winter thermostat setting is 20°C, with no night setback. More information on the single-family house characteristics are found in refs. 3 and 8.

The heating and cooling energy use of the base case house was estimated using the thermal analysis program, NBSLD (National Bureau of Standards Loads Determination Program).[16] NBSLD uses hourly weather data to calculate heat flows through the shell of the residence. These heat flows are then summed over the year to provide the annual heating and cooling loads.

To improve the thermal integrity of the house, several conservation measures are considered. These include:

1. additional insulation in walls, ceilings, and floor,
2. multi-pane windows,
3. multi-pane sliding glass doors, and
4. storm doors.

Table A.1. Single-family dwelling envelope parameters

				Area in m^2
Ceiling				112
Windows				
North facing	4 @ 1.28 = 5.12			
South facing	1 @ 1.86			
	1 @ 1.12			
Sliding glass door (South facing)	1 @ 3.72			
Total glass area				11.82
Entry door				1.86
Opaque wall area:	Insulated	+ Stud	= Total	
North facing	16.85	5.91	22.76	
East facing	19.43	2.87	22.30	
South facing	17.60	5.45	23.05	
West facing	19.43	2.87	22.30	
Total	73.31	17.10	90.41	90.41
Floor				112
Total envelope area				327

Source: References 3 and 8.

These options are permanent and passive, and were available to consumers in new homes constructed in 1975 and 1976. Costs for each option are from the National Association of Home Builders (NAHB).[17] These include dealer or builder markup and represent the U.S. average cost to the consumer. The costs (in 1975 $) represent the incremental expense to the consumer as a result of purchasing a single-family home with the conservation measures in addition to the measures present in the base configuration. These costs are listed in Table A.2.

To calculate the costs of the conservation measures in different cities, cost indices for labor and material for each city were used. These indices adjust the national average costs in Table A.3 to the costs incurred by local builders in each city. These indices are listed in Table A.3.

Table A.2. Design option cost data

Item	Average unit cost[a] (1975-\$)/m^2	Amount	Additional costs (1975-\$)	
			Labor only	Total
Wall insulation thermal resistance[b]				
0 → 1.94	1.44[c]	104 m^2[c]	40	150
1.94 → 2.26	0.48	104 m^2	0	50
2.26 → 3.35[d]	1.92	104 m^2	40	200
3.35 → 4.06[e]	1.92	104 m^2	60	200
Attic insulation thermal resistance[b]				
0 → 1.94	1.44	112 m^2	43	160
1.94 → 3.35	0.67	112 m^2	0	75
3.35 → 5.29	1.05	112 m^2	0	117
5.29 → 6.70	0.67	112 m^2	0	75
6.70 → 8.64	1.05	112 m^2	0	117
Floor insulation thermal resistance[b]				
0 → 1.94	1.72	112 m^2	75	192
1.94 → 3.35	0.76	112 m^2	0	85
Glazing				
Double	19.15	8.1 m^2	36	155
Triple	21.52	8.1 m^2	36	174
Door				
Storm	28.94	1.9 m^2	30	107[f]
Double glazed sliding glass	33.57	3.7 m^2	31	125

[a] Includes labor cost.

[b] Thermal resistance in m^2°C/W.

[c] Gross area, includes windows and doors.

[d] Includes additional cost for 15.5 x 46.5 mm studs.

[e] 3.35 m^2°C/W plus styrofoam sheathing.

[f] Three doors, each with a ten year life, discounted to present.

Source: References 3, 8, and 17.

Table A.3. Material and labor cost indices for each city

City	Material	Labor
Minneapolis	1.05	0.92
Chicago	0.92	1.06
Boston	1.03	1.05
Seattle	1.03	0.96
Kansas City	0.95	1.00
Washington, D.C.	0.98	0.94
Atlanta	0.89	0.83
Fort Worth	0.82	0.96
Phoenix	0.89	0.98
Miami	0.89	1.07

The criterion used for determining the order of implementation of the conservation measures is marginal benefit to cost ratio. The stream of fuel bill savings over the lifetime of the measure is considered the benefit, while the initial cost of the measure is its cost. The most cost effective order of implementation is:

1. Baseline
2. 1.94 $m^2 °C/W$ attic insulation
3. 1.94 $m^2 °C/W$ wall insulation
4. 3.35 $m^2 °C/W$ attic insulation
5. 1.94 $m^2 °C/W$ floor insulation
6. Storm windows
7. 5.29 $m^2 °C/W$ attic insulation
8. 3.35 $m^2 °C/W$ floor insulation
9. Double glazed sliding glass door (SGD)
10. 2.29 $m^2 °C/W$ wall insulation
11. 6.70 $m^2 °C/W$ attic insulation
12. 3.35 $m^2 °C/W$ wall insulation
13. Triple pane windows
14. 8.64 $m^2 °C/W$ attic insulation
15. Storm door
16. 4.06 $m^2 °C/W$ wall insulation (using styrofoam)

Each step is cumulative. The decision to proceed from one step to the next is based on benefits and costs relative to those incurred from the previous steps.

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