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Effects of Federal Residential Energy Conservation Programs

Conservation programs can substantially cut energy use and save money for households.

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This article addresses two key issues concerning residential energy conservation strategies, their effects on energy use and on household economics. Two conclusions can be drawn. (i) Future levels of residential energy use are subject to considerable control; the analyses reported here show a range in energy use in the year 2000 of 16 to 28 quads (1 quad = 10^{15} British thermal units) (*1*). (ii) Implementing conservation programs generally saves money for consumers; for example, we estimate that the programs proposed by President Carter (*2*) will save households $27 billion between now and the year 2000.

The basis for these conclusions is a set of analyses prepared with a detailed engineering-economic model of residential energy use developed at Oak Ridge National Laboratory (ORNL) (*3, 4*). This model simulates household energy use at the national level for four fuels (electricity, gas, oil, and other), eight end uses (space heating, water heating, refrigerators, freezers, cooking, air conditioning, lighting, and other), and three housing types (single-family, multifamily, and mobile homes). Each of these 96 fuel-use components is calculated for each year of the simulation as functions of the stocks of occupied housing units and new construction, equipment ownership by fuel and end use, the thermal integrity of housing units, the average unit energy requirements for each type of equipment, and usage factors that reflect household behavior. The model also calculates annual fuel expenditures, equipment costs, and capital costs for improving the thermal integrity of new and existing structures at the same level of detail. These cost figures allow us to develop simple benefit/cost ratios for each program evaluated. Figure 1 shows the major elements of the simulation model; the structure is such that the model is sensitive to the major demographic, economic, and technological determinants of residential energy use.

Nine different residential energy "futures" are evaluated with the energy model. The high projection (case 1) assumes that "real" fuel prices remain constant from 1976 through the end of the century and that no federal conservation programs are adopted. In case 2, fuel prices are allowed to rise between 1976 and 2000. As with case 1, no government conservation programs are implemented. Changes in energy use are entirely voluntary and come about as a result of normal market forces only. Case 2 is considered our "base line," against which all the other cases are compared.

Cases 3 through 6 consider the residential conservation programs authorized by the 94th Congress (*5, 6*) and expanded upon in President Carter's April 1977 energy message (*2*). These include appliance efficiency standards, thermal performance standards for new construction, a retrofit program to affect 90 percent of the nation's housing stock, and a combination of these three programs. Cases 7 through 9 consider the energy and economic effects of additional conservation programs, including much larger fuel price increases, elimination of all market imperfections affecting residential energy use, and both of these factors.

Each program and policy is evaluated for its effects on residential energy use (by fuel, end use, and in aggregate) and on household economics (fuel bills and capital costs for equipment and structures) between 1977 and 2000. Tables 1 and 2 summarize the energy and economic effects of each of the nine cases discussed here (*7*).

High Energy-Use Projection

Inputs to the ORNL energy-use model required to develop a projection include population, fuel prices, per capita income, and specifications for government conservation programs (for example, appliance efficiency standards, tax incentives for retrofitting homes, and fuel price increases). Table 3 shows the values of population (*8*), households (*3*), housing distribution (*3*), and per capita income (*9*) used in all the projections discussed in this article. The bases for these inputs are discussed in (*4*).

For case 1, we assume that real fuel prices remain unchanged between 1976 and 2000 at their 1976 values (*10*): $2.81 per 10^6 Btu's for electricity, $1.88 per 10^6 Btu's for gas, and $2.83 per 10^6 Btu's for oil. Finally, we assume that there are no government programs that encourage households to reduce energy use. In other words, we ignore recent legislation [the Energy Policy and Conservation Act (*5*) and the Energy Conservation and Production Act (*6*)] and the Carter Administration's proposed programs.

However, the model estimates changes in new equipment and structure efficiencies and changes in usage (that is, the intensity with which households use

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existing stocks of equipment) because of the fuel price increases during the early 1970's. Based on information obtained from Owens-Corning Fiberglas Corporation (4), we assume that 14.3 million single-family and 2.0 million multifamily units will be retrofitted during the period from 1974 through 1980. We assume that these actions (additional attic insulation, clock thermostats, caulking and weather stripping, furnace tune-up) will cut energy use for space heating 20 percent and will cost $225 for each single-family and $130 for each multifamily unit (4).

Outputs from the energy model, given these inputs, show residential energy use growing from 16.3 quads in 1976 to 18.3 quads in 1980, 23.6 quads in 1990, and 28.1 quads in 2000. The average growth rate during this 24-year period is 2.3 percent per year as compared with 3.6 percent per year between 1950 and 1975 (11).

The contribution of different fuels to the total changes during the projection period. Because of the sharp increase in petroleum prices during the early 1970's and consumer preference for gas and electricity, the fraction of household energy use accounted for by oil is expected to decline from 17 percent in 1976 to only 7 percent in 2000. Electricity's share will probably increase from 45 to 61 percent for the reasons given above and also because of growing ownership of electric air-conditioners and electric food freezers. The contribution of gas to the total is expected to decline from 34 to 31 percent during this period; the use of other fuels also will probably decline from 4 to 1 percent.

Energy use grows more slowly in case 1 than historically for several reasons. First, fuel prices are assumed constant in case 1 while historically fuel prices have declined. Second, the effects of the fuel

Table 1. Alternative residential energy-use projections: energy use.

Case	Description	Energy use (quads)				Cumulative (1977–2000)	Average annual growth rate, 1976–2000 * (%)
		1980	1985	1990	2000		
	No government program						
1	High: constant (1976) fuel prices, no government conservation programs	18.3	21.0	23.6	28.1	543.6	2.3
2	Base line: same as case 1 with rising fuel prices	17.8	19.5	21.1	24.2	493.6	1.7
	Federal conservation programs						
3	Base line plus appliance efficiency targets	17.5	19.0	20.5	23.6	482.3	1.5
4	Base line plus new construction standards	17.6	19.1	20.6	23.4	482.8	1.5
5	Base line plus retrofit program	17.1	18.3	20.0	23.1	468.9	1.4
6	Base line plus combined federal program	16.7	17.5	18.9	21.6	447.2	1.2
	Additional conservation programs						
7	Combined federal program plus 50 percent fuel price increases	16.7	15.2	15.4	17.0	384.2	0.2
8	Combined federal program plus no market imperfections	16.7	17.1	18.0	19.9	428.9	0.8
9	Combined federal program, 50 percent fuel price increases, no market imperfections	16.7	14.9	14.8	15.8	371.4	−0.1

*The model's estimate of residential energy use in 1976 was 16.3 quads.

Table 2. Alternative residential energy-use projections: direct economic effects. Totals in column 5 have been rounded off.

Case	Description	Present worth of cumulative (1977–2000) expenditures at 8% real interest rate (10^9 1975 dollars)				Energy-related residential expenses in 2000 as a percentage of personal income†
		Fuels	Equipment*	Structure thermal integrity*	Total	
	No government program					
1	High: constant 1976 fuel prices, no government programs	596.2	0	0	596.2	2.5
2	Base line: same as case 1 with rising fuel prices	659.6	2.1	1.0	662.7	3.0
	Federal conservation programs					
3	Base line plus appliance efficiency targets	646.3	10.7	0.7	657.7	2.9
4	Base line plus new construction standards	647.8	2.2	5.0	655.0	2.9
5	Base line plus retrofit program	628.0	2.7	16.7	647.3	2.9
6	Base line plus combined federal program	603.4	11.2	20.7	635.3	2.7
	Additional conservation programs					
7	Combined federal program plus 50 percent fuel price increases	698.8	6.1	20.8	725.8	3.2
8	Combined federal program plus no market imperfections	585.8	20.0	22.9	628.7	2.6
9	Combined federal program, 50 percent fuel price increases, no market imperfections	680.1	15.8	23.4	719.3	3.1

*The incremental capital cost figures for equipment and structures are relative to those for the high case. For equipment, the increments include changes in both ownership and efficiences. For structures, the increments include only thermal integrity changes. †The comparable figure for 1976 was 3.1 percent.

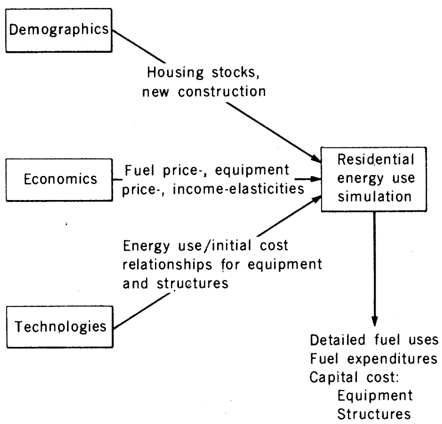


Fig. 1. Schematic of ORNL residential energy-use model.

price increases in the early 1970's are felt slowly over time and dampen energy growth in the projection period as households replace equipment and structures with systems that are more energy-efficient. A third reason relates to "saturation." Between 1950 and 1975, household ownership of air conditioners, refrigerators, freezers, heating systems, and water-heating systems increased dramatically. By 1975, almost all households had heating and water-heating equipment; more than half of all households had air-conditioning systems. Thus, the potential for increasing ownership of known energy-using systems is slight (*12*).

Base-Line Projection

Case 2 differs from case 1 only with respect to fuel prices. The fuel price trajectories used as inputs in our model for this and succeeding projections are obtained from the Federal Energy Administration (*9*) and the Brookhaven National Laboratory (*13*) energy models. These projections indicate a substantial increase in real gas prices (average annual growth of 2.3 percent between 1976 and 2000) and moderate increases in electricity (0.9 percent per year) and oil (1.2 percent per year) prices (Fig. 2). In the base line, residential energy use grows from 16.3 quads in 1976 to 17.8 quads in 1980, 21.1 quads in 1990, and 24.2 quads in 2000 with an average annual growth rate of 1.7 percent (see Fig. 3).

Changes in the distribution of energy use by fuel (case 2) are similar to those in case 1: electricity is expected to increase its share of the total and all other fuels will probably decline in importance. Because of rapidly rising gas prices, the share accounted for by gas is expected to drop to 24 percent in 2000 (compared with 31 percent in case 1) (Fig. 3).

The economic penalty associated with rising fuel prices is surprisingly mild. In 1976, fuel costs amounted to 3.1 percent of total personal income. In case 2, fuel costs amount to 3.0 percent of personal income in the year 2000. Thus, even though the average fuel bill per household increases from \$570 in 1976 to \$730 in 2000, growth in personal income more than compensates for fuel cost increases.

The mild economic penalty associated with the increase in the average fuel price of almost 40 percent between 1976 and 2000 is due primarily to the voluntary response of households to price increases. This response takes two forms. In the short run, households are expected to reduce their usage of existing stocks of equipment. For example, thermostats are set back during the winter. Thus, in the year 2000, households in case 2 use 10 percent less fuel for heating than they do in case 1. In the long run, as existing stocks of equipment and structures wear out, households will probably replace them with more efficient systems. For example, the average efficiency of new heating equipment in the year 2000 is about 15 percent higher in case 2 than in case 1.

Federal Conservation Programs

Here we evaluate the energy and economic effects of residential conservation programs in four elements: (i) appliance efficiency targets, (ii) thermal performance standards for new construction, (iii) weatherization (retrofit) of existing housing units, and (iv) all of the above. The time between congressional authorization and full implementation of a program can be several years. The programs discussed here were all authorized by the 94th Congress (*5, 6*); President Carter has proposed stronger programs in each area (*2, 9*). However, none of the programs has yet been implemented.

Each of these programs is compared to case 2 in terms of energy use and household costs. The inputs discussed earlier

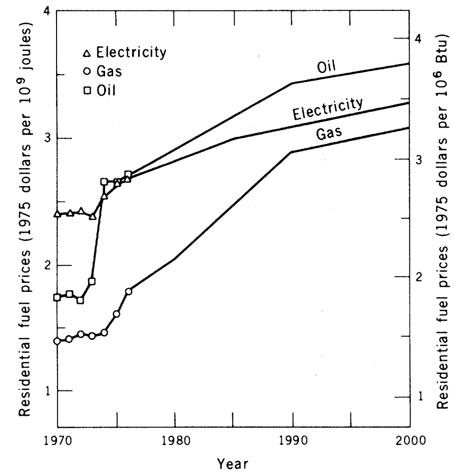


Fig. 2. Assumed fuel prices to the year 2000.

(Table 3 and Fig. 2) remain unchanged for these evaluations.

Appliance efficiency targets (case 3). The Federal Energy Administration (FEA) (now part of the Department of Energy) administers the program to develop and implement a set of appliance efficiency targets such that the average efficiency of new appliances sold in 1980 is at least 20 percent higher than the 1972 average (*5, 6*). President Carter has proposed that the existing voluntary program be made mandatory (*2*). The FEA targets are shown in Table 4 (*9*).

Consider the efficiency targets for water heaters as an example (Figs. 4 and 5). The target calls for a 15 percent reduction in energy use for electric water heaters. Our analysis (*14*) suggests that this target could be met by replacing existing jacket insulation (2 inches of fiberglass) with 4 inches of urethane foam and adding 1 inch of fiberglass insulation to the distribution line (1 inch = 2.5 centimeters).

These measures would increase the purchase price of the water heater \$42. The reduction in annual fuel bills would be \$36 (at the 1976 electricity price). The extra cost of the improved electric water heater is repaid in a year.

The target for gas water heaters (20 percent reduction in energy use) could

Table 3. Inputs assumed for all projections of residential energy use (*3, 8, 9*).

Year	Population (10^6)	Households (10^6)	Distribution of occupied housing units (%): Single-family	Multi-family	Mobile home	Per capita income (1975 dollars)
1970	205	63	69	27	3	5,420
1975	213	71	67	29	4	5,850
1976	215	72	67	29	4	6,050
1980	223	81	65	31	5	7,150
1985	234	91	63	32	5	7,970
1990	245	99	62	32	6	8,890
2000	262	114	61	33	6	10,570

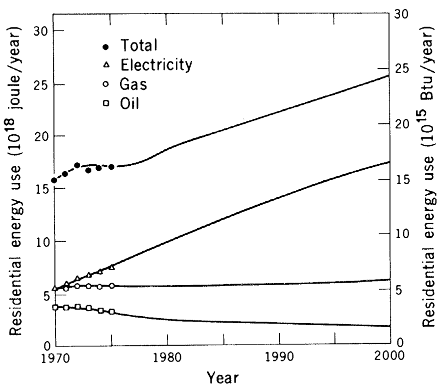


Fig. 3. Base-line projection of residential energy use to the year 2000.

be met by replacing the 1 inch of fiber-glass insulation on the jacket with 2 inches of urethane foam, adding 1 inch of insulation to the distribution line, and reducing the pilot rate. This would increase the cost of the water heater \$39. The reduction in annual gas bills would be \$13. This investment is repaid within 3 years. These examples (and our analyses of other appliances) suggest that the FEA appliance efficiency targets provide good investment opportunities for households.

Tables 1 and 2 summarize the energy and economic effects of adopting these efficiency targets (Table 4) in 1980. In evaluating this case, the model chooses either the given appliance efficiency target or the voluntary response to fuel price changes, whichever yields more efficient equipment. Thus the standards affect equipment choices only when the marketplace does not.

Energy savings increase from 0.2 quad in 1980 to 0.6 quad in 1990 and 0.7 quad in 2000. The cumulative energy saving (from 1977 through 2000) is 11.3 quads. About 85 percent of the energy savings is electricity; this is so because of shifts to electricity for heating and water heating and because the other end uses are powered only by electricity.

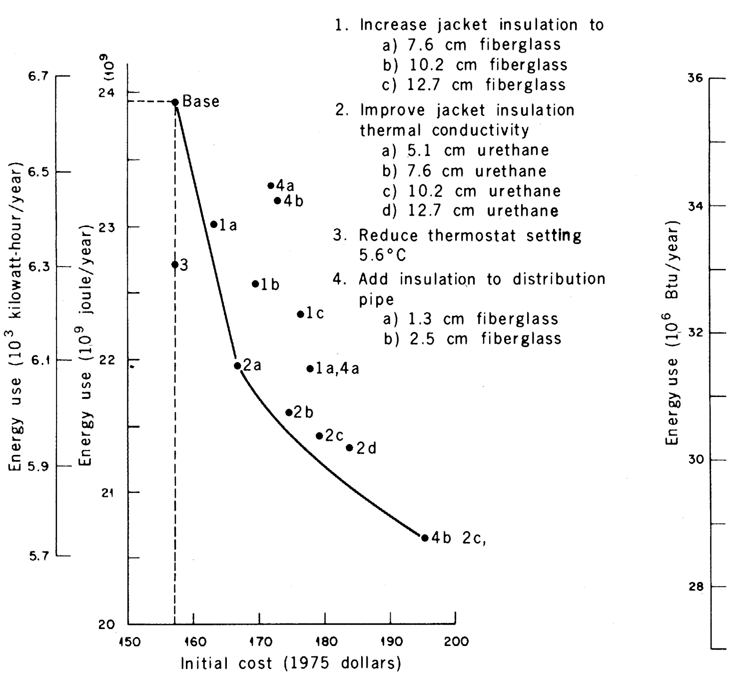
The reduction in fuel bills exceeds the increase in capital costs by \$5 billion. The benefit/cost ratio for the appliance program (at the assumed real interest rate of 8 percent) is 1.6. This result suggests that the proposed appliance program would save both energy for the nation and money for households.

New construction standards (case 4). The Energy Conservation and Production Act (ECPA) (*6*) requires the Department of Housing and Urban Development (HUD) to develop thermal standards for the construction of new buildings within 3 years (by 1979). These standards must then be implemented by the states, but only if Congress first approves them. The President's energy program proposed to "advance by one year, from 1981 to 1980, the effective date of the mandatory standards required for new residential and commercial buildings" (*2*, p. 8). Table 5 summarizes the likely improvements in space-heating and air-conditioning loads resulting from these standards (*15*). These standards provide larger percentage savings in multifamily units than in single-family units. This result is consistent with the changes likely from implementing the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90-75 standards or the June 1974 HUD standards (*16*). We also assume that all mobile homes constructed between 1976 and 2000 will meet the recent HUD standards (*17*).

The incremental capital cost of constructing a gas-heated single-family home in accordance with the standards shown in Table 5 is about \$500 (*3*). This figure includes the cost of labor and materials for additional insulation, storm doors, and storm windows minus the savings for smaller heating and air-conditioning equipment. The reduction in the annual heating bills would be \$90 (at the 1976 gas price), and the reduction in an-

Table 4. Assumed reductions in 1980 energy requirements for new equipment from FEA appliance efficiency targets (1970 = 1.0) (*9*).

Space heating	
Electric	1.0
Gas	0.81
Oil	0.93
Water heating	
Electric	0.85
Gas	0.80
Oil	0.81
Refrigerators	0.68
Freezers	0.77
Air conditioners	
Room	0.65
Central	0.80
Other appliances	0.90



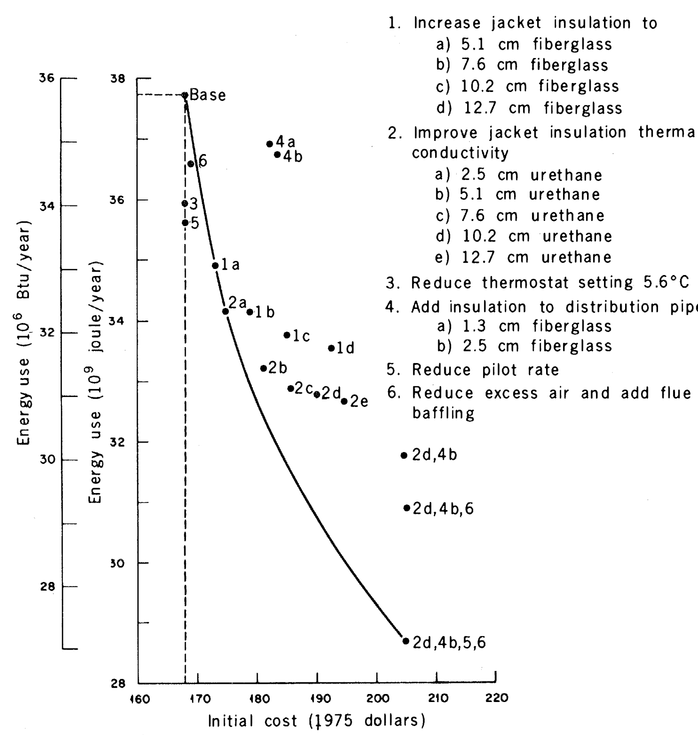


Fig. 4 (left). Energy use versus retail price for a typical electric water heater. Fig. 5 (right). Energy use versus retail price for a typical gas water heater.

nual cooling bills would be $35. Thus, the investment in tighter building construction is paid back in 4 years.

Tables 1 and 2 summarize the energy and economic effects of implementing the new construction standards of Table 5. The energy savings increase from 0.1 quad in 1980 to 0.5 quad in 1990 and 0.8 quad in 2000. The cumulative energy savings total 10.8 quads, almost as much as the savings due to the appliance efficiency program.

About 67 percent of the cumulative energy savings is electricity, 21 percent gas, and the remainder oil. Electricity accounts for so much of the savings because all air-conditioning savings are electricity and because more than 40 percent of new housing units are heated with electricity.

The economic benefits of the new construction standards are 50 percent larger than those for the appliance efficiency targets. Fuel bill reductions exceed additional construction costs by almost $8 billion. The benefit/cost ratio for these standards is 2.9.

Retrofit program (case 5). A number of provisions in the Energy Policy and Conservation Act (EPCA) (*5*) and ECPA (*6*) encourage weatherization of existing structures. For example, ECPA authorizes the FEA to provide financial assistance to low-income households to weatherize their structures; it also authorizes HUD to conduct demonstration programs to provide financial assistance for improving the energy performance of existing buildings. The April 1977 energy message proposes a number of measures to meet the goal of "insulating 90 percent of all residences" (*2*, p. 3). These measures include tax credits for retrofits, requirements that electric and gas utilities assist their customers in weatherizing structures, increased funding for the weatherization program of low-income households, and implementation of a rural home weatherization program.

Table 5. Assumed improvements in thermal integrities for residential structures (1970 = 1.0).

Housing unit	1980 HUD	Retrofit actions*	
		Voluntary	Federal
Single-family units			
Space heating	0.70/0.60†	0.80	0.65
Air conditioning	0.71	0.84	0.70
Multifamily units			
Space heating	0.48	0.80	0.72
Air conditioning	0.58	0.84	0.78
Mobile homes‡			
Space heating	0.80		
Air conditioning	0.84		

*Voluntary retrofits are assumed to apply to 14.3 million single-family and 2.0 million multifamily units between 1974 and 1980. The federal retrofit program is assumed to apply to 42.3 million single-family and 7.3 million multifamily units between 1974 and 1984; this includes the voluntary retrofits. †The first number applies to electrically heated homes; the second number applies to homes heated with gas and oil. ‡Mobile home standards were published by HUD in December 1975 and went into effect in June 1976. We assume that these standards will remain in force unchanged through the year 2000.

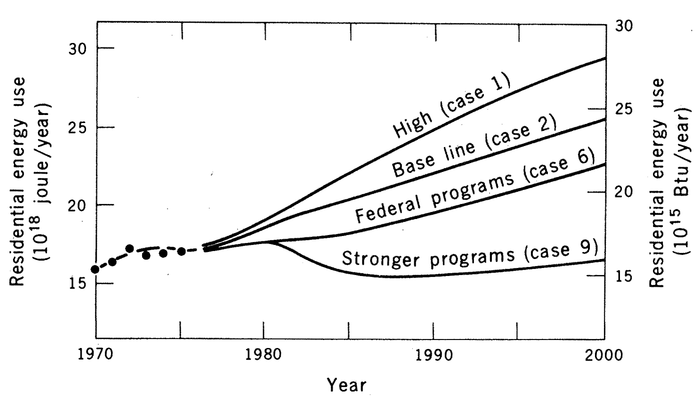
Based on conversations with FEA staff (*15*), we assume the parameters for the retrofit program shown in Table 5. The retrofit costs per housing unit are $580 for a single-family unit and $240 for a multifamily unit. We assume that these reductions in heating and cooling demands will be implemented in 42 million single-family homes and 7 million multifamily homes by 1985.

Tables 1 and 2 summarize the energy and economic effects of retrofitting these housing units. The energy savings increase from 0.7 quad in 1980 to 1.2 quads in 1985; the savings then decline slowly through the end of the century (1.1 quads in 2000). The cumulative savings of 25 quads is double the savings from either the appliance efficiency targets or the new construction standards. The retrofit savings are large both because so many housing units are affected and because the assumed improvements are large.

The economics of the retrofit program are quite attractive. Reductions in fuel bills exceed increased capital costs by $15 billion. The benefit/cost ratio for this program is 1.9.

Combined federal program (case 6). Tables 1 and 2 summarize the energy and economic benefits of adopting all three of the programs discussed above (see also Figs. 6 and 7). The energy savings increase from 1.1 quads in 1980 to 2.2 quads in 1990 and 2.6 quads in 2000. The cumulative saving of 46 quads is 9 percent of the base line. Energy growth between 1976 and 2000 is reduced from 1.7 to 1.2 percent per year.

The combined program reduces energy-related costs to consumers by $27 billion. The overall benefit/cost ratio for the program is 2.0. Energy-related expenditures are reduced from 3.0 to 2.7 percent of personal income in the year 2000. Figure 7 shows that the incremental capital costs of improved equipment and structures exceed fuel bill reduction until 1982. After 1982, however, the annual fuel bill reductions exceed extra capital costs.



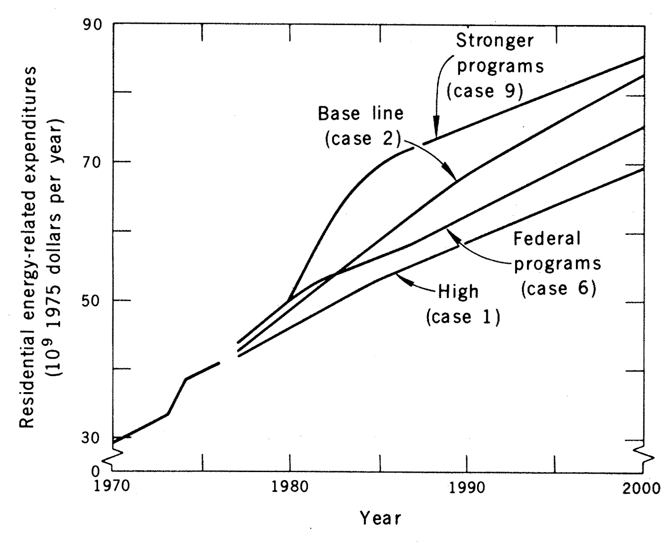


Fig. 6 (left). Alternative projections of residential energy use to the year 2000. Fig. 7 (right). Alternative projections of residential energy-related expenditures to the year 2000.

Additional Programs

Results in the preceding section suggest that the conservation programs proposed and planned by the federal government are likely to save large amounts of energy (46 quads) and money ($27 billion). Now let us examine two additional (stronger) programs for their effects on energy use and household economics.

The first program (case 7) involves large increases in fuel prices. Case 7 is the same as case 6 (combined federal program) except that fuel prices are increased by 10 percent in 1981, 20 percent in 1982, and so on until fuel prices are higher by 50 percent for the years 1985 through 2000. Such fuel price increases might occur because of increasingly strict environmental standards (for example, sulfur removal from power plants, strip-mine reclamation, increased costs for nuclear fuel reprocessing and storage), because of the increasing scarcity of gas and oil and the consequent higher costs of extraction (and the higher opportunity costs for these fuels), and because of the social costs associated with large energy production facilities. Alternatively, governments might choose to tax fuels (*18*).

Increasing the fuel prices shown in Fig. 2 reduces energy use by 2.3 quads in 1985, 3.5 quads in 1990, and 4.6 quads in 2000 relative to the "future" with the combined federal program (case 6). Growth in energy use is cut from 1.2 to 0.2 percent per year.

These higher fuel prices increase consumer expenditures on fuels and also on efficient equipment and structures. Energy-related expenditures in the year 2000 amount to 3.2 percent of personal income, compared with 3.0 percent in case 2 and 2.7 percent in case 6. The cumulative increase in expenditures (at 8 percent) is $90 billion relative to case 6 and $63 billion compared with case 2. Although the relative economic costs of the increased fuel prices are small compared with personal income, the absolute costs are large. If the additional fuel expenditures are returned to consumers through tax rebates, there will be no economic cost of the higher fuel prices. There will, however, be an income transfer from households that use large amounts of fuel to those that use small amounts.

The second program (case 8) involves greater efficiency improvements in new equipment and structures than those shown in Tables 4 and 5. The federal government's proposed standards reduce life cycle costs to consumers but they do not minimize life cycle costs. In case 8, the model selects the "optimal" [in the sense of minimum life cycle costs at consumers' implicit rates of return; see appendix tables of (*4*)] combination of equipment and structures beginning in 1980. Such changes could come about through stronger government regulatory programs, or they might occur through increased awareness and motivation on the part of consumers. At the present time, it is difficult for consumers to collect and process the information they need to make "rational" decisions concerning equipment and structure efficiency. However, government education programs, energy efficiency labels, and other information programs could provide those data and thereby encourage consumers to choose more efficient equipment and structures.

In case 8 we allow the model to select the mix of equipment and structures that minimizes life cycle costs to consumers beginning in 1980. Relative to case 6, energy savings increase from 0.4 quad in 1985 to 0.9 quad in 1990 and 1.8 quads in 2000. The average growth in energy use is cut from 1.2 to 0.8 percent per year. The energy benefits of eliminating market imperfections after 1980 are much greater when compared with case 2 (see Tables 1 and 2).

The economic benefits of either forcing or encouraging consumers to make purchase decisions at their implicit interest rates are significant. The reduction in fuel bills relative to the base line exceeds the increase in capital costs by $34 billion.

In case 9 we combine the two preceding changes. Energy use drops 10 percent between 1980 and 1985 and then increases slowly to the end of the century. Energy use in 2000 is 3 percent less than it was in 1976. Thus, case 9 yields zero energy growth in the residential sector (see Fig. 6).

Energy-related household expenses in 2000 (case 9) total $86 billion, compared with $75 billion in case 6 and $83 billion in case 2 (see Fig. 7). As a portion of personal income, case 9 costs amount to 3.1 percent in 2000, compared with 2.7 percent for case 6 and 3.0 percent for case 2. The cumulative increase in energy-related costs amounts to $57 billion compared with the base line (case 2).

Summary

We used a detailed engineering-economic simulation model of residential energy use to evaluate the effects of nine different residential energy-use "futures." These "futures" are described in terms of annual and cumulative energy use from 1977 through 2000 by fuel, end use, and in aggregate. Outputs from the model also include economic information on the costs to households of fuels, equipment, and thermal improvements to new and existing structures. The major outputs from these nine cases are shown in Tables 1 and 2 and Figs. 6 and 7.

Our conclusions are as follows:

1) Residential energy use will almost surely grow more slowly during the remainder of this century than it did in the past. Energy use grows at 2.3 percent per year in our high projection (case 1), compared with an average growth of 4.0 percent per year between 1950 and 1972. If residential energy use grew at 4.0 percent per year from 1976 through 2000, it would reach 42 quads in 2000—almost 50 percent higher than the estimate from case 1. This significant reduction in energy growth is due to the long-term effects of fuel price increases from 1970 through 1976, reductions in population growth, the absence of new energy-intensive household activities, and the near-saturation of existing household activities.

2) In case 1 we assume that real fuel prices will remain constant between 1976 and 2000. However, all projections we have seen show increases in fuel prices to the year 2000. In case 2, the base line, we use fuel prices that are roughly 40 percent higher in 2000 than in 1976. The effect of these price increases is to cut energy use 14 percent in 2000. In case 2 we assume no government programs. Changes in the energy efficiencies of equipment and structures and changes in household behavior occur only because of voluntary responses to fuel price changes. Thus, the "business as usual" response to the assumed higher fuel prices is to cut energy growth to 1.7 percent per year; energy use in 2000 is only about half of what it would be if historical trends (4.0 percent per year) continued through the end of the century.

3) Implementation of conservation programs that encourage or force manufacturers to produce and consumers to purchase more efficient equipment and structures saves energy and money. These programs (cases 3 through 6)—appliance efficiency standards, thermal performance standards for new construction, and a program to retrofit existing housing units—reduce energy growth from 1.7 percent per year (case 2) to 1.2 percent per year. The cumulative energy savings total 46 quads (69 percent electricity, 22 percent gas, 9 percent oil). In addition, these programs reduce life cycle costs to consumers of owning and

operating households. The present worth of the net benefits (at 8 percent) amounts to $27 billion.

Of the three programs, retrofitting existing homes provides the largest energy and economic benefits. This is so because we assume that all the retrofits are accomplished by 1984; most of these housing units are assumed to remain in the housing stock through the year 2000. However, many of the new units affected by the HUD standards will not be built until the 1990's; they will provide much smaller cumulative energy savings.

The energy savings due to the appliance program would be larger if standards for electric space-heating systems were imposed. Significant improvements in the efficiencies of electric systems are possible through the use of electric heat pumps. Presently available heat pumps require about 55 percent as much electricity for heating as resistance heating systems; more advanced heat pumps might require only 40 percent as much electricity.

4) Because the federal programs examined here offer benefits to society in terms of reduced energy consumption and benefits to households in terms of reduced costs and less frugal usage patterns, we examined the potential for stronger conservation programs (cases 7 through 9). Specifically, we evaluated the effects of large fuel price increases and the elimination of market imperfections in the production and consumption of residential appliances, equipment, and structures after 1980. The model results show that zero energy growth in the residential sector can be achieved with higher fuel prices. However, these fuel price increases raise costs to consumers. For example, case 9 (a combination of two additional, stronger programs) shows an increase in the energy-related expenditures for the year 2000 from 3.0 percent in the base line to 3.1 percent of personal income. The cumulative direct cost to consumers of higher fuel prices is $63 billion.

The ORNL energy model used to develop these projections contains many assumptions and limitations (*3, 4*). Some of these are particularly important with respect to interpretation of the results presented here:

1) The model contains a simple algorithm to determine the extent and pace with which manufacturers and households improve equipment and structure efficiencies in response to changes in fuel prices. Lack of both theory and data prevent us from adequately validating this portion of the energy model. If the model overestimates the market response to fuel price changes, then our estimates of the benefits of government conservation programs are too low. On the other hand, if the model underestimates market response, then the need for government intervention is less than indicated.

2) The model uses relationships between the annual energy use and capital cost of equipment (or structures). These relationships are based on engineering analysis and cost estimates from manufacturers and other sources. If we underestimate the costs of improving efficiencies (for example, Figs. 4 and 5), then we overestimate the economic benefits of government regulation, and vice versa.

3) Inputs concerning the government programs obviously affect our estimates of their effectiveness. These inputs are based on extensive discussions with FEA staff and analyses of the technical and economic feasibility of their programs. We assume that the programs are implemented in a timely, orderly, and logical fashion. If the programs are delayed, are weaker than specified in Tables 4 and 5, or both, then the energy and economic benefits will be less than estimated.

4) Many government policies and programs in effect, under development, and under consideration were not analyzed. These include consumer information programs, energy-efficiency labels for household equipment and structures, elimination of master-metering in apartment houses, changes in electricity and gas rate structures, and government R & D programs to develop new energy-efficient systems. Some of these may be even more effective at saving energy and money than the programs examined here.

Despite these caveats, it seems clear (to us at least) that government residential energy conservation programs can substantially reduce energy use and household expenditures. Programs stronger than those in the National Energy Plan (*2*)—especially programs to improve equipment and structure efficiencies in the last 1980's and 1990's—are likely to yield even larger energy and economic benefits.

References and Notes

1. Quantities are given in British units: 1 quad = 10^{15} Btu's; 1 Btu = 1055 joules. Electricity use figures are in terms of primary energy (11,500 Btu's per kilowatt-hour); that is, they include losses in generation, transmission, and distribution. Figures for gas and oil do not include losses associated with refining and transportation.
2. The White House, *The President's Energy Program* (20 April 1977); Executive Office of the President, *The National Energy Plan,* 29 April 1977 (Government Printing Office, Washington, D.C., 1977).
3. E. Hirst, J. Cope, S. Cohn, W. Lin, R. Hoskins, *An Improved Engineering-Economic Model of Residential Energy Use* (Publ. ORNL/CON-8, Oak Ridge National Laboratory, Oak Ridge, Tenn., April 1977); E. Hirst, W. Lin, J. Cope, *Q. Rev. Econ. Bus.* **17** (No. 2), 7 (1977).
4. E. Hirst and J. Carney, *Residential Energy Use to the Year 2000: Conservation and Economics* (Publ. ORNL/CON-13, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 1977).
5. 94th Congress, *Energy Policy and Conservation Act,* PL 94-163, 22 December 1975.
6. ———, *Energy Conservation and Production Act,* PL 94-385, 14 August 1976.
7. Although the results of our projections are given here as certainties, there is considerable uncertainty about what will happen by the year 2000. Part of the uncertainty relates to the exogenous variables such as fuel prices and population. The rest relates to the model itself, both its structural form and the particular coefficients used in the model equations.
8. Bureau of the Census, "Projections of the population of the United States: 1975–2050" (Current Population Reports, Series P-25, No. 601, U.S. Department of Commerce, Washington, D.C., October 1975).
9. J. Carlin, personal communication.
10. All prices and incomes are in terms of constant 1975 dollars. Electricity is in terms of primary energy (*1*).
11. E. Hirst and J. Jackson, *Energy* **2** (No. 2), 131 (June 1977); Bureau of Mines, "Annual U.S. energy use up in 1976" (press release, U.S. Department of the Interior, Washington, D.C., 14 March 1977).
12. Our energy model does not explicitly allow for the introduction of new end uses (for example, sidewalk deicing, inside air filtration, swimming-pool heating). However, the model does include an "other" end use, and this is allowed to grow as incomes rise (depending on the growth of fuel prices). In the high projection, energy use for other purposes increases from 1.4 to 2.6 quads between 1976 and 2000.
13. S. Carhart, personal communication.
14. R. Hoskins and E. Hirst, *Energy and Cost Analysis of Residential Water Heaters* (Publ. ORNL/CON-10, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1977).
15. D. Quigley, personal communication.
16. *An Impact Assessment of ASHRAE 90-75, Energy Conservation in New Building Design* (A. D. Little, Inc., Cambridge, Mass., December 1975); *An Energy and Economic Assessment of HUD's Minimum Property Standards* (A. D. Little, Inc., Cambridge, Mass., October 1976).
17. *Fed. Regist.* **40** (No. 244), 58752 (18 December 1975).
18. The National Energy Plan (*2*) proposes to price fuels at their "replacement cost" so that fuel prices reflect the costs of providing additional units of that fuel. Under this proposal, natural gas, for example, might be priced at the cost of importing liquefied natural gas or at the cost of producing synthetic gas from coal.

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