Chapter I

TRENDS

Chapter I.—TRENDS

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TRENDS IN RESIDENTIAL ENERGY USE

This chapter analyzes residential energy use since 1960, gives energy use projections to the year 2000, and discusses the potential for energy savings in the residential sector. Aided by computer analysis of residential electricity and natural gas use since 1968, consumer response to changing prices is examined. Finally, computer projections are made of energy demand over a range of possible future energy prices assuming ideal economic behavior.

ENERGY, DEMOGRAPHICS, AND PRICES

Table 1 shows aggregate energy use for the residential sector, adjusted for annual weather differences and broken down by fuel use and by function, for 1960, 1970, and 1977. From 1960 to 1970, adjusted residential energy use increased at an average rate of 4.7 percent, while from 1970 to 1977 it grew by only 2.6 percent. This substantial reduction has not been spread evenly through the 1970's, however. Between 1970 and 1972, the average annual growth rate for weather-adjusted residential energy use was 3.4 percent; from 1972 to 1975 consumption declined by 1.8 percent; and from 1975 to 1977 it leapt back up to a 3.7-percent average annual growth rate.

Electricity use is growing fastest. From 1960 to 1970 electricity use grew at an average annual rate of 8.3 percent; from 1970 to 1977 the increase was about 5.5 percent. In 1977, electricity represented 45 percent of all the energy used in the residential sector. Unlike total energy use, however, the growth rate in electricity use since the embargo has not departed from that over the entire 1970-77 period.

Even though growth rates have declined for both electricity and total energy use for 1970-77 compared with 1960-70, the ratio of electricity growth to total energy growth has increased. This is a result of rapid expansion in electric heating over the period; about 50 percent of new homes have been constructed with electric heat since 1974, compared with less than 30 percent in 1970. The proportion of new electrically heated homes using heat pumps is rising rapidly. This trend toward electric heating may be slowing, however, as there appears to be a resurgence of gas space-heating in new homes.

Table 1 .–Residential Energy Use by Fuel (Quads)

	1960	1970	1977
Electricity	2.41	5.36	7.80
Oil	2.37	2.81	2.98
Natural gas	3.34	5.31	5.83
Other	1.00	0.90	0.60
Total	9.12	14.38	17.21

NOTE: The 1960 and 1970 figures are from "Residential Energy Use to the Year 2000: Conservation and Economics," ORNL/CON-13, September 1977. The 1977 figures are from the Energy Information Administration, Department of Energy.

1977 Components of Residential Energy Use (Quads)

	Space heating	Cooling	Water heating	Other*
Electricity	1.55	1.13	1.16	3.96
Oil	2.67		0.31	
Natural gas	3.97		1.03	0.83
Other	0.55	–	0.04	0.01
Total percent of national consumption	11.8	1.5	3.4	6.5

*Includes cooking, clothes drying, refrigeration and freezing, lighting, appliances, TV, etc.
NOTE: These are estimated from the 1977 figures using the relative breakdown for 1975 given by ORNL/CON-13.
1 Quad = 1.055 EJ.

[1] Data for total residential energy use are corrected for weather differences by assuming that 50 percent of the total is for heating, and is therefore weather-sensitive, and by adjusting that portion using a ratio of the average number of annual degree days between 1960 and 1970 (4,869) to the actual number in each year.

Many variables have contributed to the gradual reduction in residential energy growth in this decade, but it is difficult to demonstrate a cause-and-effect relationship between demographic trends, prices, and other economic fluctuations on the one hand, and energy consumption statistics on the other. The sharp dip to an absolute decline in weather-adjusted residential energy use between 1972 and 1975 can probably be attributed to the dominant events of that period —the Arab oil embargo and the 1974-75 national bout with "stagflation," or combined recession and double-digit inflation. Beyond that, however, it becomes more difficult to isolate causes of reduced consumption.

Demographic contributions to reduced home energy use can be glimpsed by reducing the consumption statistics to the individual household level. Between 1960 and 1970, energy consumption grew rapidly in each household–that is, total residential energy use grew considerably faster than either the population or household formation growth rates. While total weather-adjusted residential energy use grew by 4.7 percent annually, population increased at an annual rate of only 1.3 percent and the number of households rose by only 1.9 percent annually. The rapid increase in each household's energy consumption can be attributed to the trend toward saturation in major energy-consuming home appliances such as air-conditioners, dishwashers, and clothes dryers, and to increased energy-intensiveness in such appliances as frost-free refrigerators.

The trend toward higher per-household energy consumption has been halted in the 1970's. A recent study by the General Accounting Office reports that total energy use per household has remained essentially constant in this decade.[2] Demographic trends help to explain this reversal: as population growth has slowed to an annual increase of 0.6 percent, the rate of household formation has picked up to 2.4 percent. At the same time, the average number of persons in each household has declined. One- and two-person households increased their share of total households from 45.8 to 51.2 percent between 1970 and 1976, while households with four or more persons dropped from 21.1 to 15.9 percent. The high rate of household formation and smaller household size result from the "coming-of-age" of baby-boom children and, to a lesser extent, higher divorce rates, greater longevity, and the increasing tendency of older persons to live alone.

Smaller households, typically occupying smaller homes, use less energy. But each additional household adds more energy consumption to the total than the same number of persons would use in a combined larger household, as each new household normally means an additional furnace and water heater and additional appliances. Therefore, while energy use per household does not grow, total household energy use does increase faster than population.

Projections of future population growth and household formation suggest that the demographic trends of the 1970's are likely to continue. The Bureau of the Census medium-growth projection (Series 11) for population in 2000 is 260 million, or an average annual growth of 0.8 percent between 1976 and 2000. A housing model developed by the Oak Ridge National Laboratory (ORNL)[3] predicts a household formation rate that continues to outstrip population growth; ORNL projects an average growth of 1.6 percent in the housing stock between 1975 and 2000. The highest growth (2.1 percent annually) will occur in the 1975-85 period, with a drop to 1.3 percent per year between 1985 and 2000. Households in 2000 are expected to total approximately 106.5 million. Combined with the Series I I population projection, this would mean an average household size of 2.40 persons, compared to 2.95 persons in 1976.

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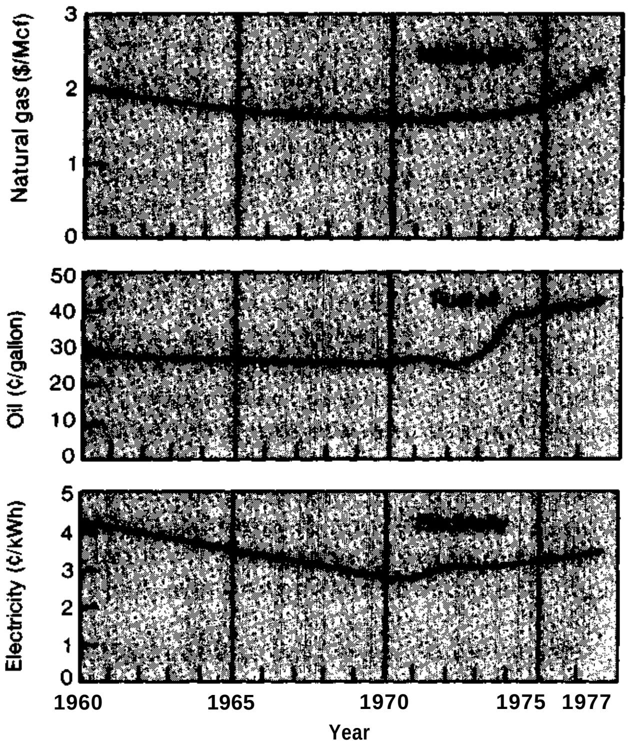
[2] *"The Federal Government Should Establish and Meet Energy Conservation Goals,* Comptroller General of the United States, June 30,1978, Washington D.C.

[3] *"An Improved Engineering–* Economic Model of Residential Energy Use,'' Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Most observers agree that the price of energy, and particularly dramatic changes in price, affect residential (and other) energy use. Again, however, documenting the exact relationship between price changes and reduced household energy consumption is virtually impossible, given the scanty data collected during the short period of time when price increases have occurred. Figure 2 shows prices for electricity, natural gas, and heating oil from 1960 to 1977 in constant 1976 dollars (to remove the effects of inflation). The figure shows that all energy prices, in real terms, have increased dramatically in the last few years.

Figure 2.— Fuel Prices 1960.77
(in constant 1976 dollars)



SOURCE: U.S. Energy Demand: Some Low Energy Futures, *Science, vol.* 200, Apr. 14, 1978, p. 144.

Since 1970, real oil prices have increased an average of 7.6 percent per year (with a 35-percent increase from 1973 to 1974); real natural gas prices increased 4.9 percent annually; and electricity prices rose 3.4 percent per year. Between 1960 and 1970, by contrast, all these prices decreased in real terms.

Viewing these price changes in another way, table 2 presents national average annual heating bills (in 1976 dollars) for electricity, fuel oil, and natural gas, for the years 1960, 1970, 1975, and 1977. These figures show that the real cost of heating dropped substantially from 1960 to 1970 for all three fuels before beginning to grow. The greatest increase has occurred in the oil heating bill, which has increased 65 percent since 1970. Natural gas and electric heating bills have increased 37 percent and 27 percent respectively since 1970.

Table 2.—National Average Annual Heating Bills by Fuel (1976 dollars)

Year	Electricity	Oil	Natural gas
1960	$690	$280	$220
1970	450	260	175
1975	510	400	200
1977	570	430	240

NOTE These estimates of electricity and natural gas were obtained by using the heating energy requirements for 1970, 1975, and 1977 shown in figure 3 and prices for all years from figure 2. The 1960 estimate of use per household is assumed equal to 1970 and the heating energy requirement for oil is assumed to be equal to that for natural gas. Keep in mind that oil heat is used largely in the coldest parts of the country.

The relative costs of the three fuels are also instructive. As expected, electricity is the most expensive, about 2.3 times that of gas in 1977 and about 32 percent higher than oil. In 1970, however, electric heat was about 73 percent more expensive than oil and 2.6 times higher than gas. If electricity prices continue to grow at a slower rate than oil and gas, and heat pumps capture a greater share of the electric heat market, these price differentials should continue to narrow substantially and could contribute to increased electrification of the residential heating market.

ANALYSIS OF ELECTRICITY AND NATURAL GAS USE AS FUNCTIONS OF WEATHER AND PRICE

In an effort to isolate the impact of price increases on residential use of electricity and natural gas, OTA employed regression analyses that separated weather-related and non-weather-related use of each energy source on a per-household basis. The analysis covered 1967-77 for natural gas and 1970-77 for electricity. The results of these analyses are shown graphically in figure 3. Major conclusions from the analyses are:

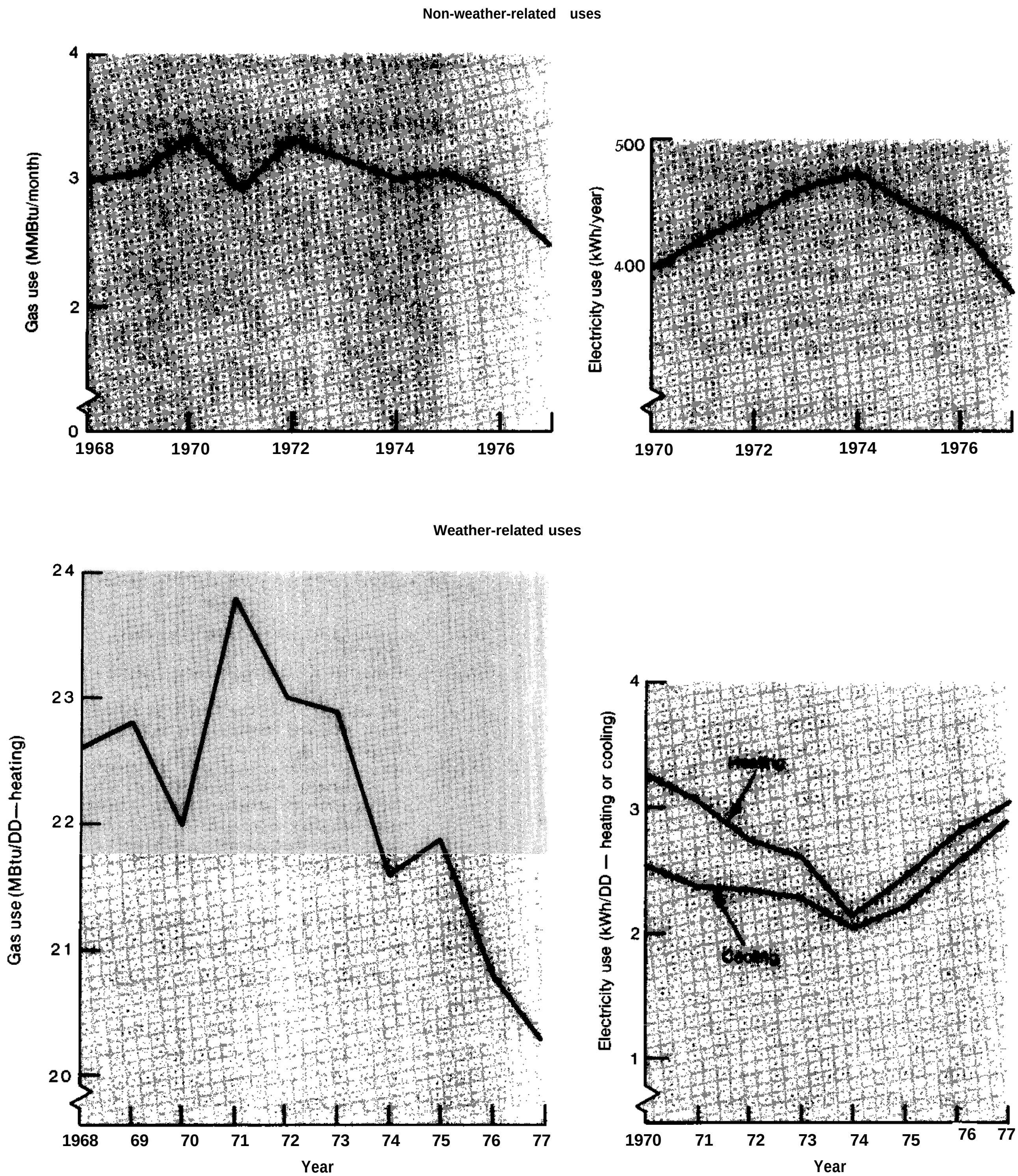
1. The per-household use of natural gas for heating, measured in 1,000 ft^3 per degree day, declined by about 10 to 15 percent between 1967 and 1977. (Similar results were obtained in a study by the American Gas Association.)
2. Similar changes have occurred in non-weather-related household use of natural gas (such as cooking) over the decade examined. Interesting shorter term trends are also evident: consumption in this category rose about 10 percent through 1973, and dropped by about 25 percent between 1973 and 1977.
3. Per-household weather-related use of electricity, measured as kilowatthours consumed per heating and/or cooling degree day, dropped sharply from 1971 to 1974, but has been rising over the last 3 years.
4. Conversely, non-weather-related uses of electricity per household increased steadily from 1970 to 1974 and then dropped sharply from 1974 to 1977.

The linear model used in OTA's analysis was not able to indicate a quantitative relationship between those consumption changes and price changes over the same periods. This does not mean that the price effect can be dismissed, however, as the above results do track with increasing prices in most cases. In the case of natural gas, real prices have increased by 35 percent since 1973 (see figure 2). The drop in gas use per degree day that occurred in 1974 was probably caused largely by the embargo, but the continued downward trend since then has likely been a result of price. The nonheating use of gas shows an even greater correlation to price in that the decline has accelerated in the last 2 years, when price increases have been the greatest. The principal conclusion here is that some price response is evident but it is complex and extremely difficult to demonstrate conclusively or quantitatively.

Electricity use shows a much weaker correlation to price. It must be noted that real electricity prices have increased the least among the residential energy sources—only 14 percent since 1973. In fact, the real price of electricity in 1977 was just equal to that in 1965. Therefore, one would not expect to see as much change in electricity use as in other energy sources. There has been a substantial increase in weather-related electricity use per household since 1974 while non-weather-related uses have declined about 25 percent. While these trends are correct, it is possible that the size of the changes which have occurred is smaller than shown in figure 3. Effects due to changed thermostat settings and weatherproofing could cause the linear model used to overstate the actual changes. Perhaps these changes indicate that the modest electricity price increases that have occurred have motivated users to conserve where conservation involves the least discomfort— in lighting, cooking, and use of appliances — but not in the basic amenities of heating and cooling.

The ability of any model to document a relationship between price and consumption in a decade or less– and particularly in the post-embargo period of sharp changes in both variables — is limited. Analysis over a longer period should shed further light on the price effects, especially since a longer period is required to test for, the most significant response to price, a replacement of energy-consuming durable goods such as furnaces, refrigerators, water heaters, and other appliances. While short-term behavioral changes such as setting back

Figure 3.—Energy Use per Household



SOURCE: Office of Technology Assessment. See *Technical **Note—Residential Energy** Consumption Analysis,* at the end of this chapter.

the thermostat and lowering the water heater temperature have some effect on total consumption, this effect is small compared with the potential of a new and more efficient furnace or water heater.

PROJECTIONS OF FUTURE RESIDENTIAL DEMAND

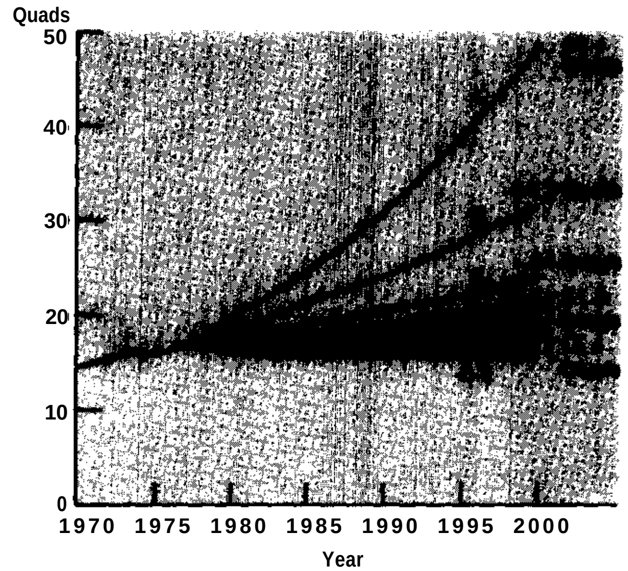
This section presents a series of projections of residential energy demand — not to indicate what is likely to happen, but to establish the potential for residential energy conservation. Demand is projected to 2000 along two curves as if 1960-70 and 1970-77 trends were to continue. Another projection shows potential demand if all consumers behave in an economically optimum manner. The latter case is applied to a range of possible future energy prices.

The results of these projections are shown in figure 4. The upper curve, showing residential use reaching 48.4 quadrillion Btu* (Quads) by 2000 if the growth rate resumes its 1960-70 value, is for illustrative purposes only and is not considered likely to occur. Although the growth rate has picked up over the last 3 years, it still does not approach the 1960-70 levels, and it is unlikely to do so because energy prices are unlikely to fall and saturation is being reached in a number of energy-intensive appliances in the residential sector.

The second trend curve, reaching 31.3 Quads in 2000, is more realistic because it represents continuation of the 1970-77 growth rate of 2.6 percent per year. This projection implies that future response to increased prices and supply uncertainty would follow 1970-77 patterns, and energy prices would not increase relative to income for the remainder of the century. Because the last 3 years have shown a marked increase in the growth rate, a continuation of the 1975-77 trend until 2000 would result in substantially more actual energy use. It is important to remember, however, that the trends of the last few years do not yield enough information, especially in light of the enormous price changes that have occurred, to be considered accurate forecasts of the future. Because energy prices are, in fact, expected to increase, it is probable that actual residential energy demand will fall below 31.3 Quads.

*A Quad = 1 quadrillion Btu = 105 exajoule (EJ)

Figure 4.—Comparative Energy Use Projections (Residential sector)



A – Residential consumption based on simple extrapolation of 1960-70 trend.

B – Residential consumption based on simple extrapolation of 1970-77 trend.

C – Residential consumption based on constant level of energy use per household; growth results from increase in number of households.

D-E – Range of "optimal economic response" based on assumption that energy saving devices are installed as they become cost-effective. Range is formed by price; upper boundary represents response to lowest projected price, lower boundary represents response to highest projected price. (See figure 5—Price)

1 Quad= 1.055 EJ.

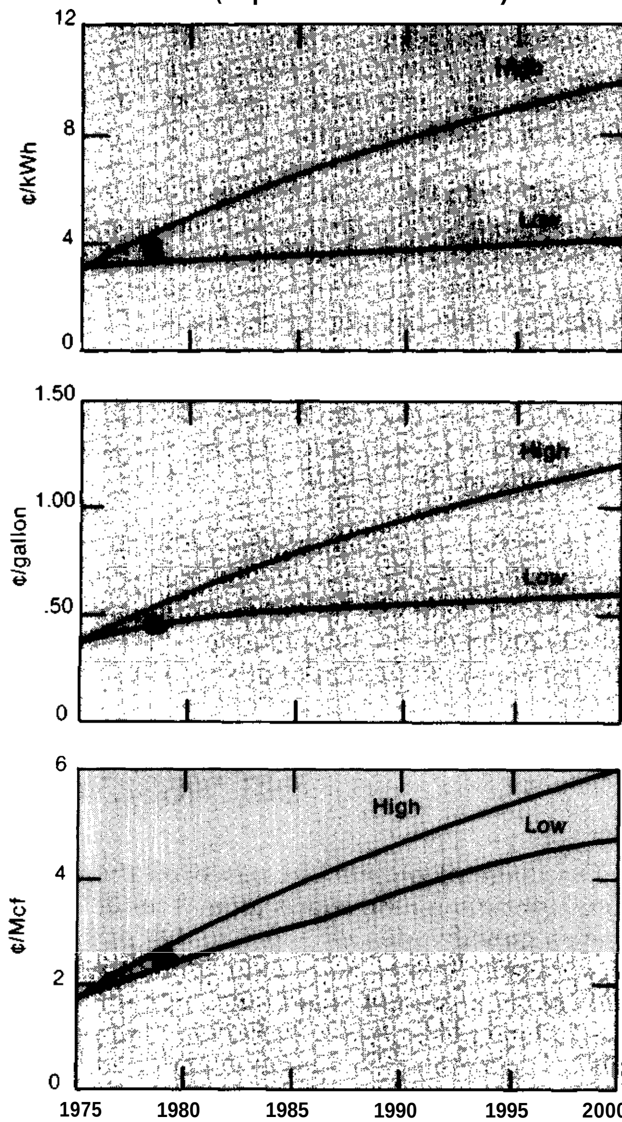
How far below is the key question, To test the conservation potential of hypothetical consumer behavior based on maximum economic self-interest, projections were calculated from the residential energy demand model developed by ORNL. The projections assume that consumers make selected investments designed to increase residential energy efficiency to a point where their marginal cost equals marginal savings — that is, the point where an additional dollar invested would return less than a dollar over the life of the investment— and then no more is invested. The resulting consumption levels range from 15.4 to 21.8 Quads in 2000.

Certain assumptions about future energy prices, available equipment, and financial variables are inherent in the projections; the range of future energy prices used is displayed in figure 5. The low price projections correspond to the 1977 Department of Energy price projections. These curves from 1975 to 2000 show a growth rate for prices in 1975 constant dollars of 4.0 percent per year for natural gas, 1.0 percent per year for electricity, and 1.7 percent per year for fuel oil. The Department of Energy is currently revising its price projections upward. The high price projections are placed somewhat above the high Government projections prepared by the Brookhaven National Laboratory (BNL). The rationale for doing this is explained in the OTA report *Application of Solar Technology to Today's Energy Needs, Volume II,* September 1978. According to this price range calculation, between 1975 and 2000 the average annual rate of increase in constant dollars is 5.0 percent for natural gas, 4.7 percent for electricity, and 4.8 percent for fuel oil. The 1978 prices (in 1975 dollars) are shown for each of these three fuels for easier comparison.

This analysis assumes that a residential customer would decide to invest his money in a manner calculated to realize a maximum return while meeting his future energy needs. The customer would divide his available funds between energy conservation technologies and fuel purchases to minimize the amount of money spent over the useful life of his investment. Therefore the amount spent on the conservation technologies would be less than the cost of energy saved.

Another way of seeing this tradeoff is to consider the equivalent cost of a barrel of oil saved by an investment in residential conservation and compare it to the cost of the energy purchased in the absence of the investment. This computation may be made using the ORNL model, which considers investments in technologies that reduce the heating and cooling load by improving thermal integrity of new single-family homes (e. g., insulation, storm windows). This calculation shows that an initial investment of $550 in selected measures would reduce the combined heating and cooling load for a new home by about 52 million Btu per year in an average climate. Over a 20-year period (the life of the technologies purchased with the investment) the total energy savings would amount to 1.04 million Btu or the equivalent of 180 barrels of oil. Therefore

Figure 5.—Comparative Price Projections (All prices in 1975 dollars)



■ 1978 price (1975 dollars).
Low = 1977 DOE projections.
High = Arbitrary upper limit (see OTA Solar Report, vol. II)

the investment is equivalent to paying a little over $3.00 per barrel in 1977 dollars— a price far lower than retail consumers actually pay for oil. Thus, a clear advantage exists for investments in conservation as long as fuel prices stay above this value.

Even though the dollar savings in the above example would be substantial, investments in improvements to the building shell alone may not be the best way to maximize return from residential conservation investments. By putting some money into more efficient equipment (e. g., appliances, air-conditioners, space heaters) an even greater return may be realized. Other calculations using the ORNL model indicate this result.

The model also assumes that only technologies now available will be purchased for increasing efficiency of buildings and equipment for the remainder of the century. In this sense the model is quite conservative. The model also assumes that investors will discount future investments and savings using a discount rate of 10 percent, after inflation. This, too, is a conservative choice and tends to understate the potential for conservation. Finally, the model accounts for the effect of legislation enacted prior to 1978 in carrying out the computations. It has not, however, accounted for the tax credits granted in the National Energy Act of 1978. The effect of these measures in this calculation would be to change the rules governing computation of the optimal investment level. With the credit, the investor will realize a greater return for a given investment than without the credit. Therefore he can go to a higher level of thermal protection before the marginal costs and savings become equal. In essence, Congress decided by enacting the tax credit that our national energy situation requires energy savings greater than those that could be achieved through market price considerations without Government intervention.

DISCUSSION OF PROJECTIONS

The range of projections based on the economic optimum case shows annual residential energy growth rates of – 0.5 to 1.0 percent, considerably below any value that could be verified as a present trend, and probably too low to be realistic future projections. Residential consumers often fail to make economically optimum investments in energy conservation for many reasons, which are discussed elsewhere in this report. Also, the model uses as a payback period for each investment the entire life of the technology being purchased, while most residential conservation "investors" have a time horizon considerably shorter, typically no more than 5 years. Finally, these projections assume continued energy price increases at higher rates than inflation; if this should not occur, energy use in 2000 would fall between the economic optimum path and the 1970-77 trend curve. (A thorough discussion of the plausibility of future energy price increases is given in the OTA solar report previously cited.)

The economically optimal projections do show, however, what one could expect if consumers had access to all necessary information and no other constraints existed. A residential consumer would then presumably make the investment decisions assumed in the model, as doing so would maximize economic return. Although these projections should not be considered as predictions of what will happen, they are a valid target, and a valid basis for policy measures to reinforce private decisions.

It is worthwhile putting these projections in another perspective. If one assumes that national average household energy use in 1977 does not change for the remainder of the century, then the residential sector would use 24.7 Quads in 2000. This is based on the ORNL projection of about 106 million residences in 2000. Therefore the 31.1 Quad projection from the 1970-77 trend line implies an increase in the average amount of energy used per household. From another point of view, energy use can be estimated in *2000* if space-heating and cooling requirements were cut in half from the value projected by the 1970-77 trends. A reduction of this size is reasonable as shown in the section on current technology, chapter II. In 1977 about 57 percent of residential energy went for space heating and cooling. Continuation of that percentage, coupled with the 1970-77 trends projection, would mean that about 18 Quads would be needed for heating and cooling in 2000. Reducing heating and cooling by 50 percent to 9 Quads would give a total residential consumption of 22.3 Quads. Therefore, the projections made under the optimal investment assumption are not as far from reach as they may at first seem.

Going back to these latter projections, one can see a substantial potential for savings in residential energy use. In the highest price projection, a 50-percent reduction in energy use from the 1970-77 trend is possible. For the lower price projection, the savings potential is still more than 30 percent compared with the extrapolation of 1970-77 experience. This savings represents 9.2 to 15.6 Quads in 2000, or the equivalent of about 4.6 million to 7.8 million barrels of oil per day. The cumulative savings that could be achieved from now until the end of the century, compared to the 1970-77 trends extrapolation, range from 96.7 to 167.8 Quads for the equivalent of about 16.7 billion to 28.9 billion barrels of oil — roughly comparable to two to three Alaskan oilfields of the size discovered in 1967.

It is apparent that large savings are possible in the residential sector, and that they can contribute substantially to reducing imported energy needs. Although the potential savings may be too optimistic, because consumers are not now likely to behave in a strict economically optimum manner, they are not impossible and are worth reaching for. This study discusses many reasons why a gap between actual and optimum savings exists and what might be done to narrow the gap.

TECHNICAL NOTE–RESIDENTIAL ENERGY CONSUMPTION ANALYSIS

Regression analyses was applied to total residential consumption of gas and electricity to obtain figure 3.

Residential electric usage was separated into weather-related and non-weather-related consumption by regressing consumption against heating and cooling degree days in the form:

$$S = C + Bh\ Ceh\ Dh/Ce + Bb\ Cec\ Dc/Ce$$

where S is total electric sales per residential customer; C is the non-weather-related use per residential customer; Dh and Dc are heating- and cooling-degree-days respectively; Ce, Ceh, and Cec are total residential electric, electric heating, and electric cooling customers, respectively; Bh is the electric heating use per residential electric heating customer per heating degree day; and Bc is the electric cooling use per residential electric cooling customer per cooling degree day. Monthly data was used to determine C, Bh, and Bc for each year. Annual customer data was interpolated to estimate customers on a monthly basis.

Gas usage was treated similarlyl except cooling was not included in the regression. Data used was obtained from the following sources:

- Monthly electric sales: Edison Electric Institute, "Annual Report, " 1970-77
- Electric customers: Edison Electric Institute,
- Electric heating customers: Bureau of the Census, "Characteristics of New One-Family Homes: 1973" and a "Characteristics of New Housing: 1977. "
- Electrlc cooling customers: Bureau of the Census.
- Monthly gas sales: American Gas Association, "Monthly Bulletin of Utility Gas Sales," 1967-77.
- Gas Customers: American Gas Association, "Gas Facts "
- Gas heating customers: American Gas Association, "Gas Facts. "
- Monthly heating degree-days: "Monthly State, Regional, and National Heating Degree Days Weighted by Population, " U.S. Department of Commerce, NOAA Environmental Data Service, National Climatic Center, Asheville, N.C.
- Monthly cooling degree-days: Monthly State, Regional, and National Cooling Degree Days Weighted by Population," National Climatic Center, Asheville, N C