trode materials appear to be promising candidates as well, most notably V_6O_{13} and $NbSe_3$ (55).

Although we have restricted this discussion to cathode materials, more than a good cathode material is required to make a practical battery. The lithium electrode, which functions by a metal stripping and plating mechanism, presents a cycle life problem because of poor stripping efficiency. Improvements in lithium plating efficiency have been achieved through the use of lithium-aluminum alloy as the source of lithium (56), electrolyte solvents such as dioxolane (12) or 2-methyltetrahydrofuran (57), and solutes such as lithium hexafluoroarsenate or lithium tetraorganoborates (58, 59). There are also a myriad of other considerations, such as safety and the effects of overcharging or cell reversal, which must be evaluated in a development program before the full potential of these new, high energy battery systems can be assessed.

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Effects of Energy Conservation in Residential and Commercial Buildings

Eric Hirst and Bruce Hannon

In this article, we evaluate the economic and the net (direct and indirect) energy and employment effects of adopting different conservation programs and new technologies in residential and commercial buildings. The time span considered is from now to the end of the century. Our analyses were conducted with detailed engineering-economic models developed at Oak Ridge National Laboratory for each of the two building sectors (1) and input-output models developed at the University of Illinois (2).

The scenarios include the following:

1) The first scenario is a base line in which fuel prices rise over time as predicted by Department of Energy (DOE) and Brookhaven National Laboratory (BNL) energy models. Population, households, commercial floor space, and per capita income all grow at rates roughly comparable to their historical values.

2) The National Energy Plan (NEP) is a conservation case that includes higher gas and oil prices plus regulatory, financial incentive, and information programs authorized by the 94th Congress and expanded upon in the April 1977 NEP.

3) The third scenario is a conservation case that differs from the preceding one

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Summary. In 1977, heating, cooling, lighting, and other operations in residential and commercial buildings used 27 quads (1 quad = 10^{15} British thermal units) of energy. This is more than one-third of the nation's total energy budget. Future trends in energy use in buildings are likely to depend strongly on fuel prices and government policies designed to save energy. Three scenarios are examined: (i) a base line in which fuel prices rise as projected by the Department of Energy; (ii) a conservation case that includes higher gas and oil prices plus the regulatory, financial incentive, and information programs authorized by the 94th Congress and proposed in the April 1977 National Energy Plan; and (iii) another conservation case that also includes new technologies (more efficient equipment, appliances, and structures). These scenarios are analyzed for changes in energy use, costs, and employment by means of detailed engineering-economic models of energy use in residential and commercial buildings developed at the Oak Ridge National Laboratory and input-output analyses developed at the University of Illinois.

only in the allowance for new residential and commercial technologies that provide improved equipment, appliances, and structures.

We evaluated each scenario in terms of its effects on energy use in buildings (by fuel, end use, and in aggregate), on direct economics (fuel bills and capital costs for equipment and structures), and on employment between now and 2000.

The residential sector is defined as those structures (for example, single-family units, multifamily units, and mobile homes) occupied by households. Group quarters (such as jails, hotels, and hospitals) are considered part of the commercial sector, which is defined as those structures (office buildings, schools, hospitals, and stores) that house the service sectors of our economy such as retail and wholesale trade, finance and insurance, and government activities. Energy use in the combined buildings sector grew from 9.6 quads in 1950 to 27.3 quads in 1977, with an average annual growth rate of 4.0 percent per year (*3*). Growth was rapid and steady from 1950 to 1973, with an average growth rate of 4.2 percent per year; however, since 1973, growth has been slow and erratic (2.5 percent per year).

The importance of coal during this 27-year period changed dramatically: in 1950 direct use of coal accounted for 30 percent of the sector's fuel use, whereas in 1977 it accounted for only 1 percent of the total. Oil's share dropped from 27 to 20 percent during this period. On the other hand, shares accounted for by electricity and gas increased from 25 and 17 percent to 49 and 30 percent, respectively.

In 1950, residential buildings accounted for almost 70 percent of the fuel use of the residential-commercial sector, whereas in 1977 residential buildings accounted for only about 60 percent. Thus, although energy use in households grew at 3.6 percent per year, energy use in commercial buildings grew at 4.7 percent per year. These historical differences are likely to continue in the future as the service sectors of our economy grow at a faster rate than the overall gross national product (GNP).

Generally, residential fuel prices were declining or stable until the early 1970's; since then, prices for all fuels, especially gas and oil prices, have risen. Real oil prices increased 65 percent between 1972 and 1977, whereas gas prices increased 35 percent during this period. (All monetary values are given in terms of 1975 dollars. Use of constant dollars corrects for the effects of inflation.) During this time, electricity prices rose only 15 percent. (Trends in fuel prices in the commercial sector are similar to those for residential prices.)

Base-Line Scenario Construction

We have developed projections of residential and commercial energy uses to the year 2000 under the assumption that real fuel prices increase over time, as projected by DOE and BNL (*4*). Figure 1 shows projected fuel prices to the residential sector (prices for the commercial sector follow much the same trends). These curves show substantial increases in base-line gas prices (3.1 percent per year), whereas oil (1.7 percent per year) and electricity (1.0 percent per year) prices increase more slowly.

We assumed that population grows according to the Bureau of the Census series II projection (*5*). Per capita income was derived from a recent projection of GNP prepared by Data Resources, Inc., for DOE and the series II population projection (*4*). Projections of household formation, stocks of occupied housing units and new residential construction (*2*), and commercial floor space (*1*) are from our own models. Table 1 shows the values of population, households, commercial floor space, and per capita income used in all the projections. In the base-line scenario, we assumed that there are no government programs to encourage energy conservation (that is, we ignored recent legislation and the proposed 1977 NEP; the likely effects of these programs are discussed below).

Outputs from our energy models, given these base-line inputs, show energy use growing from 27 quads in 1977 to 28 quads in 1980, 37 quads in 1990, and 48 quads in 2000, with an average annual growth rate of 2.7 percent (see Figs. 2 and 3). Commercial fuel use grows much more rapidly (4.0 percent per year) than residential fuel use (1.8 percent per year), primarily because growth in commercial floor space is so much higher than growth in households (4.3 versus 1.6 percent per year). We expect commercial floor space to grow more rapidly than GNP during the rest of the century because of the continuing shift to a services economy. However, the difference in growth rates (4.3 versus 3.2 percent per year) is probably too high; this is due to specification problems in our forecasting equations for floor space (*1*). Growth in energy use is slower in the projection period than it was historically (2.7 versus 4.0 percent per year). This reduction is due to the effects of higher fuel prices during the mid-1970's and during

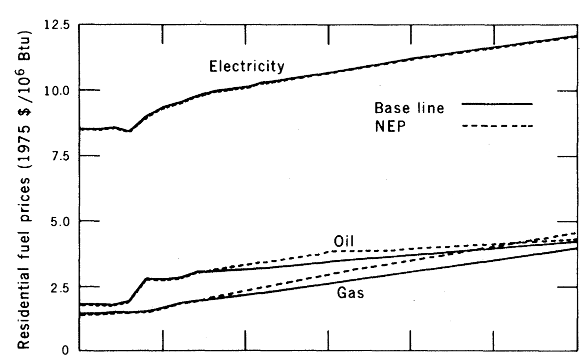


Fig. 1. Projections of real residential fuel prices, with and without the NEP.

the projection period, which are predicted to produce voluntary operational changes and improvements in technical efficiency (for example, lower winter temperatures and the purchase of more efficient heating and cooling equipment).

The contribution of different fuels to total energy use changes during the projection period. Because of sharp increases in petroleum and gas prices, consumer preference for electricity, and rising incomes (which lead to greater ownership of air-conditioners, refrigerators, freezers, lighting fixtures, and small electrical appliances), the fraction of sector fuel use devoted to electricity is predicted to increase from 52 percent in 1976 to 67 percent in 2000 in the base-line case. Shares contributed by gas and oil decline from 29 and 16 percent to 18 and 15 percent, respectively.

Conservation Programs

The residential and commercial conservation programs authorized by the 94th Congress (*6, 7*) and expanded upon by the Carter Administration in its NEP (*8*) include (i) appliance efficiency standards (residential only) implemented in 1980; (ii) thermal performance standards for the construction of new buildings to be adopted in 1978, with stronger standards to go into effect in 1980; (iii) weatherization programs for existing buildings, that is, retrofitting (federal grants to schools, hospitals, and low-income households for the weatherization of existing buildings, federal tax credits for the weatherization of residential and commercial buildings, and a federal energy management program to reduce energy use in federal buildings); (iv) higher prices for gas and oil (see Fig. 1); and (v) research and development programs to produce new technologies.

Table 1. Inputs used in projections of residential and commercial energy use to 2000.

Year	Population ($\times 10^6$)	Households ($\times 10^6$)	Commercial floor space ($\times 10^9$ square feet)	Per capita income (1975) dollars
1970	205	63	24.3	5,420
1975	214	71	28.3	5,850
1976	215	73	29.2	6,050
1980	222	80	32.3	7,150
1985	233	88	39.6	7,970
1990	244	95	49.8	8,890
2000	260	106	79.6	10,570

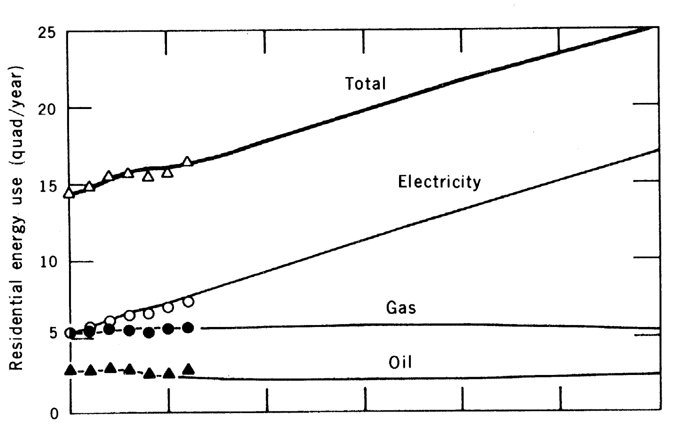
The National Energy Act, signed into law on 9 November 1978, differs somewhat from the April 1977 NEP evaluated here. Specifically, the National Energy Act did not include the proposed crude oil equalization tax, provided for slightly higher prices for natural gas, provided a smaller tax credit for residential retrofit (15 percent rather than the proposed 25 percent), and did not include the 10 percent federal tax credit for the retrofit of commercial buildings. The overall effect of these changes on the results presented here is to slightly reduce and delay the energy and economic benefits shown in Tables 2 through 4.

Appliance efficiency targets. The DOE administers the program to develop and implement a set of efficiency targets such that the average efficiency of new household appliances and equipment sold in 1980 is at least 20 percent higher than the 1972 average (*6*). Thirteen classes of appliances are considered; the most important (from an energy use standpoint) are space-heating equipment, water heaters, refrigerators, freezers, and air-conditioners. President Carter has proposed that the existing voluntary program be made mandatory (*8*). Efficiency improvement targets range from about 10 percent (oil furnaces) up to almost 50 percent (room air-conditioners) (*9, 10*).

Performance standards for new construction. The DOE and the Department of Housing and Urban Development (HUD) are developing thermal performance standards for the construction of all new buildings. These standards must then be implemented by the states but only if Congress first approves them (*7*). 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" (*8*, p. 8). These standards are expected to be somewhat more stringent than those developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers in 1975 (*11*).

Retrofit programs. Existing authorizations and the NEP contain several programs to encourage weatherization of existing residential and commercial buildings. In the commercial sector, these programs include a 10 percent investment tax credit in effect from 1977 through 1982 for efficiency improvements, a 3-year $900-million grants program for schools and hospitals, and the federal energy management program to reduce energy use in buildings operated by the federal government (*8, 12*). In the residential sector, these programs include a 25 percent tax credit for retrofit actions costing up to $800 (plus a 15 percent credit on the next $1400) in effect from 1977 through 1984, weatherization grants to low-income families totaling $530 million for the period from 1978 to 1980, several DOE and HUD demonstration programs, mandatory electric and gas utility programs (home audit services), and implementation of a rural home weatherization program (*8, 9*).

Higher fuel prices. The NEP proposes



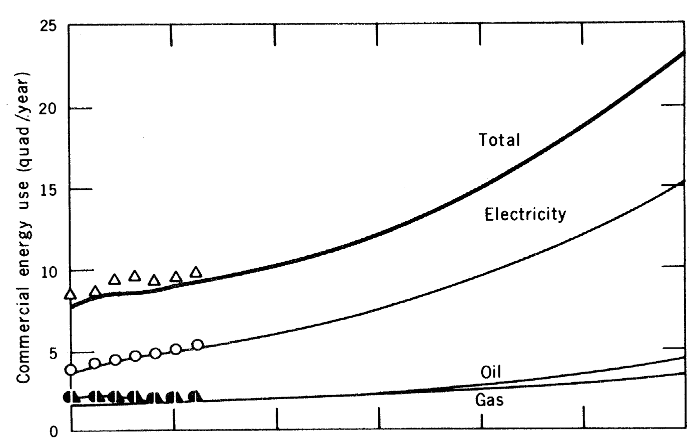


Fig. 2 (left). Base-line projection of residential energy use to 2000. Fig. 3 (right). Base-line projection of commercial energy use to 2000.

to raise domestic oil prices to world levels with a crude oil equalization tax. Natural gas prices would be regulated but at higher levels than in the past (*8*). The likely effect of these measures on residential fuel prices is shown in Fig. 1 (*4*). In this analysis, we assume that additional revenues generated because of these tax and regulatory changes are completely refunded to consumers (*13*).

New technologies. Both private industry and the federal government (DOE) are conducting research, development, and demonstration (RD & D) programs to bring to the market new systems for satisfying building energy-related functions. These new systems are likely to be much more energy-efficient than existing ones (*14*).

For example, gas-fired heat pumps are expected to provide annual space-heating requirements in typical buildings with about half the natural gas consumption of conventional gas furnaces and boilers. Development of improved control systems (especially for commercial buildings) that include sensors, actuators, controllers, and logic circuits are likely to reduce equipment energy use and peak electric loads. These systems can sense outdoor air temperature and enthalpy and use fresh air for air conditioning when appropriate. Such systems can also recirculate inside air when some zones in a building require heating (for example, the north-facing perimeter) and some require cooling (for example, the core).

Effects of Conservation Programs

Tables 2, 3, and 4 and Figs. 4 and 5 summarize the energy and economic effects of adopting these federal conservation programs. Details on the effects of each program individually are given in (*9*) and (*12*). Direct energy savings (Table 2) relative to the base line increase from 1.4 quads in 1980 to 5.2 quads in 1990 and 9.1 quads in 2000. The growth in the amount of energy used in buildings is cut from 2.7 to 1.8 percent per year. The cumulative direct energy saving between 1977 and 2000 resulting from these programs is 113 quads, split 60:40 between the residential and commercial sectors.

Figure 4 shows that residential energy savings increase rapidly through 1984. This is so because of the aggressive retrofit program assumed in the NEP, which ends in 1984 (*8*). Commercial energy savings begin to grow rapidly during the 1990's (and exceed residential energy savings after 1997) because of high

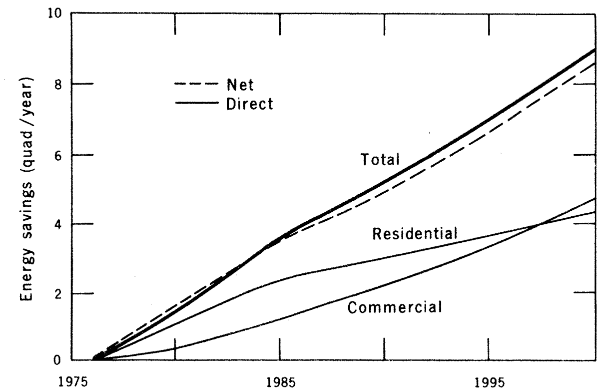


Fig. 4. Direct and net energy savings in the buildings sector due to implementation of NEP conservation programs and the development of new technologies.

Table 2. Alternative residential and commercial energy projections: energy use.

Scenario	Energy use (quads) 1980	1985	1990	2000	Cumulative (1977–2000)	Average annual growth rate, 1977–2000* (%)
Base line						
Residential	17.7	19.7	21.6	24.9	502	1.8
Commercial	10.2	12.1	14.9	23.1	356	4.0
Base line plus NEP						
Residential	16.7	17.7	19.6	23.0	460	1.4
Commercial	9.9	11.0	13.1	19.3	314	3.2
Base line, NEP, and RD&D						
Residential	16.6	17.3	18.6	20.6	438	0.9
Commercial	9.9	10.9	12.7	18.3	307	2.9
Energy savings due to NEP and RD&D						
Direct	1.4	3.6	5.2	9.1	113	
Net	1.5	3.6	5.0	8.7	109	

*Model projections for 1977 are 16.6 quads for residential and 9.4 quads for commercial energy use.

Table 3. Alternative residential and commercial energy projections: direct economic effects on fuel users.

Scenario	Present worth of cumulative (1977–2000) expenditures at 8 percent real interest rate relative to base line (billion 1975 dollars)				
	Fuels	Equipment	Structures	Tax rebate*	Net
Base line					
Residential	0	0	0	0	0
Commercial	0	0	0	0	0
Base line plus NEP					
Residential	−31.3	8.5	21.2	−21.3	−22.9
Commercial	−24.4	4.4	0.2	−15.4	−35.2
Base line, NEP, and RD&D					
Residential	−54.3	10.1	21.4	−20.3	−43.1
Commercial	−30.9	5.1	0.3	−15.1	−40.6

*We assume that the fuel taxes due to the NEP are completely refunded to customers.

Table 4. Economic effects of adopting NEP and RD&D programs.

Expenditure category	Expenditures (10^9 1975 dollars) 1980	1985	1990	2000	Cumulative* (1977–2000)
Fuels	−2.4	− 7.1	−12.2	−28.3	−85.2
Equipment	2.0	1.4	1.8	2.6	15.2
Structures	3.5	0.4	0.4	0.4	21.7
Tax rebate	−2.4	− 5.0	− 4.3	− 2.8	−35.4
Net	0.7	−10.3	−14.3	−28.1	−83.7
Net employment effect (thousands of jobs)					
	145	340	350	425	

*Cumulative expenditures represent the present worth in 1977 discounted at a real rate of 8 percent.

growth in commercial floor space (Table 1) and the performance standards for new buildings. The energy saving in 2000 (9 quads) amounts to about 20 percent of the projected national energy consumption for that year.

The dynamics of energy savings due to RD & D (new technologies) differs substantially from those due to the NEP programs. Energy savings due to the higher fuel prices and regulatory, financial incentive, and information programs of NEP increase rapidly during the 1980's and then more slowly during the 1990's. RD & D benefits, on the other hand, are initially quite small (less than 20 percent of NEP savings in 1985); during the 1990's, however, RD & D energy savings grow much more rapidly (50 percent of NEP savings in 1995). The energy savings of RD & D are delayed because of the time required for these new technologies to be developed and introduced to the marketplace, and the time needed to allow consumers to purchase new systems as existing ones wear out.

The net energy savings of a particular conservation program differ from the direct savings for several reasons (*15*).

1) Energy production and delivery require energy consumption. For example, producing and delivering 1 Btu of refined petroleum products (for example, kerosene and distillate fuel oil) to a customer consume energy in exploration, production, refining, transporting, and retailing. Altogether, these processes require about 0.2 Btu per delivered Btu of refined petroleum products.

2) Investment in more efficient equipment and structures requires energy. For example, it takes energy to manufacture, transport, distribute, and install extra insulation in a structure.

3) We assume in this analysis that total spending (or equivalently the GNP) is unchanged by the conservation programs considered here. Therefore, the money saved each year because of reductions in fuel bills (less the extra capital costs of more efficient structures and equipment) plus the rebate of the energy tax revenues is spent on other goods and services. These outputs, in turn, require energy for their production and delivery. For example, in 1990 the net saving to households of the conservation programs evaluated here amounts to \$5.4 billion due to reduced spending on energy plus \$2.5 billion due to a rebate of the energy tax revenues. This \$7.9 billion is "respent" on average goods and services, which consume energy. [In the early years of a conservation program, consumers face a deficit because their

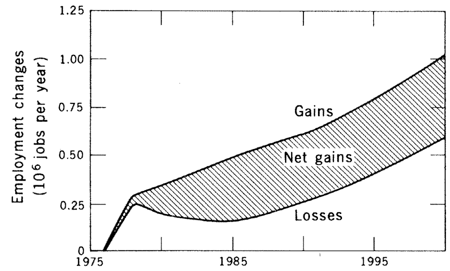


Fig. 5. Employment gains and losses due to implementation of NEP conservation programs and the development of new technologies for the buildings sector.

expenditures on more efficient systems exceed the savings on their fuel bills. For these years there is an energy saving due to this respending deficit (*16*).]

We used energy and labor intensities projected to the year 2000 at the 40-sector level (the economy is divided into 40 mutually exclusive sectors, for example, primary metal production, household appliance manufacture, and medical services) to evaluate the net energy and net employment effects of these conservation programs. Use of these input/output coefficients (*2*) assumes that average energy and labor intensities are reasonable approximations to marginal intensities and that the specific changes considered (for example, improved efficiencies of heating equipment) are adequately represented by aggregate input/output coefficients (for example, consumer products).

As shown in Table 2 and Fig. 4, differences between net and direct energy savings are small. Until the early 1980's, net energy savings are larger than direct energy savings. From then on, the reverse is true. Even in 2000, however, the net energy saving is only 4 percent less than the direct energy saving.

Initially, the net energy savings of the conservation program for residential and commercial buildings exceed the direct savings because of a negative respending effect. Until 1981, annual outlays for more efficient equipment and structures exceed annual reductions in fuel bills and fuel tax rebates.

The energy requirements to produce energy amount to about 10 percent of the direct energy savings (which already include losses in electricity generation, transmission, and distribution). The energy requirements for more efficient equipment and structures are typically 10 percent of the annual direct energy savings; these requirements are projected to decline over time.

Tables 3 and 4 show the economic effects of these programs on the residential and commercial sectors. The present worth of fuel bill reductions due to these programs is \$85 billion. Fuel tax rebates add another \$35 billion. Offsetting these gains are the extra expenses due to more efficient equipment (\$15 billion) and structures (\$22 billion). Thus, the net economic benefit of these conservation programs between 1977 and 2000 is almost \$84 billion. The ratio of benefits (fuel bill reductions and tax rebates) to costs is almost 3.3 from the viewpoint of the consumer.

Table 4 shows how energy-related expenditures change over time as a result of the adoption of the regulatory, financial incentive, information, and RD & D programs of scenario 3. Until 1980, there is an increase in direct expenditures due to the cost of improved equipment and structures. In all later years, reductions in fuel bills plus tax rebates exceed the extra costs of more efficient systems.

The previous discussion of net energy applies equally well to employment changes due to conservation programs. Although jobs may be lost in the industries that provide energy, additional jobs may become available in the construction industry, in equipment and appliances manufacture, and in the economy as a whole as a result of the respending effect. Table 4 and Fig. 5 show that net employment increases over time, from 145,000 new jobs in 1980 to 425,000 new jobs in 2000. The net increase in employment is made up of job losses in energy production (almost 600,000 jobs lost in 2000, primarily in the electric utilities) and job gains in manufacturing, construction, and the economy in general (particularly services and retail-wholesale trade). Although the net creation of jobs is large in absolute value, it is quite small compared to the total labor force (for example, compare 425,000 new jobs with an estimated labor force of 100 million in 2000). The detailed occupational effects of these employment changes is the subject of a current research project at the University of Illinois.

Conclusions

Our results suggest that future growth in energy use in buildings can vary widely. For the cases considered here, energy growth ranges from 2.7 to 1.8 percent per year between now and the year 2000.

Our base-line scenario shows an energy growth much slower than historical (4.2 percent per year between 1950 and 1973). This suggests that the combined effects of recent and projected increases in fuel prices plus slower growth in population and households with no government programs to encourage the adoption of conservation measures will lead to substantially lower growth in energy use in buildings.

Starting from this base line of much slower than historical growth in energy use, it is surprising to see how much further energy use can be cut as a result of government conservation programs (including fuel price increases) and the development of new technologies: by 9 quads in 2000, which is almost 20 percent of the base-line figure. The cumulative energy saving between 1977 and 2000 due to all effects is 113 quads, equal to 4 years of present-day direct energy use in buildings. In addition to these energy savings, conservation programs and new technologies offer large economic benefits to occupants of residential and commercial buildings. Our results suggest that the present worth of fuel bill reductions and tax rebates is likely to exceed the present worth of extra capital costs by $84 billion. The ratio of benefits to extra costs (benefit/cost ratio) for the NEP and RD & D programs is 3.3. The real interest rate would have to be very much higher than the 8 percent used here before costs could exceed benefits. If an energy tax on primary fuel use could be legislatively connected to an explicit energy conservation tax rebate plan, then the adverse inflationary effects of the tax could be canceled by augmenting personal income. Such a provision should overcome the individual and political opposition to energy taxes and pave the way toward efficient energy conservation.

In addition to these direct benefits, society is likely to enjoy other indirect benefits because of these conservation programs. The net energy savings to society are approximately equal to the direct energy savings. Employment increases as a result of these programs; the net number of new jobs increases over time to 425,000 in 2000.

These significant energy and economic benefits are possible in the buildings sector because many cost-effective conservation options are available. These include simple operational changes such as reduced lighting levels in office buildings on weekends and higher thermostat settings on air-conditioners. At the other end of the spectrum are new technologies for heating, cooling, ventilating, and lighting buildings. In between are applications of known technologies that are more efficient than typical practices, such as the addition of insulation in attics, more careful placement of windows in new structures, and the use of electric heat pumps rather than electric resistance furnaces (*17*).

Although our results show the technical and economic feasibility of energy conservation programs, it is not clear that the estimated energy and dollar savings will be easily realized. These programs require strong public support; dynamic, cost-effective, and timely regulations for the efficiencies of new equipment and structures; continued government and private RD & D to develop and produce improved buildings technologies; and active cooperation from manufacturers and from organizations working in the design, construction, and financing of structures (architects, builders, contractors, suppliers, and bankers). All these "requirements" suggest that it may be difficult to achieve the estimated energy and economic benefits.

Nevertheless, it is clear to us that regulatory, financial incentive, information, and RD & D programs for energy conservation can substantially reduce energy use in buildings and slightly increase overall employment between now and the end of the century. Such programs will also save money, reduce the adverse environmental effects of energy production and use, and provide more time to develop new energy sources.

References and Notes

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13. Actually, only some of the revenues generated by higher fuel prices will be collected by the government. The rest will be collected by energy industries and used to increase exploration, production, nonenergy activities, and stockholder dividends. Our assumption that all the additional revenues are collected by the government and returned to consumers has only a negligible effect on our net energy results (Table 2). Economic benefits to consumers and net increases in employment (Tables 3 and 4) become smaller, but only slightly, as less revenues are returned to consumers. Moreover, the feedback effect that reduced fuel use might have on fuel prices is not considered here.
14. *Buildings and Community Systems Program Approval Document: FY 1978* (Division of Buildings and Community Systems, U.S. Energy Research and Development Administration, Washington, D.C., August 1977); *Consumer Products and Technology Branch Program Plan* (Division of Buildings and Community Systems, Publication ERDA 77-81, U.S. Energy Research and Development Administration, Washington, D.C., September 1977); E. Hirst, *Energy Syst. Policy* **3** (No. 1), 37 (1979).
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16. Research now under way at the University of Illinois is directed toward determining more accurately how consumers are likely to spend this extra income. The project will also treat the effects of higher energy prices on the prices of all goods and services and subsequent shifts in the mix of goods and services chosen by consumers. This second-order effect, which we expect to be small, is ignored in the present analysis.
17. Not all energy conservation measures necessarily yield reductions in net energy use (*15*). For example, adding attic insulation to an already well-insulated home in a mild climate may not be cost-effective from an energy standpoint; that is, the energy required to produce, deliver, and install the insulation might exceed the direct energy savings in space heating.

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