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**An Econometric-Engineering Analysis
of Federal Energy Conservation Programs
in the Commercial Sector**

Jerry R. Jackson

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ENERGY DIVISION

AN ECONOMETRIC-ENGINEERING ANALYSIS OF FEDERAL
ENERGY CONSERVATION PROGRAMS IN THE COMMERCIAL SECTOR

Jerry R. Jackson

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ABSTRACT

This report examines the energy savings and capital cost consequences of four commercial sector conservation programs: thermal performance standards for new buildings, the Federal energy management program (FEMP) for Federal buildings, a grants program for nonprofit institutions, and a tax credit for conservation-related investments. The effects of these programs are evaluated using an econometric-engineering model of commercial energy use. A baseline projection is developed as the first step in the analysis to determine energy use in the absence of conservation programs. Each conservation program is then evaluated independently and in combination with all other programs. We also develop a scenario which removes the effects of market imperfections such as lack of information and institutional barriers. This perfect-market scenario provides an estimate of the maximum conservation potential in the commercial sector.

Our analysis of the four conservation programs indicates a preeminent role for thermal performance standards in reducing commercial energy use over the next quarter century. The grants program and investment tax credit are shown to be effective and economically attractive programs for conserving energy in the immediate future; in the longer run, the effects of these programs are swamped by the thermal performance standards. The FEMP program is a mixture of short- and long-run efforts and consequently shows a more balanced effect on energy use over time. Finally, our perfect market scenario indicates a large conservation potential in the commercial sector. Current programs move commercial energy use about half way from the baseline trend to the minimum energy use represented by the perfect market scenario.

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AN ECONOMETRIC-ENGINEERING ANALYSIS OF FEDERAL ENERGY CONSERVATION PROGRAMS IN THE COMMERCIAL SECTOR

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1. INTRODUCTION AND SUMMARY

This report examines the energy and capital cost impacts of four commercial sector conservation programs: thermal performance standards for new buildings, the Federal energy management program (FEMP) for Federal buildings, a grants program for nonprofit institutions, and a tax credit for conservation-related investments. The effects of these programs are evaluated using an econometric-engineering model of commercial energy use. A baseline energy use projection is developed as the first step in the analysis to determine energy use in the absence of conservation programs. Each conservation program is then evaluated independently and in combination with all other programs. We also develop a commercial energy use scenario which attempts to remove the effects of market imperfections such as lack of information and institutional barriers. This perfect-market scenario provides an estimate of the maximum conservation potential in the commercial sector.

Our definition of the commercial sector includes wholesale and retail trade; finance, insurance, and real estate; services; public administration; and buildings energy use in transportation, communication, electricity, gas, and sanitary services. We exclude from our analysis consumption of energy for feedstock purposes, transportation services, and power generation services connected with the above activities.

Results of the baseline projection and projections incorporating the four conservation programs are presented in Tables 1, 2, and 3. We discuss the assumptions and examine the results of the perfect market scenario in the last section of this report. The tables in this section present energy use, energy savings, capital cost, and fuel expenditure estimates for each of the four conservation programs and for the combined programs. The dominance of the thermal performance standards in terms of energy savings is evident in Tables 1 and 2. Although the energy savings are a direct function of the length of time the program has been in effect because of its impact on only new buildings, energy savings are greater for the standards program by the third year of operation (1982) than the combined savings for the tax credit, grants program, and FEMP which have been implemented from four to nine years by that time. By 1985 savings from the standards are over three times that of combined other programs; over the twenty-two years shown in the tables, cumulative energy savings from implementation of the standards are about eight times those of the other combined programs.

Table 1. Commercial energy use: baseline and Federal programs projections

Description	Energy use (QBtu)						Cumulative (1978-2000)	Average annual growth rate, 1977-2000 (%)
	1978	1980	1982	1985	1990	2000		
Baseline	9.79	10.49	11.28	12.69	15.63	24.69	363.7	4.22
Thermal performance standards	9.79	10.36	10.89	11.84	13.89	20.38	323.3	3.36
Federal energy management program	9.77	10.46	11.23	12.62	15.54	24.52	361.7	4.19
Grants program	9.75	10.37	11.18	12.60	15.57	24.65	362.2	4.22
Investment tax credit	9.77	10.45	11.18	12.62	15.58	24.66	362.6	4.22
Combined programs	9.71	10.15	10.65	11.63	13.75	20.36	319.7	3.31

Table 2. Federal conservation program energy savings

Description	Energy savings (QBTu)						Cumulative (1978-2000)
	1978	1980	1982	1985	1990	2000	
1. Thermal performance standards		0.15	0.39	0.85	1.74	4.31	40.4
2. FEMP	0.02	0.03	0.05	0.07	0.09	0.16	2.0
3. Grants program	0.04	0.12	0.10	0.09	0.06	0.04	1.5
4. Investment tax credit	0.02	0.04	0.10	0.07	0.05	0.03	1.1
5. Combined programs	0.08	0.34	0.63	1.06	1.88	4.33	44.0

Table 3. Capital cost required by Federal conservation programs

Description	Capital costs (10 ⁹ 1975-\$)						Present worth of cumulative expenditures (1978-2000) ^a		
	1978	1980	1982	1985	1990	2000	Capital	Fuel savings	Benefit/cost
1. Thermal performance standards		0.39	0.40	0.41	0.36	0.57	2.88	30.36	10.5
2. FEMP	0.03	0.03	0.03	0.03			0.16	2.04	12.8
3. Grants program	0.79	0.65					1.64	2.01	1.2
4. Investment tax credit	0.06	0.07	0.30				1.11	1.38	1.2
5. Combined programs	0.88	1.14	0.73	0.44	0.36	0.57	5.79	34.77	6.0

^a A real discount rate of 10% is used for all present worth calculations.

The energy saving of thermal performance standards is large primarily because inefficient building practices are expected to change rather slowly in the future and not because of deficiencies in the other programs. In fact, a comparison of the energy savings, discounted value of the energy savings and the discounted cost of the programs indicates that the other programs are economically attractive (last column of Table 3). The other programs also have the advantage that they are easily implemented and can be used to impact commercial energy use more quickly than the standards program. The FEMP, grants, and investment tax credit programs save 0.2 QBTu before the standards are implemented. It is also

interesting to note that the investment tax credit and the grants program are in effect for only five and three years respectively but they impact energy use over much longer periods so that discounted fuel expenditures savings compare very favorably to the relatively large annual costs of the programs. Only the investment tax credit, the grants program, and a portion of the FEMP program impact existing buildings. The total cumulative energy savings of 44 QBtu over the twenty-two years is composed of 41 QBtu savings from new buildings and 3 QBtu from retrofit programs.

The energy use, energy expenditure, and capital cost figures of Tables 1-3 suggest that the commercial sector represents a fertile area for future conservation efforts. As indicated in the final section, gains represented by this National Energy Plan (NEP) program, while impressive, represent a modest portion of potential energy conservation resulting when market imperfections are removed.

The remainder of this report is organized as follows. A brief overview of historical commercial energy use is presented in Section 2. Our econometric-engineering model of commercial energy use is described in the third section. Section 4 presents the baseline projection and Section 5 presents analyses of the four conservation programs listed above. A perfect-market scenario is developed in the final section.

2. COMMERCIAL ENERGY USE: HISTORICAL PERSPECTIVE

Our analysis of energy use and conservation in the commercial sector begins with an examination of historical patterns of energy use. These data establish the importance of conservation initiatives in the commercial sector, provide useful benchmark data to help evaluate conservation programs, and provide some of the detailed background information (relative fuel use importance of subsectors, end uses, and fuels) necessary for conservation program development. The data on commercial energy use presented in this section are developed by adjusting American Gas Association [1], Edison Electric Institute [5], and Bureau of Mines [15] data to be consistent with our definition of the commercial sector. Detailed energy use data by end use and subsector are developed using fuel use estimates, information from detailed engineering studies of energy use in buildings, and estimates of the floor space (as a proxy for the stock of energy-using capital) in each commercial subsector. See [9] for a detailed discussion of our methodology and detailed energy use estimates.

Commercial energy use is presented in Table 4 for selected years from 1950 through 1975. Commercial energy use grew very rapidly over the pre-embargo period as shown in Table 4 (4.7% from 1950 through 1972). The rapid growth is even more pronounced for shorter periods immediately preceding the oil embargo; energy use increased at an annual rate of 6.2% from 1960 through 1972. Energy use in the commercial sector grew at a faster rate than energy use for the nation. Commercial energy consumption represented 9.9% of total energy use in 1950;

Table 4. Commercial energy use: 1950 through 1975
(QBtu)

Year	Electricity ^a	Gas	Oil	Other ^b	Total	Total as percentage of national energy use
1950	0.90	0.40	0.93	1.14	3.37	9.9
1955	1.32	0.61	1.22	0.71	3.86	9.7
1960	1.43	0.99	1.64	0.47	4.53	10.2
1965	2.43	1.22	1.96	0.43	6.04	11.3
1970	3.83	1.77	2.25	0.43	8.28	12.3
1971	4.11	1.98	2.12	0.43	8.64	12.6
1972	4.46	2.05	2.32	0.45	9.28	12.9
1973	4.71	2.03	2.30	0.41	9.45	12.6
1974	4.73	2.01	2.06	0.39	9.19	12.6
1975	5.04	2.05	1.92	0.37	9.38	13.3

^aElectricity is reported in this study as primary energy; that is, losses in generation, transmission, and distribution are included.

^bCoal and liquid natural gases.

with the exception of 1973 and 1974, the share of total energy consumed in the commercial sector steadily increased. In 1975 the commercial sector consumed 13.3% of total U.S. energy use.

The rapid growth and increasing importance of commercial energy use is the result of a demand for services that increased at a faster rate than total output of the economy. A number of changing societal factors contributed to this increasing relative demand. Increases in secondary workers in the labor force created an increase in demand for services formerly provided in the home. The recent growth of fast-food establishments is probably the most outstanding example of this phenomenon. Increasing real family incomes also contributed to the increasing economic importance of the commercial sector. Many of the services of commercial establishments are purchased with increasing frequency (e.g.,

medical, recreational, and lodging services). While the importance of many of these causal influences is expected to diminish in the future (e.g., there is obviously an upper limit for female labor force participation rate), the increasing importance of commercial sector energy use appears likely to continue. Our baseline commercial energy projection presented in Section 4 indicates that by 2000 commercial energy use will nearly equal the residential sector which presently consumes almost 50 percent more energy.*

Evidence from numerous conservation case studies indicates a tremendous conservation potential in the commercial sector; savings of up to 60 percent have been reported [4]. The large conservation potential along with the rapid growth relative to other sectors suggests that this sector should receive more importance than might be generated by the relative share of energy presently used in the commercial sector.

An examination of commercial fuel use reveals several interesting trends (Table 4). "Other" (coal and liquified natural gas) is the only fuel category that shows a continuous downward trend during the 25-year period. Gas and oil use increased through 1972; oil use then declined in 1973, 1974, and 1975; gas use also declined in 1973 and 1974 but increased again in 1975. The electricity series shows a continuous increase over the 25 years shown in Table 4.

Figure 1 presents commercial fuel use in relative terms. Electricity's share of the energy market has doubled from 27% in 1950 to 54% in 1975. The coal and liquid natural gases ("other") market-share dropped precipitously from 34% in 1950 to 4% in 1975. Gas' share of the market increased

* See [8] for comparable residential energy use forecasts.

Fig. 1. Commercial energy use by fuel.

from 12% in 1950 to 22% in 1960 and has held relatively constant since then. Oil captured an increasing portion of the commercial energy market from 1950 to 1960; however, oil's market-share has slowly declined from 36% in 1960 to 21% in 1975.

Table 5 presents commercial energy use disaggregated by building type and Table 6 by fuel/end use combination for 1975. As indicated in Table 5, the major portion (71%) of commercial energy is consumed in four building types: retail-wholesale, office, health care, and education. No other building type (excluding miscellaneous) accounts for more than 7% of energy use. The fuel/end use disaggregation (Table 5) shows that

Table 5. Commercial energy use by building type, 1975

Building type	Energy use ^a (QBtu)	Percentage of total energy use
Retail-wholesale	2.20	23.9
Educational	1.77	19.3
Finance and other office	1.44	15.7
Health	1.08	11.7
Hotel-motel	0.56	6.1
Public administration	0.40	4.3
Warehouse	0.32	3.5
Religious	0.26	2.8
Garages and service stations	0.09	1.0
Other	1.08	11.7
Total	9.20	100.0

^aEnergy use figures do not correspond exactly to the total in Table 4 because of the slightly different estimates of "other" fuel use utilized in our estimation program. Electricity, gas, and oil totals are consistent with estimates in Table 4. See [9] for a detailed discussion of these estimates.

Table 6. Commercial energy use by fuel and end use, 1975
(QBtu)

	Space heating	Cooling	Water heating	Lighting	Other ^a	Total
Electricity	0.33	1.83	0.04	2.09	0.76	5.05
Gas	1.66	0.14	0.08		0.17	2.05
Oil	1.88		0.10			1.98
Other ^b	0.12					0.12
Total	3.99	1.97	0.22	2.09	0.93	9.20

^aOther end uses include cooking and electromechanical uses.

^bOther fuels include coal and liquid natural gases.

the largest end use is space heating, which accounted for 42% of commercial energy use in 1975. Lighting (23%) and cooling (21%) account for nearly identical shares. These two end uses are fueled almost entirely by electricity in contrast to space-heating where electricity represents only 8% of total space-heating fuels. The "other" end use, which represents

largely electromechanical uses, is fueled primarily by electricity (natural gas in the "other" end use represents cooking). Ten percent of commercial energy use is consumed by this "other" end use. In contrast to residential end-use patterns (where water heating represents 14% of total energy use), commercial water heating is an almost insignificant fraction (2%) of total energy use in the sector.

A historical perspective on the importance of different end uses is presented in Fig. 2. In terms of relative importance, end use characteristics of commercial energy demand have changed slowly over the last ten years. Electromechanical, cooling, and lighting energy use gained increasing shares of total energy consumption, while space heating and water heating shares declined.

Fig. 2. Commercial energy use by end use.

3. ECONOMETRIC-ENGINEERING MODEL OF COMMERCIAL ENERGY DEMAND

Since a detailed description of our commercial sector model is available elsewhere [10], we only summarize the model structure below. The ORNL model is similar in its emphasis to the capital-stock energy demand models introduced by Fisher and Kaysen [7]. Our model differs from previous efforts in that prior information (in the form of detailed engineering estimates of energy use by equipment, structure type, fuel type, and age of capital stock) is used to develop a highly disaggregated model of commercial energy demand. The capital-stock modeling approach explicitly recognizes that energy is consumed by capital goods to provide desired services. For instance, electricity is combined with an electric heat pump to produce heating services. Since energy is consumed only in combination with such capital goods, the problem of estimating energy use in the short run (period of time where the stock of capital goods is fixed) requires only estimation of the equipment stock and the utilization rate (intensity with which the stock is used). Over a longer period of time, changes in the stock of capital goods and changes in the energy-using characteristics of capital goods are also considered.

The short-run demand for energy for a given building type can be represented as:

$$Q_{i,k} = U(P)_{i,k} \cdot S_{i,k} \quad (1)$$

where

Q = energy use,

i = fuel type (electricity, gas, oil, other)

k = end use (space heating, cooling, lighting, water heating, other),

$U(P)$ = utilization rate,

P = price of services provided by equipment, and

S = stock of equipment, measured in terms of potential energy use.

As an example, consider demand for electric space heating.

Equation (1) states that the quantity of electricity demanded for space heating equals the maximum potential demand of the existing stock of electric space heating equipment times a utilization rate that represents actual use relative to potential use. The utilization rate is a function of the price of providing space heating services; the price of space heating services depends both on the efficiency of the existing heating system equipment stock and the price of electricity. Because the stock of equipment and efficiency characteristics of the stock are fixed in the short run, the demand for energy fluctuates in the short-run only in response to fuel price changes.

Our characterization of short-run energy demand is refined further by noting that end-use capacity requirements are usually determined on the basis of floor space served; therefore, system capacity (in terms of potential energy use) can be measured by floor space.

For a given building type, the stock of floor space served by fuel i and end use k ($S_{i,k}$) can be related to the total stock of floor space as:

$$S_{i,k} = e_{i,k} \cdot a_{i,k} \cdot F \quad (2)$$

where e is the potential energy use required to service each square foot of floor space and $a_{i,k}$ represents the fraction of total floor space (F) served by fuel i and end use k . To allow for variation in energy efficiency of structures and equipment of different vintage, we disaggregate the stock of floor space by age:

$$F^T = \sum_{t=t_0}^T A^t \cdot d(T-t) \quad (3)$$

where T is the reference time (i.e., F^T is floor space standing in year T), A^t is additions to the stock of floor space in year t , and d is a removal rate. The time superscript, t , begins at t_0 which is the year of construction of the oldest additions still standing in the stock.

Equation (1) may now be rewritten as:

$$Q_{i,k}^T = \sum_{t=t_0}^T U(P_T)_{i,k}^t \cdot e_{i,k}^t \cdot a_{i,k}^t \cdot A^t \cdot d(T-t) \quad (4)$$

Time superscripts have been added to all factors so that utilization rate (U), unit energy requirements (e), and floor space fraction (a) now relate to each year's stock additions. As before, Equation (4) relates to a specific building type.

Measurability problems with the utilization rate (U) and potential energy use (e) can be circumvented by multiplying e and dividing U by the utilization rate for an arbitrary base year, 1970. Utilization can now be measured relative to that observed in 1970, and the energy use requirement can be determined using the 1970 utilization rate.

The short-run determination of demand can be described using the demand for electric space heating in office buildings in 1970 as an example. Energy demand arising from t -vintage capital stock is determined by multiplying t -vintage office building floorspace still standing in 1970 ($A^t \cdot d(1970-t)$) times a fraction which represents the portion of that floor space heated electrically ($a_{i,k}^t$), times the measured 1970 energy requirements of office building electric space heating systems in terms of Btu/ft², times the utilization rate which in this case is 1.0 (because our reference year is 1970 and our estimation year is also 1970). Summing these demands over all building ages represented in the capital stock yields total electricity used in office buildings for space heating in 1970.

Fixity of the capital stock allows energy use, Q , to change in the short-run only in response to changes in fuel price. In the long-run, of course, the opportunity for adjusting energy consumption in response to fuel price changes and other influences is considerably greater. Changes occur in each of the factors in Equation (4) from one year to the next. These changes are summarized below for each factor.

1. $\underline{U(P_T)_{i,k}^t}$. The relative utilization rate changes in response to changes in the price of end-use services. For that portion of the capital stock served by new equipment installed in the current year of the simulation (e.g., new buildings and existing buildings where end-use equipment is being replaced), the utilization rate change is a function of both changes in fuel prices and changes in efficiency of new equipment. Changes in efficiency partly offset the influence of a fuel price increase. For example, an increase in electricity price

will reduce utilization of electric space-heating equipment but replacement of resistance heating with electric heat pumps will tend to increase equipment utilization because it costs less to maintain more desirable temperatures.

For buildings characterized by capital equipment installed in previous years only changes in the price of fuel can influence changes in the utilization rate.

2. $\underline{e}_{i,k}^t$. The unit energy requirement of specific fuel-end use services can change from year to year for new systems. These changes arise because of a capital-energy substitution in the production of end use services. That is, only by substituting capital (e.g., insulation on air ducts, heat pump for resistance heat) for energy can space heating systems produce the same level of services and use less energy. This, of course, is exactly what is expected when the price of energy increases relative to the price of capital. This substitution will occur both in new buildings and in buildings where end-use systems are being replaced.

3. $\underline{a}_{i,k}^t$. The fraction of floor space served by each fuel will change for new buildings and for buildings where new systems are being installed. This fuel choice depends on relative life cycle costs of fuel-specific systems, and possibly the cost encountered in converting to another fuel.

4. $\underline{A}^t \cdot d(T-t)$. Future levels of floor space additions are determined primarily by the future demand for commercial services. As time passes, the portion of original t -vintage buildings still standing decreases because of deterioration of the stock and shifting population

patterns. Additions put in place in year T are determined as the difference between the stock demand and stock (put in place before year T) still standing in year T.

Since model determination of each of the above factors is detailed in a previous report [10], we simply indicate here the general approach employed to empirically determine future values of the factors. The utilization rate is 1 for 1970 and is determined for succeeding years by using fuel-specific short-run price elasticities. Unit energy requirements for fuel/end uses/building combinations are determined for 1970 by disaggregating fuel use estimates by floor space estimates (detailed by building type) and from engineering information on relative energy use across building types [9]. Price induced changes in energy-use requirements are derived from efficiency elasticities (which provide results consistent with estimated long-run fuel price elasticities) and from engineering process analysis which describes the opportunities for capital-energy substitution in heating, ventilating and air conditioning (HVAC) equipment.

The floor space fraction (α) is determined using econometrically-estimated fuel split equations. Additions to the stock of floor space are determined as the difference between stock demands and the sum of existing additions. The removal rate is a logistic function which represents a low removal in the first fifteen or twenty years and an accelerating removal until about 80 years. Average building lifetime is 45 years.

4. BASELINE PROJECTION

In this section we develop a baseline projection of commercial energy use to the year 2000. This baseline serves as a reference for evaluation of Federal conservation programs.

The values of exogenous variables supplied to the model are given in Table 7. Population estimates are from the Bureau of Census series II projection [13]. School enrollments are estimated by assuming that the same fraction of total school-age children (92.4% in 1975) will attend elementary and secondary schools in the future. Our estimate of school-age children was taken from the series II projection. Real per capita disposable personal income is assumed to grow at 2.1 percent annually. This growth rate is the same as actual growth over the last twenty five years [14]. Fuel prices are from the Department of Energy [3].

Table 7. Values of exogenous variables for baseline simulation

	1970	1975	1980	1985	1990	2000
Fuel prices, 1975-\$/10 ⁶ Btu						
Electricity	7.93	9.25	9.99	10.78	11.18	11.97
Gas	1.03	1.31	1.92	2.53	2.77	3.11
Oil	1.10	2.79	2.95	3.10	3.31	3.73
Other	1.19	1.75	2.61	3.36	3.58	4.03
Per capita disposable personal income, 1975-\$	4,660	5,070	5,640	6,270	7,620	8,620
Population, 10 ⁶	203.8	213.1	222.8	234.1	245.1	262.5
School enrollment, 10 ⁶	51.6	49.4	46.0	45.2	47.7	52.2

Figure 3 shows our baseline projection. Although total energy use grows at an annual rate of 4.2% over the 1978 to 2000 period, total

Fig. 3. Baseline commercial energy use projection.

energy use in 2000 is about 34% less than would have been the case if the historical growth rate of 6.2% (1960-1972) had continued.

This increased fuel economy is reflected in Table 8 by a measure of energy intensity over the thirty year period. Total commercial energy use is in the first row of Table 8 and total floor space is in the second row; a measure of energy intensity is developed by dividing energy use by floor space. Energy requirements drop from 347,000 Btu/ft² in 1970 to 310,000 Btu/ft² in 2000. The more efficient use of energy is disguised somewhat in this aggregate energy intensity measure because increases in

Table 8. Measures of commercial sector energy intensity

	1970	1975	1980	1985	1990	2000
Commercial energy use, QBTu	8.3	9.4	10.5	12.7	15.6	24.7
Commercial floor space, 10^9 ft ²	23.9	27.4	32.3	39.6	49.8	79.6
Aggregate energy intensity, 10^3 Btu/ft ²	347	343	325	321	313	310
Space heating energy intensity, 10^3 Btu/ft ²	164	141	132	124	117	109

air conditioning penetration and increased electromechanical uses offset the more efficient production of all end use services. The third row of Table 8 shows energy intensity for space heating alone. The impact of higher fuel prices is quite evident in this end use; energy requirements drop by 34% from 164,000 Btu/ft² to 109,000 Btu/ft² over the thirty years.

Fuel choice trends are illustrated in Figures 3 and 4. Electricity increases its share of the market from 46% in 1970 to 68% in 2000. Both gas and oil shares decline from 22 and 27% to 16% over the thirty-year simulation period. "Other" fuel use declines in relative terms over the period so that coal and liquified natural gases represent less than 1% of commercial energy use in the year 2000.

Energy use by end use is given in Fig. 5. Space heating's share of total energy declines continuously over the simulation period; the relative decline in space heating results in large part from the considerable improvement in space-heating efficiency that occurs in new and existing buildings. The adjustment in space heating also tends to be greater because price increases are greatest for fossil fuels, which are used primarily for space heating. This situation causes some switching

Fig. 4. Baseline projection of energy use by fuel.

Fig. 5. Baseline projection of energy use by end use.

to electricity as a space-heating fuel and also results in greater investment in energy-efficient space-heating systems. The fraction of total energy serving cooling and "other" end uses increases over time. Increasing penetration of air-conditioning systems accounts for a portion of the initial increase in the cooling end-use shares. Cooling shares also increase as the greater conservation potential in space heating is realized. The large increase in the "other" end use results from increasing use of electromechanical devices in nearly all sectors. Lighting's share of the total declines slightly. The smaller adjustment in lighting results from the relatively modest increase in the price of electricity.

5. FEDERAL CONSERVATION PROGRAMS

In this section we evaluate, relative to the baseline, the energy savings and capital cost requirements for each of the four Federal programs and for all programs combined. Our evaluation is based in large part on preliminary results from engineering process analysis of prototype buildings which are included in the model to represent capital-energy substitution possibilities. Our use of these relationships can best be illustrated with Fig. 6 [16]. The curves in Fig. 6 represent efficiency-capital cost tradeoffs that exist in the production of heating and cooling (HVAC) services. Points along the curve represent combinations of efficiency and equipment cost for office buildings whose structure conforms to ASHRAE 90-75 standards.*

Several kinds of questions can be addressed using relationships similar to that shown in Fig. 6. For instance, given some incremental investment in heating and cooling equipment (horizontal axis) a corresponding incremental improvement in efficiency (vertical axis) results. Multiplying the incremental cost by floor space and the efficiency factor by baseline energy use provides information on capital cost and fuel savings accompanying the incremental investment. This approach is used to evaluate impacts of the grants program. To evaluate effects of the 10% investment tax credit, we first use an estimated discount rate and fuel prices to determine the efficiency-cost combination that will

*The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) developed a voluntary standard for energy conservation in buildings. See [2] for the standards documentation and [6] for an evaluation of the energy savings and cost impacts of the standards.

Fig. 6. Space heating and air conditioning energy use vs capital cost for typical office building with dual duct system.

be chosen by firms in absence of the credit; then the curve is rotated to the left to represent the 10% reduction in capital cost observed by firms and the same calculation is done. To evaluate the cost of predetermined efficiency increases for thermal performance standards and FEMP, the target increases in efficiency can be used to calculate the increase in capital cost.

A detailed description of the engineering process analysis that is used in our conservation program evaluation will be completed and available soon as an ORNL report [16].

Thermal Performance Standards

The Energy Conservation and Production Act [12] requires DOE and HUD to develop thermal performance standards for new structures; these standards are to be implemented by 1980 [11]. Although the standards have not been completed yet, conversations with DOE and HUD personnel suggest that the standards will be similar to and about 10 percent more stringent than the ASHRAE 90-75 standards [3]. We used A. D. Little's assessment of the ASHRAE standards to estimate efficiency improvements for four building types: retail, office, educational, and hotel-motel. Efficiency impacts of the standards, as determined in the A. D. Little study^{*} using engineering process models, are increased by 10%. The first three buildings types shown in Table 9 were modeled individually; we assume that efficiency increases in the low-rise apartment building analyzed by A. D. Little are similar to our hotel-motel sector. Efficiency increases in hospitals are derived from our own process analysis work on a prototype hospital. The percentage improvements in efficiency of new buildings relative to our 1970 base year are indicated in Table 9. These improvements in efficiency are used to develop constraints in our simulation model so that efficiency improvements for new buildings must at least equal the efficiency improvements shown in Table 9.

The energy savings of the performance standards are indicated in Table 10. The large savings reflect the fact that commercial buildings are likely to be considerably less efficient in the absence of the

^{*}Engineering relationships and detailed building characteristics (construction material, geometry of building, insulation, HVAC system characteristics, etc.) are used in process models to determine energy use requirements for detailed prototype buildings.

Table 9. Efficiency improvements and incremental costs of thermal performance standards

Building type	Efficiency increases relative to 1970, %				Cost increases, 1975-\$/ft ²
	Heat	Cool	Water heating	Lighting	
Retail	58	12	34	35	0.37
Office	80	30	33	32	-0.17
Educational	67	48	33	33	-0.01
Hotel-motel	52	63	32	22	-0.14
Health	79	31	33	32	0.17
Other	61	44	33	28	0.29

standards. It is interesting to note, however, that savings from the performance standards are only about 1/3 what they would have been if the base case contained no voluntary efficiency improvements. That is, voluntary efficiency improvements in the baseline (in response to rising fuel prices) move commercial establishments about two-thirds of the way to the efficiencies dictated by the performance standards.

Our analysis of the standards indicates that the capital cost impacts of the program are small relative to fuel expenditure savings (Table 10). Capital cost estimates are based on A. D. Little's ASHRAE estimates and on an incremental capital cost resulting from the 10% efficiency improvement required by the performance standards. As indicated above, the incremental capital cost is derived from efficiency-capital cost tradeoff curves similar to that given in Fig. 6. The ASHRAE costs for the first four building types (Table 9) are taken directly from the A. D. Little study. Our preliminary engineering analysis was used to estimate the hospital savings given in Table 9. To extend the

Table 10. Energy savings and capital cost impacts of Federal conservation programs

Program	Annual energy savings (QBtu)					Annual capital costs (10 ⁹ 1975-\$)					Present worth of cumulative expenditure, 1978-2000 (10 ⁹ 1975-\$)	
	1978	1980	1982	1990	2000	1978	1980	1982	1990	2000	Fuels	Capital
1. Thermal performance standards		0.15	0.39	1.74	4.31		0.39	0.40	0.36	0.57	30.36	2.88
2. FEMP	0.02	0.03	0.05	0.09	0.16	0.03	0.03	0.03			2.04	0.16
3. Grants program	0.04	0.12	0.10	0.06	0.04	0.79	0.65				2.01	1.64
4. Investment tax credit	0.02	0.04	0.10	0.05	0.03	0.06	0.07	0.30			1.38	1.11
5. Combined programs	0.08	0.34	0.63	1.88	4.33	0.88	1.14	0.73	0.36	0.57	34.77	5.79

ASHRAE cost estimates to the new standards, we assume that most efficiency increases will be derived from the HVAC system. This assumption is supported by our engineering process analysis of office buildings and hospitals where a large number of structural and systems improvements were evaluated for prototype buildings. This assumption allows us to determine incremental costs from the efficiency-cost relationships. Total performance standards costs estimates are shown in Table 10.

Federal Energy Management Program

We use the model only indirectly to evaluate the FEMP program. The FEMP targets for energy savings by 1985 are 20%/ft² for existing buildings and 45%/ft² for new buildings relative to 1975 energy use [1]. Information on energy use/ft² does not presently exist for many agencies. In addition, uncertainties over how much of this savings would be derived from the buildings portion of federal energy use as opposed to process energy use makes it difficult to specify efficiency increases with much certainty. Therefore, we decided to evaluate the effects of the FEMP program by using model estimates of energy use per ft² for the Federal sector in 1975 and to determine total energy use given estimated Federal buildings floor area in 1985 and the target efficiency increases for new and old buildings. The difference between calculated energy use and baseline energy use in the Federal sector reflects the savings due to FEMP. These savings are shown in Table 10.

Capital cost increases are based on our analysis of office buildings and hospitals in the building standards analysis. We do not include measures such as reduced lighting levels and reduced ventilation levels

since these changes are likely to have taken place by 1975 under the FEMP program. FEMP capital cost figures in Table 10 reflect retrofit activities; the economically attractive cost figures for new office buildings (Table 9) cancel the increased cost of new hospitals so that the new buildings portion of FEMP (i.e., non-retrofit) incur no additional cost.

Grants Program

The proposed grants program is a three year Federal program of matching grants to states for energy conservation improvements to schools and hospitals [11]. We assume that Federal grants of \$300 million/year will begin in 1978. Our engineering relationships between efficiency and capital cost are used to estimate efficiency increases. By apportioning the total \$1.8 billion over the three-year period and over the eligible stock we estimate an increase in efficiency arising from the additional capital expenditure. Funds are also apportioned between hospitals and schools on the basis of energy use/ft² for each building type. The resulting incremental investments are \$0.34 and \$0.67 per square foot for schools and hospitals, respectively, based on the assumption that half of the eligible stock participates and that one-third of the stock is affected each of the three years.

As indicated in Table 10, capital costs of the program total \$1.8 billion. Changing assumptions on fraction of the stock participating in the program changed results only slightly. As the \$1.8 billion is channeled to smaller portions of the stock the total savings decreases. This is a result of the diminishing returns to investment of capital in

the HVAC production process; e.g., when investments are doubled, energy savings are less than doubled. This relationship follows from the concavity of the efficiency-cost curve of Fig. 6.

Investment Tax Credit

The cost of eligible conservation investments will be reduced for commercial establishments by a proposed investment tax credit available from 1978 through 1982 [11]. The existence of the tax credit is assumed to influence efficiencies of systems in two ways. We assume that planned investments will still be initiated; however, the cost of conservation options is viewed by firms as being reduced by 10 percent. This results in an increased level of investment by commercial establishments. We use the engineering curves (Fig. 6) to estimate the increase in efficiency that can be expected to follow from this decline in capital cost.

In addition to this direct effect, towards the end of the program, firms who had originally planned investments after the 1982 cutoff date of the tax credit may find it economically advantageous to move their investment schedule forward because of the reduction in cost. Given HVAC average lifetimes of about 18 years and an amortized yearly cost of about 5 percent, we would expect firms to move investment schedules forward by about two years even if existing components must be scrapped. We capture this effect in the model by assuming that planned investments in 1983 and 1984 are undertaken in 1982. The energy savings and resulting capital cost increases as determined in our engineering relationship are indicated in Table 10. The capital cost of this program represents the cost of the incremental investment induced by the tax credit.

Combined Programs

The effects of the standards, the grants program, and the investment tax credit are additive; that is, these programs all impact different portions of the commercial sector. Since efficiency increases mandated for new federal buildings will be met under the thermal performance standards, only the efficiency improvements resulting from retrofit under the FEMP program can be added to the effects of the three programs listed above to derive the combined effects of all programs in the National Energy Plan.

The standards have by far the largest energy savings. The program circumvents many institutional barriers such as reluctance of architectural and engineering firms to use new designs, costly information concerning efficient building design practices, and other institutional constraints.

The four programs show distinctly different time profiles. The savings of the investment tax credit and the grants program are near-term in nature since many of the improvements would have been undertaken in following years in the absence of the programs. By the year 2000 the energy savings directly attributable to these programs is less than half of the savings in peak years. The savings of the thermal performance standards and the FEMP program continue to increase over time. Savings grow rapidly because of the continued rapid growth of commercial sector floor space and because this floor space is built according to the new buildings standards specifications. Discounted fuel expenditure savings and discounted capital costs allow us to make rough comparisons of direct costs and benefits of these programs. The benefit-cost ratio

determined from the direct expenditure impacts of the programs (i.e., ignoring administrative and regulatory costs) are 11, 13, 1.2, and 1.2 for the standards, FEMP, grants, and tax credits programs respectively. (The benefit-cost ratio for the FEMP program is reduced to 4.8 if fuel expenditure savings resulting from efficiency improvements for new buildings after 1980 are all allocated to the thermal performance standards.) The ratio for combined programs is 6.0.

The implications of these benefit-cost ratios are clear. Each of the programs provides energy savings and savings in fuel expenditures. Even the investment tax credit and the grants program, which represent the largest expenditure by the federal government and are relatively short-lived programs, have benefit-cost ratios greater than 1.0; these near-term programs are more attractive than these ratios indicate because of their immediate impact on commercial energy use. The combined National Energy Plan programs offer a savings of 44 QBTu over the twenty-two years considered in this analysis at a cost of \$5.8 billion. The increased cost associated with these programs is more than offset by the savings in fuel expenditures of \$34.8 billion, with a resulting net benefit of \$29.0 billion to commercial establishments.

6. PERFECT MARKET SCENARIO

A perfect market scenario is developed with results from our engineering process analysis of total buildings energy use and on the basis of our efficiency-capital cost curves. Our process analysis indicates that, on average, total energy saving of about 40% can be achieved through operational changes that require little or no cost. For instance, our analysis of existing office buildings indicates an energy saving of 49% when equipment is shut off during unoccupied times and lighting is reduced. We feel that resistance to these low-cost conservation changes is primarily a result of lack of information, habit, and institutional barriers such as leasing arrangements that shield renters from energy costs. We impose a decrease in the behavioral energy use component of 40% to capture removal of these effects.

Uncertainty over future fuel prices, possibilities of future federal programs to assist in financing conservation investments, and costly information relating to conservation improvements all contribute to choice of less efficient equipment that might be chosen in a perfectly competitive market situation. We remove these effects by using the efficiency-cost tradeoff curve, fuel prices, and a 10% discount rate^{*} to determine optimal efficiency choice for new and refurnished systems.

Energy use, energy savings, and capital cost impacts of the perfect market scenario are presented in Table 11. Energy use in Table 11 represents a reasonable lower bound for future commercial energy use

^{*}We feel that a 10% discount rate reflects a reasonable investment criterion for commercial establishments in this perfect market scenario.

Table 11. Energy use, savings, capital cost, and fuel savings for the perfect market scenario

	Year						Cumulative (1978-2000)
	1978	1980	1982	1985	1990	2000	
Energy use, QBtu	5.90	6.35	6.88	7.75	9.44	15.14	222.2
Savings, QBtu	3.81	4.01	4.24	4.68	5.64	8.89	134.6
Capital cost increase relative to baseline, 10 ⁹ 1975-\$	0.56	0.97	1.07	1.25	1.61	2.00	14.0 ^a
Fuel savings, 10 ⁹ 1975-\$	8.70	9.94	11.28	13.64	18.73	27.6	134.9 ^a
Savings from NEP programs as a percent of perfect market savings	2	8	15	23	33	49	

^aCumulative figures for capital cost and fuel savings are present worth figures calculated using a 10% discount factor.

given our assumptions on income and population growth and future prices. Investment in more energy efficient equipment is optimal in the sense that investment is made up to the point where discounted fuel saving is exactly equal to the change in capital cost for small efficiency changes. The last row in Table 11 relates combined Federal program savings to potential savings. These figures indicate that about 49% of commercial sector conservation potential is captured by the Federal programs by the year 2000.

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