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Residential Energy Use to the Year 2000: Conservation and Economics

Eric Hirst
Janet Carney

OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

This report evaluates the energy and direct economic effects of implementing various residential energy conservation programs. These evaluations are conducted using a detailed engineering-economic model that simulates residential energy use on an annual basis from 1970 through 2000. These programs include several authorized by the 94th Congress and expanded upon by the present administration: appliance efficiency standards, thermal standards for construction of new residences, and weatherization of existing housing units. In addition to these federal programs that are being (or will be) implemented in some form, we consider two additional measures to save energy: large fuel price increases and elimination of all market imperfections associated with the production and purchase of new equipment and homes. Altogether, nine different residential energy "futures" are considered.

The highest projection, which assumes constant real fuel prices from 1976-2000, shows residential energy use growing from 16 QBtu in 1976 to 28 QBtu in 2000, with an average annual growth rate of 2.3%. The baseline, which assumes rising fuel prices, yields an energy use estimate of 24 QBtu in 2000. Implementing all the federal programs listed above would cut energy use in 2000 by 11%, to 22 QBtu. Adopting these programs also reduces energy-related costs to households by $27 billion.

Raising fuel prices by 50% after 1984 and eliminating all market imperfections yields essentially zero energy growth in the residential sector. However, the cost to households of higher fuel prices amounts to about $60 billion.

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CONTENTS

RESIDENTIAL ENERGY USE TO THE YEAR 2000: CONSERVATION AND ECONOMICS

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Janet Carney

1. INTRODUCTION

This report addresses two key issues concerning residential energy conservation strategies: their effects on energy use trends and on household economics. Our conclusions concerning these issues are:

(1) 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 QBtu to 28 QBtu.* Thus, conservation programs can provide considerable reductions in residential energy use.

(2) Implementing conservation programs generally saves money for consumers; for example, the programs proposed by President Carter in his April 20, 1977 energy message[1] are estimated to 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 ORNL.[2] This model simulates household energy use at the national level for four fuels, eight end uses, and three housing types. Each of these 96 fuel use components is calculated for each year of the simulation as functions of: stocks of occupied housing units and new construction, equipment ownership by fuel and end use, thermal integrity of

*Quantities are given in British units. 1 QBtu = 1 Quad = 10^{15} Btu. 1 Btu = 1,055 joules. Electricity use figures are in terms of primary energy (11,500 Btu/kWhr); that is they include losses in generation, transmission, and distribution. Figures for gas and oil do not include losses associated with refining and transportation.

housing units, 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 thermal integrity of new and existing structures at the same level of detail. These cost figures allow us to develop simple benefit/cost measures for each program evaluated.

Nine different residential energy "futures" are evaluated with the ORNL residential energy model. The first (high projection) assumes that "real" fuel prices remain constant from 1976 through the end of the century and that no federal conservation programs are adopted.

In the second case, fuel prices are allowed to rise between 1976 and 2000. Again, no government conservation programs are implemented. Changes in energy use are entirely voluntary and come about because of normal market forces only. This second case is considered our "baseline," against which all the other cases are compared.

The next four cases consider the residential conservation programs authorized by the 94th Congress and expanded upon in the April 1977 energy message: appliance efficiency standards, thermal performance standards for new construction, a retrofit program to affect 90% of the nation's housing stock, and the combination of these three programs.

The last three cases consider the energy and economic effects of additional conservation programs: much larger fuel price increases, elimination of all market imperfections affecting residential energy use, and both.

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, capital costs for equipment and structures) between 1977 and 2000. Tables 1 and 2 briefly summarize the energy and economic effects of each of the nine cases discussed here.*

The remainder of this report is organized as follows. Section 2 reviews historical trends in residential energy use. Section 3 describes the inputs for our high projection and the consequent outputs from the ORNL model. Section 4 presents the baseline projection. Section 5 reviews the conservation programs authorized by the 94th Congress and the President's proposed modifications, and the likely effects of implementing these programs. Section 6 discusses the stronger programs mentioned above and their energy and economic consequences. Finally, section 7 reviews the different futures and summarizes the likely effects of each.

We also include an appendix to explain the market penetration portion of our energy use simulation model. Other details on the structure and operation of our model are in ref. 2.

2. HISTORY

Table 3 shows residential fuel use from 1950 through 1975† for electricity, gas petroleum products (kerosine and fuel oil), and other

*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.

†Preliminary figures[4] for residential energy use in 1976 are: 7.3 QBtu electricity, 5.7 QBtu gas, 3.4 QBtu oil, and 0.6 QBtu other fuels for a total of 17.0 QBtu. This is a 4.7% increase over the 1975 total of 16.2 QBtu. The model's estimate of 16.3 QBtu for 1976 is 4% lower than the preliminary Bureau of Mines number.

Table 1. Alternative residential energy use projections: energy use

Run no.	Description	Energy use (QBtu) 1980	1985	1990	2000	Cumulative (1977-2000)	Average annual growth rate, 1976-2000 (%)[a]
1	High: constant (1976) fuel prices, no government conservation programs	18.3	21.0	23.6	28.1	543.6	2.3
2	Baseline: Same as 1 with rising fuel prices	17.8	19.5	21.1	24.2	493.6	1.7
Federal Conservation Programs							
3	Baseline plus appliance efficiency targets	17.5	19.0	20.5	23.6	482.3	1.5
4	Baseline plus new construction standards	17.5	19.1	20.6	23.4	482.8	1.5
5	Baseline plus retrofit program	17.1	18.3	20.0	23.1	468.9	1.4
6	Baseline 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% 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% fuel price increases, no market imperfections	16.7	14.9	14.8	15.8	371.4	-0.1

[a] The model's estimate of residential energy use was 16.3 QBtu in 1976.

Table 2. Alternative residential energy use projections: direct economic effects

Run no.	Description	Present worth of cumulative (1977-2000) expenditures at 8% real interest rate (10^9 1975-$)				Energy-related expenses in 2000 as a % of personal income[b]
		Fuels	Equipment[a]	Structure thermal integrity[a]	Total	
1	High: Constant 1976 fuel prices, no government programs	596.2	0	0	596.2	2.5
2	Baseline: same as 1 with rising fuel prices	659.6	2.1	1.0	662.7	3.0
Federal Conservation Programs						
3	Baseline plus appliance efficiency targets	646.3	10.7	0.7	657.7	2.9
4	Baseline plus new construction standards	647.8	2.2	5.0	655.0	2.9
5	Baseline plus retrofit program	628.0	2.7	16.7	647.3	2.9
6	Baseline plus combined Federal program	603.4	11.2	20.7	635.3	2.7
Additional Conservation Programs						
7	Combined Federal program plus 50% 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% fuel price increases, no market imperfections	680.1	15.8	23.4	719.3	3.1

[a] 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 efficiencies. For structures, the increments include only thermal integrity changes.

[b] The comparable figure for 1976 was 3.1%.

Table 3. Houehold consumption of fuels: 1950-1975

	Electricity	Gas	Oil[a]	Other[b]	Total
			(QBtu)		
1950	1.2	1.5	1.7	2.3	6.7
1955	1.7	2.4	2.5	1.9	8.5
1960	2.4	3.4	2.9	1.0	9.7
1965	3.3	4.3	3.2	1.1	11.9
1970	5.4	5.4	3.5	1.0	15.3
1975	7.0	5.5	3.1	0.6	16.2

[a]Oil includes kerosine and Nos. 1, 2, and 4 distillate fuel oils; these figures do not include LPG.

[b]Other includes coal and LPG, and statistical discrepancies among data sources (about 2% of totals).

Sources: refs. 3 and 4.

fuels (coal, liquified gases).[3,4] The overall annual growth rate (see Fig. 1) in energy use during this period was 3.6%, nearly double the growth rate in household formation (2.0%). However, between 1972 and 1975 growth in fuel use was erratic and essentially static.

The distribution of fuels among the total changed sharply during these 25 years, as shown in Fig. 1. In 1950, coal accounted for more than one-third of household fuel use, while in 1975 coal accounted for only 2% of the total. Petroleum's share of the total also declined, from 26% to 19%. Electricity, on the other hand, increased its share from 18% in 1950 to 43% in 1975. The share accounted for by gas increased from 22% to 34% during this period.

Figure 2 shows trends in fuel prices from 1950-1975.[3] Generally, prices were declining or stable until 1970; since then prices for all fuels, especially petroleum products, have risen. The sharp increases

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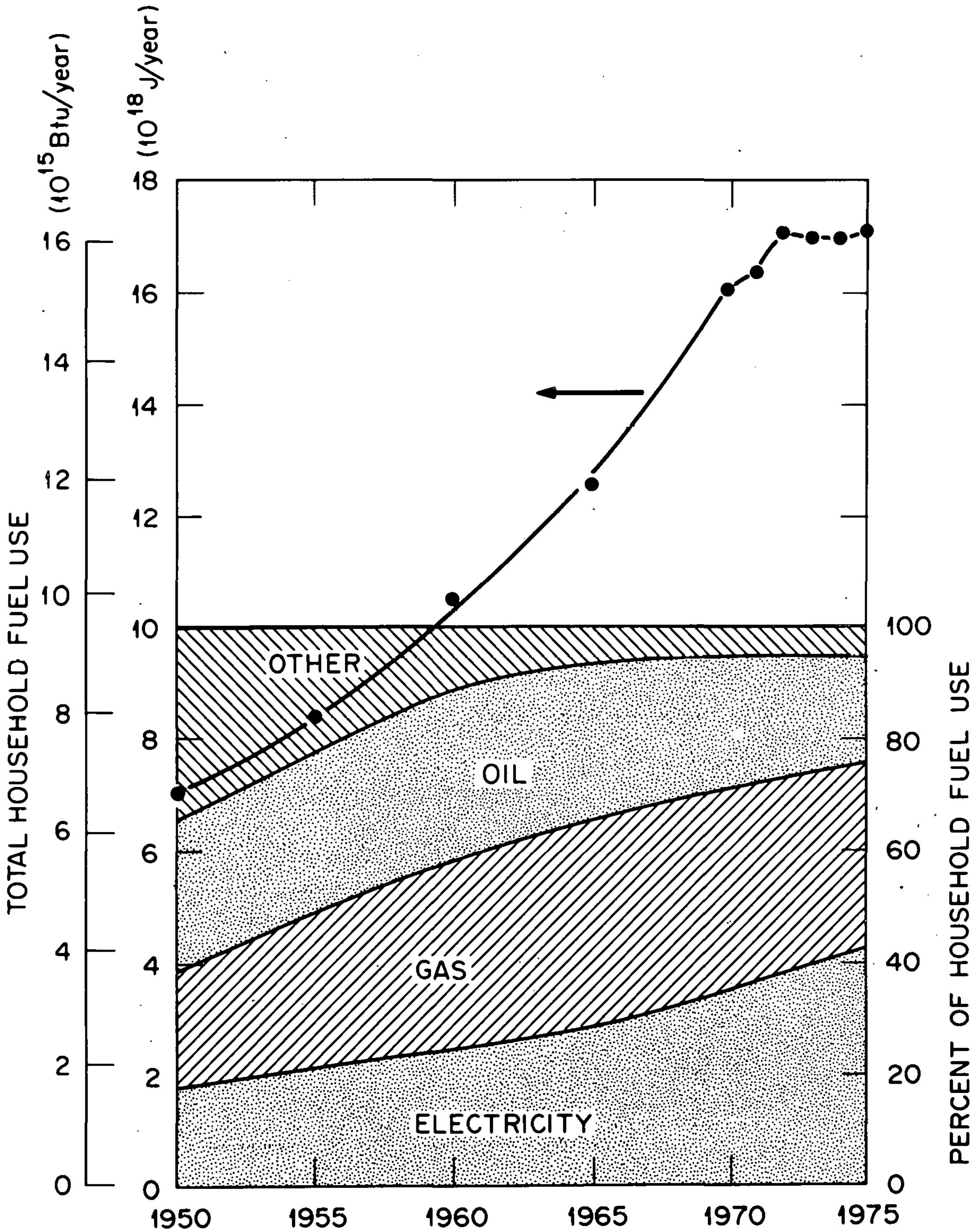

Fig. 1. Household energy use by fuel: 1950-1975.

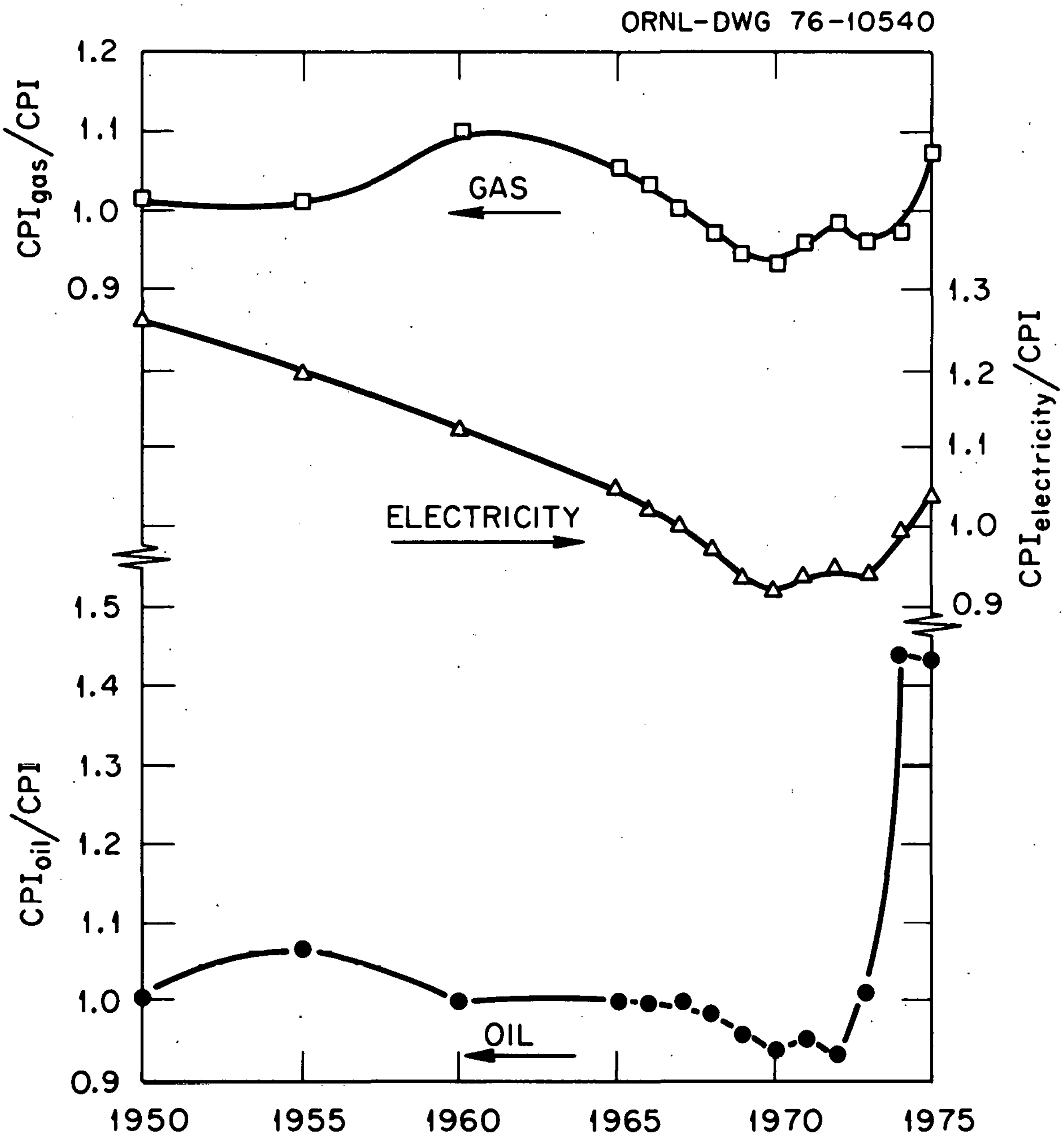

Fig. 2. Trends in retail fuel prices: 1950-1975. Prices are deflated by the Consumer Price Index (CPI) to remove the effects of inflation.

in fuel prices in the early 1970s increased dollar expenditures and reduced growth in demand for household fuels.*

Table 4 shows our estimated distribution of residential energy use by fuel and end use for 1975. Space heating is the largest use of fuel in homes, accounting for 53% of the total. Water heating, the second largest use, accounts for 14%. Thus, these two uses account for two-thirds of total household fuel uses. Adding refrigerators, freezers, and air conditioning brings the subtotal to more than 80%. Thus, lighting, cooking, clothes washing and drying, televisions and radios, and operation of small appliances consume less than one-fifth of residential energy use.

Table 4. Residential energy use by fuel and end use: 1975

	Electricity	Gas	Oil	Other	Total
			(QBtu)		
Space heating	1.36	3.81	2.88	0.54	8.59
Water heating	1.05	0.96	0.22	0.05	2.28
Refrigerators	0.92				0.92
Freezers	0.38				0.38
Cooking	0.46	0.29		0.01	0.76
Air conditioning	1.08				1.08
Lighting	0.90				0.90
Other	0.86	0.45			1.31
Total	7.01	5.51	3.10	0.60	16.22

Sources: refs. 2-4.

*Real fuel prices in 1976 were higher than in 1975 by the following amounts: electricity 1%, gas 10%, and oil 1%.

In summary, the 1950-1975 period can be conveniently divided into two time periods: 1950-1972 and 1972-1975. During the first period, energy use grew steadily and rapidly at an average rate of 4.0%/year while fuel prices either declined smoothly (electricity) or erratically (gas, oil).

Household fuel use grew because of increasing population and households, rising incomes, and declining fuel prices.[3] Because of these economic and demographic changes there was considerable growth in ownership of energy-intensive household equipment, shifts from small energy-efficient devices to larger less efficient units (e.g., replacement of small manual defrost refrigerators with larger automatic defrost models that consume 50-100% more electricity), and increasing use of equipment (e.g., taking longer showers, leaving lights on, setting thermostats higher in the winter).

Between 1972 and 1975, residential energy use remained essentially constant while real fuel prices increased sharply: 9% for electricity, 12% for gas, and 54% for oil. During this three year period, per capita income remained nearly constant, compared with an average annual growth of 2.6% between 1950 and 1972. Similarly, population growth has slowed considerably in recent years. Between 1950 and 1972 population grew at an average annual rate of 1.5%, while between 1972 and 1975 population grew at 0.8%/year. Clearly, trends in residential energy use and its determinants have changed during the past few years.

3. HIGH ENERGY USE PROJECTION

In this section we develop a projection of residential energy use to the year 2000 based on assumptions designed to yield a "high" growth in energy use.

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 (e.g., appliance efficiency standards, tax incentives for retrofitting homes, fuel price increases). Each of these inputs must be provided for the 1970-2000 period.

We assume that population grows according to the Bureau of the Census Series II projection.[5] Per capita income is derived from a recent Data Resources, Inc. projection of Gross National Product (GNP) prepared for FEA[6] and the Series II population projection.

Projections of household formation and stocks of occupied housing units are obtained from our housing model[2] using the DRI per capita income and Census population projections. In developing our estimates of housing stocks, we assume that trends in housing choices (among single-family, multi-family, and mobile homes) between 1960 and 1970 will continue through the end of the century.[2] Table 5 shows the values of population, households, housing distribution, and per capita income used in all projections discussed in this report.

For the high projection, we assume that real fuel prices remain unchanged between 1976 and 2000 at their 1976 values:* 2.81 $\$/10^6$ Btu for electricity, 1.88 $\$/10^6$ Btu for gas, and 2.83 $\$/10^6$ Btu for oil.

*All prices and incomes are in terms of constant 1975-$. Recall that electricity is in terms of primary energy.

Table 5. Inputs assumed for all projections of residential energy use

	Population (10^6)	Households (10^6)	Distribution of occupied housing units (%) single-family	multi-family	mobile home	Per capita income (1975-$)
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

Sources: refs. 2, 5, and 6.

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[7] and the Energy Conservation and Production Act[8]) and the present administration's proposed programs. (The likely effects of these and other conservation measures will be considered later).

However, the model estimates changes in new equipment and structures efficiencies and changes in usage (i.e., the intensity with which households use existing stocks of equipment) because of the fuel price increases during the early 1970s. Based on information obtained from Owens-Corning Fiberglas (OCF),[9] we assume that 14.3 million single-family and 2.0 million multi-family units will be retrofit during the 1974-1980 period.* We assume that these retrofit actions (e.g.,

*Information obtained from OCF[9] suggests that 8.0 million owner-occupied housing units had an average of 4-5" of attic insulation added during the 1974-1976 period.

additional attic insulation, clock thermostat, caulking and weather-stripping, furnace tuneup) will cut space heating energy use 20% and cost $225 for single-family and $130 for multi-family units.*

Outputs from the energy model, given these inputs, show residential energy use growing from 16.3 QBtu in 1976 to 18.3 QBtu in 1980, 21.0 in 1985, 23.6 QBtu in 1990, and 28.1 QBtu in 2000. The average growth rate during this 24-year period is 2.3%/year. Growth in energy use is higher in earlier years and slower in later years.

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 (positive income elasticities for these fuels[2]), the fraction of household energy use accounted for by oil declines from 17% in 1976 to only 7% in 2000. Electricity's share increases from 45% to 61% 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 declines from 34% to 31% during this period; other fuels also contribute a declining portion of the total, down from 4% to 1%.

The distribution of energy by end use also changes. Although space heating remains the dominant end use during the rest of the century, its

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*The Bureau of the Census collected (but did not publish) information on home retrofits as part of the *Annual Housing Survey: 1975*. Their data show that occupants of 10.4 million single-family detached housing units took some action in 1975 to weatherize their homes. The average expenditure per household was $150. We estimate that these improvements reduced space heating loads by about 6%. The energy saving per $ of investment is lower than our estimate because many households did not invest optimally (i.e., they purchased storm doors and wall insulation rather than attic insulation and caulking/weatherstripping). However, the aggregate energy saving is close to our assumption.

importance declines from 52% of the total in 1976 to 44% in 2000. Air conditioning, on the other hand, increases its share from 7% to 12%.

Energy use grows more slowly in the high projection than historically for several reasons. First, fuel prices are assumed constant in the projection while historically fuel prices declined. Second, the effects of the fuel price increases in the early 1970s 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. For example, higher electricity prices increase the percentage of electric space heating systems that is heat pumps from about 15% during the early 1970s to about 25% in the 1980s and 1990s. A third reason why projected growth is slower than historical 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.*

4. BASELINE PROJECTION

The baseline differs from the high projection only with respect to fuel prices. The exogenous variables listed in Table 5 for the high

*Our energy model does not explicitly allow for introduction of new end uses (e.g., 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 growth of fuel prices). In the high projection, energy use for other purposes increases from 1.4 to 2.6 QBtu between 1976 and 2000.

projection are also used for this projection. However, rather than assume that real fuel prices remain constant at their 1976 levels, we assume that fuel prices increase over time; see Fig. 3.

The fuel price trajectories used as inputs to our model for this and succeeding projections are obtained from the Federal Energy Administration PIES model[6] and the Brookhaven National Laboratory BESOM model.[10] These large energy supply/demand models integrate energy flows from resources in the ground to final demands. As Fig. 3 shows, these projections indicate a substantial increase in real gas prices (average annual growth of 2.3% between 1976 and 2000) and moderate increases in electricity (0.9%/year) and oil (1.2%/year) prices.

In the baseline, residential energy use grows from 16.3 QBtu in 1976 to 17.8 QBtu in 1980, 19.5 QBtu in 1985, 21.1 QBtu in 1990, and 24.2 QBtu in 2000 with an average annual growth rate of 1.7%; see Fig. 4.

Changes in the distribution of energy use by fuel are similar to that in the high projection: electricity increases its share of the total and all other fuels decline in importance. Because of rapidly rising gas prices, the share accounted for by gas drops to 24% in 2000 (compared with 31% in the high projection); see Fig. 4. Changes in the distribution of energy by end use are almost the same in the baseline as in the high projection.

The economic penalty associated with rising fuel prices is surprisingly mild. In 1976, fuel costs amounted to 3.1% of total personal income. In the baseline, fuel costs amount to 3.0% 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.

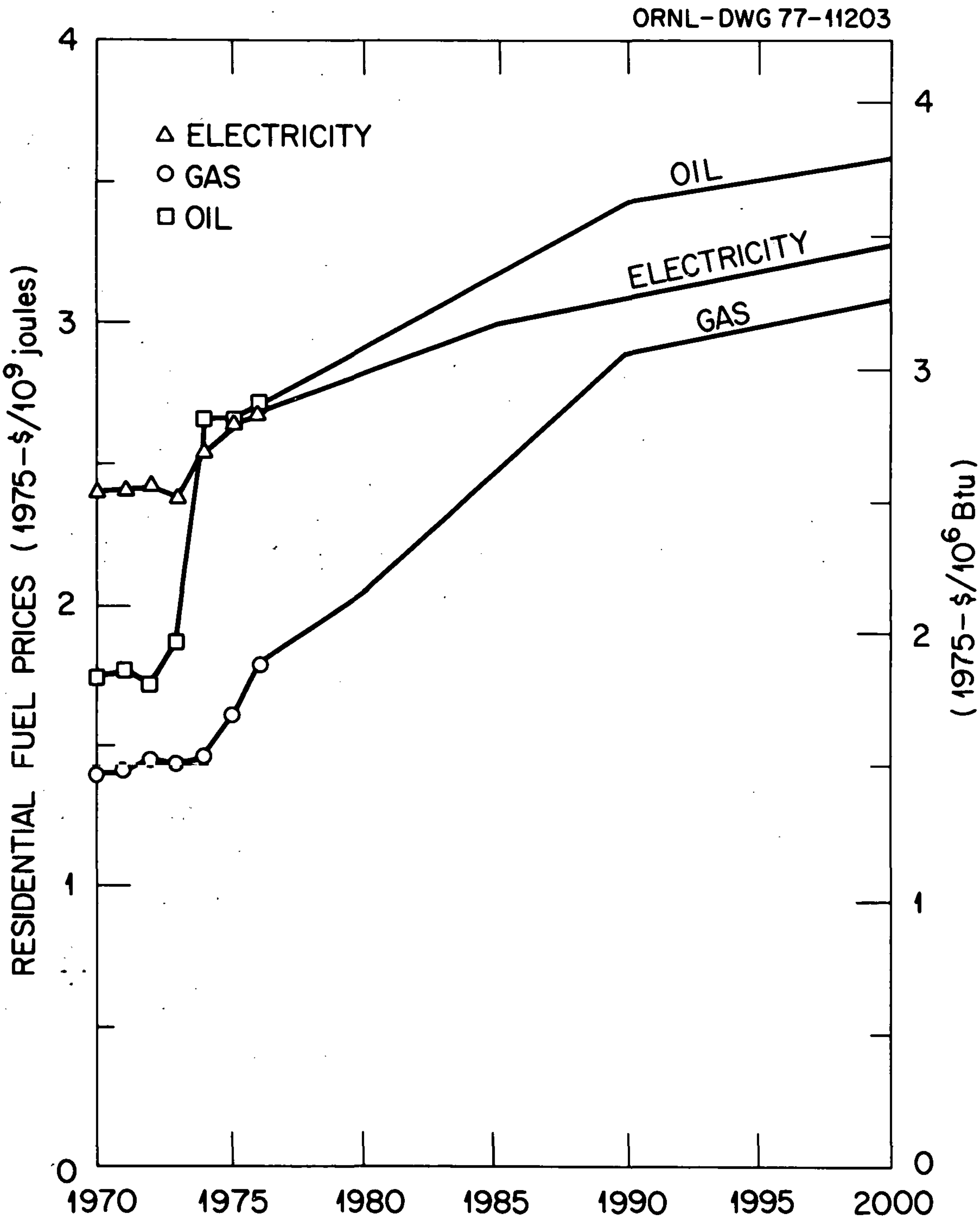

Fig. 3. Assumed fuel prices to the year 2000.

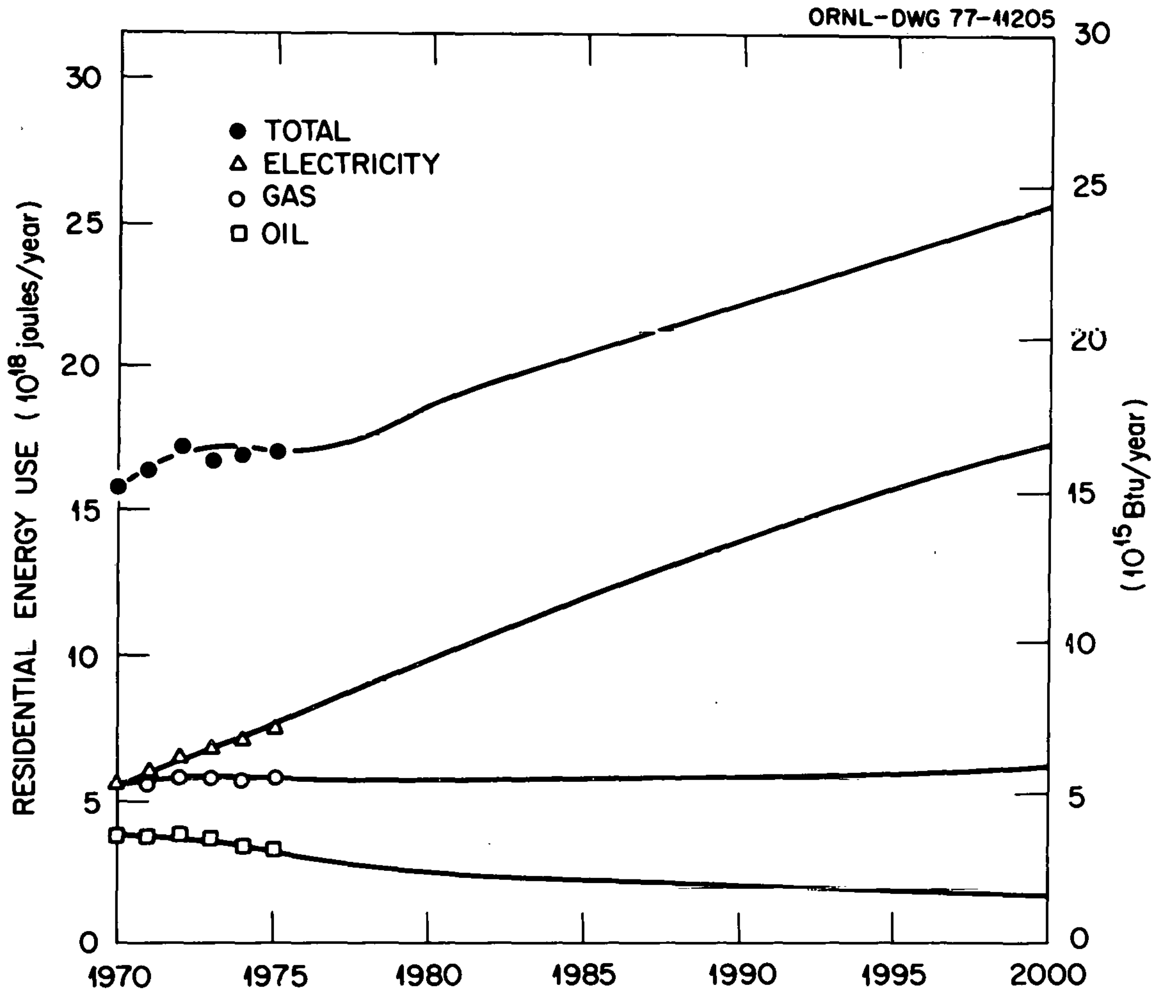

Fig. 4. Baseline projection of residential energy use to the year 2000.

The mild economic penalty associated with the increase in average fuel price of almost 40% between 1976 and 2000 is due primarily to the household voluntary response to price increases. This response takes two forms. In the short-run, households reduce usage of existing stocks of equipment. For example, thermostats are set back during the winter. Thus, in the year 2000, households in the baseline use 10% less fuel for heating than they do in the high projection.

In the long-run, as existing stocks of equipment and structures wear out, households replace them with more efficient systems. For example, the average efficiency of new heating equipment in the year 2000 is about 15% higher in the baseline than in the high projection.

Even though fuel prices increase, rising incomes are sufficient to increase household ownership of freezers, air conditioners, lighting fixtures, and "other" uses. Freezer ownership increases from 35% in 1976 to 49% in 2000. Air conditioner ownership increases from 54% to 89%. The number of lights per household increases 10% between 1976 and 2000. Ownership of "other" equipment increases 9%.

5. FEDERAL CONSERVATION PROGRAMS

In this section, we evaluate the energy and economic effects of the residential conservation programs authorized by the 94th Congress[7,8] and expanded upon by the present administration.[1,6] Table 6 summarizes existing authorization and proposals concerning residential energy conservation programs. We evaluate the programs in four elements:

Table 6. Recent federal legislation and proposals affecting residential energy use

Energy Policy and Conservation Act (PL 94-163, December 22, 1975)
Residential equipment and appliance labeling (FEA, FTC)
Residential equipment and appliance efficiency targets (FEA)
State energy conservation plans (FEA):
thermal efficiency standards for new and renovated buildings
Energy Conservation and Production Act (PL 94-385, August 14, 1976)
Thermal standards for new buildings (HUD)
Financial assistance to weatherize existing buildings (FEA)
State conservation plans (FEA):
public education programs
energy audits
Conservation assistance for existing buildings (HUD):
demonstration programs
financial assistance
Energy conservation obligation guarantees (FEA)
President's Energy Program (April 20, 1977)
Replace voluntary appliance efficiency targets with mandatory standards
Thermal standards for new buildings (HUD) by 1980
Retrofit 90% of existing residences:
tax credits
utility conservation programs
provision of capital at low interest rates
rural home weatherization program
increase funding for low-income weatherization program

Sources: refs. 1, 7, and 8.

1. appliance efficiency targets
2. thermal performance standards for new construction
3. weatherization (retrofit) of existing housing units
4. all of the above.

The time between Congressional authorization and full program implementation can involve several years. The programs discussed here were all authorized by the 94th Congress; the President has proposed stronger programs in each area. However, none of the programs is yet implemented.

Each of these programs is compared to the baseline in terms of energy use and household costs. The inputs discussed earlier (Table 5 and Fig. 3) remain unchanged for these runs.

Appliance Efficiency Targets

The Federal Energy Administration 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% higher than the 1972 average.[7,8] The President proposed that the existing voluntary program be made mandatory.[1] The latest set of FEA targets is shown in Table 7.[6]

Table 7. Assumed improvements in energy requirements for new equipment from FEA appliance efficiency targets (1970 = 1.0)

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	
electric	0.90
gas	0.90

Source: ref. 6.

Consider the efficiency targets for water heaters, as an example (Figs. 5 and 6). The target calls for a 15% reduction in energy use for electric water heaters. Our analysis[11] 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.*

These measures would increase 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% reduction in energy use) could be met by replacing the 1 inch of fiberglass 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 three years.

These examples (and our analyses of other appliances) suggest that the FEA appliance efficiency targets provide good investment opportunities for households.

Table 8 summarizes the energy and economic effects of adopting these efficiency targets (Table 7) in 1980. In running this case, the model chooses either the given appliance efficiency target or the voluntary response to fuel price changes, whichever yields more efficient equipment.

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*1 inch = 2.5 cm.

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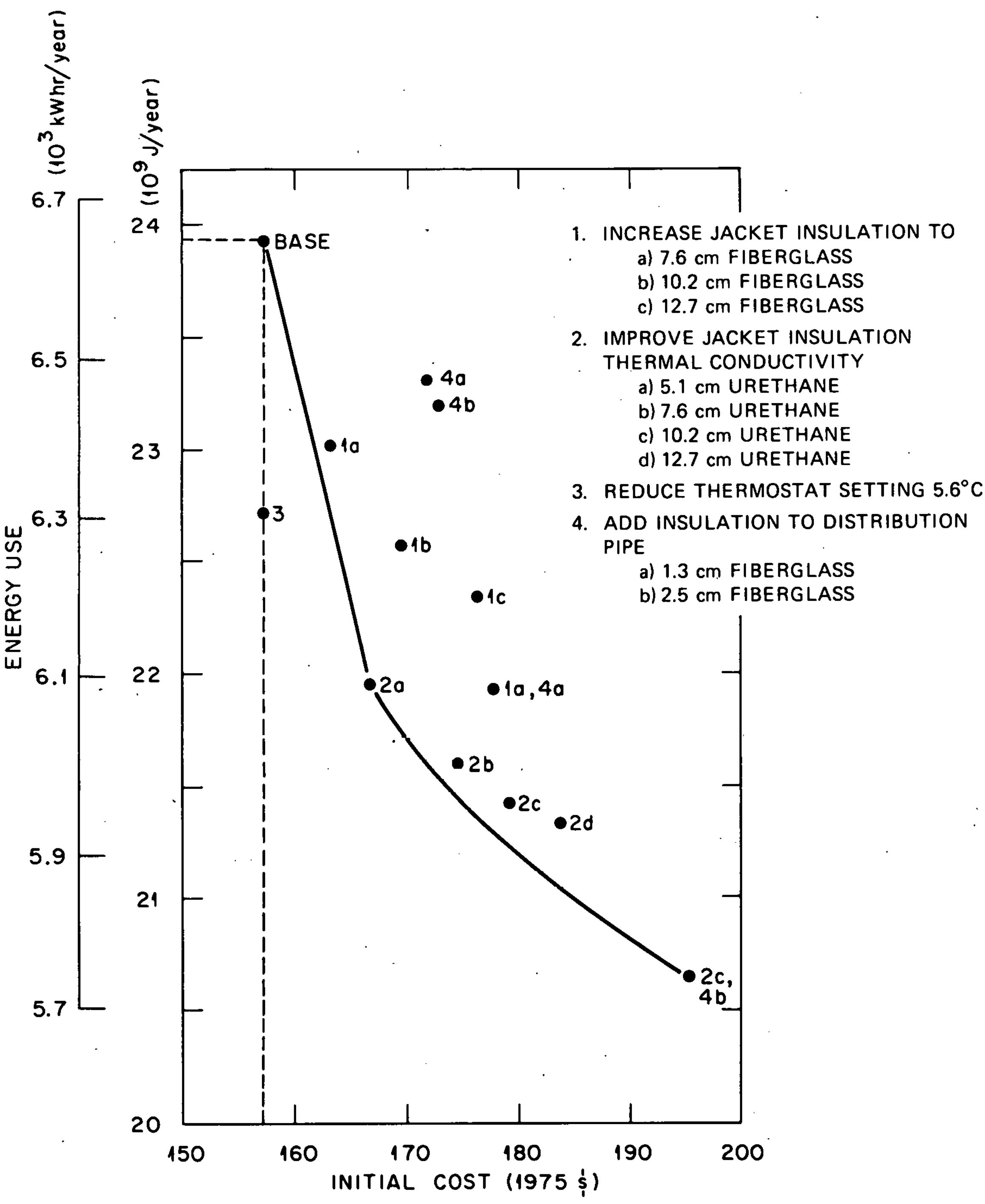

Fig. 5. Energy use versus retail price for a typical electric water heater.

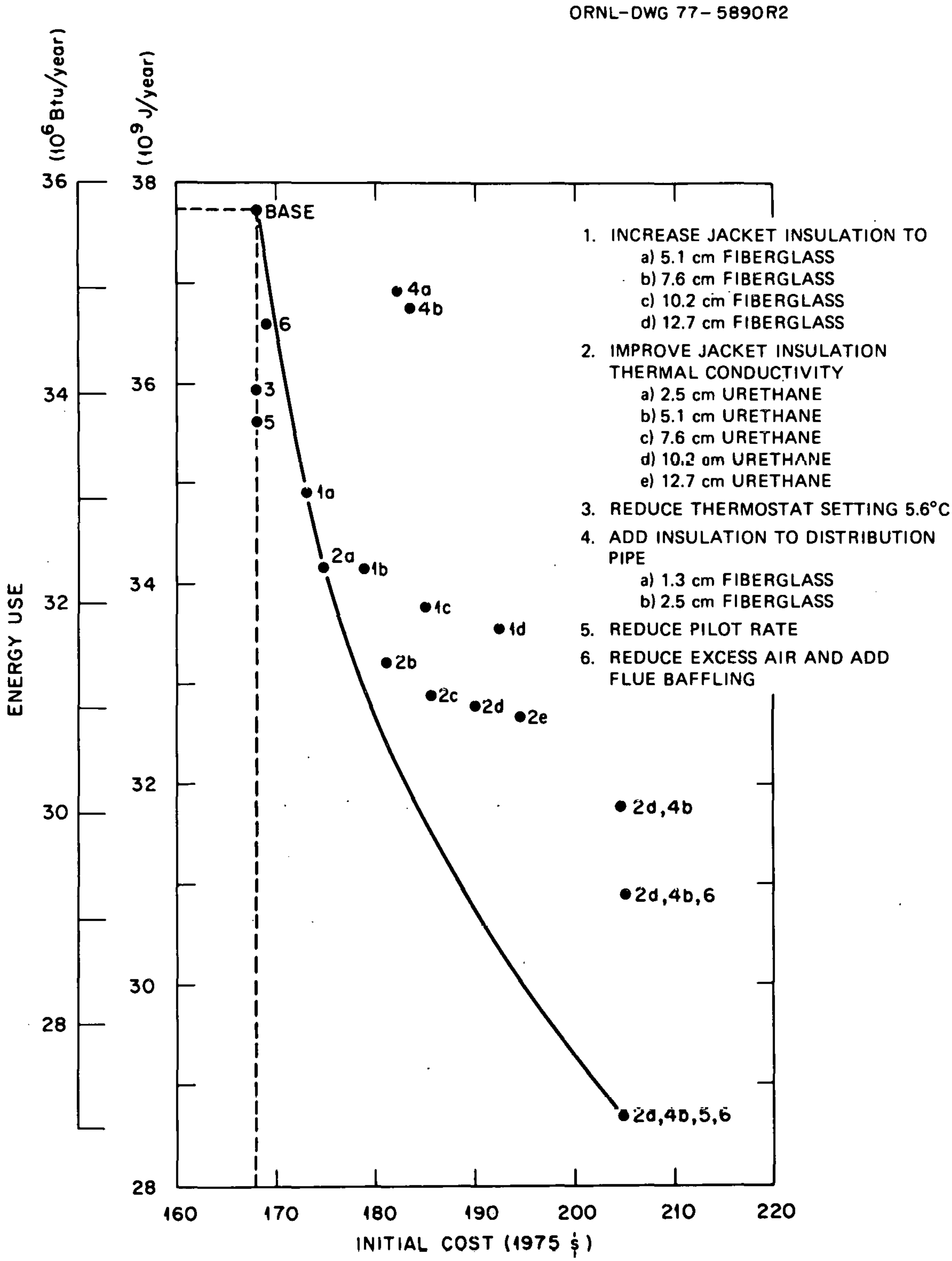

Fig. 6. Energy use versus retail price for a typical gas water heater.

Table 8. Cumulative (1977-2000) energy and economic effects of appliance efficiency targets[a]

Energy benefits	(QBtu)	% of baseline
Electricity	9.60	3.2
Gas	0.99	0.7
Oil	0.69	1.4
Total	11.28	2.3

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	13.33
Equipment	- 8.56
Structures	0.24
Total	5.02

Benefit/cost = 1.59

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

Thus the standards affect equipment choices only when the market-place doesn't.*

The energy savings due to improved appliance efficiencies increase from 0.2 QBtu in 1980 to 0.6 QBtu in 1990 and 0.7 QBtu in 2000. The cumulative (1977-2000) energy saving is 11.3 QBtu, 2% of the baseline. About 85% of the energy savings is in electricity; this is 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 (Table 8) exceeds the increase in capital costs by $5 billion. The benefit/cost ratio for the appliance program

*Except for space heating, the standards require improvements in equipment efficiency. Voluntary efficiencies are about 15% higher for oil and 20% higher for electric heating equipment than required by the standards of Table 7 during the 1990's.

(at the assumed real interest rate of 8%) is 1.6. This suggests that the proposed appliance program would save both energy for the nation and money for households.

New Construction Standards

The ECPA[8] requires HUD to develop thermal standards for construction of new buildings within three years (by 1979). These standards must then be implemented by the states, but only if Congress takes affirmative action. 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."[1] Table 9 summarizes the likely improvements in space heating and air conditioning loads because of these standards.[12] These standards provide larger percentage savings in multi-family units than in single-family units. This is consistent with the changes likely from implementing the ASHRAE 90-75 standards or the June 1976 HUD standards.[13] We also assume that all mobile homes constructed between 1976 and 2000 meet the recent HUD standards.[14]

The incremental capital cost of constructing a gas-heated single-family home in accordance with the standards shown in Table 9 is about \$500;[2] see Fig. 7.* This includes labor and materials costs for additional insulation, storm doors, and storm windows; minus savings for smaller heating and air conditioning equipment. The reduction in annual heating

*The relationship between annual heating load and capital cost shown in Fig. 7 is for a 1,500 ft^2 single-family house located in New York City, for which the annual heating degree day measure is close to the national average.

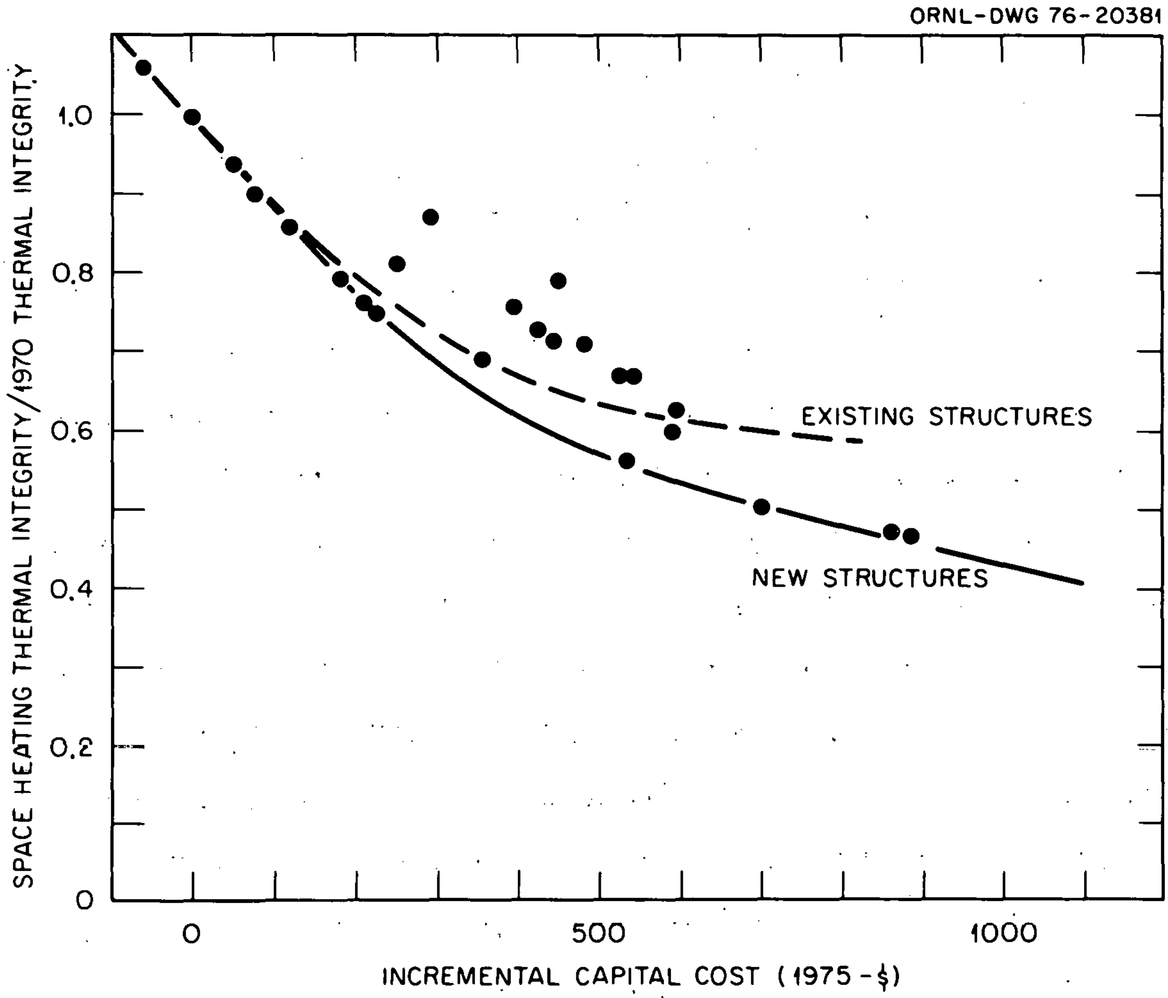

Fig. 7. Space heating thermal integrity for single-family units versus increased capital costs.

Table 9. Assumed improvements in thermal integrities for residential structures (1970 = 1.0)

	1980 HUD	Retrofit actions[a]	
		Voluntary	Federal
Single-family units			
space heating	0.70/0.60[b]	0.80	0.65
air conditioning	0.71	0.84	0.70
Multi-family units			
space heating	0.48	0.80	0.72
air conditioning	0.58	0.84	0.78
Mobile homes[c]			
space heating	0.80		
air conditioning	0.84		

[a]Voluntary retrofits are assumed to apply to 14.3 million single-family and 2.0 million multi-family units between 1974 and 1980. The Federal retrofit program is assumed to apply to 42.3 million single-family and 7.3 million multi-family units between 1974 and 1984; this includes the voluntary retrofits.

[b]The first number applies to electrically heated homes; the second number applies to homes heated with gas and oil.

[c]Mobile home standards were published by HUD in December 1975 and went into effect in June 1976. We assume that these standards remain in force unchanged through the year 2000.

bills would be $90 (at the 1976 gas price) and the reduction in annual cooling bills would be $35. Thus, investment in tighter building construction pays back in four years.

Table 10 summarizes the energy and economic effects of implementing the new construction standards of Table 9. The energy savings increase from 0.1 QBtu in 1980 to 0.5 QBtu in 1990 and 0.8 QBtu in 2000. The cumulative energy savings total 10.8 QBtu, almost as much as the savings due to the appliance efficiency program.

About 67% of the cumulative energy savings is electricity, 21% gas, and the remainder oil. Electricity accounts for so much of the savings

Table 10. Cumulative (1977-2000) energy and economic effects of new construction standards[a]

Energy benefits	(QBtu)	% of baseline
Electricity	7.26	2.4
Gas	2.27	1.7
Oil	1.22	2.5
Total	10.76	2.2

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	11.78
Equipment	- 0.05
Structures	- 4.06
Total	7.68

Benefit/cost = 2.87

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

because all air conditioning savings are electricity and because more than 40% of new housing units are heated with electricity.

The economic benefits of the new construction standards are 50% 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

A number of provisions in EPCA[7] and ECPA[8] encourage weatherization of existing structures. For example, ECPA authorizes FEA to provide financial assistance to low-income households to weatherize their structures; and authorizes HUD to conduct demonstration programs to provide financial assistance for improving the energy performance of existing buildings. The April 1977 energy message[1] proposes a number of measures to meet the goal of "insulating 90% of all residences." These measures include tax credits for retrofits, requirements that electric and gas utilities assist their customers in weatherizing structures, increased funding for the low-income weatherization program, and implementation of a rural home weatherization program.

Based on conversations with FEA staff,[12] we assume the parameters for the retrofit program shown in Table 9. The retrofit costs per housing unit are $580 for single-family and $240 for multi-family units. These reductions in heating and cooling demands are assumed to be implemented in 42 million single-family homes and 7 million multi-family homes by 1985.

Table 11 summarizes the energy and economic effects of retrofitting these housing units. The energy savings increase from 0.7 QBtu in 1980 to 1.2 QBtu in 1985; the savings then decline slowly through the end of the century (1.1 QBtu in 2000). The cumulative savings of 25 QBtu 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.

Table 11. Cumulative (1977-2000) energy and economic effects of retrofit program[a]

Energy benefits	(QBtu)	% of baseline
Electricity	15.81	5.2
Gas	6.36	4.8
Oil	2.49	5.2
Total	24.66	5.0

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	31.65
Equipment	- 0.56
Structures	-15.74
Total	15.36

Benefit/cost = 1.94

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

Combined Federal Program

Table 12 summarizes the energy and economic benefits of adopting all three of the programs discussed above; see also Figs. 8 and 9. The energy savings increase from 1.1 QBtu in 1980 to 2.2 QBtu in 1990 and 2.6 QBtu in 2000. The cumulative saving of 46 QBtu is 9% of the baseline. Energy growth between 1976 and 2000 is reduced from 1.7 to 1.2%/yr.

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 with the combined program from 3.0% to 2.7% of personal income in the year 2000. Figure 9 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.

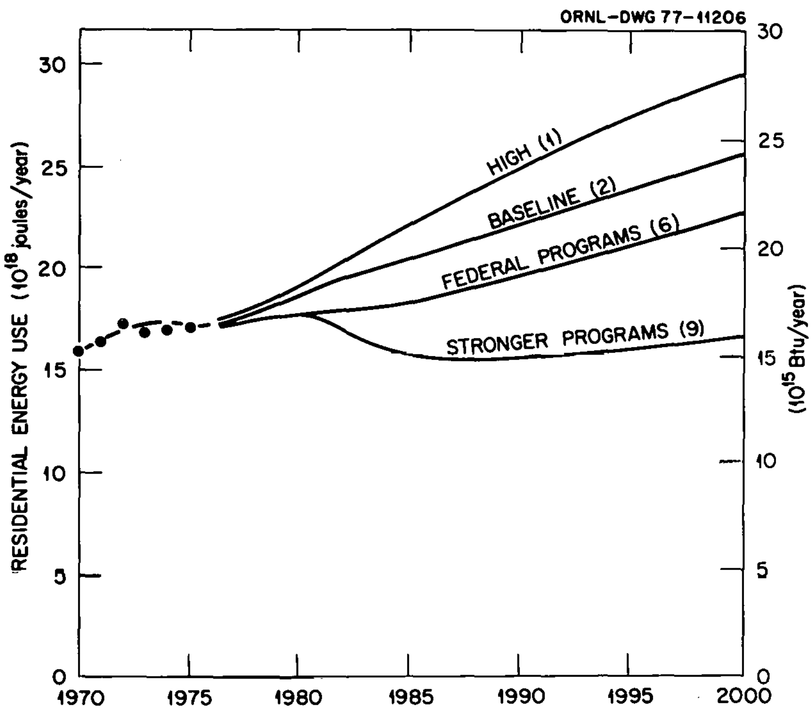

Fig. 8. Alternative projections of residential energy use to the year 2000.

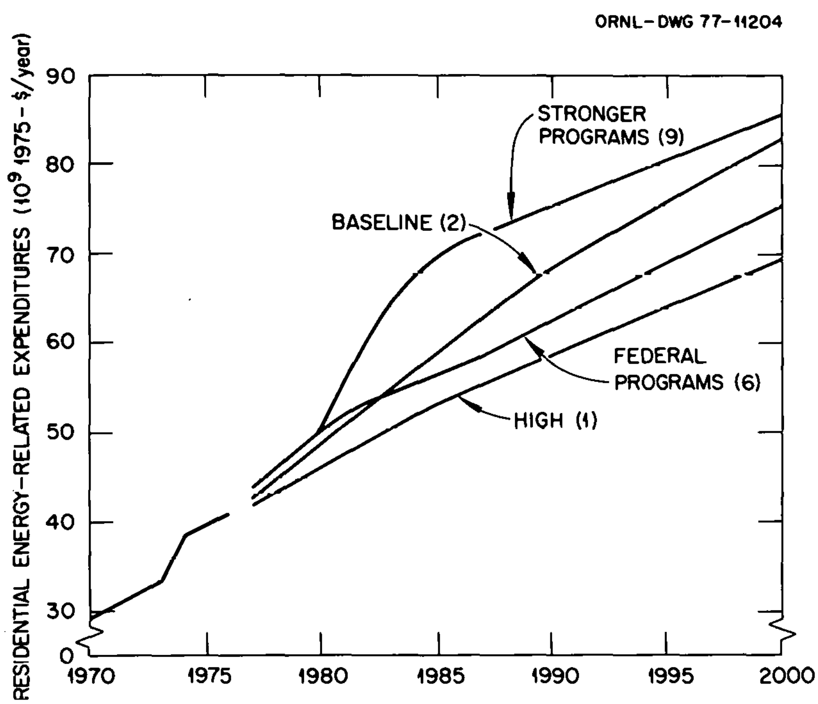

Fig. 9. Alternative projections of residential energy-related expenditures to the year 2000.

Table 12. Cumulative (1977-2000) energy and economic effects of combined Federal program[a]

Energy benefits	(QBtu)	% of baseline
Electricity	31.90	10.6
Gas	10.01	7.5
Oil	4.44	9.2
Total	46.36	9.4

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	56.25
Equipment	- 9.07
Structures	-19.79
Total	27.39

Benefit/cost = 1.95

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

The lifestyle changes implied by the federal programs are minor and all positive. The reduced operating costs implied by the programs increase the intensity with which households are expected to operate their equipment and slightly increase ownership of energy-using equipment. For example, 89% of the households in 2000 own air conditioning systems in the baseline compared to 91% with the combined federal program. Similarly, ownership of freezers is increased in 2000 from 49% to 50%.

The model results suggest that households will use their space heating systems in the year 2000 15% less frugally with the combined program than in the baseline. Households respond to fuel bill reduction induced by improved equipment efficiencies and tighter construction by raising winter thermostats and paying less attention to door and window openings. Similarly, water heating systems are used 8% more intensively in 2000 with the federal program than without.

6. ADDITIONAL PROGRAMS

The results in section 5 suggest that the conservation programs proposed and planned by the federal government are likely to save large amounts of energy (46 QBtu) and money ($27 billion). However, the question remains: What effects would stronger programs have on energy use and household economics? This section examines two additional conservation programs.

The first 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% in 1981, 20% in 1982, and so on until fuel prices are higher by 50% for the years 1985-2000. Such fuel price increases might occur because of increasingly strict environmental standards (e.g., sulfur removal from power plants, strip mine reclamation, increased costs for nuclear fuel reprocessing and storage), because of 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.*

The second program involves greater efficiency improvements in new equipment and structures than those shown in Tables 7 and 9. The Federal government's proposed standards reduce lifecycle costs to consumers but

*The National Energy Plan[1] 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 liquified natural gas or at the cost of producing synthetic gas from coal.

they do not minimize lifecycle costs. In Case 8, the model selects the "optimal" (in the sense of minimum lifecycle costs at consumers' implicit rates of return; see Appendix Tables A-1 and A-2) combination of equipment and structures beginning in 1980. Such changes could come about through stronger government regulatory programs. Or such changes 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 information they need to make "rational" decisions concerning equipment and structures efficiency. However, government education programs, energy efficiency labels, and other information programs could provide that data and thereby encourage consumers to choose more efficient equipment and structures.

Higher Fuel Prices

Increasing the fuel prices shown in Fig. 3 reduces energy use by 2.3 QBtu in 1985, 3.5 QBtu in 1990, and 4.6 QBtu 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%/year. Clearly, increasing fuel prices produces dramatic effects on energy use; see Table 13.

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% of personal income, compared with 3.0% in the baseline and 2.7% with the federal program. The cumulative increase in expenditures (at 8%) is $90 billion relative to the case with the federal program, $63 billion compared with the baseline. Although

Table 13. Cumulative (1977-2000) energy and economic effects of increased fuel prices and combined Federal program[a]

Energy benefits	(QBtu)	% of baseline
Electricity	69.83	23.1
Gas	28.91	21.6
Oil	10.58	21.9
Total	109.33	22.2
Present worth of economic benefits at 8% real interest rate (10^9 1975-$)		
Fuels		-39.23
Equipment		- 3.99
Structures		-19.86
Total		-63.07

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

the relative economic costs of the increased fuel prices are small compared with personal income, the absolute costs are large.*

It is also interesting to examine the lifestyle changes implied by these large price increases. Surprisingly, the effects on ownership of air conditioners and food freezers (the only end uses that are not already saturated) are almost negligible. In the baseline, 49% of the households own food freezers in 2000; in the high price case, 47% own freezers. Air conditioner ownership is essentially unchanged. However, the number of lighting fixtures and ownership of other appliances are reduced 30% in the year 2000 relative to the baseline.

*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.

Changes in usage are significant. Higher fuel prices cut usage for space heating by 10-15% and water heating by 15-20% in 2000. This suggests that higher fuel prices induce households to lower thermostat settings in the winter and to use less hot water than they would at lower fuel prices. However, these do not constitute major lifestyle changes. For example, space heating energy use can be cut 15% by lowering thermostat settings 5° F. A 10% reduction in hot water use plus a reduction in water temperature of 10° F would cut water heater energy use 15%.

Elimination of Market Imperfections

Here we allow the model to select the mix of equipment and structures that minimizes lifecycle costs to consumers beginning in 1980.* Fuel prices and other exogenous variables are the same as for the combined federal program.

Relative to the case with Federal programs, energy savings increase from 0.4 QBtu in 1985 to 0.9 QBtu in 1990 and 1.8 QBtu in 2000. The average growth in energy use is cut from 1.2 to 0.8%/year. The energy benefits of eliminating market imperfections after 1980 are much greater when compared with the baseline case; see Table 14.

The economic benefits of either forcing or encouraging consumers to make purchase decisions at their implicit interest rates are significant.

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*Although the markets that determine equipment and structures efficiencies are assumed to operate perfectly in this case, the solution may still not be socially-optimal. This is because the fuel prices used here may not reflect the full marginal social cost of these resources (see discussion of preceding case).

Table 14. Cumulative (1977-2000) energy and economic effects of elimination of market imperfections and combined Federal program[a]

Energy benefits	(QBtu)	% of baseline
Electricity	46.25	15.3
Gas	13.47	10.1
Oil	4.92	10.2
Total	64.65	13.1

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	73.76
Equipment	-17.90
Structures	-21.91
Total	33.96

Benefit/cost = 1.85

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

Table 14 shows that the reduction in fuel bills relative to the baseline exceeds the increase in capital costs by $34 billion.

Comparing Tables 13 and 14 shows that the energy benefits of fuel price increases are about double those from elimination of market imperfections. However, the economic cost of fuel price increases is $90 billion higher.

Higher Fuel Prices and Elimination of Market Imperfections

Here we combine the two preceding changes; see Table 15. Energy use drops 10% between 1980 and 1985 and then increases slowly to the end of the century. Energy use in the year 2000 is 3% less than it was in the year 1976. Thus, this case yields zero energy growth in the residential sector; see Fig. 8.

Table 15. Cumulative (1977-2000) energy and economic effects of increased fuel prices, elimination of market imperfections, and combined Federal program[a]

Energy benefits	(QBtu)	% of baseline
Electricity	80.10	26.5
Gas	31.11	23.2
Oil	10.99	22.8
Total	122.21	24.8

Present worth of economic benefits at 8% real interest rate (10^9 1975-$)	
Fuels	-20.54
Equipment	-13.62
Structures	-22.45
Total	-56.60

[a]The energy and economic changes are calculated relative to the baseline (Case 2).

Energy-related household expenses in the year 2000 total $86 billion, compared with $75 billion with federal programs and $83 billion in the baseline; see Fig. 9. As a portion of personal income, energy-related costs amount to 3.1% in 2000, compared with 2.7% with federal programs and 3.0% in the baseline. The cumulative increase in energy-related costs amounts to $57 billion compared with the baseline.

7. 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 (1977-2000) energy use 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. 7 and 8.

Our conclusions and interpretations of these runs are:

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%/year in our high case, compared with an average growth of 4.0%/year between 1950 and 1972. If residential energy use grew at 4.0%/year from 1976 through 2000, it would reach 42 QBtu in 2000 — almost 50% higher than the estimate from our high projection.

This significant reduction in energy growth is due to the long-run effects of fuel price increases from 1972 through 1976, reductions in population growth, absence of new energy-intensive household functions, and near-saturation of existing household functions.

2. Our high projection assumes that real fuel prices remain constant between 1976 and 2000. However, all projections we have seen show increases in fuel prices to the year 2000. In our baseline projection, we use fuel prices from FEA and ERDA (Fig. 3) that are roughly 40% higher in 2000 than in 1976.

The effect of these price increases is to cut energy use 14% in the year 2000. Cumulative energy use in the baseline is 9% less than in the high projection. The baseline projection assumes no government programs. Changes in equipment and structure energy efficiencies 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%/year; energy use in the year 2000 is only about half of what it would be if historical trends (4.0%/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 — appliance efficiency standards, thermal performance standards for new construction, and a program to retrofit existing housing units — reduce energy growth from 1.7%/year (baseline) to 1.2%/year. The cumulative energy savings total 46 QBtu (69% electricity, 22% gas, 9% oil).

In addition, these programs reduce lifecycle costs to consumers of owning and operating households. The present worth of the net benefits (at 8%) amounts to $27 billion.

Of the three programs, retrofitting existing homes provides the largest energy and economic benefits. This is because we assume that all the retrofits are accomplished by 1984; most of these housing units remain in the stock through the year 2000. However, many of the new units affected by the HUD standards are not built until the 1990s; they 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. In the 1980s and 1990s, about 35% of all new heating systems are electric. Standards that increased the efficiency of these new electric heating systems 5% would increase the appliance program energy savings almost 50% in the year 2000. Significant improvements in efficiencies of electric systems are possible through use of electric heat pumps. Presently available heat pumps require about 55% as much electricity for heating as do resistance heating systems; advanced heat pumps might require only 40% 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. Specifically, we evaluated the effects of large fuel price increases and elimination of market imperfections concerning 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, our last case shows an increase in the year 2000 energy-related expenditures from 3.0% in the baseline to 3.1% of personal income. The cumulative direct cost to consumers of higher fuel prices is $63 billion.

Table 16 summarizes the energy and economic effects of each of the five programs considered here. Fuel price increases offer the largest energy benefit; unfortunately they also increase costs to consumers. The retrofit program offers the second largest energy savings and the largest economic benefit. In fact, all the programs (except for fuel price increases) save both energy and money. Combining all the programs except fuel price increases cuts energy growth to 0.8%/year, to 19.9 QBtu in 2000. The economic benefits of this program total $34 billion. This suggests that enormous energy savings are possible, savings that also provide large economic benefits to households.

Table 16. Effects of residential energy conservation measures[a]

	Contribution (%) to cumulative (1977-2000) reduction in:	
	Energy use	Costs
Federal programs		
appliances	9	9
new construction	8	14
retrofit	19	27
50% fuel price increases	50	-162
Elimination of market imperfections	14	12
Total	100%	100%
Overall savings	122 QBtu	$-\$56.6 \times 10^9$
Overall savings as % of baseline	25%	-9%

[a]The percentages are based on the contributions of each program or policy to energy use and cost changes in going from cases 2 to 9 (baseline to zero energy growth).

ACKNOWLEDGMENTS

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Appendix: Market Penetration Analysis in the ORNL Residential Energy Use Model

Version III of the ORNL residential energy use simulation model[A1] cannot endogenously evaluate changes in new equipment efficiencies and new structures thermal integrities over time. The model does evaluate changes in equipment choices and in equipment usage in response to fuel price changes. In addition, Version III can evaluate the energy and economic effects of introducing new residential energy technologies if the user specifies the rate of implementation (i.e., the number of such systems installed each year) for the new technology.

Version IV was developed to overcome these limitations in Version III: to provide a model that endogenously determines changes in new equipment and structures efficiencies in response to changes in fuel prices and the state of technologies (i.e., relationships between equipment or structure efficiency and capital cost). This appendix summarizes the operation of Version IV. Version IV is identical to Version III except for the changes discussed here.

There are three elements involved in the market penetration analysis:

Consumer behavior
Producer behavior
Demand/supply interaction.

Consumer behavior in the energy use model is represented by fuel price, equipment price, and income elasticities, as derived in refs. A2 and A3. Manufacturer behavior is determined in the model by supply curves that relate equipment (or structure) energy requirements to equipment (or structure) purchase price. These relationships were developed in a detailed fashion at ORNL for refrigerators[A4] and water heaters.[A5]

Relationships for other end uses were developed from a review of the existing literature.[A1]

Version IV integrates the demand (consumer) and supply (manufacturer) sides to provide a dynamic equilibrium that determines efficiencies over time. There are two steps to this analysis. The first involves determination of average efficiencies for new equipment and structures for each year of the simulation. These efficiencies are functions of fuel prices, implicit interest rates (related to fuel price and equipment price elasticities), and the technology relationships.

The second step is determination of equipment choices for new installations for each year of the simulation. The model determines new equipment market-shares each year as functions of operating costs (efficiencies and fuel prices) and capital costs, as well as household income.[A2]

New Structures Efficiencies

Table A-1 summarizes the major elements of the demand and supply sides for new structures. The demand side is characterized by an interest rate and an investment lifetime, assumed to be 6% and 25 years, respectively. (These values are input to the model and can be readily changed. For example, one might hypothesize that consumers use only five years as their horizon for investment decision, although structures last much longer).

The supply side is represented by curves that relate thermal integrity to changes in capital cost for the residence; see Fig. 7 on page 26. If the curve of Fig. 7 is rotated 90°, one obtains Fig. A1. Adding operating

Table A-1. Assumed determinants of consumer and producer behavior with respect to thermal integrity of new structures

1. Consumer behavior	
	6% "real" interest rate
	25-year lifetime
	Assumptions can be readily changed in model
2. Supply-side behavior	
	relationship between structure performance and initial cost (e.g., Fig. 7)

costs (for space heating and air conditioning) to the capital cost relationship of Fig. A1 yields the lifecycle cost (LCC) curve of Fig. A2.

Figure A2 shows the typical behavior of declining and then increasing LCC as capital cost changes. The point of minimum LCC is denoted by $T_{optimal}$, the structure thermal integrity/capital cost point at which LCC is minimized. However, historical data show that the system does not operate at the optimal point; it operates at a point of higher thermal integrity (less efficient structure) and lower capital cost, denoted by T_{actual}.

We hypothesize that the difference between $T_{optimal}$ and T_{actual} persists over time as fuel prices change. Figure A3 illustrates changes in $T_{optimal}$ and T_{actual} as fuel prices change. As the price of fuel increases from P_o to P_1 and P_2, $T_{optimal}$ moves to the left and so does T_{actual}. $T_{optimal}$ is always the minimum on the LCC curve. T_{actual} is calculated from $T_{optimal}$ by assuming that D (the vertical distance between $T_{optimal}$ and T_{actual}) varies inversely with fuel price:

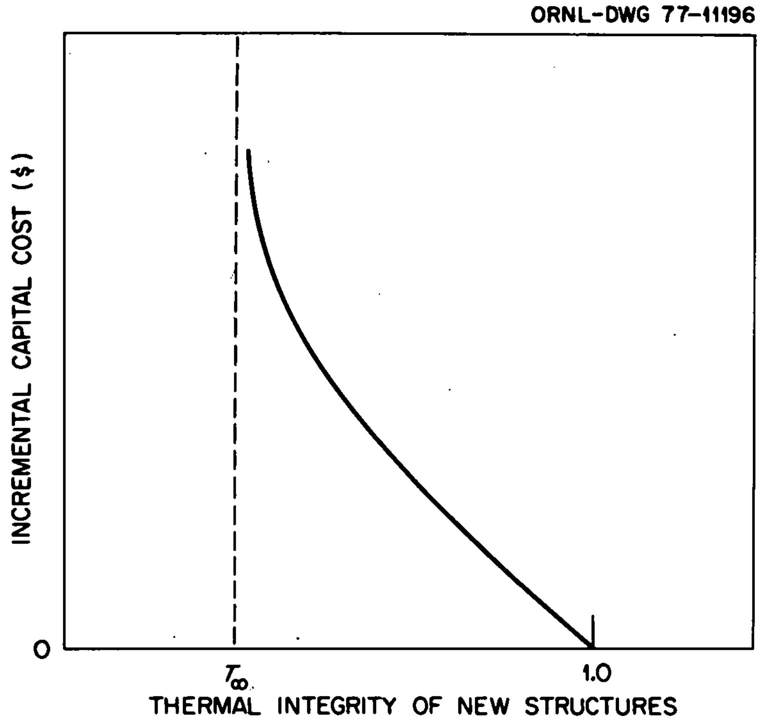

Fig. A1. Relationship between thermal integrity and incremental capital cost for new structures (T = 1.0 refers to the 1970 condition).

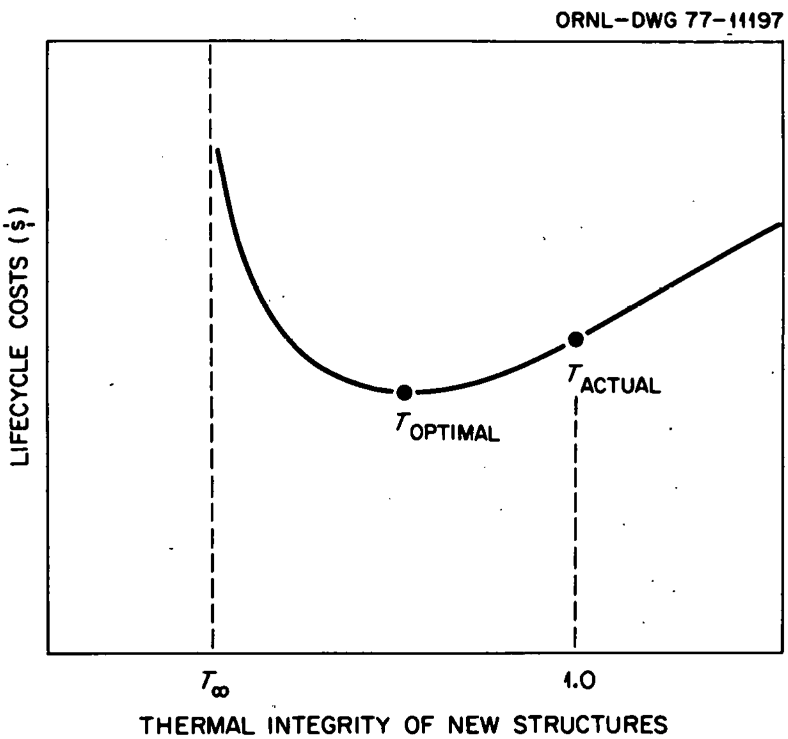

Fig. A2. Lifecycle costs for heating and cooling residences as a function of thermal integrity.

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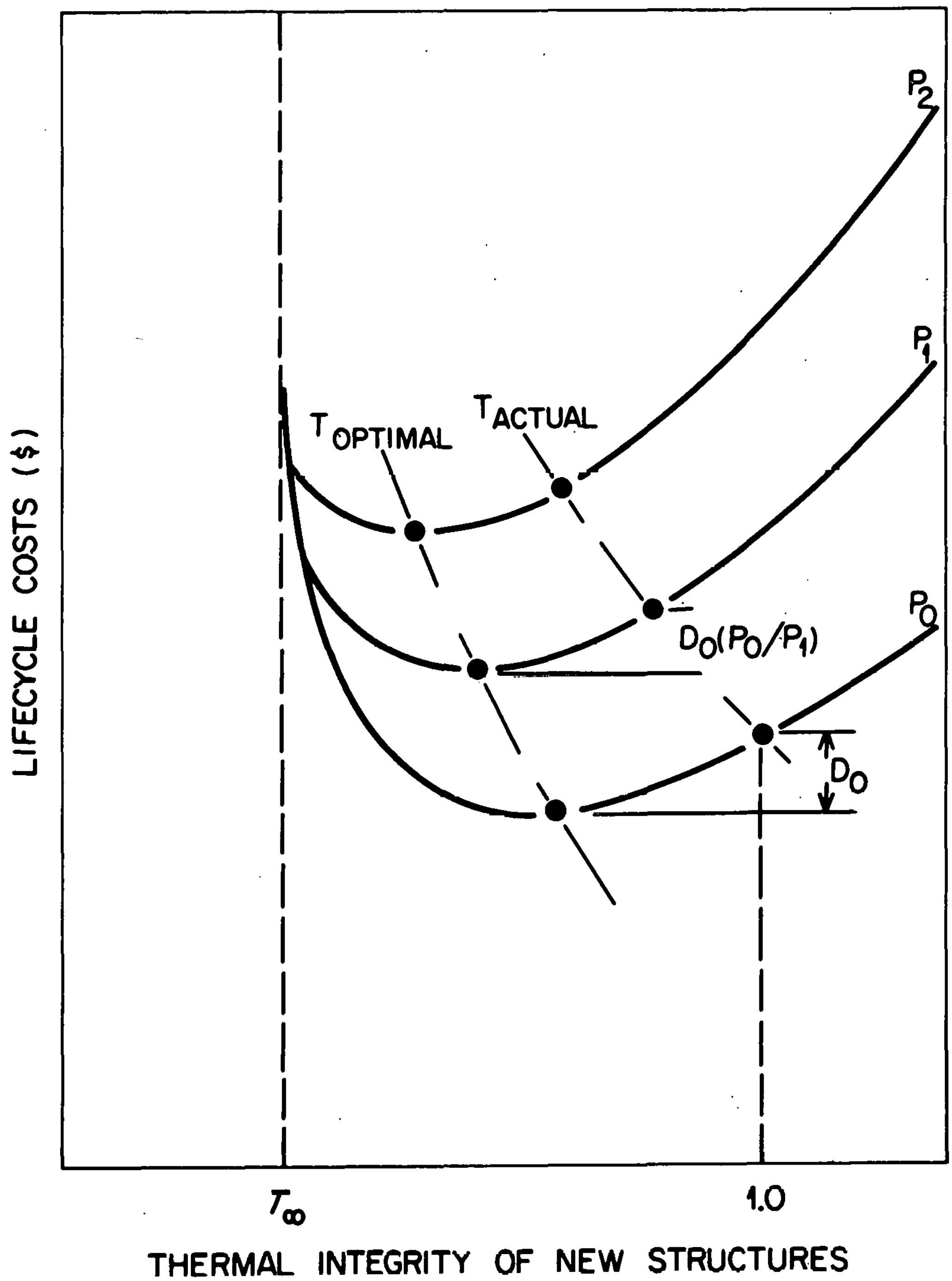

Fig. A3. Changes in thermal integrity of new structures as a function of fuel price.

$$D = D_o(P_o/P).$$

Thus as fuel prices increase, the "distortion" between the optimal and actual states will decline.

D represents the difference between the actual and optimal states. We hypothesize the (non-zero) existence of D because of market imperfections on both the demand and supply sides: lack of consumer information, costs of processing information, lack of incentive for producers to operate at the optimal point, lack of motivation from financial institutions, etc. We also assume that as fuel prices rise, these market imperfections will be reduced.

New Equipment Efficiencies

The model operates in a similar fashion in determining efficiencies of new equipment. However, an additional step is involved: determination of new equipment market-shares. Market-shares are determined in the energy model as functions of capital and operating costs for each choice and per capita personal income (from ref. A2):

$$\text{Market-share}_i = F_i \text{ (capital \& operating costs for all choices)} + G_i \text{ (income)}$$

$$i = \text{electricity, gas, oil, other/none}$$

These relationships yield lines of constant market-shares as operating and capital costs for the system change (assuming that the characteristics of competing systems and incomes do not change). The slope of these constant market-share lines determines the implicit interest rate at which consumers trade off operating for capital costs (Table A-2 and Fig. A4).[A1]

Table A-2. Real interest rates used in the ORNL residential energy model to determine equipment price elasticities

	Real interest rate (%) for:		
	Electric	Gas	Oil
Space heating			
Electric	8	11	11
Gas	11	8	11
Oil	11	11	8
Water heating			
Electric	12	15	15
Gas	15	12	15
Oil	15	15	12
Refrigeration	15		
Freezing	15		
Cooking			
Electric	15	18	
Gas	18	15	
Air conditioning			
Room	15	15	
Central	18	12	
Lighting	15		
Other			
Electric	15		
Gas		15	

Source: ref. A1.

The supply side is represented by curves that relate equipment energy requirements to equipment purchase prices; Figs. 5 and 6 (pages 22 and 23) show such relationships for water heaters.[A5]

Once again, the demand and supply relationships can be combined on a single graph (shown in Fig. A5) to determine the intersection. In

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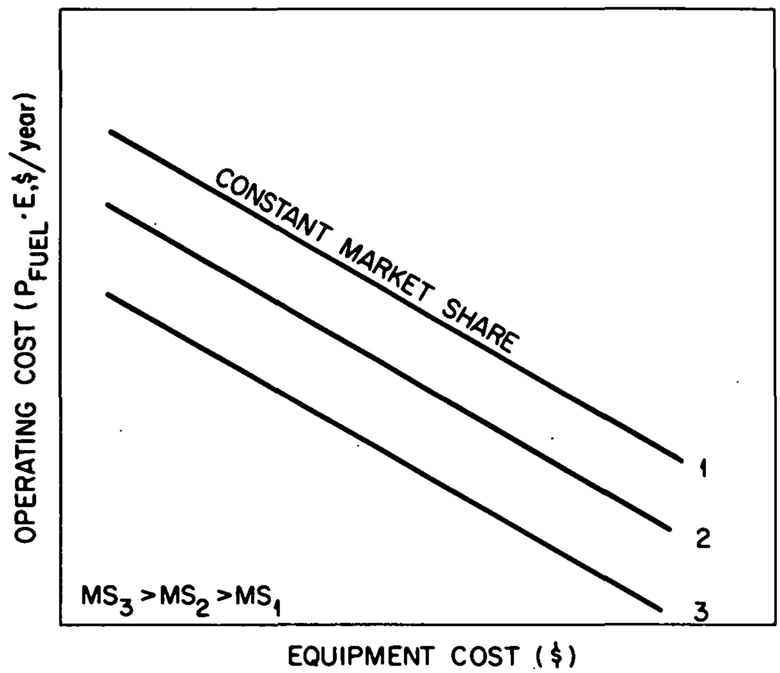

Fig. A4. Consumer preferences (market-shares) as a function of equipment operating and capital costs.

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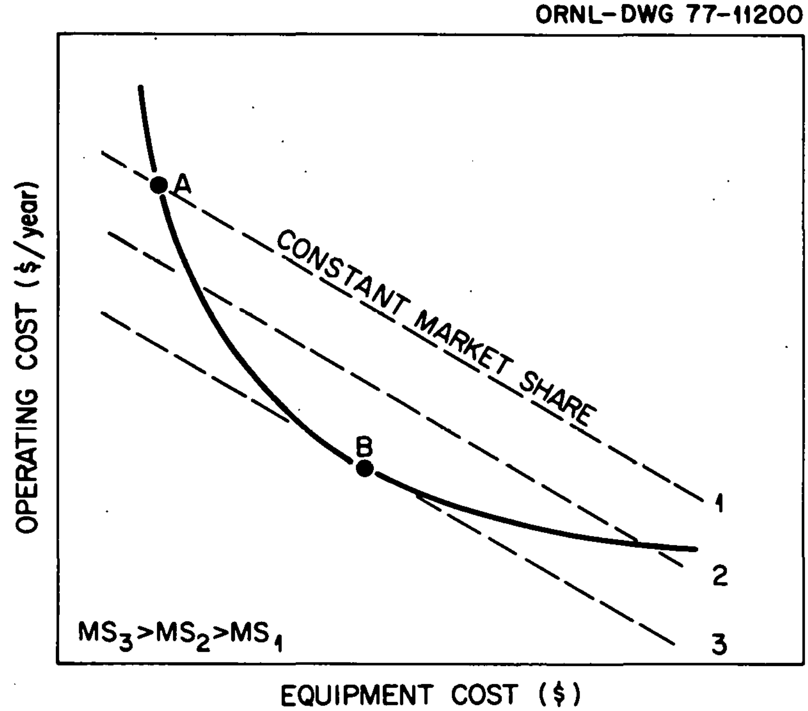

Fig. A5. Intersections between consumer preferences and technology relationships for new equipment (Point A represents the 1970 "equilibrium," point B represents the "optimal").

Fig. A5, point A represents the actual intersection for a particular year (e.g., 1970). Point B represents the optimal point, i.e., the point at which marginal improvements in equipment efficiency yield the consumer's implied rate of return.

Figure A6 shows how, as fuel prices change, the efficiency and market-share for this type of new equipment also change. Again, the difference between the actual and optimal states is denoted by D. D is assumed to vary inversely with fuel price. As fuel prices change, the optimal point (point of tangency between supply and demand curves) changes. Moving perpendicular from the optimal point the distance D yields the market-share line and efficiency for the new equipment.

Incorporation of this market penetration methodology into the ORNL residential energy use model allows us to evaluate the full range of responses to fuel price changes:

usage
fuel choices for new equipment
energy efficiencies for new equipment.

Figure A7 shows the model's prediction of the demand for gas to heat water in response to a step increase in the price of gas in year 0. The price increase induces an initial response in terms of reduced hot water usage. This response reaches a peak five years after the price increase and then begins to subside.

The price increase induces two responses concerning new water heaters. Some households that would have purchased new gas water heaters switch to electric or oil water heaters. Those households selecting new gas water heaters choose more efficient units than they would have if the price of gas had not increased. These two equipment ownership responses

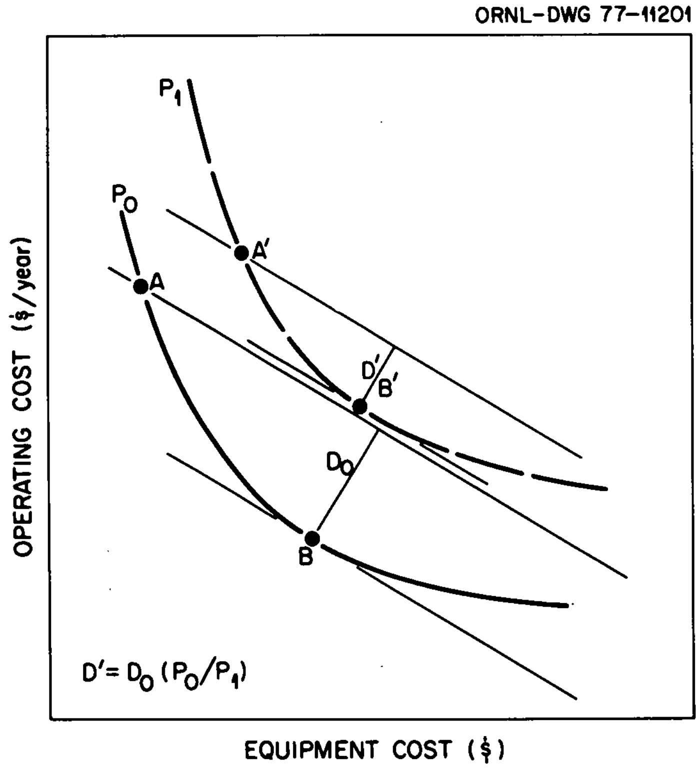

Fig. A6. Changes in new equipment efficiencies and market-shares as functions of fuel price.

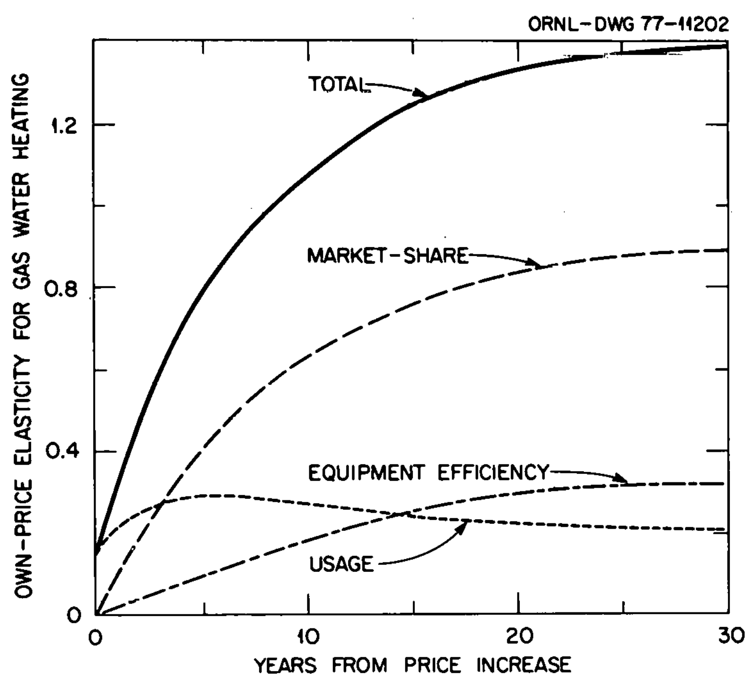

Fig. A7. Effects of a step change in the price of gas on ownership, efficiency, and usage of gas water heaters.

occur much more slowly than does the usage response: ownership changes are limited by the lifetime of water heaters (half-life of seven years). Only as existing water heaters wear out can changes be made in terms of fuel choices and energy efficiencies.

As the average efficiency of gas water heaters improves, households adjust their usage accordingly. Thus, after 30 years the usage change is two-thirds its maximum value (after five years).

The top curve in Fig. A7 shows the total change in gas use for water heating in response to the price change. The total is the sum of the three individual responses. Figure A7 shows both the complexity of responses to a change in an exogenous variable and differences in dynamics for these responses. Usage responds rapidly while ownership changes occur much more slowly.

Table A-3 shows the long-run fuel price and income elasticities produced with the overall simulation model. These elasticities include all three responses discussed above. Long-run own-price elasticities are all equal to or greater than 1.0. The elasticity of demand for total residential energy use with respect to the price of all fuels is about -0.75. Thus a 10% increase in the price of all fuels would cut residential energy demand by 7.5%. This overall fuel price elasticity is about 50% larger than the overall income elasticity of 0.52. These elasticity estimates are in good agreement with those reported elsewhere.[A3]

Additional Efforts

Although the existing model (Version IV) seems to operate quite well, additional effort is required to both validate and improve the

Table A-3. Long-run elasticities obtained with Version IV of the ORNL residential energy use model

	Price of:				
	Electricity	Gas	Oil	All fuels	Income[a]
Electricity	-1.02	0.24	0.05	-0.75	0.61
Gas	0.21	-1.05	0.15	-0.71	0.80
Oil	0.14	0.48	-1.42	-0.92	-0.02
Total	-0.45	-0.12	-0.14	-0.75	0.51

[a]These income elasticities include the effects of income on both household formation and fuel use per household.

model. As of now, we have not compared model predictions with historical data. We hope, during the next few months, to do this. We must also develop better equipment efficiency/capital cost relationships for the model because model results are quite sensitive to the shape of these curves. Additional efforts are also required to better define the consumer behavior relationships (elasticities) that are input to the model.

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