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Prepared for the U.S. Department of Energy
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ABSTRACT

U.S. trends in energy use and conservation since 1972 are analyzed in this report. That year represents the last year prior to significant energy price shocks. In 1986, an estimated 31.8 quads has been saved in the U.S. compared with what consumption would have been if the energy use per dollar of GNP had continued on the same trend after 1972 as in the period 1960-1972. Actual U.S. energy consumption in 1986 was 74.3 quads. It is clear that energy conservation is persistent and conservation investments continue to pay off even after initial energy price shocks have subsided. Separate analyses have been conducted for the major end-use sectors (residential, commercial, industrial, and transportation). Savings have been estimated in each sector, and the factors contributing to sectoral savings identified.

SUMMARY

This report on U.S. energy use and conservation trends is the culmination of work by the Pacific Northwest Laboratory (PNL) in fiscal years 1987 and 1988. Support and direction for the project has been provided by the Office of Conservation and the Office of Policy Integration, U.S. Department of Energy (DOE). The broad objective of the effort is to understand U.S. trends in energy use and conservation since 1972. That year represents the last year prior to significant energy price shocks in this country.

Earlier efforts by PNL and DOE Headquarters to estimate aggregate energy conservation savings have been updated in this report. Particular attention has been paid to the most recent years for which data is available (typically through 1986). It is clear that the significant gains achieved in energy efficiency through the early 1980s are persistent. Energy conservation continues even with falling energy prices. The year 1986 shows a savings of 31.8 quadrillion Btu (quad) for the U.S. compared with what energy consumption would have been if the energy use per dollar of gross national product (GNP) had continued on the same trend after 1972 as in the period 1960-1972. Had the 1960-1972 rate of growth in GNP also continued at its high level after 1972, aggregate energy consumption in 1986 would have been 51.6 quads greater than actually experienced.

BACKGROUND AND APPROACH

Primary energy consumption in the U.S totaled 74.3 quads in 1986, down from a high of 78.9 quads in 1979. This consumption level is much lower than that projected in the early 1970s when both GNP (in real terms) and energy use per dollar of GNP were still growing steadily. The first analytic objective of this effort is to separately estimate 1) the portion of "energy savings"[a] due to reduced economic growth per se, and 2) the portion due largely to improvements in energy efficiency. The second analytic objective is to isolate the factors contributing to these energy efficiency improvements

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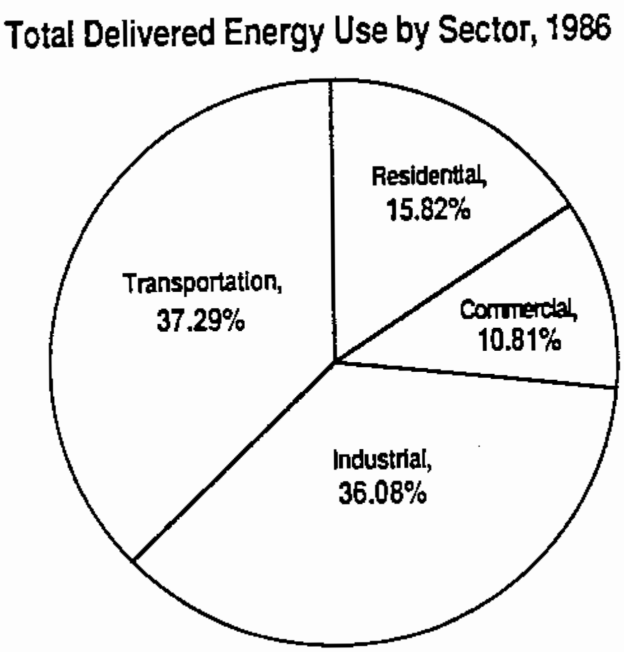
(a) "Energy savings" is used in this report to mean the difference between actual energy consumption and projected levels based on earlier trends. Detailed definitions are given in the body of the report.

in each economic sector, and to estimate the contribution of the factors to the energy savings.

Energy use can be usefully examined by looking at the four major sectors of the economy: residential, commercial, industrial, and transportation. The figure below illustrates each sector's contribution to energy use, in terms of both primary energy and energy delivered to the end-user. The industrial sector is the largest energy user, followed by transportation, residential, and then commercial.



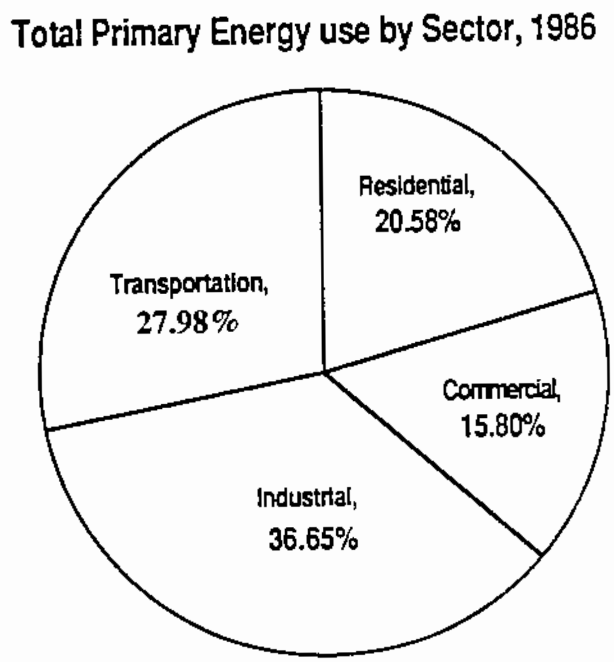


FIGURE 1. U.S. Energy Use in 1986

Two types of estimates are made in this report. This first type provides measures of aggregate energy conservation or "savings" for the U.S. as a whole and by sector. This is done based on primary energy data (which includes electricity losses in transmission). The second type of estimate associates energy savings with contributing factors for each sector. This estimate is provided based on data for energy as delivered to the end-user, which is where the bulk of the conservation decisions and actions are formed.

For the aggregate savings estimates, total (primary) energy use is defined as the product of energy use per unit of economic activity, and the economic activity level. For the U.S. as a whole, the activity level is measured by the GNP, and the energy use intensity is measured in thousand BTUs per dollar of GNP. This way of looking at actual energy use shows "what was". To estimate the amount of conservation which has taken place, one needs to know what energy use "would have been". There are many methods for estimating this, and the results will vary depending on which methodology is used. For U.S. energy consumption, the main alternative measures presented in this report are:

- Trended energy use intensity x trended GNP (based on the average annual rate of change in EUI and GNP over the 1960-1972 period).
  This measure--labeled "E" in the report--intuitively represents what energy use would have been, had overall trends in energy use intensity and economic activity continued.

- Trended energy use intensity x actual GNP.
  This measure--labeled "B" in the report--represents what energy use would have been had trends in energy use intensity had continued, in light of the actual changes experienced in the economy.

- Constant energy use intensity (1972 level) x actual GNP.
  This measure--labeled "C" in the report--represents what energy use would have been had the 1972 level for energy use intensity held constant in later years, given the actual changes experienced in the economy.

As indicated, each of these measures is a viable way of looking at what energy use "would have been", under certain conditions. Because each is appropriate under certain conditions and each will yield different estimates, these (and other measures) are applied and reported in the study. These methods are applied to each of the sectors individually; the only difference among sectors is the choice of the economic activity measure used. For the U.S. economy the measure employed is U.S. gross national product. The sectoral measures are residential--number of households; commercial--building square footage; industrial--gross national product originating in the agriculture, mining, construction, and manufacturing industries (adjusted for inflation); and transportation--passenger/freight ton-miles.

UNITED STATES

With the continuation of trends in both energy use intensity and GNP growth after 1972 at the 1960-1972 rates, U.S. energy use would have reached 125.8 quads by 1986. Given actual changes in GNP since 1972, a continuation of the earlier trend in energy use intensity would have led to U.S. primary energy consumption of 106.1 quads in 1986. That level would be 31.8 quads greater than actual 1986 U.S. consumption (74.3 quads). Thus, even though energy use is significantly reduced over what it would have been had the economic growth of the 1960s continued, a considerable amount of conservation is due primarily to the decline in the intensity of energy use. It appears that in the aggregate, conservation investments and behaviors continue to pay off. Greater savings are seen in 1986 than in 1982, indicating that the energy price declines occurring late in this period have not taken back these gains.

RESIDENTIAL SECTOR

The growth in the primary energy use per household, if continued at the 1960-1972 rate, would have led to residential consumption of nearly 28.7 quads in 1986 (given the actual changes experienced in numbers of households). The compares with actual 1986 consumption of 15.4 quads. Roughly 13 quads has been saved, according to this measure. When savings are calculated based on holding the 1972 energy use intensity constant, 1986 energy savings are 3.9 quads. These savings have been achieved in the context of increasing (actual) electricity use in the residential sector, with declines since 1972 in the market shares of natural gas and petroleum.

Residential sector savings have been allocated to various contributing components in the sector based on modeling and analysis of delivered energy. (No satisfactory fuel-specific allocations of savings by fuel were obtained, however.) With about 4 quads of savings in 1986, the largest components are space heating behavior (such as thermostat set-backs) and appliance use/efficiency, each estimated at 1.0 quad of the 4 quads savings. These are closely followed by changes in shell efficiency due to structural improvements (retrofits) of existing homes, with about 0.8 quad savings. Improvements in the aggregate shell efficiency due to the building of new energy-efficient homes accounts for an additional 0.4 quad of savings in 1986. Migration, changes in wood use, and changes in the number of persons per household each account for a further 0.3 quad of 1986 savings.

Conservation savings in the residential sector have persisted over the 1982-1986 period, indicating that conservation investments and conserving behavior may reflect long-term permanent trends. Savings due to conserving space heating behavior and housing retrofits have become relatively less dominant since 1982, but they--along with savings in appliances--continue to be the leading factors explaining aggregate savings in the residential sector.

COMMERCIAL

If the growth in floor space had maintained its 1960-1972 trend, by 1986 one quad more energy would have been consumed in the commercial sector than the actual 11.7 quads. The key factor is the break from the sharply rising trend in energy intensity of the pre-embargo period. Had the 1960-1972 trend in energy use intensity persisted, 1986 consumption would have been over seven quads higher than actually observed.

Given a constant energy use intensity for fossil fuels based on the 1972 level, an additional 2.2 quads of fossil fuels would have been used by the commercial sector in 1986. In that year the largest savings factors are building envelope retrofits and the impact of new, more efficient, buildings. Envelope retrofits are estimated to account for about 7 percent of the observed savings; new buildings account for about 8.5 percent. Roughly 1.5 quads of fossil fuel savings may be attributed to non-envelope retrofits (such as HVAC retrofits).

Electricity "savings" are negative since electricity intensity of the building stock, as compared to 1972, actually increased over the entire time period. Had electricity fuel intensity remained at its 1972 value, 1986 consumption would have been over half a quad lower in 1986. The higher electricity intensities in new buildings, prompted in large degree by the more extensive use of central air conditioning systems and heat pumps, increased consumption by nearly a tenth of a quad in 1986. (This is measured using a constant energy use intensity at the 1972 level, along with actual changes in floorspace.) Both the regional shift and the change in the mix of building types contributed to overall higher electricity use. There also appears to be increased electricity use in existing buildings, related to additional office equipment, computer loads, and increased mechanization.

From 1982 to 1986, conservation activity with respect to fossil fuels has continued in spite of flat or falling fuel prices. Nearly 0.7 quad was saved during this four-year period, nearly as much as the preceding four years. The increase in electricity intensity has accelerated in that period.

INDUSTRIAL

Actual industrial sector primary energy use in 1986 was 26.5 quads. If GNP originating in the industrial sector had followed earlier trends, and if energy intensity had remained at 1972 levels, primary energy use in the industrial sector would have been over 38 quads in 1986. Given the actual changes in industrial sector GNP, a constant energy intensity (at the 1972 level) would have resulted in the use of an additional 12 quads of energy to produce 1986 industrial sector output.

Three factors were used to help explain energy conservation savings due to the decline in energy use intensity. A market impact factor was analyzed to reflect conservation actions induced by changes in fuel costs and the cost of fuel-using equipment, as well as indirect effects such as the speed of adjustment to fuel price changes. An index of the compositional changes in the industrial sector captures the effect of industries with different energy-use profiles growing at differential rates. The rate of capacity utilization was also analyzed to account for energy end uses that may not change proportionately with the level of output.

By 1986, the difference between energy use at 1972 intensity levels and actual energy use is almost entirely the first two factors: the market impacts resulting from firms being faced with higher energy prices and the effect of a changing mix of industries (i.e., composition). The third factor, capacity utilization, is particularly important during the two major business recessions during the period, in 1975 and 1982.

TRANSPORTATION

While total transportation energy use grew at an average annual rate of 1.4 percent between 1972 and 1986, total transportation economic activity grew annually at 3.3 percent.[a] The 1982-1986 time period, in particular, showed much larger annual increases in energy use and economic activity than in the 1972-1982 time period, nearly doubling the rate of decrease in the energy use intensity from 1.1 to 2.2 percent annually. Changes in activity and energy use intensity since 1972 (based on 1960-1972 trends in passenger-freight ton-miles and energy use intensity) show 4.7 quads of energy conservation savings. Nearly all of this savings is due to improvements in energy efficiency. Given actual activity, a constant 1972 energy use intensity would have led to energy use 4.5 quads higher than that actually experienced.

For light duty vehicles, energy savings that occurred due to efficiency improvements since 1972 are about 2.5 quads in 1986. The positive savings can be attributed to technological improvements and reductions in vehicle size. The shifts from rural to urban driving and from automobiles to light duty trucks increased energy consumption and displaced 14 percent of the savings that occurred in the subsector.

In commercial airlines, several different factors account for energy savings. The major factors are the shift in the mix of aircraft being used, and related seating capacity. Technological and operational improvements, as well as improved load factors, also contributed to the savings.

CONCLUSIONS

Energy conservation is persistent and conservation investments continue to pay off even after initial energy price shocks have subsided. In each of the sectors significant savings have occurred. The relative contribution to savings in 1986, when measured based on a continuation of 1960-1972 trends in energy use intensity along with actual economic activity, are shown in the chart below:

(a) Rail and water-borne transportation energy have been excluded from the analysis.

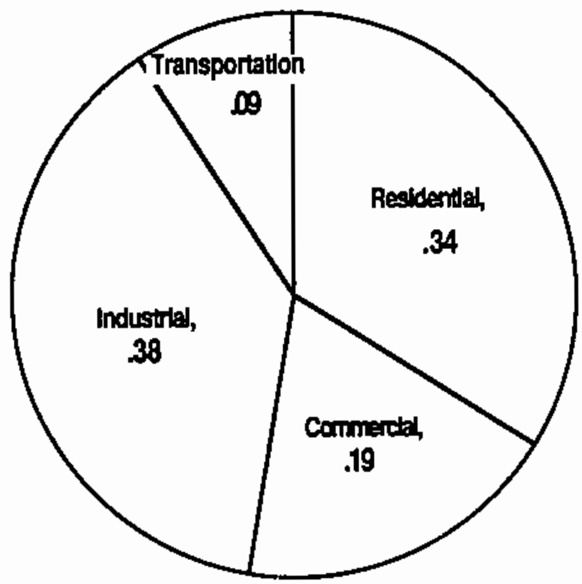


FIGURE 2. U.S. Relative Contribution to Energy Savings, 1986.

U.S energy savings totaled 31.8 quads in 1986, given actual GNP and assuming that 1960-1972 trends in energy use per dollar of GNP had continued. Had trends in GNP growth also continued, energy consumption would have been 51.6 quads higher than actually experienced (74.3 quads).

For the residential sector, the major contributing factors are changes in 1) space heating behavior (such as thermostat setbacks), 2) appliance use patterns and efficiencies, and 3) building envelope retrofits. The major factors in the commercial sector appear to be 1) non-envelope retrofits of existing buildings (such as HVAC retrofits), 2) building envelope retrofits, and 3) the addition of new efficient buildings to the stock. In the industrial sector, the key factors are 1) market-induced conservation actions resulting from firms being faced with higher energy prices, and 2) the effect of a changing mix of industries toward less energy-intensive activity. For transportation, savings are largely associated with improvements in technology for light duty vehicles, downsizing of vehicles, changes in aircraft mix, and changes in airline seating capacity factors.

For 1985, the U.S. energy savings was 28.7 quads (when measured based on actual GNP growth and the continuation of 1960-1972 trends in energy use intensity). The value of this savings is roughly $244 billion, based on an average price for total U.S. energy of $8.50/ million Btu.[a] By using the average 1985 energy price to each sector, the sectoral value shares are: residential--44%; commercial--25%; industrial--25%; and transportation--6%.

Clearly, changes in energy efficiency (as measured by energy intensity changes) have paid large dividends since the early 1970s. These dividends have continued over the period 1982 to 1986, indicating that overall energy conservation gains have not been lost in the face of declining energy prices.

(a) Prices for 1986 are not yet available. Figures for 1985 are taken from State Energy Price and Expenditure Report: 1985, Energy Information Administration, October 1987, DOE/EIA-0376(85).

GLOSSARY

Agents - the actors in an end-use sector whose behavior is of interest. In the residential sector these are households; in the commercial sector these are building managers/owners or tenants; in the industrial sector these are entrepreneurs and business management; and in the transportation sector these are individuals and transportation service entrepreneurs or managers.

Behavioral response - see glossary entry for market impact.

British thermal unit (Btu) - a measure of energy; the amount of heat required to raise one pound of water one degree Fahrenheit.

Composition index - the fraction that five energy-intensive industries contribute to industrial sector GNP. These five industries are food and kindred products; pulp and paper; petroleum refining; stone, clay and glass; and primary metals. These industries are defined at the 2-digit standard industrial classification (SIC) level.

Delivered (or Site) Energy Use - energy consumption measured at the site where the energy is consumed (such as at the house).

Elasticity - a measure of responsiveness of a variable --here, energy use-- to changes in another variable; formally, the percentage change in variable X induced by a 1% change in variable Y.

Energy Savings - for this report, means the reduction of energy use over what consumption would have been under different circumstances. A negative value for energy savings represents an increased use of energy over what it would have been under different circumstances.

Energy Use Intensity (EUI) - energy use (million Btu) per unit of measure of activity. For the U.S. economy the measure used is gross national product. Other measures are a) residential: number of households, b) commercial: building square footage, c) industrial: gross national product originating in the agriculture, mining, construction, and manufacturing industries (adjusted for inflation), and d) transportation: passenger/freight ton-miles.

Energy Use Measure A - actual primary energy use, which can be represented as the actual energy use intensity multiplied by the actual measure of activity.

Energy Use Measure B - a hypothetical value for primary energy use, calculated as the actual measure of activity multiplied by the trended energy use intensity (where the trending continues the annualized rate of growth of the EUI at the same rate as that experienced between 1960-1972). Measure B intuitively represents what energy use would have been if trends in the EUI had continued, in light of actual changes in economic activity.

Energy Use Measure C - a hypothetical value for primary energy use, calculated as the actual measure of (economic) activity multiplied by a constant EUI (at the 1972 level). Measure C intuitively represents what energy use would have been had the 1972 EUI persisted, in light of actual changes in economic activity.

Energy Use Measure D - a hypothetical value for primary energy use, calculated as the actual EUI multiplied by the trended measure of economic activity (where the trending continues the annualized rate of growth of the economic activity at the same rate as that experienced between 1960-1972). Measure D intuitively represents what energy use would have been had trends in economic activity continued, in light of actual changes in the energy use intensity.

Energy Use Measure E - a hypothetical value for primary energy sue, calculated as the trended value of the EUI multiplied by the trended value for economic activity (where the trending continues the annualized rate of growth of each factor at the same rate as that experienced between 1960-1972). Measure E intuitively represents what energy use would have been, had overall trends in energy use intensity and economic activity continued.

GNP Deflator - a current-weight index of the prices of the newly produced goods and services that make up gross national product. The deflator is based to a specific year (for recent GNP accounts, 1982) and is reported as a percent (i.e., the deflator is 100 in 1982).

Gross National Product (GNP) - The value of all new goods and services produced by the economy over a specified period of time. GNP is reported in nominal terms--i.e., at current value--and in real terms--i.e., adjusted for inflation. The adjustment uses a deflator to convert from nominal to real terms.

Market impact - variable used to capture both the direct and indirect economic effects such as factors that apply directly to the fuel, factors that apply to the equipment that uses the fuel, and speed of adjustment of the industry. This is also referred to as behavioral response. The analysis uses the relative price variable to represent these effects.

Output - a measure of economic activity. See GNP.

Primary Energy Use - a measure of the elemental energy used in the economy evaluated at input value. Primary energy includes coal; crude oil; natural gas; oil shales; solar heat; hydroelectric, nuclear, geothermal, wind, solar and tidal electric power production; and energy sources derived from anaerobic or distillation processes. When allocated to end-use sectors, the losses that occur when converting one energy form to another are distributed to the sectors based, generally, on the use of the final energy product.

Quad - quadrillion (10^{15}) Btu.

Regression analysis - a statistical process by which the changes in the variable of interest (dependent variable) are "explained" by changes in another variable or set of variables. This process minimizes the square of the errors between the forecasted values of the dependent variable and the actual values and because of this is frequently referred to as the method of least squares.

Relative energy prices - in the industrial sector this variable is defined as the ratio of the wholesale price index for purchased fuel and power relative to the output deflator for the industrial sector, normalized to 1967=100.

Space Heating Behavior - for this report, means short-term reversible actions a person can take which alters the use of energy for space heating in the home. Examples are setting the thermostat at 66 degrees F rather than 70 degrees F during a day in the winter, or setting the thermostat lower every night and raising it during the day, or closing off rooms (zoning).

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

1.1 STUDY OBJECTIVES

The primary objective in this study is to develop a detailed analysis of historical energy use trends for the U.S. during the 1972-1986 period. The analysis first offers additional information regarding the continuation or abatement of conservation trends since the previous analysis of historical end-use sector trends (Adams, et al., 1985). Secondly, the study highlights developments in energy use that have occurred since the decline in the price of oil. By extending the study period from 1972 through 1986, a deeper understanding of energy use trends may be developed, especially in light of the dramatic changes in oil prices, ranging from the oil embargo of 1973-1975 to the rapid decrease in oil prices experienced in the mid-1980s. This study expands upon the previous study in terms of methods of analysis and understanding of behavioral responses to changes in the energy environment.

1.2 SCOPE AND LIMITATIONS

This study presents a historical analysis of U.S. energy use trends during the period of 1972-1986. Energy use trends for the total U.S. economy are addressed here, although the focus of the report is on sectoral trends in energy use. Primary energy consumption in the U.S totaled 74.4 quads in 1986, down from a high of 78.9 quads in 1979. This represents a large amount of conservation when viewed from the perspective of energy projections made in the early 1970s.

Energy use can be usefully examined by looking at the four major sectors of the economy: residential, commercial, industrial, and transportation. The figure below illustrates each sector's contribution to energy use. The industrial sector is the largest energy user, followed by transportation, residential, and then commercial. Concentrating on the end-use sector provides a more meaningful analysis because the analytical approach for each sector is distinct and it sheds light on energy use trends in that sector.

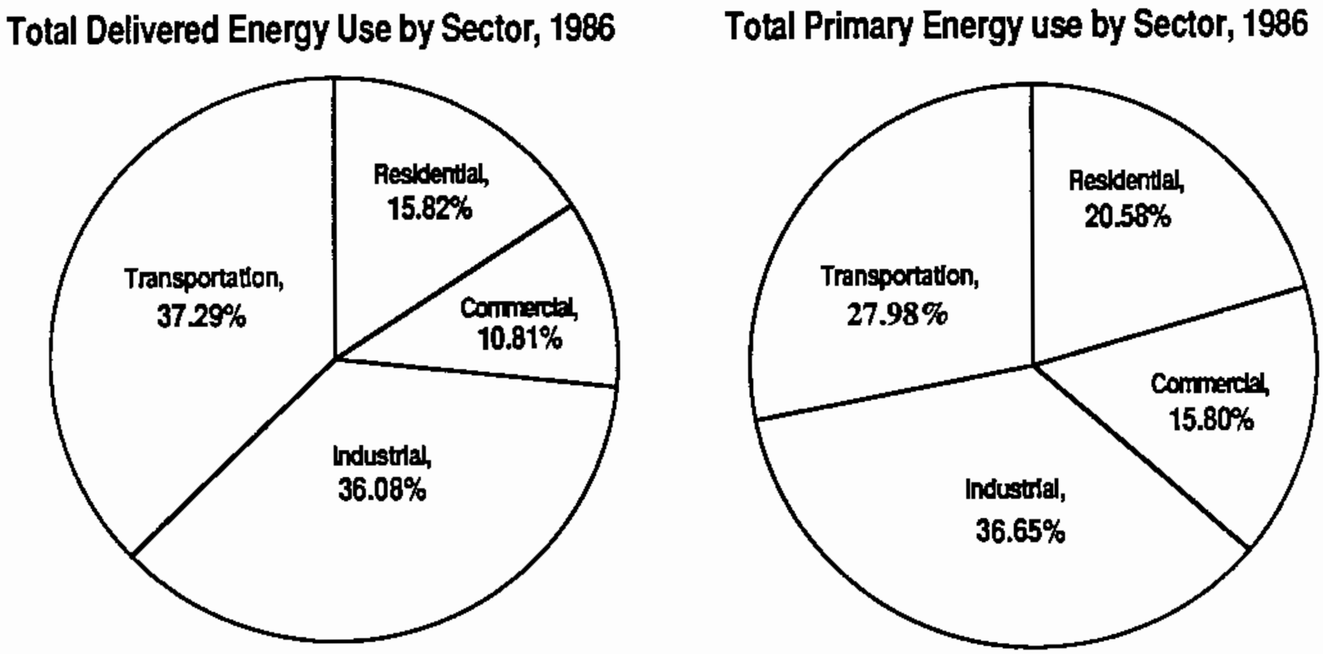


FIGURE 1.1 Total U.S. Energy Use by Sector, 1986

The focus of this project is to examine energy use trends and energy savings in light of the changes in the level and mix of economic activity since 1972. This examination explains much of the improved efficiency changes that have occurred since that time. For each of the sectors, estimates of base case energy use are developed in order that estimates of energy savings resulting from changes in activity levels and efficiencies over the study period can be calculated. The focus of the analysis, however, is on the savings that have occurred due to efficiency changes since 1972. In particular, the period 1982-1986 is examined to determine whether conservation gains have declined substantially following energy price declines. The estimated energy conservation savings are decomposed in order to offer insight into economic and other causes leading to conversation.

While the methods used for developing the base case energy use estimates are the same as that developed in the previous report (Adams, et al., 1985), the sectoral methodologies for breaking out the components of energy savings since 1972 differ somewhat from the previous report. One important distinction is that the previous report presented the decomposition of savings in terms of primary energy. In this study, the decomposition of savings is done in terms of delivered (site) energy use, due to the behavioral emphasis of this study. The particular areas where the present methodology differs from the previous methodology will be discussed in the text as they arise.

1.2.1 Alternative Measures of Base Case Energy Use

In order to estimate changes in energy use trends, a base case is developed that calculates a level of energy use that would have occurred using various assumptions about the growth of economic activity and changes in energy use intensities. By calculating the total energy use as the product of economic activity and energy use intensity (EUI), five different base cases of primary energy use are defined.

The five base cases are represented consistently throughout the report as follows:

Measure A: actual activity level x actual EUI, or actual energy use
Measure B: trended EUI (at 1960-1972 growth rate) x actual activity level
Measure C: constant 1972 EUI x actual activity level
Measure D: actual EUI x trended activity level (at 1960-1972 growth rate)
Measure E: trended EUI x trended activity level (at 1960-1972 growth rate)

Energy Use Measure A is actual primary energy use, which can be represented as the actual energy use intensity multiplied by the actual measure of activity. Energy Use Measure B is a hypothetical value for primary energy use, calculated as the actual measure of activity multiplied by the trended energy use intensity (where the trending continues the annualized rate of growth of the EUI at the same rate as that experienced between 1960-1972). Measure B intuitively represents what energy use would have been if trends in the EUI had continued, in light of actual changes in economic activity.

Energy Use Measure C is an alternative hypothetical value for primary energy use, calculated as the actual measure of (economic) activity multiplied by a constant EUI (at the 1972 level). Measure C intuitively represents what energy use would have been had the 1972 EUI persisted, in light of actual changes in economic activity.

Another hypothetical value for primary energy use is Measure D, calculated as the actual EUI multiplied by the trended measure of economic activity (where the trending continues the annualized rate of growth of the economic activity at the same rate as that experienced between 1960-1972). Measure D intuitively represents what energy use would have been had trends in economic activity continued, in light of actual changes in the energy use intensity.

Energy Use Measure E is the final alternative hypothetical value for primary energy use presented, calculated as the trended value of the EUI multiplied by the trended value for economic activity (where the trending continues the annualized rate of growth of each factor at the same rate as that experienced between 1960-1972). Measure E intuitively represents what energy use would have been, had overall trends in energy use intensity and economic activity continued.

The measures can be related to one another by examining Table 1.1.

Table 1.1 Alternative Measures of Primary Energy Use

ENERGY USE INTENSITY[1]	ECONOMIC ACTIVITY MEASURE[2]	
	Actual	Trended[3]
Actual	A	D
Trended[3]	B	E
Constant at 1972 level	C	--

Notes:

1 Energy use intensity (EUI) is the energy use in BTUs per unit of economic activity.

2 For the U.S. economy the measure used is gross national product. Other measures are a) residential: number of households, b) commercial: building square footage, c) industrial: gross national product originating in the agriculture, mining, construction, and manufacturing industries (adjusted for inflation), and d) transportation: passenger/freight ton-miles.

3 Refers to the continuation of the 1960-1972 trend, as measured by the annual (average) growth rate.

1.2.2 Alternative Measures of Energy Savings

By comparing the base case estimates and their underlying assumptions of changes in activity level and EUI, energy savings can be calculated. Four different estimates of energy savings can be derived as follows:

- E-A: energy savings resulting from changes in both energy intensity and economic activity from earlier trends.
- D-A: energy savings due solely to changes in economic activity away from earlier trends.
- C-A: energy savings due solely to efficiency changes as represented by the change in energy intensity from 1972 levels.
- B-A: energy savings due solely to efficiency changes as represent by the change in energy intensity from earlier trends.

There are obviously many ways of looking at what energy use "would have been", and thus at "savings". The estimates produced are not scientific measurements. Rather, they are each valid representations of what would have been under different sets of assumptions. Each is used, as appropriate, in the analyses which follow.

1.2.3 Primary and Delivered Energy Savings

While the base case estimates are calculated on the basis of primary energy, as in the previous study (Adams, et al., 1985), the subsequent decomposition of energy savings due to efficiency improvements since 1972 is made in terms of delivered energy use. Delivered energy use includes electricity sales to the sector, evaluated at 3412 Btu per kWh. Primary energy use includes site use plus an estimate of the heat content of electrical energy losses, allocated to the sector on the basis of electricity use.

Understanding primary energy use on a sector-by-sector basis offers the policymaker a broader perspective of conservation trends and provides insight into how households, governments, and industry behave. The analysis of the components of energy savings, however, is based on behavioral responses. Consumers' fuel choices and fuel switching decisions are responses to the price of delivered electricity, not the embodied fuels. Because the analysis addresses the impacts of relative fuel prices on fuel choices and fuel switching decisions by end-use sector, the site energy use approach is credible and appropriate.

2.0 TOTAL U.S. ECONOMY

2.1 GENERAL ENERGY USE TRENDS

The growth in energy use in the U.S. economy has slowed from the rate of growth experienced during the 1960s. Efficiency gains, as reflected by the overall energy use intensity (EUI) account for a larger part of energy savings. Slower overall growth of the U.S. Gross National Product (GNP) accounts for a minor portion of the energy savings that have been accrued in primary energy consumption in the U.S. economy.

During the 1960-1972 time period, primary energy use grew from 43.8 quads to 71.3 quads. Since 1972, primary energy use increased from 71.3 quads to a high of 78.9 quads in 1979 after experiencing a decrease during the 1973-1975 period. Between 1979 and 1983, primary energy use declined in every year to 70.5 quads in 1983. Since 1984, energy use has increased in every year to 1986's level of 74.3 quads.

Between 1972 and 1986, primary energy use increased a total of 4.2 percent, an average annual rate of 0.3 percent.[a] This rate of growth in energy use contrasts sharply with the increase between 1960 and 1972 which was at an average annual rate of 3.8 percent.

The rate of growth in the U.S. GNP has also slowed since 1972, as is shown in Figure 2.1. In the 1972 through 1986 period, the U.S. GNP rate of growth slowed to an average of 2.6 percent per year.

The EUI for the total U.S. economy has similarly decreased since 1972, as shown in Table 2.1. Between 1960 and 1966, the EUI, measured as thousand BTU per real dollar of U.S. GNP, fell from 26.3 to 25.3 thousand Btu per dollar. The period of 1966 through 1970, on the other hand, showed an increased EUI, from 25.3 to 27.5 thousand Btu per dollar. In 1970, the EUI began to decrease

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(a) Average annual percentage growth rates are calculated based on the periodic growth rate needed for a present value to grow to a future value over the compounding period. The average annual percentage growth rates is equal to K x 100, where K is the fractional rate in:

$$\text{Present Value } (t) = \text{Compound Value } (t) \times [1 / (1 + K)]^t$$

and continued to decrease every year, with the exception of slight increases in 1972 and 1976. Between 1972 and 1986, the EUI declined 26.7 percent, or an average of 2.2 percent per year.

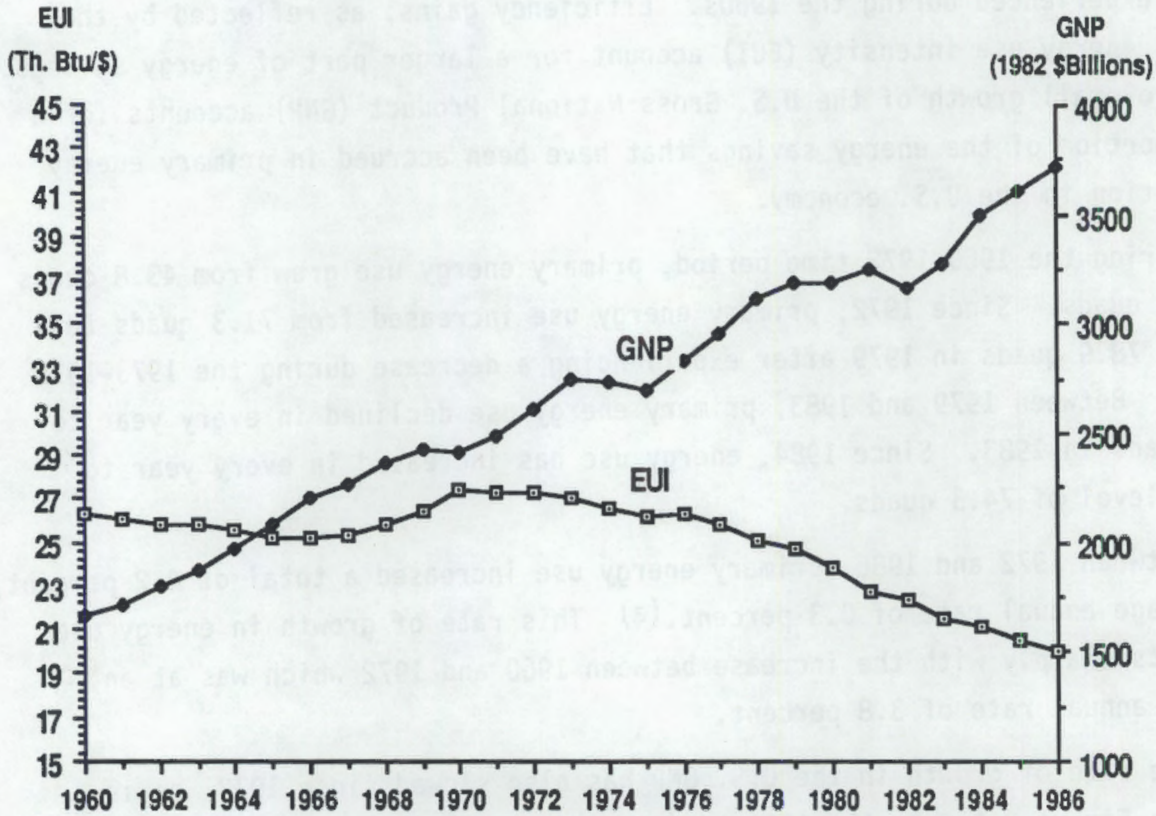

FIGURE 2.1. The GNP and Energy Use Intensity for the U.S. Economy

Recent increases in GNP growth have led to an average annual rate of growth of 4.1 percent for the 1982-1986 period. Greater growth in the activity level decreases the amount of primary energy savings that can be attributed to decreased economic activity since 1972.

The EUI has decreased more rapidly between 1982 and 1986 than in the 1972-1986 period as a whole. In the 1982-1986 period, the EUI fell at an average annual rate of 2.8 percent. The increased rate at which the EUI falls implies that a larger portion of the total primary energy savings can be attributed to increasing efficiency levels.

TABLE 2.1. Primary Energy Use, GNP, and Energy Use Intensity in the U.S. Economy, 1960-1986

Year	Primary Energy Use (Quad)(a)	GNP (Billions of Constant 1982 dollars)(b)	EUI (Thousand BTU per dollar of GNP)
1960	43.8	1665.3	26.3
1961	44.5	1708.7	26.0
1962	46.5	1799.4	25.9
1963	48.3	1873.3	25.8
1964	50.5	1973.3	25.6
1965	52.7	2087.6	25.2
1966	56.0	2208.3	25.3
1967	57.6	2271.4	25.4
1968	61.0	2365.6	25.8
1969	64.2	2423.3	26.5
1970	66.3	2416.2	27.5
1971	67.8	2484.8	27.3
1972	71.3	2608.5	27.3
1973	74.4	2744.1	27.1
1974	72.5	2729.3	26.6
1975	70.6	2695.0	26.2
1976	74.4	2826.7	26.3
1977	76.3	2958.6	25.8
1978	78.2	3115.2	25.1
1979	78.9	3192.4	24.7
1980	76.0	3187.1	23.8
1981	74.0	3248.8	22.8
1982	70.8	3166.0	22.4
1983	70.5	3279.1	21.5
1984	74.0	3501.4	21.1
1985	74.0	3607.5	20.5
1986	74.3	3713.3	20.0

(a) Source: State Energy Data Report (EIA, 1988)
(b) Source: Economic Report of the President, 1988 (GPO, 1988)

2.2 ENERGY SAVINGS

2.2.1 Alternative Measures of Primary Energy Use

Figure 2.2 presents the alternative measures of energy use in the total U.S. economy. The five estimates are:

Measure A: Actual EUI x actual GNP, or actual primary energy use

Measure B: Trended EUI (1960-1972) x actual GNP

Measure C: Constant 1972 EUI x actual GNP

Measure D: Actual EUI x trended GNP growth, at 1960-1972 trends
Measure E: Trended EUI x trended GNP growth, at 1960-1972 trends

2.2.2 Major Findings

Several important points about energy savings are revealed in Figure 2.2 and the underlying numbers of Table 2.2:

- Changes in the growth rate trends of the U.S. GNP and the EUI since the 1960-1972 time period account for a total of 51.6 quads of primary energy savings in 1986 (Measure E minus Measure A).
- Efficiency gains alone since the 1960-1972 period account for 31.8 quads savings in 1986 (Measure B minus Measure A).
- Energy savings that have occurred due to a decrease in the EUI from the 1972 level amounts to 27.2 quads (Measure C minus Measure A).
- Energy savings based on efficiency gains have remained roughly constant over the 1982-1986 period at about 14 quad, indicating that recent energy price decreases have not "taken back" earlier gains in conservation.

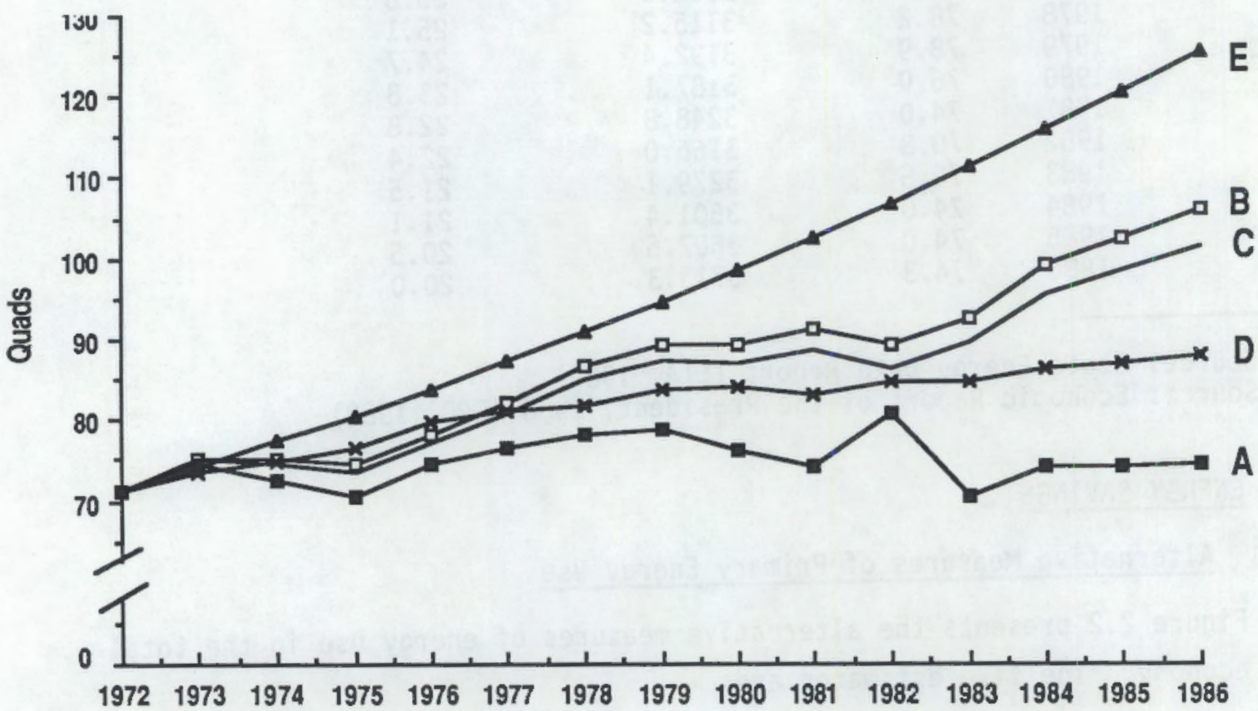

FIGURE 2.2. Alternative Measures of Energy Use in the U.S. Economy, 1972-1986

TABLE 2.2. Alternative Measures of Energy Savings in the U.S. Economy, 1972-1986

	Quadrillion (10^{15}) BTU			
Year	Decreased Economic Activity and EUI E-A	Decreased Economic Activity D-A	Decreased EUI Relative to 1972 C-A	Decreased EUI Relative to Pre-72 Trends B-A
1972	0.0	0.0	0.0	0.0
1973	-0.1	-1.0	0.6	0.9
1974	4.8	2.2	2.0	2.5
1975	9.9	5.8	3.1	3.8
1976	9.4	5.3	2.8	3.8
1977	11.0	4.8	4.5	5.8
1978	12.8	3.8	7.0	8.6
1979	15.8	4.9	8.3	10.3
1980	22.6	7.9	11.1	13.4
1981	28.7	9.2	14.7	17.3
1982	36.2	14.0	15.7	18.5
1983	40.9	14.1	19.1	22.3
1984	42.0	12.4	21.7	25.4
1985	46.8	13.0	24.6	28.7
1986	51.6	13.8	27.2	31.8

2.3 SUMMARY

If trends in energy use intensity and GNP growth had continued after 1972 at the 1960-1972 rates, U.S. energy use would have reached 125.8 quads in 1986. If the trend in energy use intensity alone had persisted since 1972, U.S. consumption would have been 106.1 quads in that year. That level would be 31.8 quads greater than actual U.S. consumption (74.3 quads). Thus, even though energy use is somewhat less than it would have been had the economic growth of the 1960s continued, a considerable amount of conservation is due primarily to the decline in energy use intensities. It appears that in the aggregate, conservation investments and behaviors continue to pay off. About the same savings are seen in 1986 as in 1982, indicating that energy price declines have not taken back these gains.

3.0 RESIDENTIAL SECTOR

3.1 GENERAL ENERGY USE TRENDS IN THE RESIDENTIAL SECTOR

Primary energy use has fluctuated in the residential sector since 1972, peaking in 1978 at 15.6 quadrillion Btu (quad) as shown in Table 3.1. In 1986, actual energy use reached 15.4 quads, again approaching the 1978 peak.

The number of households serves as a useful measure of economic activity in the residential sector. For this report, the basic energy consuming unit is the household, and the measure of energy efficiency or energy use intensity is energy use per household. This measure has been used in order to maintain consistency with the earlier Trends work. Other possible measures are energy use per capita or energy use per square foot. The number of households has increased steadily nearly 33 percent, from 66.7 million households in 1972 to 88.5 million households in 1986.

Energy use per household, on the other hand, has decreased since 1972. This is shown in Table 3.1 and illustrated graphically in Figure 3.1. In 1972, each household consumed 217.7 million Btu per year in primary energy. By 1975, the rate of consumption had decreased to 203.3 million Btu per household, thereby remaining relatively stable until 1979 when it fell to 196.6 million Btu per household. The rate continued to decrease until 1984 when it turned slightly upward, reaching 176.7 million Btu per household in 1986. In terms of primary energy consumption, this represents an 18.8% decline between 1972 and 1986. When factoring out losses, the EUI decline between 1972 and 1986 has been 34.3%.

As is shown in Figure 3.2, electricity has grown in its share of residential primary energy consumption over almost the entire 1960-1986 period, reaching 60% in 1986. Since 1982, however, electricity use as a share of total residential energy use has remained stable. The record since 1972 shows natural gas losing market share primarily to electricity, with continued small declines since 1982. Petroleum use has stabilized since 1982, indicating some responsiveness to recent oil price reductions. Petroleum's share had dropped sharply between 1972 and 1982.

TABLE 3.1 Primary Energy Use, Households, and Energy Use Intensity in the Residential Sector, 1960-1986

Year	Total Energy Use	Households (Millions)	Energy Use Intensity (c) (Thousand Btu per Household)
1960	8284.4	52.8	156.9
1961	8582.1	53.6	160.1
1962	9102.3	54.8	166.1
1963	9366.6	55.3	169.4
1964	9684.4	56.2	172.3
1965	10118.7	57.4	176.3
1966	10654.0	58.4	182.4
1967	11142.4	59.2	188.2
1968	11864.7	60.8	195.1
1969	12716.7	62.2	204.4
1970	13309.9	63.4	209.9
1971	13841.7	64.8	213.6
1972	14517.7	66.7	217.7
1973	14642.0	68.3	214.4
1974	14361.2	69.9	205.5
1975	14453.4	71.1	203.3
1976	15005.9	72.9	205.8
1977	15211.5	74.1	205.3
1978	15624.6	76.0	205.6
1979	15194.2	77.3	196.6
1980	15067.1	80.8	186.5
1981	14605.9	82.4	177.3
1982	14732.5	83.5	176.4
1983	14644.3	83.9	174.5
1984	15026.1	85.4	175.9
1985	15263.6	86.6	175.8
1986 (a)	15085.0	88.5	170.5
1987 (b)	15256.1		

Source: 1960-1985, State Energy Data Report, DOE/EIA, 4/87.
Housing data from Current Population Series, U.S. Bureau of Census.
(a)1986 fuel type estimates calculated as same portion of total fuel use as in 1986 estimates in Monthly Energy Review (9/87). Fuel shares for residential and commercial sectors calculated based on SEDR 1985 proportions. Total fuel consumption estimates for 1986 are from Table 1.1, C.E. Databook.
(b)1987 fuel share allocated as reported in Monthly Energy Review (9/87).
(c)Energy Use Intensity Calculation = Total Energy Use / Households
Revision Date 5/23/88

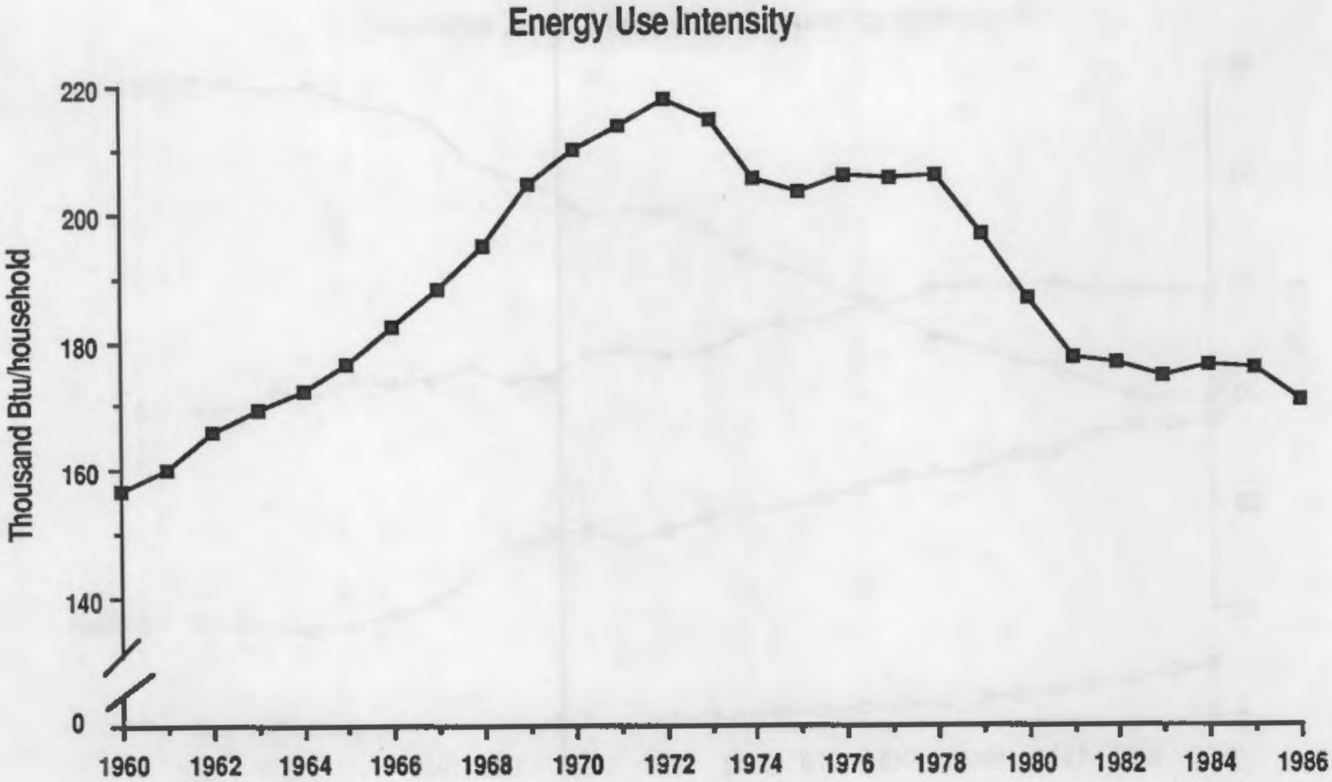

FIGURE 3.1 Residential (Primary) Energy Consumption per Household, 1960-1986

Note that residential primary energy use includes losses from generating electricity. Only about 30% of energy attributed to electricity is actually consumed in the home. The rest is lost at the electrical generating plant and in the transmission and distribution lines.

3.2 ENERGY SAVINGS (PRIMARY)

Alternative estimates of residential primary energy use and savings are presented below, along with major findings for the sector-level results.

3.2.1 Alternative Measures of Primary Energy Use

Five alternative measures of primary energy use (including actual) are constructed using the methodology discussed in Chapter 1.0. In the residential sector, the EUI is measured in terms of the primary energy use per household.

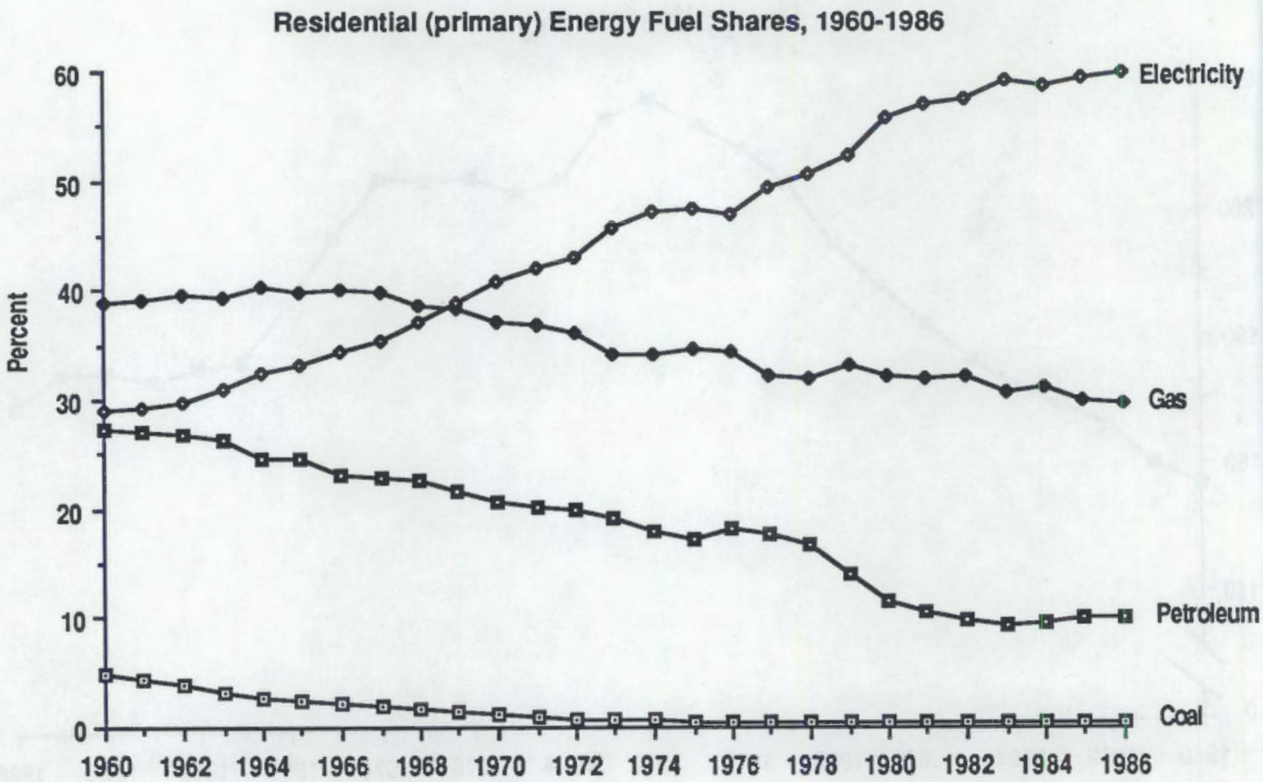

FIGURE 3.2 Residential (Primary) Energy Fuel Shares, 1960-1986

Alternative views of residential energy use are shown in Figure 3.3 The graph is constructed according to the following calculations for Lines A, B, C, D, and E:

- Line A: Actual energy use for all households
- Line B: Actual households and trended energy use per household
- Line C: Actual households x 1972 energy use per household
- Line D: Trended households x actual energy use per household
- Line E: Trended households x trended energy use per household

"Trended" here refers to the continuation of the annualized (average) rate of growth as measured from 1960-1972.

3.2.2 Major Findings

Several important points regarding residential energy consumption can be deduced from Figure 3.3 and the underlying data (see appendix):

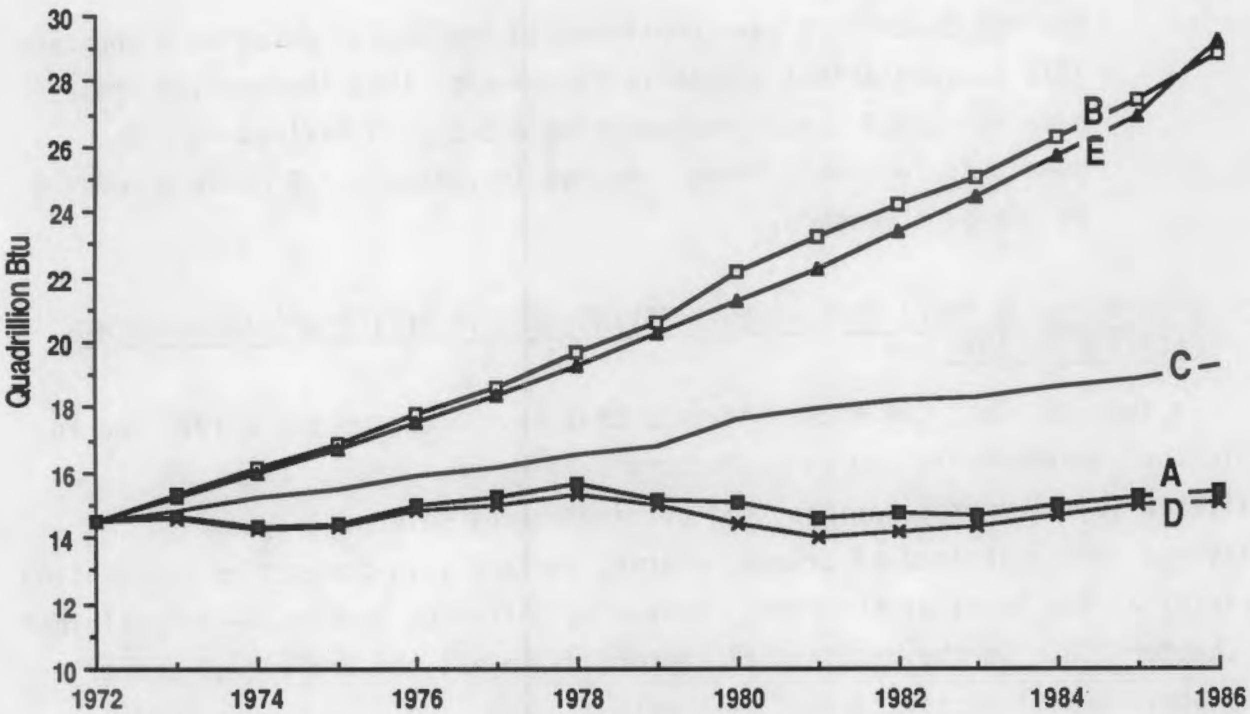

FIGURE 3.3 Alternative Measures of Primary Energy Use, 1972-1986

- Residential energy consumption would have reached 19.3 quads in 1986 assuming actual activity growth (households) and energy use intensity (EUI) remained at the 1972 level (Line C). This compares to actual consumption of 15.4 quads (Line A) and represents a 3.9 quad savings.
- If the EUI had continued to grow at the rate experienced in 1960 - 1972 period, residential energy consumption would have reached 28.7 quads in 1986 (Line B), which is 85% higher than actual energy use (Line A). From this perspective, a 13.3 quad savings has been realized.
- Savings for the above measures are attributable almost entirely to the absolute and relative (to trend) decline in EUI since 1972. When trended and actual households from 1972-1986 are each multiplied by actual energy use per household, there is little difference in the energy use trends (Lines A and D).

- Savings since 1982 have continued to increase. Based on a constant 1972 EUI and actual growth in households, 1982 consumption would have been 18.2 quads, representing a 3.5 quad savings in that year. As indicated above, savings in 1986 are 3.9 quads according to the same measure.

3.3 COMPONENTS OF (DELIVERED) ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

In this section, the energy savings that have occurred since 1972 due to efficiency improvements and other factors will be analyzed in terms of delivered (site) energy savings, not primary energy savings. By using delivered energy instead of primary energy, the analysis focuses on consumption behavior at the level of the energy consuming unit--the household--as explained in Chapter 1.0. In the residential sector, as in all the individual sector decompositions of energy savings, the methods used have been constrained by the availability of reliable data, and the particular fuel-specific characteristics of the sector. In this sector, no satisfactory decomposition of energy savings by fuel type was obtained, and thus no fuel-specific results are reported. The aggregrate decomposition is based, however, on some fuel-specific data.

In this analysis, regression models for electricity consumption and natural gas consumption were developed based on data from the 1984 Residential Energy Consumption Survey (RECS). These statistical models provided estimates of responsiveness (elasticities) of energy use to changes in key explanatory variables for each fuel.[a] Also, a fuel-aggregated simulation model was constructed which was driven, in part, by the responsiveness estimates obtained above. This model made it possible to simulate what residential energy consumption would have been under alternate assumptions for each of the four end-uses modeled: space heating, air conditioning, water heat, and appliances. Actual residential consumption is approximated with the calibrated model by driving it with achieved values for the key model variables. The savings to be explained in the modeling and analysis process are defined as the difference

(a) Models were also developed for several earlier years of RECS data. Few statistical differences were found in the measurements of interest.

between a simulated "what would have been" and a simulated "what was". This difference is then decomposed into explanatory components.

The components of residential energy savings are shown in Figure 3.4 with energy consumption based in terms of delivered energy. "What would have been" is based on the delivered energy version of energy measure C (as defined earlier): actual households x 1972 energy use per household. Savings in 1986 are estimated as 4.0 quads here. These savings are attributed to changes in population distribution (migration), household size, wood use, shell efficiency (new homes), shell efficiency (retrofits), space heating behavior, and appliance use and efficiency.

The selection of variables by which to decompose energy savings in the residential sector generally follows the scheme used in the previous Trends work. This strategy was followed to provide general continuity in the results, wherever practical. This convention has not been followed, however, when changes in data availability since the last published report allow for significant improvements in the methodology and the detail in activity

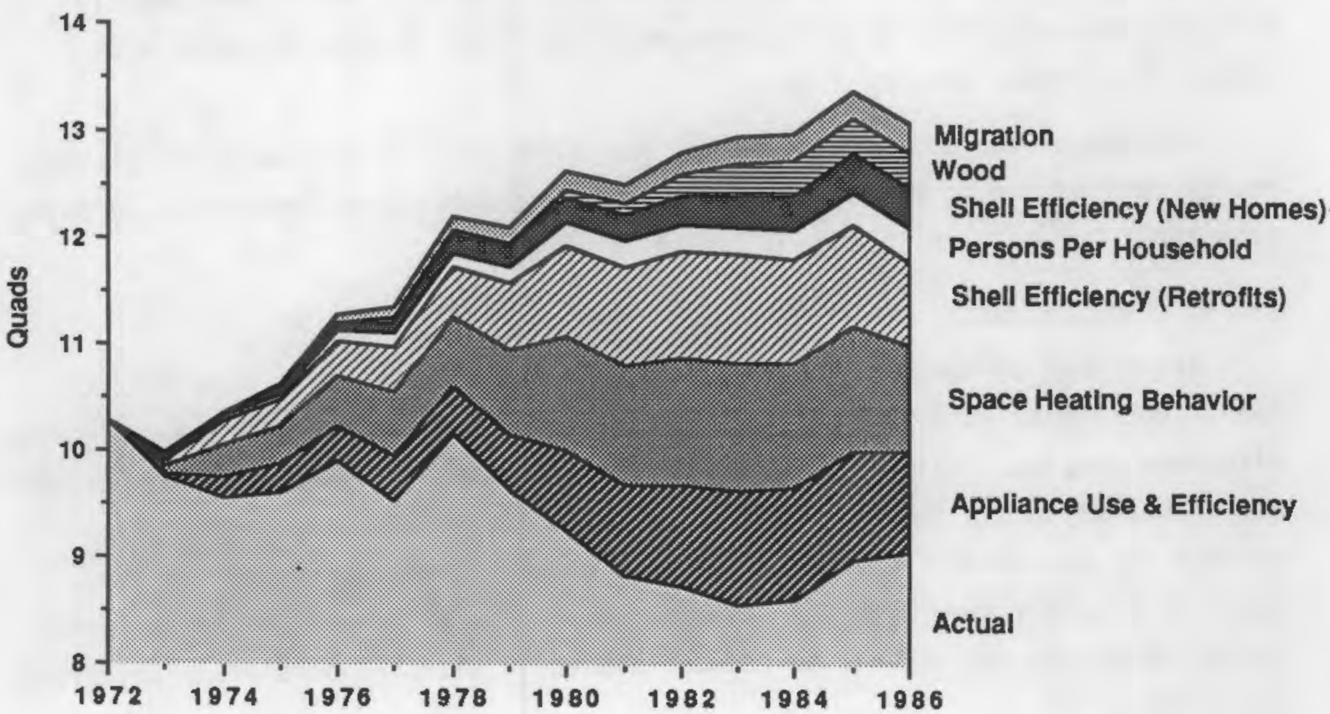

FIGURE 3.4 Components of Energy Savings Since 1972

explained. In the prior Trends report, for example, shell efficiency was presented as a single category, and behavioral changes were not broken out separately, but rather given as part of a "residual" category. The current report provide separate estimate for each as indicated above. Wood use continues to be represented as savings in the use of standard residential fuels, on the other hand, because no significant data or methodological improvements for explaining wood use were found.

3.3.1 Migration

For 1986, approximately 0.3 quad of residential sector energy savings can be attributed to migration. The number of households in each census region has been growing with the South and West regions having the largest percentage gains over the last 10 years. Simply put, a household in the South uses much less energy for space heating than a house in the North, leading to reduced energy consumption overall.

Because of the population moving to warmer climates, national weighted heating-degree-days are about 3% lower in 1986 than they would have been in 1972 if there had been no shift in population. This results in about a 3% reduction in space heating load.

Looking at the most recent period for which data is available (1982-1986), energy savings due to migration has increased somewhat over the period, growing from about 0.2 quad in 1982 to 0.3 quad in 1986.

3.3.2 Household Size

The number of persons per household has decreased steadily from 1972 to 1986. Households with fewer people, on average, use less energy than households with more people. This is true even for a given size dwelling, due to increased use of hot water and increased appliance use. The reduction in number of persons per household accounts for about 0.3 quad of energy savings in 1986, which is slightly more than the savings calculated for 1982. The trend toward increased energy savings due to reduced household size has persisted, therefore, in recent years.

3.3.3 Wood Use

Wood use in this report is viewed as displacing energy consumption from the major fuels. The efficiency of wood burning equipment varies greatly across equipment type. Fireplaces have a very low efficiency (0-30%), while central wood heating equipment can have efficiencies as high as 70%. Hard data is not available for all years, but RECS survey information indicates that only 2.4% of households were primary wood users in 1978, whereas 7.5% are so in 1984. The increase in secondary wood users is similar.

Wood use is estimated to account for 0.3 quad savings in 1986. This is about 0.1 quad more than the savings estimated for 1982, demonstrating that recent price declines have not dampened the interest in wood burning (at least through 1986).

3.3.4 Shell Efficiency (New Homes)

For this report, the broad notion of thermal efficiency has been estimated as three separate components. These are 1) changes in the aggregate efficiency of the housing stock due to the introduction of new, energy-efficient homes (since 1974), 2) changes in the aggregate efficiency of the housing stock due to structural changes to existing houses (denoted here "retrofits"), and 3) changes in achieved thermal efficiency due to behavioral changes such as lowering thermostat set-points and using thermostat set-backs.

The RECS regression analysis indicates that a home built after 1974 uses 25% less energy for space heating than older homes, when controlling for other factors. This translates into a decrease in aggregate space heating load due to an increasing percentage of homes in the stock built after 1973. New homes account for an estimated savings of 0.4 quad in 1986. This is about 0.1 quad greater than the estimated savings for 1982, indicating the continued addition of energy efficient homes to the housing stock. This is presumably due, in part, to the increased adoption of energy efficiency building standards for new homes around the country.

3.3.5 Shell Efficiency (Retrofits)

A prior PNL estimate of the structural retrofit responsiveness to changes in fuel price (from the 1985 Trends report) was used to separate changes made to the thermal shell by the consumer and changes in consumer home-heating behavior. The estimated savings from retrofit activity peaked in 1982 and 1983 at 1.0 quad, and was 0.8 quad in 1986. This decline appears to be due to the leveling off or decline of fuel prices (in constant dollars) since that time, along with the warmer winters recently.

3.3.6 Space Heating Behavior

Energy savings due to changes in space heating behavior are defined here as short-term reversible actions such as thermostat setting. Savings were calculated based on the difference between total price-induced changes in thermal efficiency of the pre-1974 stock of houses and price-induced structural changes, termed "retrofits".

Space heating behavior energy changes account for 1.0 quad of savings in 1986, down from a peak of 1.2 quads in 1982 and 1983. This may be attributed to the same price and weather factors noted for retrofit activity.

3.3.7 Appliance Use and Efficiency

This component reflects the combined savings for changes in use intensity and stock efficiency of air conditioning equipment, water heaters, and other appliances. The relevant explanatory factors include the fuel price, cooling-degree-days, the number of persons in the home, and appliance penetration. Ideally, this category should be separated into stock replacement/additions and changes in use patterns, much as was down for the shell. However, the available data do not support such a detailed breakdown. Savings due to changes in appliance use and efficiency total 1.0 quad in 1986. The is about the same as the 1982 level of estimated savings, indicating little change in attitudes and new stock characteristics in the last few years.

3.4 SUMMARY

The growth in the primary energy use per household over the 1960-1972, if continued at that rate, would have led to residential consumption of nearly 28.7 quads in 1986. The compares with actual consumption 15.4 quads. Roughly 13 quads has been saved, according to this measure. When savings are calculated based holding the 1972 EUI constant, 1986 energy savings are 3.9 quads. These savings have been achieved in the context of increasing (actual) electricity use in the residential sector, with declines since 1972 in the market shares of natural gas and petroleum.

Residential sector savings have been allocated to various contributing components in the residential sector, based on modeling and analysis of delivered energy. With about 4 quad of savings in 1986, the largest components are space heating behavior and appliance use/efficiency, each at 1.0 quad. These are closely followed by changes in shell efficiency due to structural improvements (retrofits) of existing homes, with about 0.8 quad savings. Improvements in the aggregate shell efficiency due to the building of new energy-efficient homes accounts for an additional 0.4 quad of savings in 1986. Migration, changes in wood use, and changes in the number of persons per household, each account for a further 0.3 quad of 1986 savings.

Conservation savings in the residential sector have persisted over the period 1982-1986, indicating that conservation investments and conserving behavior tend to reflect long-term and fairly permanent trends. Savings due to conserving space heating behavior and housing retrofits have become relatively less dominant since 1982, but they--along with savings in appliances--continue to be the leading factors explaining aggregate savings in the residential sector.

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Conservation savings in the residential sector have persisted over the period 1982-1985, indicating that conservation investments and conserving behavior tend to reflect long-term and fairly permanent trends. Savings due to conserving space heating behavior and housing retrofits have become relatively less dominant since 1982, but they--along with savings in appliances--continue to be the leading factors explaining aggregate savings in the residential sector.

4.0 COMMERCIAL SECTOR

The gleaming new office buildings in the nation's metropolitan centers are dramatic evidence of the U.S. economy's shift toward services. In 1986, the commercial sector accounted for 15.8 percent of total U.S. primary energy consumption, as compared to 12.9 percent in 1972. The growth in electricity demand has been the most startling: over 40 percent of the growth in electricity consumption since 1972 is attributable to the commercial sector.

Section 4.1 of this chapter briefly discusses general trends in total commercial energy use, energy intensity, and economic activity for the period, 1960-1986. Section 4.2 describes alternative measures of primary energy savings, measures derived from extrapolation of pre-1972 trends. Section 4.3 explores various factors that have contributed to the change in commercial energy consumption since 1972.

4.1 GENERAL ENERGY USE TRENDS

Major trends with respect to total primary energy consumption per square foot are shown in Table 4.1. From 1960 to 1986 total energy use per square foot rose at an annual rate of 1.2 percent per year. As Figure 4.1 illustrates, most of the growth was attributable to electricity. By 1982, total energy per square foot had fallen more than four percent from its 1973 peak. This decline occurred primarily in fossil fuel consumption, which was about 37 percent lower than its 1973 level. From 1973 through 1978 electricity use per square foot continued to rise at 1.9 percent per year; this is a sharply lower rate than before the embargo. Since 1978 the growth rate has slowed further, averaging about one and a half percent per year.

Because of the many activities encompassed by this sector, no theoretically satisfactory activity measure is available on a time series basis. Since most of commercial sector energy consumption is used to space condition and light buildings, the activity measure employed in this study is floor space measured in square feet. Floor space is the common means of normalizing energy use in most engineering studies and models of building energy consumption.

TABLE 4.1 Energy Use, Commercial Floor Space and Energy Use Intensity in the Commercial Sector, 1960-1986

Year	Annual Energy Consumption (TBtu)	Commercial Floor Space (Bill. Sq. Ft.)	Energy Use per Square Foot KBtu)
1960	4749	26107	181.9
1961	4845	26710	181.4
1962	5154	27354	188.4
1963	5333	28038	190.2
1964	5531	28742	192.4
1965	5900	29537	199.8
1966	6386	30365	210.3
1967	6946	31166	222.9
1968	7361	32044	229.7
1969	7858	32995	238.2
1970	8344	33830	246.6
1971	8694	34700	250.5
1972	9166	35666	257.0
1973	9532	36729	259.5
1974	9357	37614	248.7
1975	9443	38237	247.0
1976	10019	38871	257.7
1977	10171	39632	256.6
1978	10477	40569	258.2
1979	10615	41578	255.3
1980	10586	42394	249.7
1981	10644	43213	246.3
1982	10853	43865	247.4
1983	10943	44612	245.3
1984	11339	45538	249.0
1985	11577	46613	248.3
1986	11728	47623	246.3

(a) Energy Information Administration (1988a)
(b) PNL estimates developed for Commercial End-Use Energy Model

No readily available time series of floor space are available for the aggregate commercial sector in the U.S. The floor space series for this study was constructed to support PNL's Commercial Building Energy Model. Some description of how this series was developed is presented in section 4.3.7.

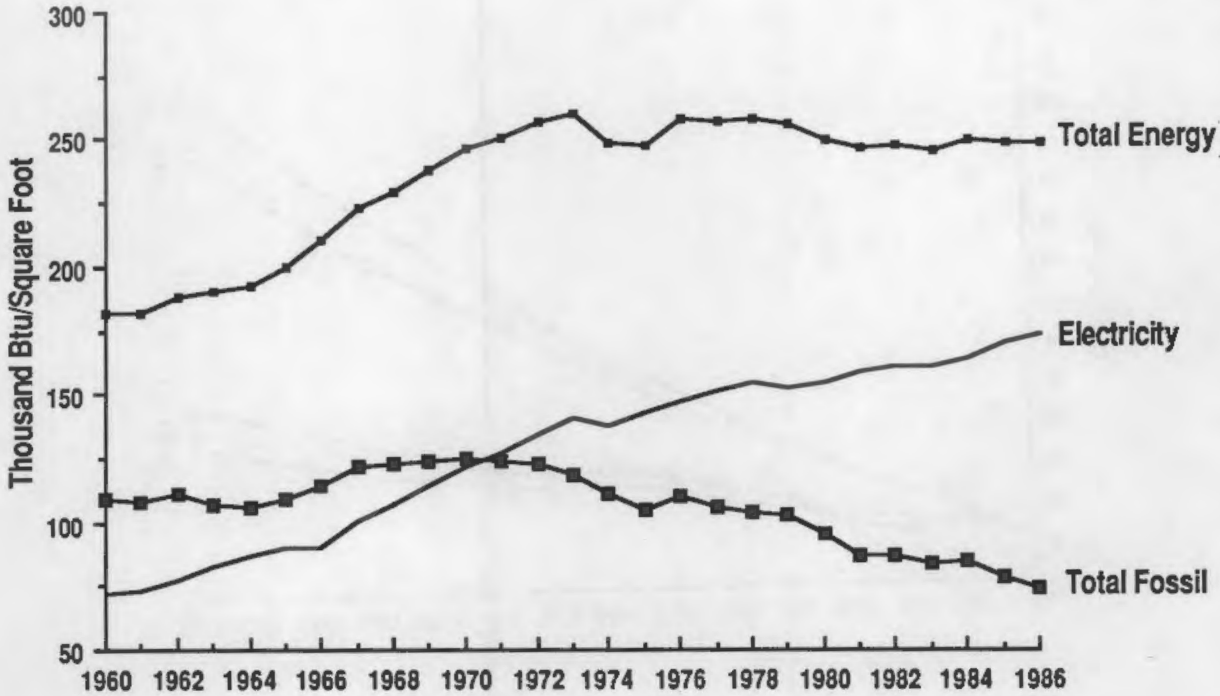

FIGURE 4.1 Energy Consumption per Square Foot in Commercial Buildings, 1960-1986

4.2 ENERGY SAVINGS

In this section the methodology described in Chapter 2 is used to estimate four baseline cases of energy consumption in the commercial sector. Varying assumptions about economic activity (i.e., square feet of commercial floor space) and energy use intensity (i.e., energy use per square foot) are use to estimate the baseline cases. Total energy use in the commercial sector is then represented by energy use intensity multiplied by the level of economic activity.

4.2.1 Alternative Estimates of Primary Energy Use

Graphical representations for the five measures of total commercial energy use are displayed in Figure 4.2. The lines displayed here correspond to the definitions presented in section 1.3.1:

Line A: actual energy use intensity (EUI) x actual activity floorspace
Line B: trended EUI x actual floorspace
Line C: constant 1972 EUI x actual floorspace
Line D: actual EUI x trended floorspace, at 1960-1972 trends
Line E: trended EUI x trended floorspace, at 1960-1972 trends

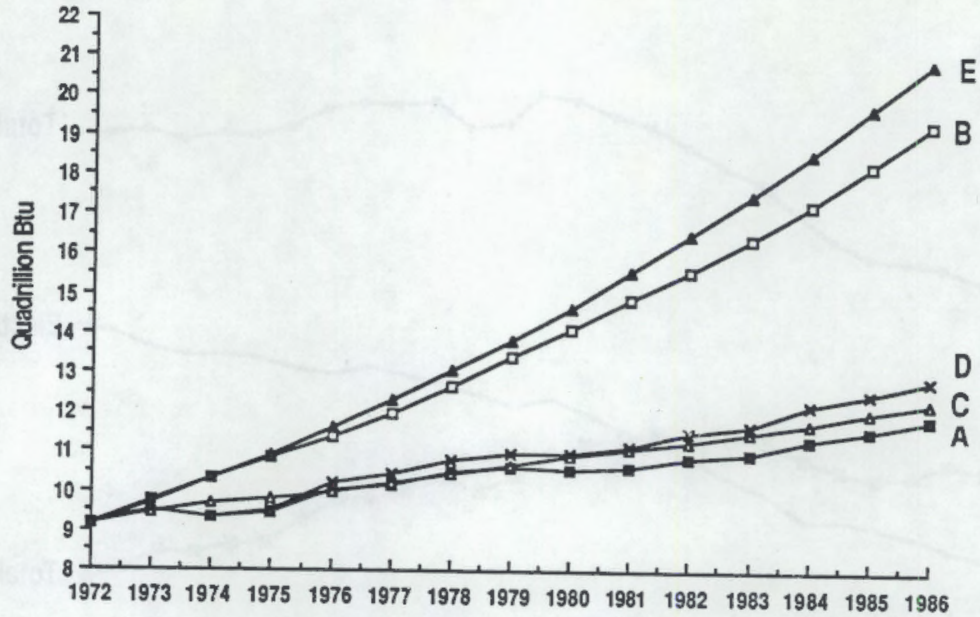

FIGURE 4.2 Alternative Measures of Primary Energy Use in the Commercial Sector, 1972-1986

Line A represents actual observed energy use from 1972 to 1986. In the following section we use this information to construct alternative estimates of energy savings for the commercial sector.

4.2.2 Major Findings

The alternative estimates of energy savings calculated by comparing the lines in Figure 4.2 are presented in Table 4.2.

- If the growth in floor space had maintained its trend of the 1960's, by 1986 one quad more energy would have been consumed in the commercial sector (Line D minus Line A).
- A more important factor, however, is the break from the sharply rising trend in energy intensity of the pre-embargo period. Had the 1960-1972 EUI trend persisted, 1986 consumption would have been over seven quads higher than actually observed (Line B minus Line A).

4.3 COMPONENTS OF ENERGY SAVINGS DUE TO EFFICIENCY CHANGES RELATIVE TO 1972

Section 4.3 examines a number of factors that have contributed to the trends in commercial sector energy consumption discussed above. Section 4.3.1

provides an overview of the various components considered in the analysis. Section 4.3.2 summarizes the major findings, first looking separately at fossil fuel and electricity consumption. Total energy savings, as the sum of electricity and fossil savings, is primarily evaluated on a site basis (electricity is converted to Btu's by using 3412 Btu per kWh). In addition to being consistent with the other end-use sectors, the use of site energy facilitates comparison with published energy survey data collected by the Energy Information Administration.

A variety of statistical and numerical methods were used to develop estimates of the individual components; only a broad outline of these methods is presented in this section. Appendix B describes in some detail how the estimates were obtained for each of the components.

4.3.1 Overview of Components Analyzed

As in the residential sector, a variety of factors have contributed to the savings "wedge", represented by the area between Line C and Line A in Figure 4.2. Among these factors are: 1) changes in the utilization of heating, ventilation, and air conditioning equipment (HVAC) and lighting; 2) changes in the average efficiency of HVAC equipment, stemming from both turnover of old equipment and improved operation of existing equipment; 3) changes in the occupancy patterns within buildings; 4) changes in the building envelope to improve thermal integrity, and 5) shifts in the geographical distribution of buildings.

This study addresses, at least in a partial way, each of the above factors. Utilization of heating and cooling equipment depends upon both internal thermostat settings and outside temperature. Little information is available regarding any systematic changes in thermostat settings in the wake of higher energy prices. (Although the Emergency Building Temperature Restrictions program in force during 1979 and 1980 may have had some influence, this was not considered in this study.) On the other hand, in considering outside temperature, the occurrence of several extremely cold winters in the late 1970's could be expected to have significant impact on year-to-year changes in fossil fuel consumption. Using a longitudinal analysis of the 1979 and 1983 Nonresidential Building Energy Consumption Surveys (NBECS) conducted by

TABLE 4.2 Alternative Estimates of Energy Savings in the Commercial Sector, 1972-1986

Trillion Btu

Year	E - A	D - A	C - A	B - A
1972	0	0	0	0
1973	189	-29	-92	219
1974	952	-5	311	958
1975	1489	89	385	1354
1976	1574	194	-29	1345
1977	2123	269	14	1806
1978	2562	309	-50	2188
1979	3212	333	71	2792
1980	4077	407	310	3534
1981	4907	489	463	4224
1982	5636	628	420	4734
1983	6545	743	523	5434
1984	7207	840	365	5928
1985	8091	895	404	6680
1986	9128	968	511	7538

E-A: Energy savings due to differences between trended actual activity levels and trended Energy Use Intensities (EUIs) and actual EUIs

D-A: Energy savings due to differences from trend activity level to actual activity levels (no change in actual EUIs)

C-A: Energy savings due to difference between act EUIs and constant 1972 EUI

B-A: Energy savings due to difference between trended EUIs and actual EUIs

EIA, the response of building energy use to annual heating degree days was estimated. This response was then used to infer the changes in commercial energy use resulting from weather in other years.

Changes in average efficiency resulting from new buildings entering the stock were based on a cross section analysis of the 1983 NBECS. However, this is only one aspect of improved equipment efficiency. No data exist to measure the increase in efficiency from turnover of HVAC equipment in existing buildings or the degree to which improved maintenance procedures have increased overall efficiency.

One of the most important factors related to occupancy patterns is the amount of vacant space in the existing stock. A longitudinal analysis of the 1979 and 1983 NBECS was employed to measure the impact of vacancy rates in office buildings. The results of this analysis were combined with information from the Coldwell Banker real estate service on average vacancy rates of office space to estimate the influence on energy consumption in the commercial sector.

Estimates of the impact of building retrofits came from several sources. The NBECS asked building owners or managers several questions regarding activities taken to improve thermal integrity, including increased insulation, weatherstripping and the installation of special windows. Statistical analysis of the 1979 and 1983 NBECS, together with selected engineering simulations, was used to estimate the average impact of each of these measures. The NBECS results were augmented from the summary findings of a recent assessment of DOE's Institutional Conservation Program by Lawrence Berkeley Laboratory (Carroll et al., 1987).

Changes in the mix of buildings were examined from the point of view of two separate trends: 1) the shift in the mix of building types (e.g. more office buildings) and 2) the shift in the regional composition of new buildings (e.g. toward the west and south). The decomposition methodology employed two separate data sets. First, average intensities by building type, fuel, and census region were computed from the 1979 NBECS. Secondly, a set of regional stocks by building type were developed over the period 1972 through 1986. Along with the two strictly compositional effects, the analysis also considered the influence of new buildings (with different intensities from the pre-1972 stock) upon aggregate energy consumption.

4.3.2 Summary of Results

The general approach of the analysis was to estimate the impacts of each component separately for total fossil fuels and for electricity. For each component, the objective was to estimate the energy use impact starting from a 1972 base. For example, if weather were under consideration, the energy impact in each year would be determined by estimating the difference in consumption due to difference in weather (i.e. heating degree days) from 1972.

The summary decomposition for total fossil fuels is shown in Table 4.3.[a] The first column shows the total savings relative to a 1972 base. (These figures correspond in concept to the difference in line A and Line C described in section 4.2.1, except that total fossil fuel figures are used instead of total primary energy.) Had the 1972 fossil fuel EUI remained at its 1972 value, an additional 2.2 quads (2269 trillion Btu as shown on the bottom of the first column) of fossil fuels would have been used by the commercial sector in 1986.

Focusing our attention on 1986, all of the components considered in the analysis, with the exception of the building mix, make a contribution to the observed savings. The largest factors are the envelope retrofits and the impact of new, more efficient, buildings. Envelope retrofits are estimated to account for about 7 percent of the observed savings; new buildings account for about 8.5 percent.

Although not as important as in the residential sector, changes in weather can partially mask longer term trends in the EUI. The influence of a much warmer winter in 1981 as compared to 1978 accounted for almost ten percent of the increase in energy savings over that three year period. Mild winter temperatures in calender year 1986 accounted for an estimated three percent of the savings relative to 1972.

The remaining factors all account for relatively small proportions of the total fossil fuel savings for 1986. The Institutional Conservation Program (ICP) was estimated to have saved 37.6 trillion Btu through 1986. This program was directed only at schools, colleges, and hospitals and less than a majority of eligible buildings participated in the program. Although more visible than other factors, the impact of increased vacancy rates was estimated to have accounted for less than 20 trillion Btu of the savings. For the purely compositional changes in the building stock, the conclusions are mixed. The trend in new construction in the south and west contributed to savings in fossil fuel consumption, approximately 40 trillion Btu. However, changes in

(a) The decomposition results for the commercial sector are presented in tabular form only. The small magnitude of some of the components, and the fact that several had "negative" contributions to savings, made several trial graphs hard to read and difficult to interpret.

the composition of the type of buildings was estimated to have more than outweighed this factor. The building mix component was estimated to have increased fossil fuel consumption by over 80 trillion Btu in 1986.

The last column in Table 4.3 shows what was not explained in the analysis, the residual computed by subtracting the sum of the individual components from total savings. On the face of it, the fact that some 80 percent of the total savings is not explicitly accounted for is somewhat disappointing. However, the scope of the overall analysis permits us to make some informed judgement as to what factors may comprise the residual. The LBL analysis of the retrofits of the ICP may point us in the right direction in rationalizing the overall results.

The LBL study provides some evidence that envelope retrofits have been responsible for only a small portion of the savings from all type of retrofit activities. In their analysis of ICP grant applications, LBL categorized four types of retrofits could be considered as having their primary impact on fossil fuels: envelope, controls, heating, and HVAC. On the basis of a simple summation across the three building types, the estimated savings from the envelope measures was only about 10 percent of the total savings. The conclusion that the envelope measures would represent a distinct minority of total retrofit savings is also the judgment of building engineers at PNL who have looked at the building conservation program for federal buildings (Federal Energy Management Program or FEMP).

If the measures taken by institutional buildings are any guide to the activities in the remainder of the commercial building stock, we can develop a rough order-of-magnitude estimate for the non-envelope measures. Such an estimate is based upon an assumption that the priority given to conservation measures in the non-ICP buildings was similar to the buildings participating in the program. Given this assumption, we estimate that the 162 trillion Btu of savings from envelope measures represents about ten percent of total retrofit savings. Thus, roughly 1.5 quads of fossil fuel savings may be accounted for by non-envelope retrofits. This figure accounts for most of the 1.8 quads residual as shown in Table 4.3. No data is available that could point to any temporal changes in thermostat settings (e.g. increasing deadbands), or hot water temperatures that may also be a part of the residual.

TABLE 4.3 Components of Change in Commercial Fossil Fuel Consumption, 1972-1986

(Trillion Btu)

Year	Total Savings	Weather	Office Vacancy	Envelope Retrofits	IC Program	Building Type	Regional Shift	New Buildings	Residual
1972	0.0	-0.0	0.0	-0.0		-0.0	-0.0	-0.0	0.0
1973	117.2	70.6	0.0	0.8		-3.4	2.3	-0.0	46.9
1974	410.5	50.3	0.0	1.7		-6.0	4.0	12.4	348.2
1975	685.9	45.0	0.0	5.0		-7.9	5.2	20.8	617.8
1976	454.6	-6.1	0.0	12.2		-10.2	6.5	29.6	422.6
1977	666.2	13.6	0.0	21.9		-12.4	8.0	40.2	595.0
1978	739.2	-41.9	0.0	47.5		-14.9	10.1	53.5	685.0
1979	800.6	-14.4	0.0	77.8		-18.4	12.3	67.9	675.5
1980	1142.9	-5.4	-0.7	113.3	4.7	-24.8	15.9	83.9	956.0
1981	1519.1	25.0	0.1	125.8	10.5	-34.5	19.6	100.6	1272.0
1982	1572.5	15.9	5.3	138.1	19.2	-43.6	22.8	114.4	1300.4
1983	1697.3	10.9	10.5	150.2	23.6	-53.5	26.3	130.0	1399.3
1984	1688.6	30.5	13.6	162.1	30.0	-62.9	30.3	149.0	1335.9
1985	2053.2	12.7	16.8	162.1	33.7	-72.9	34.8	170.8	1695.2
1986	2268.7	61.8	17.5	162.1	37.6	-82.1	39.1	191.1	1841.6

In the most recent period, from 1982 to 1986, the savings figures in Table 4.3 show that conservation activity with respect to fossil fuels has continued in spite of flat or falling fuel prices. Nearly 0.7 quad was saved during this four-year period, nearly as much as the preceding four years.

Electricity

The summary decomposition for electricity is shown in Table 4.4. Column one shows the total savings relative to a 1972 base, as measured at the building site with no generation losses included. The savings are negative since electricity intensity of the stock, as compared to 1972, actually increased over the entire time period. To maintain consistency with Table 4.2 and the tables for the other major sectors, the negative values were retained in the table. As for fossil fuels, figures correspond in concept to the difference in line A and Line C described in section 4.2.1, except that electricity figures are used instead of total primary energy. Had electricity fuel intensity remained at its 1972 value, 1986 consumption would have been over half a quad, 563 trillion Btu (as shown on the bottom of the first column) lower in 1986.

Focusing again on 1986, Table 4.4 reveals that all of the compositional elements contributed to the increase in electricity use. The higher electricity intensities in new buildings, prompted in large degree by the more extensive use of central air conditioning systems and heat pumps, increased consumption by nearly a tenth of a quad (92 trillion Btu), relative to a case in which post-1972 buildings would have shown the same intensity as the existing stock. Both the regional shift and the change in the mix of building types contributed to overall higher electricity use.

The other components all work in the direction of reducing electricity consumption, but their accumulated impact is not large. As described below, the statistical analysis could not identify a significant impact on electricity consumption due to weather. As a result, its contribution was set equal to zero in Table 4.4.

As was the case for fossil fuels, there remains a large residual element that represents increased electricity usage from other factors. Since we have explicitly incorporated an estimate of the impact of new, more electricity-intensive, buildings into the analysis, we can infer that the residual stems

TABLE 4.4 Components of Change in Commercial Electricity Consumption, 1972-1986

(Trillion Btu)

Year	Total Savings	Weather	Office Vacancy	Envelope Retrofits	IC Program	Building Type	Regional Shift	New Buildings	Residual
1972	0.0	-0.0	0.0	-0.0		-0.0	-0.0	-0.0	0.0
1973	-67.3	-0.0	0.0	0.2		-3.7	-0.9	-0.0	-62.9
1974	-15.7	-0.0	0.0	0.3		-5.8	-1.8	-12.8	4.5
1975	-86.7	-0.0	0.0	0.7		-6.8	-2.5	-21.5	-56.6
1976	-141.5	-0.0	0.0	1.3		-8.5	-3.2	-30.7	-100.4
1977	-187.8	-0.0	0.0	2.5		-10.8	-4.0	-41.7	-133.7
1978	-211.2	-0.0	0.0	4.7		-14.2	-5.0	-55.8	-141.0
1979	-210.7	-0.0	0.0	7.7		-18.5	-5.9	-70.9	-123.2
1980	-231.2	-0.0	-0.7	11.1	0.8	-22.7	-7.2	-73.6	-138.9
1981	-325.4	-0.0	0.1	12.5	1.9	-28.7	-8.6	-76.4	-226.2
1982	-343.7	-0.0	5.4	13.9	3.4	-34.0	-9.7	-78.7	-244.0
1983	-355.3	-0.0	10.8	15.3	4.2	-39.9	-11.1	-81.3	-253.3
1984	-441.3	-0.0	14.0	16.7	5.3	-46.2	-12.7	-84.5	-333.9
1985	-513.4	-0.0	17.3	16.7	5.9	-53.2	-14.5	-88.2	-397.3
1986	-578.9	-0.0	17.9	16.7	6.6	-59.3	-16.3	-91.7	-452.9

from increasing electricity use in existing buildings. For office buildings, the increase in office equipment and computers is perhaps the most visible development in this regard. For other building types, the reasons are not clear, although some degree of increased mechanization may be applicable to all building types. The availability of time series of energy use by function, as will result from Bonneville Power Administration's program to meter a large sample of commercial buildings, should help to answer this question directly in the future.

Looking again at the most recent past (1982 and forward), the increase in electricity intensity, as reflected in the change in savings from -348.5 TBtu to -563.4 TBtu in the first column of Table 4.4, seems to have accelerated. Less than fifteen percent of this change can be explained by the specific factors analyzed in the study. As suggested in the previous paragraph, additional research will be required to pin down the specific reasons for the most recent trends.

Total Energy

Table 4.5 shows the decomposition of total site energy consumption, developed by summing the individual entries in Table 4.3 and Table 4.4. On a site basis, the savings in 1986 are still very large, which reflects the predominance of fossil fuel reductions over the increase in electricity use. The two retrofit factors considered explain about 13 percent of total savings. The shift in the composition of buildings was estimated to have increased site energy consumption by over 140 trillion Btu.

Table 4.5 is similar to Table 4.4, but the changes in consumption are now expressed in terms of primary energy. Operationally, the table is derived by simply multiplying the elements of Table 4.4 by 3.4 and adding them to the corresponding elements of Table 4.3.[a] On a primary energy basis, the savings

(a) The savings in column one in Table 4.6 do not match those in column three in Table 4.2. In moving to primary energy in Table 4.6, the calculations are based upon a constant ratio of electricity losses to direct sales for each year from 1972 to 1986. This ratio was taken as the average value over the 1972-1986 period; the actual value used was 2.398. Table 4.2, on the other hand, is based directly on the the published data from EIA which show slight changes from year to year in the ratio of losses to direct sales, depending upon the generation mix of fuels used in actually peaked in 1983; the continuing growth in electricity intensity has served to reduce the level of saving since then.

Tables 4.5 and 4.6 point out the difficulty in interpreting the various components as "explaining" the savings in total energy in the commercial sector. In terms of primary energy, 1986 savings is less than four-tenths of a quad. The sum of factors contributing to lower energy use almost exactly equals the sum of the remaining (compositional) factors leading to higher energy use. Following the logic of the preceding tables, this outcome generates a residual that is roughly the same as the "savings" figure. When we focus on electricity and fossil fuels separately, as the discussion above indicated, the decomposition analysis more readily lends itself to an engineering interpretation.

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generation. The higher level of savings in Table 4.2 relative to Table 4.6 (511 Tbtu vs. 301 Tbtu) stems from a lower ratio of losses to sales in 1986 as compared to 1972. Because the figures in 4.6 exclude the influence of the utility sector, they could be viewed to more accurately portray the savings attributable to the behavior in the commercial sector.

TABLE 4.5 Components of Change in Commercial Site Energy Consumption, 1972-1986

(Trillion Btu)

Year	Total Savings	Weather	Office Vacancy	Envelope Retrofits	IC Program	Building Type	Regional Shift	New Buildings	Residual
1972	0.0	-0.0	0.0	-0.0	0.0	-0.0	-0.0	-0.0	0.0
1973	49.8	70.6	0.0	1.0	0.0	-7.0	1.3	-0.0	-16.1
1974	394.8	50.3	0.0	2.0	0.0	-11.8	2.1	-0.5	352.7
1975	599.2	45.0	0.0	5.7	0.0	-14.6	2.7	-0.7	561.2
1976	313.1	-6.1	0.0	13.5	0.0	-18.7	3.2	-1.0	322.2
1977	478.4	13.6	0.0	24.4	0.0	-23.2	4.0	-1.5	461.3
1978	528.0	-41.9	0.0	52.2	0.0	-29.1	5.1	-2.2	544.0
1979	589.9	-14.4	0.0	85.5	0.0	-36.8	6.4	-3.0	552.3
1980	911.6	-5.4	-1.4	124.4	5.6	-47.6	8.7	10.3	817.1
1981	1193.7	25.0	0.2	138.3	12.3	-63.1	11.1	24.2	1045.8
1982	1228.8	15.9	10.7	152.0	22.6	-77.6	13.1	35.7	1056.5
1983	1347.3	10.9	21.3	165.5	27.8	-93.4	15.2	48.7	1146.0
1984	1247.3	30.5	27.6	178.8	35.3	-109.1	17.7	64.4	1002.1
1985	1539.9	12.7	34.1	178.8	39.7	-126.2	20.3	82.6	1297.9
1986	1689.8	61.8	35.4	178.8	44.2	-141.3	22.8	99.5	1388.7

TABLE 4.6 Components of Change in Commercial Primary Energy Consumption, 1972-1986

(Trillion Btu)

Year	Total Savings	Weather	Office Vacancy	Envelope Retrofits	IC Program	Building Type	Regional Shift	New Buildings	Residual
1972	0.0	-0.0	0.0	-0.0	0.0	-0.0	-0.0	-0.0	0.0
1973	-111.7	70.6	0.0	1.5	0.0	-15.7	-0.8	-0.0	-167.0
1974	357.3	50.3	0.0	2.7	0.0	-25.4	-2.1	-30.4	363.6
1975	391.3	45.0	0.0	7.3	0.0	-30.4	-3.2	-50.9	425.5
1976	-26.2	-6.1	0.0	16.5	0.0	-38.5	-4.3	-72.6	81.4
1977	28.1	13.6	0.0	30.2	0.0	-48.5	-5.4	-98.9	140.7
1978	-21.6	-41.9	0.0	63.2	0.0	-62.1	-6.5	-132.4	205.9
1979	84.4	-14.4	0.0	103.5	0.0	-79.9	-7.5	-168.4	256.9
1980	357.0	-5.4	-3.1	150.3	7.5	-100.6	-8.2	-161.4	483.9
1981	413.3	25.0	0.4	167.5	16.6	-130.0	-8.9	-154.0	503.2
1982	404.5	15.9	23.4	184.4	30.5	-156.9	-9.6	-148.0	471.3
1983	490.0	10.9	46.4	201.2	37.5	-186.4	-10.5	-141.0	538.5
1984	188.9	30.5	60.3	217.8	47.6	-216.9	-11.9	-132.8	201.3
1985	308.5	12.7	74.3	217.8	53.5	-250.3	-13.6	-123.3	444.9
1986	301.4	61.8	77.3	217.8	59.7	-279.7	-15.2	-114.4	302.4

5.0 INDUSTRIAL SECTOR

Since the first oil price shock of 1972-73, important changes have occurred in energy use in the industrial sector. The major objective of this section is to describe these changes in energy use in the industrial sector by statistical estimation of energy savings over time. The estimating procedure will be applied to the sector as a whole and to fuel use for each of the four major fuels: coal, oil, gas and electricity.

Trends in energy use can be observed using primary energy (i.e., including attributed electricity losses) or energy consumed at the site of use (i.e., ignoring these losses). These trends may be somewhat different; each is useful in its own way, and each conveys different information to the analyst. Primary energy use is the appropriate focus if one's concern is the total energy used in the economy, regardless of its origin. Energy consumed on site is the pre-ferred concept if one is interested in the behavior of those using the energy.

Accordingly, this section looks at both primary and on-site use of energy. Primary energy is used in examining overall trends; on-site use when trying to understand how intensity of use and activity levels have changed.

Just as there are alternative ways to look at energy use in various end-use sectors, there are different levels of aggregation that may be appropriate for different end-use sectors. In the industrial sector the level of aggregation is the same as that used by the Energy Information Agency--the industrial sector includes agriculture, mining, construction and manufacturing. Accordingly, the level of activity is the gross product originating in these sectors, and other variables are selected to represent this collection of industries.

The estimating procedure is as follows. First energy use is expressed as a product--activity times intensity. Three such trends receive the most emphasis: 1) energy use that would have occurred if trends in the activity level and intensity from 1960 to 1972 has persisted, 2) energy use that would have occurred at 1972 intensity levels, and 3) actual energy use. The first shows how energy would have been used at historic growth rates for both industry output and intensity levels. The second is an alternative energy measure constructed by multiplying activity by the fixed 1972 intensity level--this represents what energy would have been used if there had been no improvement in energy use efficiency. Two other measures are also used-- 4) actual activity and trended intensity, and 5) actual intensity and trended activity--but little emphasis is placed on these measures.

Since actual activity has been less than extrapolated activity, the difference between the first and second measures is attributed to slower economic growth, which is assumed not to be under the control of the decision-making agents within this sector. The difference between actual energy use and constant-intensity energy use (the intensity component), which is assumed to reflect changes in behavior, is then further decomposed. Regression analysis is used to explain the difference between these two measures of energy use for total fuel and by fuel type. The regression uses a number of variables--behavioral, compositional and others--to decompose the difference into elements explained by these factors.

5.1 GENERAL ENERGY USE TRENDS

Figure 5.1 shows five trends in primary energy use in the industrial sector over the period 1972-1986. Actual energy use (Line A) decreased from 1973 through 1975, then rose from 28.4 quadrillion Btu (quad), the low reached during the 1974-75 recession, to 32.6 quads in 1979. Since then, energy use has declined in every year except 1984. In 1986, actual industrial energy use was 26.5 quads. Had intensity and economic activity grown at historic rates (0.4 and 2.9 percent annually, respectively) energy use (line E) would have grown to 47.5 quads by 1986, an increase of 21 quads, more than 90 percent above actual energy use (line A). If 1972 intensity had remained constant (i.e., if there had been no improvement in energy-use efficiency) then energy use would have grown to 38.2 quads by 1986 (line C), an increase of about 45 percent more than actual energy use. Line B, which shows actual activity and trended intensity, is very similar to Line C, because there was very little trend in intensity over the period 1960-1972. Line D, trended activity and actual intensity, indicates that substantial

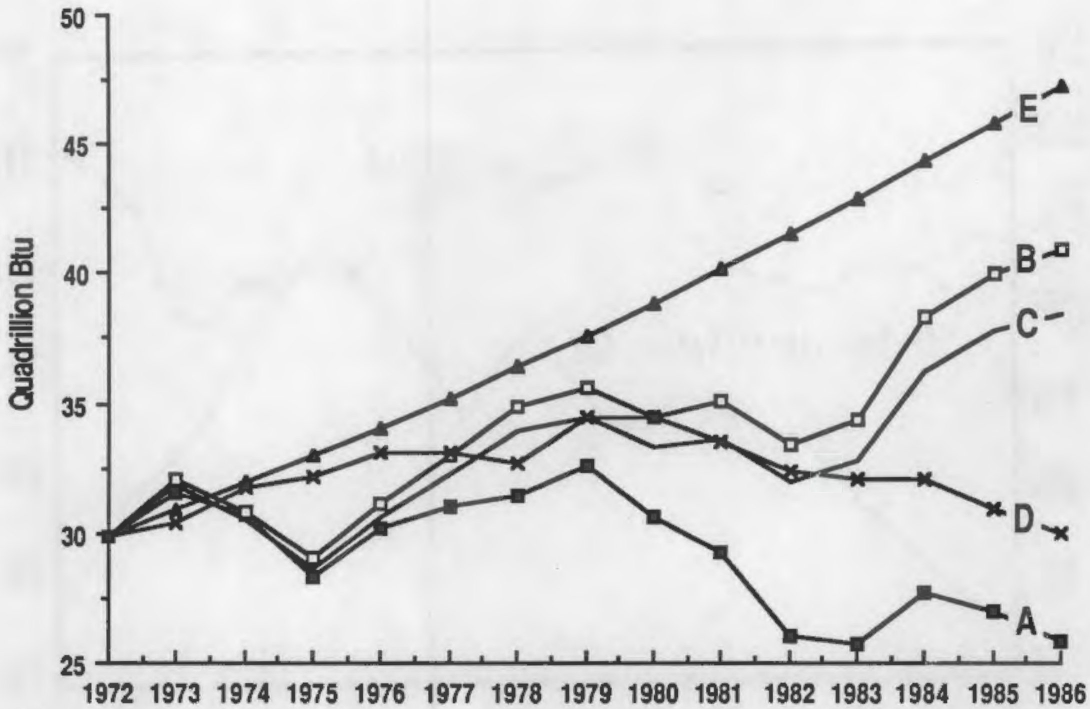

FIGURE 5.1. Trended and Actual Primary Energy Use in the Industrial Sector

savings would have occurred, even at the higher activity growth rate experienced during the period 1960-1972 if actual intensity changes had been realized. Only some of these changes in energy use mirror the changes in economic activity over this same time period.

Since the end of the recession in 1982, actual output has increased steadily, as reflected in Lines B, C and E. Actual energy use declined slightly in 1983, increased sharply in 1984, then declined again in both 1985 and 1986 as shown in Line A. Line D points our the fact that it was the strong growth in 1984 that accounted for the growth in energy use, since energy consumption would have remained unchanged under trended economic growth.

Figure 5.2 shows the activity measure for the industrial sector, defined as the inflation adjusted gross national product originating in agriculture, mining, construction and manufacturing, and energy use intensity (EUI), as constructed by dividing primary energy use by the activity measure. No significance should be attached to the intersection of these two lines.

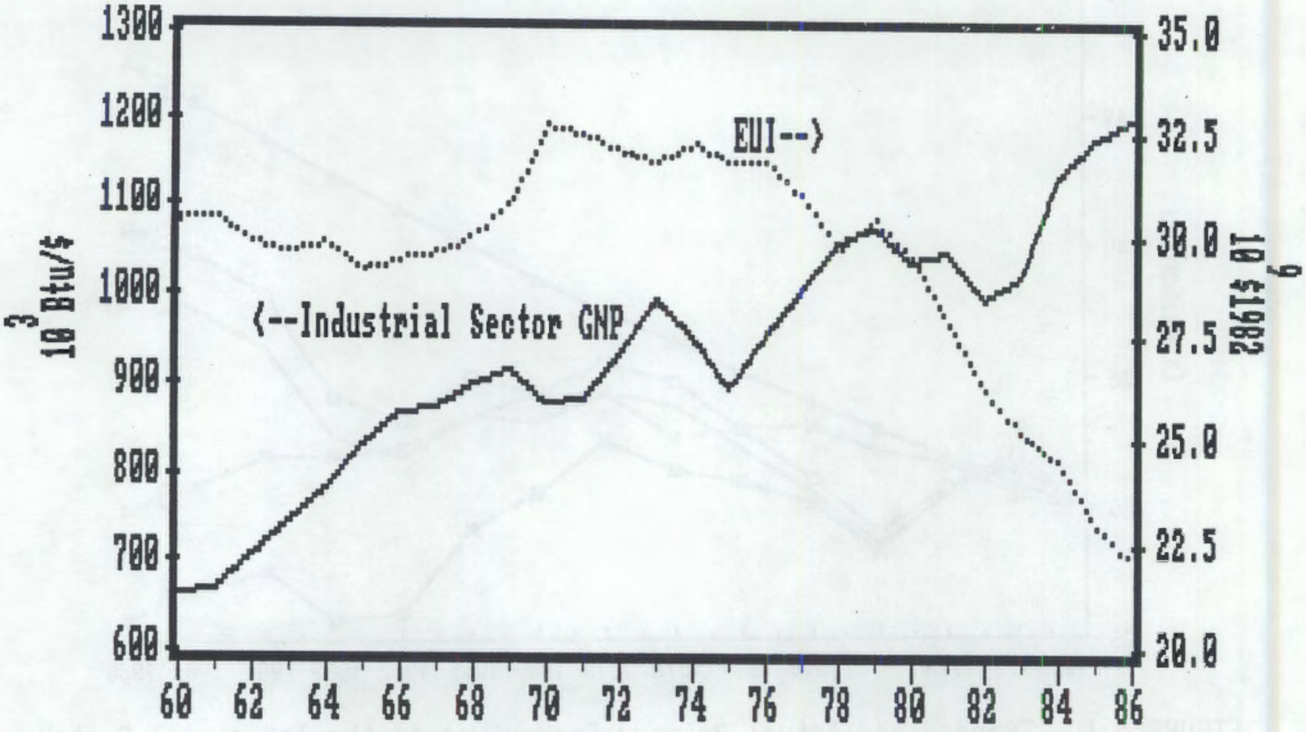

FIGURE 5.2. Activity and Energy Use Intensity

Figure 5.3 shows industrial sector fuel shares for this same period, but accounts for electricity's share based on site consumption (see Appendix A.2 for losses).

From 1960 to 1982, the patterns of output growth and energy use were similar. Output and energy use both grew to a peak in 1973, declined during the 1974-75 recession, then increased until 1979. The mild recession of 1980 and the more severe recession of 1982 caused a modest decline in industrial output that again rose between 1982 and 1986. In the third or fourth quarter of 1983 industrial output exceeded the peak of 1979, while industrial energy use remained about 6 quads less than the 1979 peak. More significantly, energy use continued to decline in 1985 and 1986 while industry output was rising. The energy use intensity reported in Figure 5.2 shows how dramatically the industrial sector has decreased its reliance on energy. After a rapid increase in EUI during the 1960s, intensity remained between 31 and 33 thousand Btu per dollar of output over the period 1970-1976. The EUI then declined until capacity was approached in 1979, when the EUI increased.

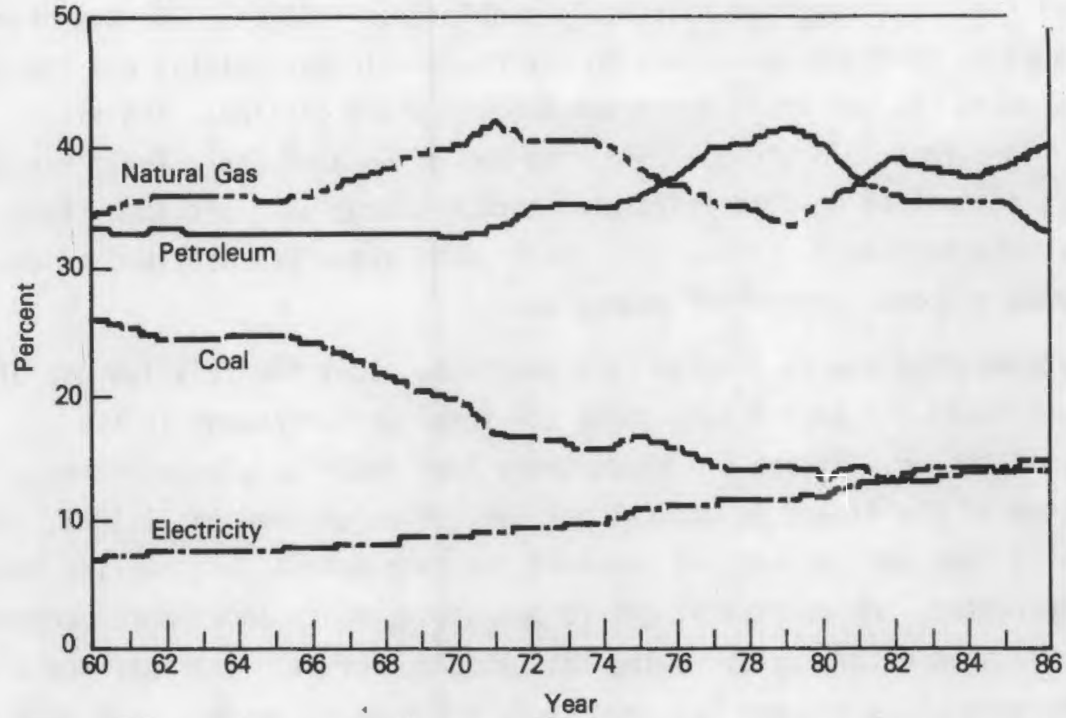

FIGURE 5.3. Fuel Shares in the Industrial Sector

Since then, EUI has declined from about 30 thousand Btu per dollar to 22.5 thousand Btu per dollar, a decline of 25 percent in seven years. One objective of this section is to determine the factors that account for this decline and to see if this reduction in intensity applied to all the major fuels.

Figure 5.3 shows these major fuel shares in the industrial sector over the period 1960 to 1986, after eliminating the electricity sector losses allocated to the industrial sector. Over this 27-year period, natural gas increased its share of industrial energy use from about 34 percent to a peak of 42 percent in 1971. After this period, the share has fluctuated, declining overall to about 33 percent. Electricity has shown a steady increase in its share from about 7 percent in 1960 to nearly 15 percent in 1986. Coal, on the other hand, has shown a steady decline, from about 26 percent in 1960 to 13 percent in 1982; since then, the share has remained stable. The decline in coal's share appears to have accelerated in the mid 1960s, dropping nearly 10 percentage points from 1965 to 1973. Petroleum, as a percent of total fuel use, remained reasonably stable from 1960 to 1970, but thereafter appears to change inversely to the changes in the natural gas share. That is, when the gas share increases the oil share declines, and vice--versa. Thus from 1973 through 1982, the sum of both of these fuels has been about 75 percent of on-site industrial sector energy use, although their relative shares change. Since 1982 their joint share has declined to about 72 percent of total industrial energy use.

Although the shares diagram says something about the relative use of different fuels, it says little about the total use of energy in the industrial sector. Figure 5.4 shows these four fuels in stacked format. At the bottom of the figure is natural gas use, of which grew until 1973. From 1975 until 1980 gas consumption remained fairly constant, but decline somewhat thereafter. Above natural gas is petroleum, which shows more variation after 1972 than natural gas. Using this stacked format, it is difficult to tell how much petroleum use has increased, although it appears that petroleum use is larger in 1986 than in 1960. Above petroleum is coal, which begins the period as a large fraction of total energy use, but steadily declines in

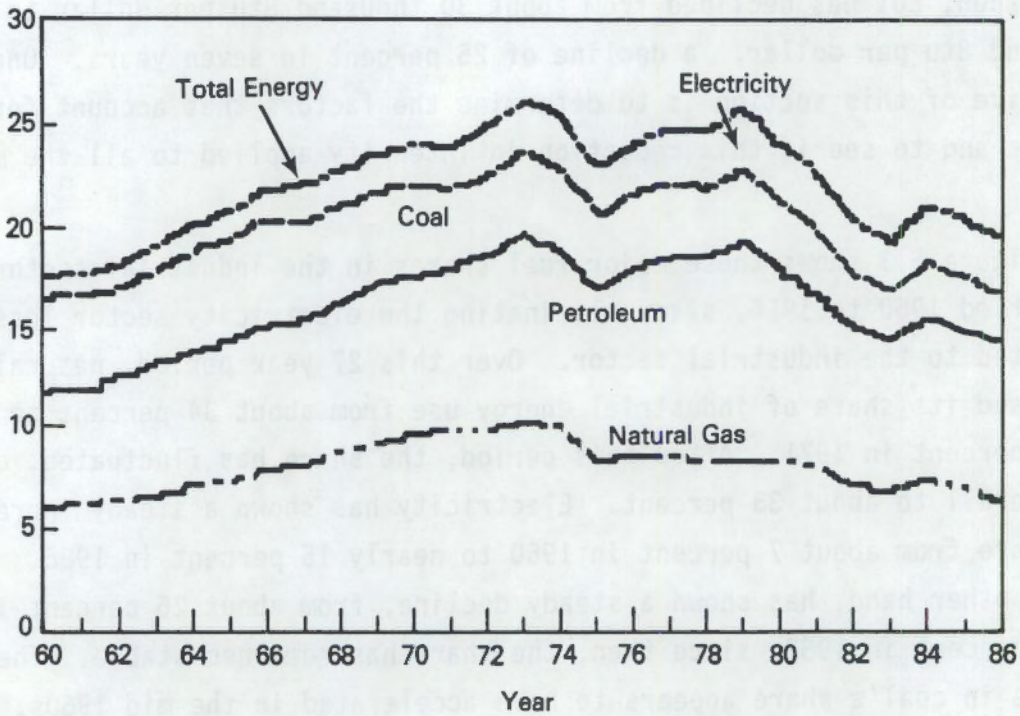

FIGURE 5.4. Energy Use in the Industrial Sector

importance until the early 1980s. Electricity is the final component of total energy use. It is obvious that electricity has increased both relatively and in total over the period from 1960 to 1986.

This stacked format shows energy consumption at the site of use (i.e., ignoring electricity losses). Total site energy use increased steadily from 1960 to 1973, declined for two years, then increased again until 1979. Since then, except for 1984, total energy use has declined steadily. This pattern is similar to primary energy use, except that the level in 1960 is about 2.8 quads lower and about 6.4 quads lower in 1986. This divergence between end-use and primary energy use reflects the increased electricity share shown in Figure 5.3. To better understand the decline in both measures of energy use, energy use intensity needs to be examined in more detail.

The sharp decline in energy intensity that began in 1979 only accelerated a trend that began in the early 1970s, as shown in Figure 5.5.

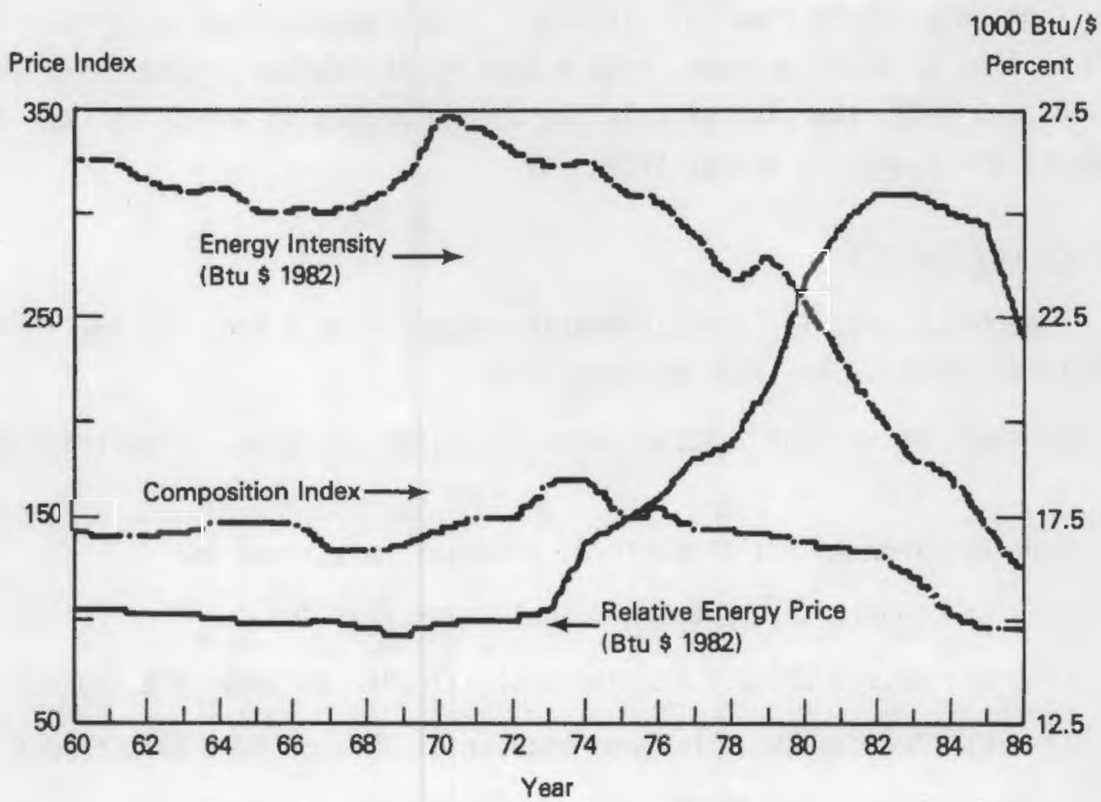

FIGURE 5.5. End-Use Intensity, Composition and Energy Prices

Except in 1974 and 1979, years at the peak of the business cycle, energy intensity declined every year from 1970 to 1986. Even during the sharp increase in energy use in 1984, the intensity declined. Over the period 1982-1986, with the exception of 1984 when the rate of intensity declines slowed, the rate of decline appears to be at about the same rate as from 1979 to 1982.

Figure 5.5 also plots two of the variables that might explain the decline of energy intensity in the industrial sector. The first of these is a composition index that indicated the fraction that five energy-intensive industries contribute to industrial sector GNP. These five industries are food; pulp and paper; petroleum refining; stone, clay and glass; and primary metals. Since the first oil price shock the fraction of industrial sector GNP that originated from these industries has declined but at an unsteady rate. From 1982 to 1985 the rate of decline was especially rapid. The second variable is a measure of energy prices relative to industrial sector output prices, set to equal 100 in 1967. The dramatic rise in prices from 1973 to 1982 is clearly shown, with a decline thereafter. Except for the period past 1982, the plot of relative energy prices is nearly the converse image of the change in energy intensity.

5.2 ENERGY SAVINGS

Figure 5.1 presents the alternative measures of energy use for the industrial sector. The five measures are:

Line A: Actual EUI x actual industrial GNP (or actual industrial energy use)

Line B: Trended EUI (1960-1972) x actual industrial GNP

Line C: Constant 1972 EUI x actual industrial GNP

Line D: Actual EUI x trended industrial GNP, at 1960-1972 trends

Line E: Trended EUI x trended industrial GNP, at 1960-1972 trends

It is clear from Figure 5.4 that energy use has declined substantially since the first oil price shock of 1973. Figure 5.5 indicates that this reduction has primarily been the result of declining industrial sector energy intensity.

The line labeled "A" shows actual end-use energy for the industrial sector from 1972 to 1986 (the period over which the intensity decline was most dramatic). The line labeled "C" in the figure is constructed by multiplying actual industrial sector GNP by the intensity that prevailed in 1972 (26,400 Btu/$). Line E in Figure 5.1 shows estimated energy use had the growth rate of industrial sector GNP continued over this period at historic (1960-1972) rates while the 1972 intensity level prevailed. These labels are consistent with previous trends reports (see Adams, et al., 1985).

5.2.1 Major Findings

Figure 5.1 presents several important findings:

- If industrial sector GNP trends had prevailed and energy intensity remained at 1972 levels, primary energy use in the industrial sector would have been over 38 quads in 1986.
- If the intensity had not changed, actual GNP would have required about 31 quads in 1986.
- The intensity change alone accounted for an energy savings of nearly 15 quads, which is nearly 60 percent of actual 1986 energy use.
- The reduction in growth accounted for another 4 quads of savings.
- The reduction in energy use due both to lower growth and intensity reductions have jointly saved nearly 21 quads; this is more than 80 percent of actual 1986 primary energy use.
- If energy intensity had not declined, the industrial sector would have used an additional 12 quadrillion Btu (Quad) of energy to produce 1986 industrial sector output.

5.3 COMPONENTS OF ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

There are a number of factors that may account for efficiency changes that would lead to a reduction in energy use intensity in the industrial sector. These are technological factors, legal and institutional factors, and economic factors.

Among the technological factors, three items stand out as important for fuel use: the existing stock of technology, research and development, and options for improving fuel use.

Two major legal and institutional factors that influence energy use are government regulations and contractual arrangements. Government regulations are especially important because much of the environmental legislation that was proposed or enacted mandated pollution abatement investment that substituted from other investments. There were also major tax revisions during the period from 1965-1980.

Three sets of economic factors are important in determining the use of energy: 1) factors that apply directly to the fuel, 2) factors that apply to the equipment that uses the fuel, and 3) other factors. The two major economic considerations that apply directly to the fuels are the price of the fuel relative to alternatives and the fraction of total costs represented by fuel costs. Over short periods of time, the equipment available for use in production is fixed; new production lines take time to appear. Associated with that somewhat fixed stock of equipment is a characteristic energy use profile. In most cases, this use profile determines energy consumption in the short run, but there are exceptions to this rule, such as multi-fired burners and electric-boosted furnaces. Over longer periods of time, existing equipment can be modified to provide additional flexibility or to alter the energy-use profile of that equipment. Over even longer periods of time, entirely new technological processes, in the form of new equipment, can be integrated into the production process.

Among the other factors that may be of importance, there are two that are worth noting. The outlook for the industry can focus on growth prospects, in which case, product demand is a major consideration. Alternatively, the outlook may hinge on the ability of the industry to adjust to change--an ability influenced by the industry's structure and performance.

Many of these factors can be embodied in variables that can be used to statistically decompose intensity changes in the industrial sector. One measure is the relative price of energy, which is shown in Figure 5.5. The price variable is important in capturing both the direct economic effects mentioned above and indirect effects such as the speed of adjustment. Accordingly this variable will be referred to as a "market impact" variable. Another variable, an index of the compositional changes in the industrial sector (also shown in Figure 5.5), captures the effect of industries with different energy-use profiles growing at differential rates thereby causing energy use to change over time. Finally, the amount of energy used per unit of output may depend upon the overall operating rate of the industry. If some energy consumption is more or less fixed (e.g. space heating or lights), then higher utilization of existing capacity will also tend to produce savings.

These measures--market impacts, compositional change, and capacity utilization--are used as explanatory variables in a regression that uses the difference between energy use at 1972 intensity levels and actual energy use (i.e., line A subtracted from line C in Figure 5.1) as the dependent variable. The results of this regression are shown in Figure 5.6. The results indicate that the difference between energy use at 1972 intensity levels and actual energy use is largely explained by two factors: the market impacts resulting from firms being faced with higher energy prices and the effect of a changing mix of industries (i.e., composition). Capacity utilization effects are particularly important in 1975 and 1982-1983, both periods of severe business recessions.

Because some of the explanatory variables actually contribute to increased energy consumption ("negative" savings), some compromises have been made in showing the individual components in Figure 5.6. In the period 1973

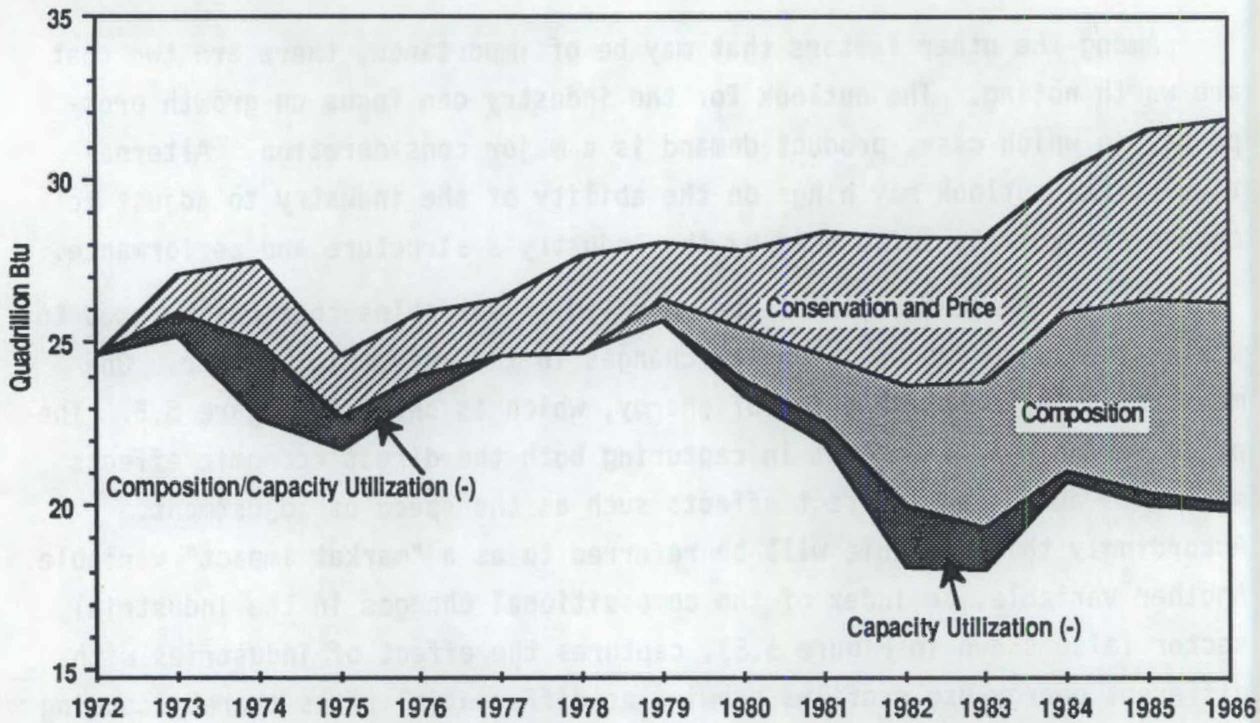

FIGURE 5.6. Decomposition of Sector Energy Use

through 1976, the combined net impact of compositional change and utilization are shown together. In each of these years the combined impact is negative; thus, the dark area shown is under the actual consumption line at the left of the figure.

In 1972 and 1973 the basic energy using sectors of the economy were making a comeback after the 1970-1971 recession. The increased percentage of industrial GNP accounted for by the these sectors lead to increased energy consumption. In 1975 and 1976, low capacity utilization rates tended to increase energy consumption by a similar degree.

Between 1975 and 1979, market impacts account for nearly all the difference between actual and constant-intensity energy use. After 1975, however, the composition variable become increasingly more important, as the relative share of the most energy intensive sectors declined. By 1983 composition and market impacts are competing equally for the fraction of the difference that each of the variables explains. Low utilization rates over the period 1980-1983 (relative to 1972) again tended to increase energy consumption per dollar of industrial output. As shown in Figure 5.6, this impact amounted to nearly 2 quads (of "negative" savings) in 1982 at the depth of the recession. (Again, actual energy consumption runs along the top border of the dark area labeled Capacity Utilization).

These graphs are generated by forecasting the difference between actual and energy use at constant 1972 EUI level, allowing the relative price variables to take on actual values while holding the compositional and capacity utilization variables at their 1972 values. When all the forecasts of total savings have been made, they are then adjusted to eliminate the residual that would otherwise appear for each forecast. Section D.2 in the appendix explains the basic method of construction and reports the results of these regressions.

consumption per dollar of industrial output. As shown in Figure 5.6, this impact amounted to nearly 2 quads (of "negative" savings) in 1982 at the depth of the recession. (Again, actual energy consumption runs along the top border of the dark area labeled Capacity Utilization).

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6.0 TRANSPORTATION SECTOR

6.1 GENERAL ENERGY USE TRENDS

Total transportation energy use grew from 16.9 quadrillion Btu (quads) in 1972 to 20.2 quads in 1986, an annual increase of 1.4 percent. Over the same time period, total transportation activity, as measured in passenger/ freight ton-miles[a] grew at an annual rate of 3.3 percent, from .31 to .45 trillion ton-miles, as shown in Table 6.1. The difference in growth rates between energy use and activity level is reflected in the decreased energy use intensity (EUI). Between 1972 and 1986, the transportation EUI fell from 54.9 thousand Btu per ton-mile to 44.9 thousand Btu per ton-mile, a 1.3 percent annual decrease. The time period of 1982 through 1986, however, mark a period of rapid changes in transportation energy use, activity level, and EUI, that contrasts the 1972-1982 time period. The changes in energy use are represented as line A in Figure 6.1.

While transportation energy use increased an annual .9 percent between 1972 and 1982, the 1982-1986 time period showed annual increases of 2.3 percent. The growth in activity level, likewise, increased from 2.0 to 4.9 percent annually between the 1972-1982 and 1982-1986 time periods. Both of these change in rates led to the decrease in the EUI. In 1972-1982 period, the EUI decreased 1.1 percent. Between 1982 and 1986, the EUI decreased two times more quickly, at a rate of 2.2 percent annually.

6.2 ENERGY SAVINGS

6.2.1 Alternative Measures of Primary Energy Use

Figure 6.1 presents the alternative measures of energy use for the transportation sector. The five estimates are:

Line A:Actual EUI x actual ton-miles or actual energy use

Line B: Trended EUI (1960-1972) x actual ton-miles

Line C: Constant 1972 EUI x actual ton-miles

Line D: Actual EUI x trended ton-miles

Line E: Trended EUI x trended ton-miles

(a) A fixed-weight combination of passenger miles and ton-freight miles. See Appendix for derivation of this unit.

TABLE 6.1. Total Transportation Energy Use and Activity

Year	Energy Use (trillion Btu)	Activity Level (trillion ton-miles)	Energy Intensity (Btu/ton-mile)
1972	16910	0.308	54939
1973	17850	0.323	55243
1974	17420	0.318	54728
1975	17630	0.317	55570
1976	18420	0.343	53696
1977	19260	0.363	53067
1978	20040	0.383	51610
1979	19680	0.389	60614
1980	19060	0.380	50157
1981	18840	0.380	49532
1982	18480	0.376	49207
1983	18628	0.394	47333
1984	19338	0.412	46954
1985	19600	0.427	45892
1986	20200	0.450	44920
Annual Percent Growth:			
1972-1982:	0.9	2.0	-1.1
1982-1986:	2.2	4.6	-2.3

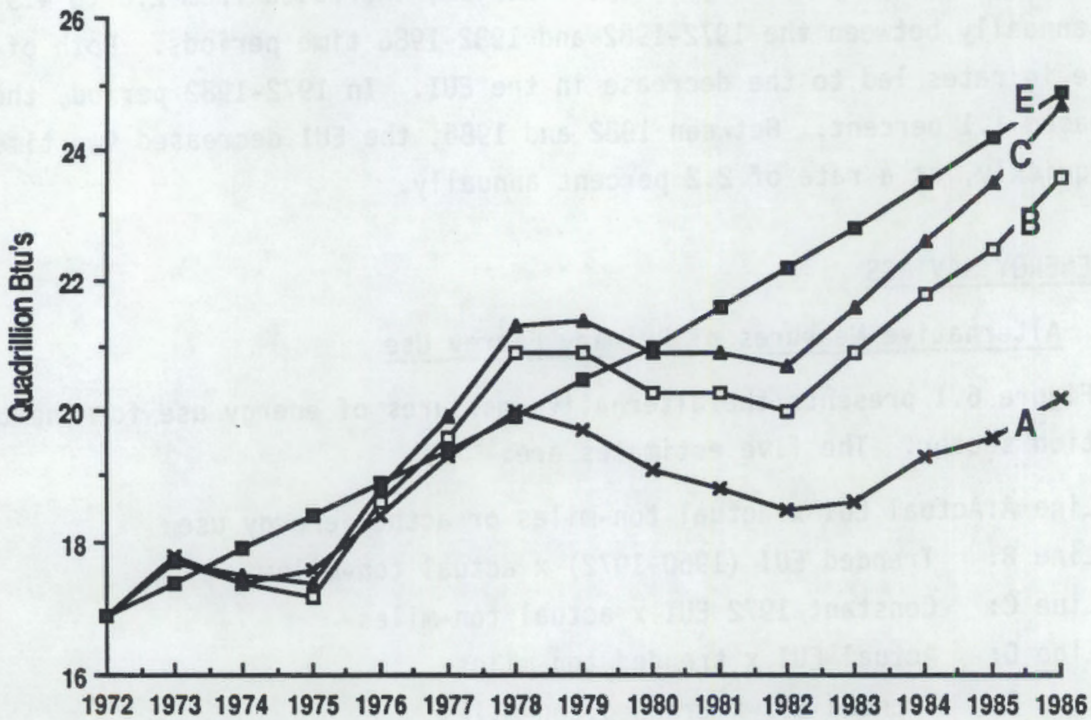

FIGURE 6.1. Energy Trends in the Transportation Sector

6.2.2 Major Findings

Figure 6.1 and Table 6.2 show total energy savings in the transportation sector over the 1972-1986 time period.

- In 1986, transportation energy use is 19 percent (4.7 quads) below that which would have occurred had trends in EUI and activity continued at historical rates of change. (Line E minus Line A in Figure 6.1).
- Improvements in the technological and operating efficiency of transport over and above the 1972 level account for net energy savings of 4.5 quads in 1987. (Line C minus Line A).
- If one accounts for the continuation of the underlying trend in the reduction of EUI observed in the 1960-1972 time period, the energy savings attributable to the "marginal" improvements in the 1970s and 1980s drop to 3.4 quads in 1986.
- Reduced levels of activity also contributed to transportation energy savings. In 1986, activity is 5 percent below that implied by the continuation of historical trends and yields savings of 1.3 quads. (Line E minus Line B).

TABLE 6.2. Energy Trends in the Transportation Sector (quadrillion Btu's)

Year	Actual Energy A	Decreased Economic Activity E-B	Decreased EUI Relative to Pre-72 Trends B-A	Decreased EUI Relative to 1972 C-A
1972	16.9	-0.02	0.02	0.02
1973	17.8	-0.29	-0.11	-0.05
1974	17.4	0.54	-0.04	0.07
1975	17.6	1.15	-0.35	-0.18
1976	18.4	0.30	0.20	0.44
1977	19.3	-0.23	0.33	0.64
1978	20.0	-1.01	0.91	1.32
1979	19.7	-0.40	1.20	1.67
1980	19.1	0.65	1.25	1.78
1981	18.8	1.32	1.48	2.08
1982	18.5	2.19	1.51	2.16
1983	18.6	1.92	2.28	3.03
1984	19.3	1.73	2.47	3.32
1985	19.6	1.69	2.19	3.87
1986	20.2	1.27	3.43	4.51

These savings have fluctuated over time. In the 1980-1986 period, for example, savings due to decreased economic activity first rose and then fell following cyclical changes in the economy. Similarly, the annual growth in savings due to decreased EUI (relative to pre-1972 trends) rose from 13 percent in the 1978-1982 time period to twenty percent between 1982 and 1986. This growth in savings reflects the rapid proliferation of fuel efficient technologies in the fleet of motor vehicles in operation which began to occur in the early and mid-1980s.

6.3 COMPONENTS OF ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

6.3.1 Light Duty Vehicles

Figure 6.2 and Table 6.3 summarize the fuel savings attributable to changes in each of the factors influencing fuel use and efficiency in light duty vehicles. In 1986 fuel use is reduced by almost 28 percent (2.44 MMB/D) relative to that which would have occurred had overall light duty vehicle fuel efficiency not improved over 1972 levels.

LDT/Auto Shift. The shift towards greater use of light duty trucks (LDT) actually increased 1986 fuel consumption by 0.24 MMB/D more than what would have occurred had the proportion of LDTs of total light duty vehicles in use remained at the 1972 level of 14.5 percent instead of rising to 20.9 percent. This increase in fuel use reflects the generally lower fuel efficiency of LDTs in comparison with automobiles.

Urban/Rural Shift. In addition, the shift towards increased urban driving also has increased light duty vehicle fuel consumption relative to what would have occurred has 1972 conditions remained constant through time. However, the impact is not quite as great as the shift between LDTs and automobiles. In 1986, the shift towards greater urban driving increased fuel use by 0.06 MMB/D.

Technological Improvements. Technological improvements in new vehicle fuel economy have constituted the largest component of energy savings in lightduty vehicles throughout most of the 1972-1986 time period. As shown in Table 6.3 and Figure 6.2, this component accounted for about 2.36 MMB/D in fuel savings in 1986.

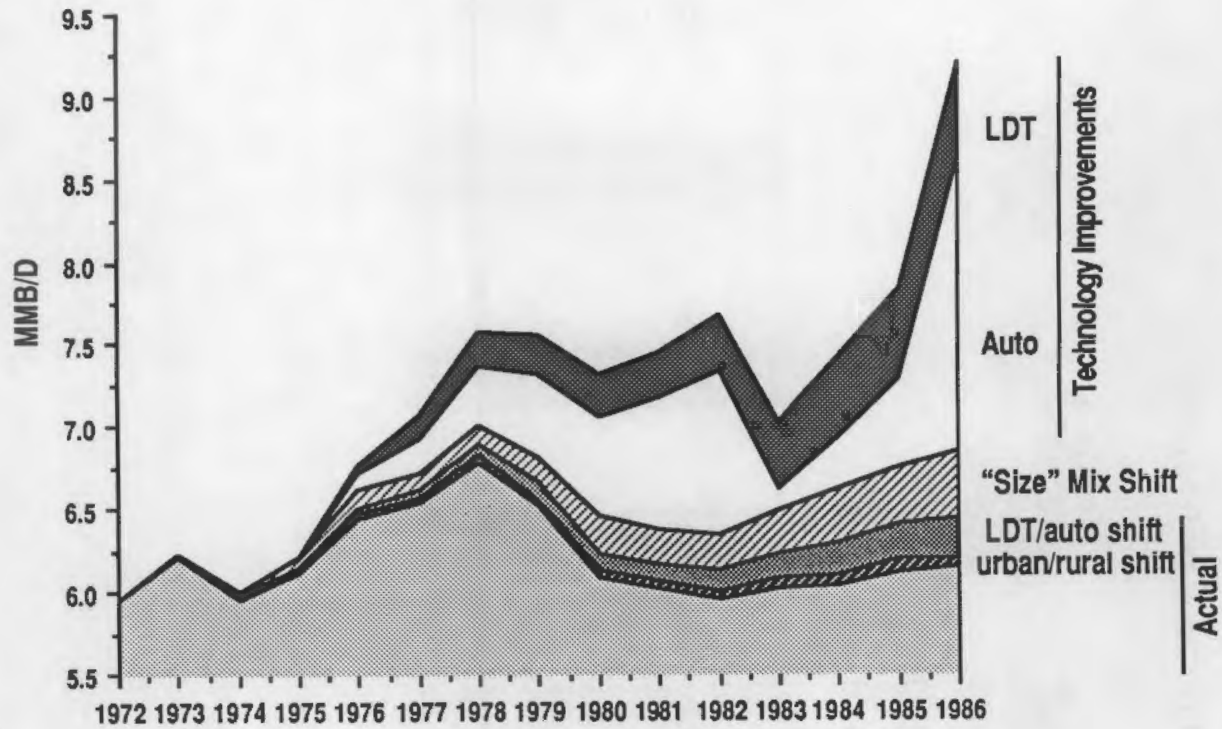

FIGURE 6.2. Components of Energy Savings in Light Duty Vehicles (automobiles and light duty trucks)

Size Shifts. Shifts in the mix of vehicle sizes in operation also have contributed to fuel savings in the light duty vehicle subsector. This component measures the increased fuel efficiency attributable to the shift towards smaller vehicles such as compact pick-ups and subcompact automobiles which generally have higher fuel economy than their larger counterparts. As shown in Table 6.3, shifts in the size mix of new automobiles and new LDTs produced savings of 0.4 MMB/D in 1986. About 62 percent of the savings measured by this component are contributed by automobiles with the balance contributed by LDTS.

6.3.2 Commercial Airlines

Between 1972 and 1986 the total revenue passenger miles flown by aircraft in U.S. commercial airline service more than doubled. Over the same time period, the total fuel consumed by U.S. commercial aircraft increased by only 28 percent. During this 14-year time span, the efficiency of the aircraft

TABLE 6.3. Components of Energy Savings in Light Duty Vehicles (MMB/D)

Year	Actual	Urban/ Rural Shift	LDT/Auto Shift	Size Mix Shift Auto	Size Mix Shift LDT	Technology Improvements Auto	Technology Improvements LDT	Total Savings
1972	5.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	6.23	-0.01	-0.01	0.00	0.00	-0.02	0.00	-0.04
1974	5.98	-0.02	-0.01	0.02	0.00	-0.06	0.00	-0.07
1975	6.15	-0.02	-0.02	0.06	0.00	-0.06	0.00	-0.04
1976	6.51	-0.03	-0.04	0.10	0.00	0.10	0.06	0.19
1977	6.62	-0.04	-0.05	0.10	0.00	0.21	0.14	0.36
1978	6.90	-0.04	-0.08	0.10	0.00	0.37	0.20	0.55
1979	6.66	-0.04	-0.10	0.13	0.02	0.51	0.23	0.75
1980	6.23	-0.04	-0.10	0.19	0.03	0.61	0.25	0.94
1981	6.17	-0.04	-0.11	0.18	0.03	0.79	0.28	1.13
1982	6.13	-0.05	-0.12	0.18	0.03	0.99	0.34	1.37
1983	6.23	-0.06	-0.15	0.20	0.05	1.13	0.41	1.58
1984	6.29	-0.07	-0.19	0.24	0.09	1.31	0.48	3.45
1985	6.41	-0.08	-0.21	0.23	0.10	1.54	0.55	2.13
1986	6.44	-0.06	-0.24	0.25	0.15	1.77	0.59	2.46

TABLE 6.4. Summary Statistics for Commercial Aircraft

Year	RPM/G(a)	TRPM(b)	Total Fuel (MB/D)	Average Load Factor	Seats per Aircraft	Seat-miles per Gallon	Gallons per 1000 Aircraft Miles
1972	16.92	1613	622	53.2	127	31.8	4005
1973	17.26	1650	623	52.1	135	33.1	4072
1974	19.15	1664	567	54.6	140	35.0	4003
1975	19.19	1663	565	53.5	143	35.9	4000
1976	20.39	1845	590	55.5	147	37.0	3979
1977	20.93	1988	620	55.7	150	37.6	3985
1978	23.62	2306	637	61.3	153	38.5	3969
1979	24.95	2576	674	62.8	156	39.7	3931
1980	24.67	2449	647	59.0	160	41.8	3839
1981	25.05	2366	616	57.4	165	43.6	3788
1982	26.78	2521	611	58.8	170	45.6	3757
1983	28.16	2752	638	60.4	172	46.6	3701
1984	27.77	2991	702	59.2	171	46.9	3641
1985	29.15	3286	735	61.4	173	47.5	3638
1986	29.17	3550	794	60.3	171	48.7	3510

(a) RPM/G = Revenue passenger miles per gallon.
(b) TRPM = Total revenue passenger miles (x 100,000,000).

fleet (as measured in revenue passenger miles per gallon of fuel consumed) rose over 72 percent (see Table 6.4). If the U.S. commercial airline industry had attempted to deliver the same number of revenue passenger miles recorded in 1986 with 1972 levels of efficiency, total fuel consumption would have been 65 percent (or 517 MB/D) higher than it actual consumption in 1986. Figure 6.3 and Table 6.5 present the fuel savings attributable to the various components of the overall trend in commercial aircraft fuel efficiency.

Mix Shift. Shifts in the mix of aircraft in use provided 200 MB/D or 38.7 percent of the total fuel savings in 1986.

Seat Capacity. Increases in the seating density per aircraft also contributed a large proportion of total 1986 fuel savings, 25.1 percent.

Technological Improvements. Improvements in jet engine efficiency and more efficient aircraft operating procedures provided 81 MDD or 16 percent of the total reduction in 1986 fuel use, while better load management accounted for the remaining 20.2 percent (or 106 MB/D). Fuel savings attributable toimprovements in technical and operating (T&O) efficiency grew 8 percent per year in the early 1980s due to the introduction and expanded use of more fuel efficient aircraft such as the Boeing 757/767 series and the re-engining of aircraft such as the McDonnell Douglas DC8-61. However, this growth slowed to about 4 percent per year in the mid 1980s (1983-1986) and is likely to continue to be low in a near future that is characterized by stable fuel prices.

As shown by the trends illustrated in Figure 6.3, future improvements in commercial aircraft fuel efficiency are most likely to result from continued shifts in the mix of aircraft in-use. This is particularly evident as the pressures of industry deregulation and increased competition are forcing the airlines to constantly re-assess and juggle aircraft route assignments to meet shifts in passenger traffic. The growth in average load factor and in average seats per aircraft appear to have reached a plateau since 1983 (see Table 6.5). Therefore, future increases in fuel savings attributable to these two components are likely to be small.

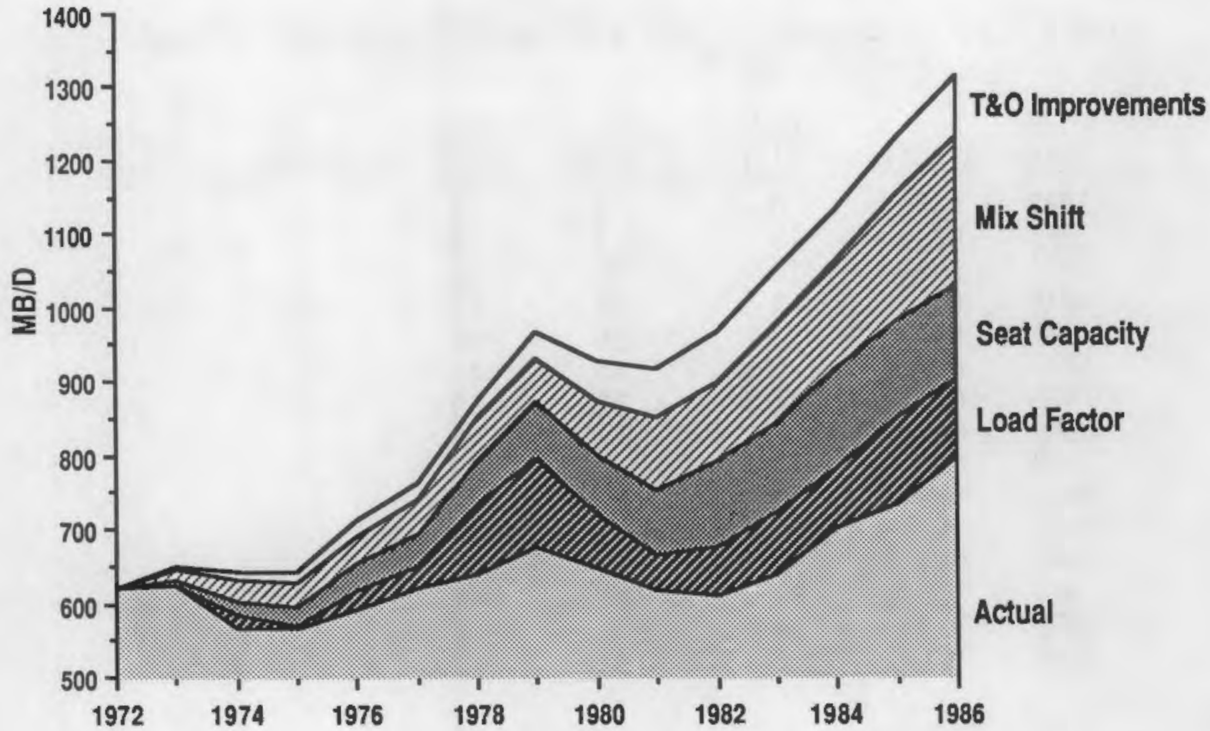

FIGURE 6.3. Energy Conservation in Commercial Aviation

6.4 SUMMARY

While total transportation energy use grew at an annual rate of 1.4 percent between 1972 and 1986, total transportation economic activity grew annually at 3.3 percent. The 1982-1986 time period, in particular, showed much larger annual increases in energy use and economic activity than in the 1972-1982 time period, nearly doubling the rate of decrease in the EUI from 1.1 to 2.2 percent annually.

Energy savings that occurred due to efficiency improvements since 1972, can be attributed to technology improvements in light duty vehicles, while several factors in the light duty vehicle subsector actually decreased savings. The shift from rural to urban driving and from automobiles to light duty trucks increased energy consumption and displaced 14 percent of the savings that occurred in the subsector. In commercial airlines, several different factors created energy savings including the shifts in the mix of aircraft being used, and seating capacity. Technological and operational improvements also contributed to the savings.

TABLE 6.5. Components of Fuel Efficiency Improvement in Commercial Aircraft (MB/D)

Year	Actual	Load Factor	Seat Capacity	Mix Shift	T&O Improvement	Total Savings
1972	622	0	0	0	0	0
1973	623	-13	7	17	1	12
1974	567	15	20	30	11	76
1975	565	3	26	33	16	78
1976	590	26	36	38	22	122
1977	620	29	45	45	23	142
1978	637	97	59	55	23	234
1979	674	122	74	61	37	294
1980	647	71	80	73	57	281
1981	616	49	88	98	65	300
1982	611	65	114	106	69	354
1983	638	86	120	133	72	411
1984	702	79	134	145	71	429
1985	735	113	132	172	76	493
1986	794	106	130	200	81	517

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APPENDIX A

UNITED STATES

APPENDIX A

UNITED STATES

The table below gives the complete data for the various measures of energy use presented in Section 2.0 of the report.

TABLE A.1. Alternative Measures of Primary Energy Use in the U.S. Economy, 1972-1986 (Quads)

Year	A	B	C	D	E
1972	71.3	71.3	71.3	71.3	71.3
1973	74.4	75.2	75.0	73.4	74.2
1974	72.5	75.1	74.6	74.7	77.3
1975	70.6	74.3	73.6	76.4	80.5
1976	74.4	78.2	77.2	79.7	83.8
1977	76.3	82.1	80.8	81.1	87.3
1978	78.2	86.8	85.1	81.9	90.9
1979	78.9	89.2	87.2	83.8	94.7
1980	76.0	89.3	87.1	83.9	98.6
1981	74.0	91.4	88.8	83.2	102.7
1982	70.8	89.3	86.5	84.8	107.0
1983	70.5	92.8	89.6	84.6	111.4
1984	74.0	99.4	95.7	86.4	116.0
1985	74.0	102.7	98.6	87.0	120.8
1986	74.3	106.1	101.5	88.1	125.8

APPENDIX B

RESIDENTIAL SECTOR

APPENDIX B

RESIDENTIAL SECTOR

The estimation of energy use and conservation trends in the residential sector is based on a regression analysis of RECS data and an associated simulation model which helps to calculate "what would have been".

B.1 REGRESSION ANALYSIS

Regression models were estimated for both electricity and natural gas. These models were structured to provide elasticities of energy consumption with respect to heating-degree-days, number of persons per household, vintage, and price. Elasticity information from the regressions was then used to help simulate energy consumption from 1972 through 1986.

B.1.1 Electricity

Electricity Regression

The following explanatory variables were used in a regression of residential energy consumption. The dependent variable was the amount of electricity consumed from April 1984 through March 1985.

R-squared = 0.690

Variable	Coefficient	t-statistic
INTERCEPT	-4712.8	-12.29
ELSH1	-7527.92	-10.09
ELSH1*NHEATDD	0.850844	10.23
ELSH1*HOMEAREA	2.299658	9.33
ELSH1*(WINDOWS + DOORS)	87.96	2.26
ELSH1*MULTI	-246.94	-0.53
ELSH1*MOBILE	1218.681	2.05
ELSH1*WOOD2	1106.376	2.83
ELSH1*YRBUILT	-1000.04	-2.91
ELSH2	-359.19	-0.97
ELSH2*NHEATDD	0.047825	0.67
ELSC	-3135.09	-13.30
ELSC*NCOOLDD	1.632167	9.61
ELSC*NROOMAC	487.99	13.12
ELWH	-2906.74	-7.61

ELWH*NHSLDMEM	894.439	10.58
NREFRIG	1015.742	6.29
ELDISH	1234.582	9.12
ELCW	851.79	4.90
ELCD	1094.297	7.65
FREEZEN	1246.356	9.86
NHSLDMEM	712.45	15.36
PRICE	-0.375563	-15.92

where ELSH1 = 1 if electricity is the primary heating fuel
ELSH2 = 1 if electricity is the secondary heating fuel
ELSC = 1 if electricity is used for space cooling
ELWH = 1 if electricity is used for water heat

NHEATDD = Number of heating-degree-days
HOMEAREA = Area of home in square feet
WINDOWS = Number of windows
DOORS = Number of outside doors
MULTI = 1 if residence is in a multi-family building
MOBILE = 1 if residence is a manufactured home
WOOD2 = 1 if wood is used as a secondary heating fuel
YRBUILT = 1 if residence was built after 1974
NCOOLDD = Number of cooling-degree-days
NROOMAC = Number of rooms air conditioned
NHSLDMEM = Number of household members
NREFRIG = Number of refrigerators
ELDISH = 1 if electric dishwasher is present
ELCW = 1 if electric clothes washer is present
ELCD = 1 if electric clothes dryer is present
FREEZEN = 1 if electric freezer is present

Electricity Elasticities

The price variable in the electricity regression is constructed so that its coefficient is an elasticity.

PRICE = (ELSH1*4905 + ELSH2*547 + ELSC*2013 + ELWH*3714 + 5202)*LOG(DOLLAREL/KWH)

where LOG is the natural logarithm
DOLLAREL is household expenditure on electricity
KWH is the number of kilowatt-hours of electricity consumed

This price elasticity calculation is therefore based on the average revenue or "average price", (DOLLAREL/KWH). All end-uses are assumed to have the same price elasticity, with each end-use weighted by its average consumption. For example, the average household that uses electricity for space heat consumes

4905 kilowatt-hours of electricity for space heat. The end-use weights were derived from an electricity regression without the PRICE term. The estimated price elasticity for electricity is -0.376, which means that a 10% price increase is associated with a 3.76% reduction in electricity consumed.

Other elasticities are calculated using the estimated coefficients and the mean of the explanatory variable. For example, to calculate the elasticity of electric water heat to the number of persons per household, the average number of persons per household (2.69 in 1984) is required. The average electric water heating load (3714 kwh) is also needed.

Water Heat Elasticity with respect to NHSLDMEM

= Regression Coefficient * (2.69/3714)
= 894.439 * (2.69/3714)
= 0.648

This means that a 10% increase in the number of persons per household is associated with a 6.48% increase in electricity consumption for water heat. It is assumed that electricity consumption for appliance usage is also correlated with the number of persons per household. Appliance usage is defined here as any electricity consumption except for space heat, water heat, and air conditioning.

Appliance Elasticity with respect to NHSLDMEM

= Regression Coefficient * (2.69/5202)
= 712.45 * (2.69/5202)
= 0.368

We are also interested in the weather response of electric space heat consumption. According to the 1984 RECS survey, the average electrically heated home experienced 3481 heating-degree-days during the 1984/1985 heating season. The following elasticity calculation shows that a 10% change in heating-degree-days (on a cross-sectional basis) is associated with a 6.04% change in electricity consumption for space heat.

Space Heat Elasticity with respect to HHEATDD

= Regression Coefficient * (3481/4905)
= 0.851 * (3481/4905)
= 0.604

The regression estimates also provide information on homes built after 1974. Since the YRBUILT variable in the regression only takes on values of zero or one, an elasticity is not calculated. The regression coefficient (-1000.04) indicates that the average electrically space heated home built after 1974 uses 1000 fewer kwh than a comparable home built before 1974. This translates to a 20.4% reduction in electric space heat load.

B.1.2 Natural Gas

Natural Gas Regression

The following explanatory variables were used in a regression of residential energy consumption. The dependent variable was the amount of natural gas consumed from April 1984 through March 1985.

R-squared = 0.586

Variable	Coefficient	t-statistic
INTERCEPT	43.577	0.97
NGSH1	-421.034	-10.42
NGSH1*NHEATDD	.085223	22.20
NGSH1*HOMEAREA	.136165	12.48
NGSH1*(WINDOWS + DOORS)	17.843	12.45
NGSH1*MULTI	-18.155	-0.78
NGSH1*MOBILE	1.560236	0.04
NGSH1*WOOD2	-56.412	-2.51
NGSH1*YRBUILT	-183.621	-7.02
NGSH2	-52.332	-0.73
NGSH2*NHEATDD	0.030101	2.10
NGWH	48.334	1.14
NGWH*NHSLDMEM	29.055	2.30
NGCOOK	116.085	6.94
GASDRYER	34.530	1.92
GASLIGHT	210.590	4.22
NHSLDMEM	23.749	2.06
PRICE	-0.455	-12.30

where NGSH1 = 1 if natural gas is the primary heating fuel
NGSH2 = 1 if natural gas is the secondary heating fuel
NGWH = 1 if natural gas is used for water heat

NGCOOK = 1 if natural gas is used for cooking
GASDRYER = 1 if a natural gas clothes dryer is present
GASLIGHT = 1 if natural gas is used for outside lighting

Natural Gas Elasticities

The price variable in the natural gas regression is constructed so that its coefficient is an elasticity.

PRICE = (NGSH1*653 + NGSH2*141 + NGWH*214 + 145) *LOG(DOLLARNG/THERMNG)

where LOG is the natural logarithm
DOLLARNG is household expenditure on natural gas
THERMNG is the number of therms of natural gas consumed

This price elasticity calculation is therefore based on the average price, (DOLLARNG/THERMNG). All end-uses are assumed to have the same price elasticity, with each end-use weighted by its average consumption. For example, the average household that uses natural gas for space heat consumes 653 therms for space heat. The end-use weights were derived from a natural gas regression without the PRICE term. The estimated price elasticity for natural gas is -0.455, which means that a 10% price increase is associated with a 4.55% reduction in natural gas consumed.

As with electricity, other elasticities are calculated below.

Water Heat Elasticity with respect to NHSLDMEM

= Regression Coefficient * (2.69/214)
= 29.055 * (2.69/214)
= 0.365

Space Heat Elasticity with respect to HHEATDD

= Regression Coefficient * (4848/653)
= 0.0852 * (4848/653)
= 0.633

Note that both electricity and natural gas have very similar elasticities of spaces heat with respect to heating-degree-days. Since natural gas is used more often in colder climates, the average number of heating-degree-days is greater.

The regression estimates also provide information on homes built after 1974. Since the YRBUILT variable in the regression only takes on values of zero or one, an elasticity is not calculated. The regression coefficient (-183.621) indicates that the average home built after 1974 uses 184 fewer therms than a comparable home built before 1974. This translates to a 28.1% reduction in natural gas space heat load.

B.2 SIMULATION

A simulation model was constructed to explain (site) energy use per household from 1972 through 1986. This model is an aggregate model, aggregated by fuel type. The model is driven by explanatory variables and elasticities derived from the 1984 RECS survey. Four end-uses are modeled: space heating, air conditioning, water heat, and appliances. The simulation model does not distinguish among fuel types, so that fuel switching (except to wood) is ignored. Most of the end-uses are dominated by one fuel.

Shares of Total Energy Consumed by Households in 1984

	Electricity	Natural Gas	Other
Space Heat	3.3%	38.7%	14.6%
Air Conditioning	4.0%	--	--
Water Heat	3.7%	12.2%	2.3%
Appliances	16.9%	3.9%	0.4%
Total	27.4%	55.1%	17.4%

Source: Annual Energy Review, 1986, page 49.

The Other category includes distillate fuel oil, kerosene, and liquefied petroleum gases. Note that fossil fuels dominate space heat and water heat, while electricity dominates appliance consumption. Natural gas is the dominant fuel overall, accounting for 55% of residential energy consumption. It is especially important to note that all of the above figures are based on site electricity, which does not include generation and transmission losses. If losses w re included, then electricity would be the dominant fuel instead of natural gas.

B.2.1 Key Variables in the Simulation

Using the 1984 RECS survey, cross-sectional regression models were constructed for electricity and natural gas. These models identified variables which helped explain cross-sectional variation in residential energy consumption. Some of these variables also change over time, and these form the basis of a simulation from 1972 through 1986. For example, household energy consumption varies with the number of persons per household, and the average number of persons per household has been steadily decreasing from 1972 through 1986. National average heating-degree-days vary from year to year. The percentage of the housing stock built after 1974 is steadily increasing. Newer households tend to be located in warmer climates. The percentage of households using wood heat has increased. Fuel prices (in 1985 dollars) have increased. The percentage of households with air conditioning has increased dramatically.

Annual time series data were collected for the variables which varied significantly over time. The time series were then converted to indexes, with their value in a base year (1984 or 1972) set equal to one. Using 1984 as a base year, a simulation model was constructed incorporating all of these variables to explain energy use per household from 1972 through 1986. Once a reasonable fit was obtained, the simulation was rebased to 1972, so that energy savings components relative to 1972 could be calculated.

B.2.2 Simulation Model Structure

Each of the four end-uses is simulated over time as the product of various indexes. Each index is equal to 1.0 (except for heating- and cooling-degree--days) during the base year, 1972. Each index also has an optional exponent, equal to the elasticity of the corresponding explanatory variable. For example, energy use for water heat decreases with the number of persons per household, but not in direct proportion. A 10% decrease in the number of persons per household results in less than a 10% decrease in energy consumption for water heat. This effect is captured by taking an index of the number of persons per household and raising it to a power equal to the elasticity of water heat with respect to the number of persons per household.

Some of the indexes used to simulate energy consumption do not have an associated elasticity, which can be modeled as having an elasticity of 1.0. The elasticities used in a time series simulation might not be equal to an estimated cross-sectional elasticity. Weather, or heating-degree-days, is a good example. Homes in colder climates are better insulated than homes in warmer climates. This means that the cross-sectional weather response is less than it would be on a time series basis, where insulation levels would not vary systematically with changes in heating-degree-days.

From the regression model for natural gas, the cross-sectional elasticity of space heat with respect to heating-degree-days was found to be 0.63. On a cross-sectional basis, an increase in heating-degree-days of 10% is associated with an increase in space heat consumption of 6.3%. This is only a lower bound for the time series elasticity, which would apply if all homes had the same insulation levels, regardless of climate. For this report, it is assumed that the time series elasticity with respect to heating-degree-days in 1.0. This means that energy consumed for space heat is assumed to be proportional to heating-degree-days.

B.2.3 End-Use Modeling

Space Heat

Time series data for the following components were constructed: heating/-degree-days, migration, new homes, wood heat, and price. All series were then converted to indexes with 1972 equal to one. Heating-degree-days is an exception; this data is scaled so that the long-run average is equal to one. A simulation model for space heat was constructed by multiplying all of these indexes together. By letting each index vary in turn, components of energy changes due to each variable are calculated.

National average heating-degree-day data was converted from a heating season to a calendar year basis for 1972 through 1986. This data is based on fixed population weights, and does not reflect migration. A second series of average heating-degree-days was constructed, but on a varying population basis. This was done by using population and weather data for the nine census divisions. To obtain the migration component, both of these series were based to 1972, and a ratio was constructed of the varying population series to the fixed population series. Because of the shift to warmer census divisions, national heating-degree-days are about 3% lower in 1986 (relative to 1972) than they would have been with no shift in population.

From the cross-sectional 1984 RECS regressions for electricity and natural gas, it was found that homes built after 1974 consume about 25% less energy for space heat than do homes built before 1974. Using annual data on the number of households built since 1974, an efficiency index was constructed for 1972 through 1986. The index equals one in 1972 and decreases to a value equal to

$$1.0 * PCTBEFORE + 0.75 * PCTAFTER$$

where PCTBEFORE = percentage of homes built before 1975
PCTAFTER = percentage of homes built after 1974

Wood use was included by constructing a time series of the percentage of homes that do not use wood as a primary heating fuel. As wood use increases, this percentage decreases along with average energy consumption for space heat.

For each of the major fuels, a time series of price in 1985 dollars per million BTU was acquired. Each of these prices were then based to 1972. Then a composite price series for space heat was derived by weighting the price indexes for each fuel by their respective share in national space heat consumption.

The price effect covers both structural price responses (such as retrofits) and behavioral responses. A previous report by PNL on residential trends estimated the structural component as a price elasticity. This elasticity is used to split the price effect for space heating, which is relatively large, into structural and behavioral components.

Air Conditioning

Air conditioning load is modeled as the product of the percentage of homes using air conditioning, an index of cooling-degree-days, and a price term. Air conditioning is different from the other end-uses in that some homes do not have this end-use.

Water Heat

Water heat is modeled with terms for the number of persons per household and price.

Appliances

Appliances, like water heat, are modeled with terms for the number of residents and price.

B.2.4 Energy Use Per (Composite) Household

The simulation model "predicts" energy use per household (for a composite household in the nation) as a function of the variables described above. Average energy use per household decreased steadily from 1972 through 1986, as shown in Figure B-1. The decrease was not as rapid in the late 1970's due to unusually cold weather. Figure B-2 plots national heating degrees days for the calendar years 1972 through 1986. In 1978, heating degree days were about 10% greater than the long-run mean. Energy use per household has almost leveled off from 1983 to 1986, due in part to a leveling off of energy prices. Fuel prices are shown in Figure B-3, where they are given in constant 1985 dollars per million Btu.

Energy savings per household is roughly defined as the difference between the 1972 and 1986 consumption levels. Some of the change is due to weather, and some is due to an increased use of air conditioning. Total national savings in the residential sector are determined by multiplying savings per household by the number of households. Figure B-4 gives a plot of the estimated national savings in the residential sector, and shows the close match between actual consumption and the simulated-actual consumption provided by the simulation model.

For this report energy savings is defined as the difference between actual energy consumption and what energy consumption would have been if households used the same amount of energy as they did in 1972, but adjusted for weather and the penetration rate of air conditioners. There is an energy change component due to the increased use of air conditioners, but it represents negative savings.

APPENDIX C

COMMERCIAL SECTOR: DETAILED METHODOLOGY

APPENDIX C

COMMERCIAL SECTOR: DETAILED METHODOLOGY

Appendix C discusses the methodology in further detail and provides some intermediate results related to the commercial sector energy savings decomposition. The key components considered in the decomposition analysis are discussed below in the following order: 1) weather, 2) vacancy rates, 3) building retrofits, 4) the ICP program, and 5) compositional effects.

C.1 WEATHER

Year to year changes in weather can be expect influence energy consumption in commercial buildings, particularly in smaller buildings. As the discussion related to the residential sector indicated, the three coldest winters in the U.S. since 1972 were experienced in 1976-1977 through 1978-1979, a period immediately preceding the sharp rise in oil and other energy prices precipitated by the Iranian revolution. As for the residential sector, a question is how much effect did the warmer winters in the early 1980's have in reducing energy consumption of fossil fuels.

Analysis of the 1979 and 1983 NBECS provides a means of estimating the impact of changes in weather (as represented by heating and cooling degree days) for a large sample of buildings in the U.S.[a] Billing information on energy consumption for both 1979 and 1983 are available for approximately 2700 buildings. EIA assigned heating and cooling degree day estimates for each building for the two separate years. Along with consumption and weather information, EIA also collected data on other key variables that would be expected to influence changes in energy use in a given building. These variables include: number of building occupants, hours of operation, building vacancy, and the installation of certain types of conservation measures.

(a) The analysis of the 1983 NBECS data was made possible by a special pre-release of the public use tape by EIA in November, 1987.

Regression analysis was performed in order the isolate and quantify the impact due to changes in weather, as represented by degree-days. On the basis of the regression testing, the weather impact was limited to buildings of less than 25,000 square feet. This is not to say that weather has no influence in larger buildings, but the NBECS sample suggests that the statistical importance of weather in such buildings was fairly small. The final results were restricted to the impact of heating degree days upon fossil fuel use (oil, gas, and steam). Heating degree days was found not to have a statistically significant impact upon electricity usage, even when combined with information that the building used electricity for heating. In addition, the change in cooling degree days, used as a proxy for air conditioning requirements, was not found to be important in explaining electricity usage.

The regression results suggested that the elasticity of fossil energy use with respect to heating degree days (with a base of 65 degrees) was approximately 0.45. Annual population-weighted heating degree days for each census region were then used to derive a time series of the effect of the change in weather (National Oceanic and Atmospheric Administration, 1987). As an example, the ratio between 1972 (the base year of the intensity measures) and 1978 can be calculated as:

	HDD	ln(HDD)	0.45 * ln(HDD)
1972:	5000	3.45	1.78
1978:	5500	3.78	1.87

Ratio of 1978/1972 = 1.87/1.78 = 1.09

To translate the calculated ratios into Btu units, 1979 consumption from NBECS was used as a benchmark. Thus, in the example above, if 1979 consumption were 400 trillion Btu, then the change in consumption would be approximated by:

$$(1.09 - 1.00) * 400 = 36 \text{ trillion Btu}$$

Changes in consumption for aggregate fossil fuels were computed for each census region and then aggregated to a national total. The time series for the national totals are given in column one of Table 4.3. The range of impacts due to weather is estimated to be approximately 0.1 quad. As expected, the impacts are not as quantitatively important as in the residential sector, although weather is responsible for changes that are roughly 8 percent of average fossil fuel use over the period.

C.2 VACANCY RATES

Any traveller to one of America's large cities cannot help but notice the number of new office buildings that have been recently built or are under construction. Besides their shiny facades, the same traveller will often also notice a familiar sign in the window: "Office Space Available." According the Coldwell Banker real estate service (Coldwell Banker, 1987), the average vacancy rate in downtown office buildings in the United States more than tripled between 1982 and 1985, from less than 5 percent to over 16 percent.

Buildings with significant portions of their usable space vacant can be expected to use less energy per gross square foot than similar, fully-occupied buildings. Fewer occupants will directly lead to reduced consumption for some end uses; such as, task lighting and plug-in loads (e.g., desk-top office equipment). With large contiguous portions of the floor area vacant, HVAC requirements may also be reduced as certain zones of the building are not heated or cooled.

Using the same approach applied to the weather impact, data from the 1979 and 1983 NBECS were analyzed to generate a rough estimate of the influence of a rising vacancy rate upon energy consumption per square foot. The analysis is restricted to office buildings since the only available time series information on vacancy rates (from Coldwell Banker) relates to this building type.

The best specification was one in which the vacancy rate is entered linearlyinto a logarithmic specification. Thus, a rise of one percentage point in the vacancy rate is interpreted from the regression results as a certain percentage decline in energy consumption. Whether the building is 90 percent occupied before the increase in the vacancy rate, or 50 percent occupied, could not be differentiated in a statistical sense within this data set. Generally, the results can be interpreted as an average effect given the distribution of vacancy rates in office buildings that existed in 1979. The use of this simple formulation is preferred on practical grounds as well.

The Coldwell Banker data only provides vacancy information at an aggregate level; no information is available regarding how the distribution of vacancy rates has changed on a year by year basis.

The response coefficient was multiplied by the national average vacancy rate from Coldwell Banker to generate a time series of energy savings. Data prior to 1978 was not available; thus, the 1978 figure was used for the period 1972-1977.

C.3 RETROFITS

As part of the NBECS in 1979 and 1983, EIA requested building owners and managers to provide information regarding particular retrofit activities. Three major activities related to the building shell were considered: 1) weatherstripping and caulking, 2) addition of roof or wall insulation, and 3) installation of tinted, reflective, or thermal pane windows. According to the 1983 NBECS, buildings representing about 30 percent of total commercial floor space weatherstripped between 1980 and 1983. The percentages of floor space retrofitted with additional insulation or energy-saving windows were 10 and 8 percent, respectively.

Unfortunately, the NBECS only asked building owners or managers whether or not these activities had taken place and, when they took place, but not about the magnitude of the action. Thus, for example, the survey does not provide information as to the specific amount of insulation that may have been added to the roof or wall.

In the PNL's previous analysis of commercial energy trends (Adams et al., 1985) a purely engineering approach was utilized. Engineers familiar with commercial building energy issues provided estimates of pre- and post-embargo "common practice" (e.g. R-values of roof insulation) in a number of representative buildings. These estimates were based in large part on design guidelines issued by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).

To translate these assumptions in estimates of energy savings, the DOE-2 engineering-energy use model was employed. For each building type (office, retail, warehouse, and assembly buildings were included) analyzed, the DOE-2 model was first simulated for a baseline building configuration and then for conditions corresponding to the three retrofit actions. Percentage changes from the simulation analysis were then used to "backcast" actual (1979) energy use from NBECS for each building type.

For the previous study, the engineering approach was the only feasible method since EIA had not yet released the building-by-building consumption data collected as part of NBECS. By contrast, the current study was able to make use of the detailed building consumption data for both 1979 and 1983. As a result, the analysis of envelope retrofits has endeavored to estimate the magnitude of the retrofit savings directly from the survey information. This approach obviously has a strong appeal, since the results can be directly tied to empirical data.

Ideally, one would measure the impact of building envelope retrofits while holding other factors constant. The preferred approach was to use the longitudinal analysis (as described above in relation to the weather response) to estimate the average impact of each of the retrofit measures. Thus, the empirical specification attempted to estimate the percentage change in energy consumption between 1979 and 1983 associated with each measure. These specifications also accounted for the change in heating degree days, vacancy rates, number of occupants, and hours of operation. After a variety of specifications were tested, the only consistent result was obtained for weatherstripping/caulking for buildings less than 25,000 square feet. Based upon the longitudinal analysis, weatherstripping was estimated to reduce fossil fuel consumption in the range of 5 to 8 percent. Neither increased insulation nor special windows was shown to produce a statistically significant reduction in energy use according to the regressions. We may speculate that the number of buildings undertaking these measures between 1979 and 1983 is too small for their impacts to be reliably picked up by the statistical analysis.

The 1979 NBECS reported that additional insulation or special windows were in installed in over 25 percent of all commercial buildings prior to 1979. A cross-sectional analysis of 1979 data was performed to gain a rough estimate of the impact of these two measures. A regression was performed in which the logarithm of energy consumption per square foot was regressed upon:

building age category (categorical variables)

building size class (categorical variables)

building type (categorical variables)

vacancy rate

heating degree days

insulation variable (0-1 dummy)

special window variable (0-1 dummy)

The results of this cross-sectional regression indicated a statistical significant effect of additional insulation in the range of an 8-10 percent reduction in fossil energy use. Again, the impact was most pronounced in smaller buildings, and so the final results were restricted to buildings less than 25,000 square feet.

Although the regression results cannot provide a precise measure of the quantitative impact of all three envelope measures, they do provide reasonable orders of magnitude. In the end, however, some element of judgement necessarily must be applied, just as in the pure engineering approach. Accordingly, to generate the estimates of retrofit savings the percentage reductions in Table C.1 were assumed for each measure.

TABLE C.1. Assumed Percentage Reductions in Fossil Fuel Use from Various Retrofit Measures

Measure	Small Buildings (<25,000 sq.ft.)	Large Buildings (>25,000 sq. ft.)
Weatherstripping	-5	-2.5
Insulation	-10	-5
Special Windows	-2	-1

Although the regression results support the assumptions in Table C.1 in at least an approximate manner for small buildings, an issue is how to treat the larger buildings. NBECS reports that the percentage of floorspace retrofitted in the larger (than 25,000 square feet) buildings is not appreciably different than that in the smaller buildings. Thus, our choices are to assume that: 1) these measures in fact saved no energy as suggested by our regression results, or 2) the measures were as effective in the larger buildings as in the smaller ones. Neither of these assumptions is particularly attractive, and so we have chosen, in effect, to take the average of the two. An estimate of annual savings from these retrofits was made by performing a simulation with a special combined 1979-1983 NBECS file. In the 1979 NBECS information was available pertaining to the year in which the retrofit was undertaken. For the 1983 NBECS, however, a specific year was not available, and it was assumed that the impact of any retrofit was spread evenly over the 1980-1983 time period. In attributing impacts by year, a one-year lag was assumed. Thus, for example, if a retrofit was reported to have been done in 1978, the simulation program computed a change in energy consumption for 1979. Consumption for 1979 was used as a benchmark for retrofits reported in both the 1979 and 1983 NBECS. To illustrate the procedure consider an insulation retrofit (with an estimated fractional reduction in energy use of 0.10) reported to have taken place in a sample building in 1977. This building consumed X Btus of fossil fuels in 1979. A "time series" of energy use is then computed for this building that has the following values:

X/(1.0-0.10)	from	1972-1977
X	from	1978-1986

Time series of the kind shown above were constructed for each of the three retrofit measures for each sample building. Each of the approximately 5000 time series of energy consumption was then multiplied by the NBECS sample weight and then summed to generate total consumption. (Benchmarking to the 1979 NBECS leads to 1979 consumption of the aggregate time series that matches reported 1979 consumption). The difference between the estimated 1972 and succeeding years' consumption represents a measure of savings due to the particular retrofit action. Total savings from the envelope retrofits were computed by the summing the three individual savings series.

Estimated energy savings of fossil fuels from the envelope retrofits was shown in column three of Table 4.3. By 1986, envelope retrofits are estimated to be about 160 trillion Btu, accounting for about 10 percent of total savings of fossil fuels in the commercial sector. For 1984, the last year based on the NBECS information, the estimated breakdown of total savings by type of retrofit measure is: 1) weatherstripping (20%), 2) additional insulation (50%), and treated windows (30%).

The regression analysis suggests a small component of savings can be attributed to electricity, brought about by reduced cooling requirements. The column of "envelope retrofits" in Table 4.3 shows the annual estimates of these savings. In 1986, the retrofits are estimated to have reduced electricity consumption by about 16 trillion Btu relative to 1972 consumption levels.

C.4 INSTITUTIONAL CONSERVATION PROGRAM

The Institutional Conservation Program (ICP) of the Department of Energy has provided energy conservation grants to not-for-profit secondary schools, colleges and universities, and hospitals. The first set of grants through this program were made in 1979 and 1980. Total federal expenditures through the ICP to-date have exceeded $700 million.

In 1987 Lawrence Berkeley Laboratory (Carroll et al., 1987) completed a study that estimated the aggregate energy savings attributable to the ICP. LBL based the estimates of energy savings upon grant applications and accompanying technical documentation. The basic approach was to estimate the savings in each building for each energy conservation measure (ECM) implemented and to aggregate the savings over all grants. In the supporting documentation for the grant applications, engineering analyses were included to estimate the expected savings for each ECM. LBL adjusted these original estimates by specific factors based upon more up-to-date engineering simulation results for analyzing retrofits. Although this approach does not use pre- and post-retrofit measured consumption, it does allow categorization of the savings into various types of ECM's (e.g. envelope, lighting, controls, etc).

Unfortunately, neither the original grant applications nor the subsequent LBL analysis attempted to break out the estimated savings by fuel type. On the basis of some discussion with LBL, percentages of savings by ECM category for both electricity and total fossil fuels were assumed. Table C.2 is based on the LBL results for schools and shows total primary energy savings for each type of ECM (column 1) along with the percentages assumed to apply to each fuel type (columns 2 and 3). The savings presented in Table C.2 are cumulative over the history of the ICP. Some additional savings, beyond those shown in the table, were imputed by LBL. These savings amounted to only about 10 percent of the total of 17.0 trillion Btu shown at the lower right in Table C.2.

The calculations in Table C.2 were designed to estimate overall fractions of savings for electricity and fossil fuels. As shown in the lower right of the table, 32 percent of the total savings were estimated to accrue to electricity, with the remainder assigned to fossil fuels for heating. These fractions were then multiplied by total savings for each grant cycle (as published by LBL in separate tables) to estimate the fuel specific savings by year. The process was carried out separately for schools, colleges, and hospitals. The aggregate results for electricity and fossil fuels were shown in Tables 4.3 and 4.4, respectively.

TABLE C.2. Energy Savings by Fuel from ICP Program for Schools

	Savings (TBtu)	Elec	Fossil	Source:	Savings (TBtu)	
		(%)			Elec	Fossil
Envelope	2.50	10.00	90.00	Est.	0.25	2.25
Lighting	1.60	100.00		Est.	1.60	0.00
Controls	7.40	20.00	80.00	Est.	1.48	5.92
Heating	2.60		100.00	Est.	0.00	2.60
Cooling	0.40	100.00		Est.	0.40	0.00
HVAC	0.20	80.00	20.00	Est.	0.16	0.04
Ventilation	1.30	80.00	20.00	Est.	1.04	0.26
Miscellaneous	1.00	50.00	50.00	Est.	0.50	0.50
				Total	5.43	11.57
				Frac.	0.32	0.68

C.5 COMPOSITIONAL EFFECTS

The composition of commercial buildings, by building type, geographic region, and vintage, has not remained constant since 1972. Office buildings now make up a significantly higher percentage of total floorspace than fifteen years ago. With declining school enrollment, the percentage of floor space in schools has continually fallen. The concentration of new construction in the south and west has lead to an increasing percentage of aggregate floorspace in these regions. Finally, over a decade and a half period, new buildings will comprise a significant portion of the total stock. Buildings built since 1972 made up approximately 30 percent of total floor space as of 1986.

Compositional changes would not matter if all buildings used the same amount of energy per square foot. Information from the NBECS, however, shows some substantial differences in energy use intensity by building type and across regions. Offices, for example, use roughly 40 percent more electricity per square foot than do schools. Thus, any trend toward more offices and away from schools will tend to increase sector-wide average electricity use per square foot. The shift to the south, requiring more cooling and less heating, will promote a higher overall intensity of electricity use but a lower intensity for oil and gas.

The calculation of compositional effects upon aggregate energy intensity requires three elements: 1) time series of stocks by region and building type, 2) energy intensity for a base period, and 3) an estimate of the difference in intensity between new buildings and the existing stock. Each of these items will be discussed briefly below.

Historical Floorspace Estimates

Building floor space estimates from 1960 through 1986 were developed for ten building types and the four census regions. The basic method was a perpetual inventory approach that computes the annual change in stock as the difference in reported new additions and an estimate of removals. The amount of floor space removed from the stock in each year was based upon an analysis of the 1979 and 1983 NBECS; a logistic type function was estimated that is assumed to represent how fast a given vintage of new buildings is retired, whether it is demolished or converted to residential or industrial use. For the period around 1980, this function was calibrated to yield an aggregate removal rate of about 0.5 percent per year.

Annual additions since 1960 were taken from national data from F. W. Dodge on new floorspace in nine building types. Before its use in the perpetual inventory program, this data was adjusted on the basis of a calibration between total 1961-1979 information from Dodge and from the 1979 NBECS. A breakdown of new construction by region was provided by NBECS. Each series of floor

TABLE C.3. Distribution of National Floor Space by Building Type and Region, 1992-1986

Percentages of Total Floorspace By Census Region

	1972	1986
Northeast	23.2	19.8
North Central	32.8	30.6
South	30.8	34.4
West	13.2	15.2
Total	100.0	100.0

Percentage of National Floorspace by Building Type

	1972	1986
Office	16.6	19.8
Retail	23.0	22.1
Food Sales	4.6	4.5
Warehouses	15.7	16.8
Education	16.1	13.9
Hospital	4.7	5.0
Assembly	14.1	12.4
Lodging	5.2	
	100.0	100.0

Note: Percentages based on sum of building types listed. Auto repair and miscellaneous buildings were excluded from analysis (about 8 percent of 1986 estimated stock).

space was benchmarked to the 1979 estimate of floorspace, by region and building type, from the 1979 NBECS.

Table C.3 shows the percentage of floor space by region and building type for 1972 and 1986. The percentages on the top part of the table illustrates the shift of floor space to the south and the west. Although not shown in the table, all building types display this same general pattern. By 1986 the share of total floor area in the south and west is estimated to have increased from 44.0 percent to 49.6 percent.

The lower portion of Table C.3 displays the shift between building types. The table shows the percentages on a national basis, although the relatively sharp increase in the share of total space in the office sector takes place in every census region. The biggest loser is educational buildings, which declines from over 16 percent of national commercial space in 1972 to less than 14 percent in 1986.

Base Year Energy Intensities

Base year energy intensities were taken from the 1979 NBECS; national average intensities are shown in Table C.4. Separate intensities were computed for electricity, gas, oil, and other fuels. The national intensities in the table (and the regional ones used in the formal analysis) cannot be interpreted strictly in terms of energy efficiency. They are computed as the simple ratio of total fuel use by the particular building type in a region to total floor space. Thus, the computed intensity represents a product of the energy efficiency in the use of a particular fuel times the fraction of floor space that utilizes that fuel. For example, the office sector's higher intensity in the use of electricity may reflect both greater use of electricity per square foot in cooling, due to higher internal loads of these buildings, as well as a higher percentage of office space that is air conditioned.

New Buildings

Unfortunately, there exists no counterpart to EPA (relative to automobile fuel economy) in the buildings sector that collects annual information regarding energy efficiency of new buildings. At present the only comprehensive information available is from the NBECS, in which the latest data is available only through 1983. Lawrence Berkeley Laboratory does compile overall energy/square foot information on new energy efficient buildings as the

TABLE C.4. National Energy Intensities by Building Type (KBtu/Square Foot)

Building Type	Electricity	Gas and Oil
Office	62.4	101.4
Retail	37.5	44.0
Food Sales	100.4	147.0
Warehouses	37.1	66.1
Education	27.4	53.8
Hospital	68.0	172.2
Assembly	25.3	52.2
Lodging	57.5	65.2

Note: Intensities computed by dividing energy consumption of fuel or combination of fuels by total floorspace of building type. Source: 1979 NBECS tape file, 1986 verision.

information is located or is contributed to them, (as part of its Building Energy Consumption and Analysis, BECA, data base) but one cannot construe this information as coming from a random national sample of new buildings.

Published data from the 1983 NBECS (EIA, 1986) suggests that at least post-1980 buildings may be using less energy per square foot than older buildings. Table C.5 shows energy consumed per square foot from the 1983 NBECS' Consumption and Expenditure report by fuel type. (These figures includes some multi-family and vacant buildings which are not included in this study's definition of the commercial sector.)

As measures of relative efficiency, even in the gross context of whole building consumption per square foot, the figures in Table C.5 cannot be used directly. First, as mentioned parenthetically above, the averages incorporate two building types that are not part of this study. Second, the averages include the imputed energy use estimates by EIA, which may or may not adequately treat the influence of vintage. A final, and perhaps the most critical, reason is that the sample of 1980-1983 buildings in the 1983 NBECS was drawn by a

TABLE C.5. Energy Consumption Per Square Foot for 1983 as Published by the 1983 NBECS

(Thousand Btu)

	Electricity	Gas	Oil
All buildings	44	62	35
1974 to 1979	65	98	33
1980 to 1983	53	47	8

different procedure than the prior built buildings. Without elaborating here, the upshot of this procedure was to generate a sample in which the average building size is substantially larger than previous vintages. The omission of very small buildings in the post-1979 vintage likely biases the 1980-1983 intensity downward, since these buildings tend to use much more energy per square foot than larger buildings.

To more accurately represent the change in efficiency in new buildings, a cross section regression analysis was performed using the 1983 NBECS. The regression was similar to that employed in the analysis of envelope retrofits, as described above in section C.3. The logarithm of energy consumption per square foot was regressed upon:

building age category, 1974-1979 (0-1 dummy)
building age category, 1980-1983 (0-1 dummy)
building size class (categorical variables)
building type (categorical variables)
vacancy rate
heating degree days
insulation variable (0-1 dummy)
special window variable (0-1 dummy)

Separate regressions were performed for electricity and combined oil and gas. After accounting for other effects besides age in the regression, the coefficients of the age dummies suggested the following differences in average consumption as compared to pre-1974 buildings:

	1974-1979	1980-1983
Electricity	+ 32%	+ 8%
Gas/Oil	- 8%	- 16%

The results for electricity correspond reasonably well to the published means; new buildings in both periods since 1974 are more intensive users of electricity than older buildings. Accounting for building type and size makes considerable difference in interpreting trends for fossil fuels, however. Combining the samples for gas and oil suggests that average efficiency has improved slightly in both subperiods subsequent to 1973.

Decomposition Procedure

The general procedure to estimate the influence of the each of the three factors, building type mix, geographical shift, and new buildings, was to hold each constant at its 1972 value and then compare the computed aggregate consumption to the consumption when all factors were allowed to change. To measure the influence of building type mix, the shares of building types were held at their 1972 levels within each census region. For geographical shift, the shares of total building stock among census regions were held at 1972 levels.

To measure the influence of new buildings on annual energy consumption, a rudimentary simulation approach was required. Starting with 1973, the influence of new buildings upon aggregate energy intensity was computed by multiplying new building stock by an index of relative energy intensity (relative to pre-1974 buildings). Thus, for example, new buildings in the 1974 to 1979 periods were assumed to use 0.92 of the stock value for consumption of fossil fuels, based upon the regression results described above. By 1980, the overall intensity index is a weighted average of 1.0 and 0.92, the weights given by the pre-1974 and post-1974 amounts of floor space.

The consideration of new buildings in the overall procedure adds one additional complicating element. Essentially the influence of new buildings and either of the building compositional elements is multiplicative. Stating this is another way, it makes a difference in computing the effect of new buildings whether the actual building composition is used, or alternatively, whether a fixed, 1972 composition is employed; and conversely, the computation of savings from the building mix elements depends on the assumptions made regarding changes in energy intensity. The ultimate issue is how best to make the estimates of the individual changes that most closely approximates the total change in energy consumption.

In response to this issue the decomposition methodology was guided by the following mathematical property regarding the change in the product of two factors. The change in the product of factor X and factor Y can be represented as:

$$XY = X * Y + Y * X$$

When using this property in the decomposition, a mean value is computed as the average value for 1972 and the given year. Thus, in evaluating the impact of new buildings in year t, the procedure uses the average shares by building type and region from the base period (1972) and year t. A similar average efficiency is defined for new building efficiency, as it is employed in estimating the building type and regional compositional changes. The final procedure still does not exactly decompose the three factors; that is, the sum of the changes computed individually does not equal the total change in energy use, because there remains a small amount of interaction between the building type and regional mix components. Nevertheless, the approximation is very good, usually within one percent of the computed total change. Table C.6 shows the individual components and the sum versus the computed total change for 1986.

TABLE C.6. Decomposition Results by Fuel for 1986

(Trillion Btu)

Fuel	Building Mix	Regional Shift	New Buildings	Sum	Computed Change
Electricity	59.3	16.3	91.6	167.2	166.2
Gas	35.8	-23.0	-132.6	-119.8	-119.7
Oil	46.2	-16.0	-58.6	-28.4	-28.1

Results of Decomposition

The savings estimates shown in Table C.6 provide a convenient comparison of the relative importance of the compositional effects. The final three columns in Tables 4.3 and 4.4 in section 3 of the report provide a time series of each factor. Table 4.2 shows the combined impact upon gas and oil and Table 4.3 shows the impact on electricity.

Looking first at the top row of Table C.6, we find that all three factors, building mix, regional shift, and new buildings, have contributed to increased electricity consumption in the commercial sector. If the composition of building types had remained at 1972 shares and had new buildings used the same amount of electricity per square foot as the 1972 stock, 1986 (site) electricity would have been about a sixth of quad lower than what was actually used. More than half this estimate is attributable to the addition of more intensive buildings to the existing stock. A little over a third, 59 trillion Btu is the result of shifts in the aggregate building stock to buildings that use more electricity. As was mentioned previously, the increase in the relative share of offices is responsible for much of this factor. Although small, the concentration of new construction in the south (and to some extent in the west) also contributes the growth in electricity. The higher electricity intensity in the south for most building types is generally the result of greater air conditioning loads.

In analyzing oil and gas use, regional shifts and vintage effects tend to lower aggregate consumption while the shift among building type contributes to higher consumption. Just looking at the first two strictly compositional effects, the positive impact of building type mix almost offsets the savings generated by lower heating requirements in the south. Assuming that the regression results reasonably reflect the increased efficiency of oil and gas use in new buildings, the penetration of such buildings has reduced aggregate fossil consumption by about two-tenths of a quad, compared to case in which intensities had remained at their 1972 values.

APPENDIX D

INDUSTRIAL SECTOR DOCUMENTATION

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INDUSTRIAL SECTOR DOCUMENTATION

The purpose of this appendix is threefold: to provide documentation for the data used in the analysis; to provide a description of the estimating methodology used to decompose the difference between actual and constant intensity energy use; and to provide a comparison between this approach and the previous approach. There will be a subsection for each of these three items.

D.1 DATA AND SOURCES

The major variables use in the aggregate sector analysis are the following: primary energy use in the industrial sector (PRIMAR), end-use energy (ENERGY), industrial sector gross product originating (ISECGP), the ratio of five energy-intensive industries' output to industrial sector GNP (GPORAT), industrial capacity utilization (CU),the ratio of new investment to capital stock (NIISEC), and the ratio of energy prices to industrial sector output prices, scaled to 1967 equal 100 (RELPR). Industrial sector output is the addition of real GNP ($1982) originating in agriculture, mining, construction and manufacturing; this data is derived from the Economic Report of the President (ERP), 1988. The variable RELPR is constructed by dividing the producer price index (PPI) for purchased fuel and power by the implicit deflator for the industrial sector, after rescaling the implicit deflator to 1967=100. These price index are also from ERP. The composition index, GPORAT, is constructed by summing the industry output (again in constant 1982 dollars) for Basic Chemicals (SIC 281), Pulp and Paper (SIC 26), Petroleum Refining (SIC 29), Stone Clay and Glass (SIC 32) and Primary Metals (SIC 33); then dividing this sum by ISECGP. These five sectors represent the five most energy intensive sectors in manufacturing. With the exception of Basic Chemicals, the industry specific data is published annually in the Survey of Current Business (SCB) by the Bureau of Economic Analysis of the Department of Commerce (as are the aggregates used to construct ISECGP). The series for

Basic Chemicals was developed by using an index of industrial production to extrapolate a 1972 estimate of GNP originating in this sector.[a]

Industrial capacity utilization rates are developed by the Federal Reserve Board. Annual data were taken from the February 1988 Economic Report of the President.

The ratio of new investment to capital stock (NIISEC) was intended to capture the effect of the introduction of new technology on energy savings. NIISEC is constructed by dividing the cumulation of the last five years' investment for manufacturing by capital stock for manufacturing. Investment by industry is published annually in the SCB, capital stock to 1981 is available from the Office of Business Analysis, U.S. Department of Commerce. After 1981, annual capital stock is approximated by depreciating old stock at its historic rate and adding capital additions. The value of NIISEC can be negative if depreciation is greater than investment--this was the case in 1983 and 1986. Table D.1 reports these major variables, along with the intensity variables (PINTEN and INTENS) constructed by dividing PRIMAR and ENERGY by ISECGP. The constant EUI energy numbers (e.g., line C of Figure 5.1) are constructed by multiplying ISECGP by the 1972 intensity--32.01511 for primary energy, 26.38384 for end-use energy.

D.2 DECOMPOSITION METHODOLOGY

The first step in the decomposition was to construct trended ISECGP and trended intensity. A log-linear regression of output against time showed that ISECGP grew at the rate of 2.87 percent per year from 1960 to 1972. That constant growth rate was applied to 1972 ISECGP over the period 1973 to 1986 to get trended output. This number was then multiplied by trended

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(a) The industrial production index for Basic Chemicals is published by the Federal Reserve Board (FRB) as one of the G.12.3 series. Historical data can be found in Industrial Production, 1986 Edition. Value added figures by industry in the 1972 input-output table of the U.S. were used to estimate the fraction of all chemicals (SIC 28) attributable to SIC 281. The share used was 0.329. Basic Chemical output in 1972 was estimated as 0.329 times GNP originating in SIC 28 ($39.8 billion) or $13.1 billion. The $13.1 billion estimate was extrapolated to the other years by the production index from the FRB.

TABLE D.1. Major Variables Used in the Analysis

obs	PRIMAR	PINTEN	ISECGP	ENERGY	INTENS
1960	20163.50	30.35300	664.3000	17409.30	26.20699
1961	20255.70	30.34107	667.6000	17454.00	26.14440
1962	21052.90	29.81997	706.0000	18100.90	25.63867
1963	21988.80	29.54293	744.3000	18908.80	25.40481
1964	23296.40	29.78318	782.2000	20004.40	25.57453
1965	24252.40	29.13901	832.3000	20759.80	24.94269
1966	25542.90	29.36978	869.7000	21747.40	25.00563
1967	25772.90	29.52222	873.0000	21819.10	24.99324
196B	26936.60	29.91294	900.5000	22694.30	25.20189
1969	28120.60	30.74970	914.5000	23561.60	25.76446
1970	28610.60	32.58239	878.1000	23890.40	27.20692
1971	28554.80	32.40445	881.2000	23692.50	26.88663
1972	29886.70	32.02604	933.2000	24621.40	26.38384
1973	31579.40	31.72534	995.4000	25975.00	26.09504
1974	30697.10	32.18063	953.9000	25000.00	26.20820
1975	28432.90	31.74732	895.6000	22772.70	25.42731
1976	30271.10	31.71077	954.6000	24072.60	25.21747
1977	31122.40	30.87846	1007.900	24645.00	24.45183
1978	31465.00	29.66437	1060.700	24710.70	23.29660
1979	32643.70	30.31829	1076.700	25710.90	23.87935
1980	30634.50	29.49028	1038.800	23870.00	22.97844
1981	29274.50	27.84600	1051.300	22559.20	21.45838
1982	26140.40	26.21380	997.2000	20040.30	20.09657
1983	25736.50	25.16525	1022.700	19404.20	18.97350
1984	27758.00	24.51470	1132.300	21082.90	18.61954
1985	27062.40	22.95953	1178.700	20409.70	17.31543
1986	26470.60	22.07723	1199.000	20073.30	16.74170

TABLE D.1. (contd)

obs	C2	CA2	RELPR	GPORAT	CU	NIISEC
1960	17526.79	117.4874	103.8655	12.93065	80.10000	10.59998
1961	17613.85	161.8513	104.4119	12.83720	77.30000	9.600037
1962	18626.99	526.0911	101.9816	12.94372	81.40000	12.70001
1963	19637.49	728.6914	102.9633	13.04463	83.50000	14.79999
1964	20637.44	633.0400	99.77943	13.50727	85.60000	23.29999
1965	21959.27	1199.469	98.55232	13.56129	89.50000	36.40002
1966	22946.03	1198.626	97.99921	13.60900	91.10000	45.09998
1967	23033.09	1213.993	100.0000	13.04546	86.70000	36.59998
1968	23758.65	1064.348	95.68036	13.09140	87.00000	30.10004
1969	24128.02	566.4226	93.58738	13.26375	86.70000	31.89996
1970	23167.65	-722.7506	97.57944	13.46735	79.20000	26.70001
1971	23249.44	-443.0594	100.4073	13.62642	77.40000	17.50000
1972	24621.40	-5.71E-05	100.6940	13.71524	82.80000	17.90002
1973	26262.47	287.4755	104.1567	14.49524	87.00000	31.29999
1974	25167.54	167.5462	135.9481	14.95280	82.60000	43.00000
1975	23629.37	856.6677	149.5117	13.39528	72.60000	29.20001
1976	25186.01	1113.414	160.0922	13.68323	77.40000	29.79999
1977	26592.27	1947.274	180.9181	13.47587	81.40000	37.90002
1978	27985.34	3274.639	186.7147	13.70513	84.20000	47.00000
1979	28407.48	2696.579	215.6589	13.37445	84.60000	50.09998
1980	27407.54	3537.535	265.9873	12.83183	79.30000	43.69995
1981	27737.33	5178.134	292.1978	12.57537	78.20000	45.50000
1982	26309.96	6269.666	309.6364	11.71803	70.30000	15.30005
1983	26982.75	7578.555	307.9722	11.26B91	73.90000	-12.40002
1984	29874.42	8791.523	300.7486	11.04870	80.50000	3.099976
1985	31098.63	10688.93	293.1154	10.61972	80.10000	3.500000
1986	31634.22	11560.92	236.9637	10.70523	79.70000	-17.50000

intensity to yield trended energy. Unfortunately there is no trend in intensity over the period 1960-1972. On a primary or end-use basis, intensity first declines, then increases sharply, then declines after 1970. To construct an intensity trend, the compound growth rate of primary energy intensity was calculated based on the values for 1960 and 1972--by this calculation, intensity increased at the rate of 0.446 percent per year. This growth rate was then applied to the 1972 value to calculate a trended intensity for the period 1973-1986.

Although the first wedge diagram is constructed with primary energy data, the analysis of changes in energy intensity is conducted using end-use energy. The independent variable for this analysis is constructed by subtracting actual energy use from energy use calculated by multiplying the constant 1972 intensity level (26.38384) by ISECGP; this variable in the regression results is referenced as CA2. Over the relevant period, there is little difference between this variable and one constructed from primary data. As plotted in Figure D.1 and reported in Table D.2 both begin at zero in 1972 and grow to nearly 12 quads by 1986; both decline for only one year--from 1978 to 1979. End-use savings is larger over most of this period, but the two only diverge by 0.9 quad in 1979 and 1980; after 1980 the savings converge with primary savings larger by more than 0.4 quad in 1986. Moreover, there is little substantive difference between regression results using one measure of savings over the other. Accordingly, only the end-use results are reported.

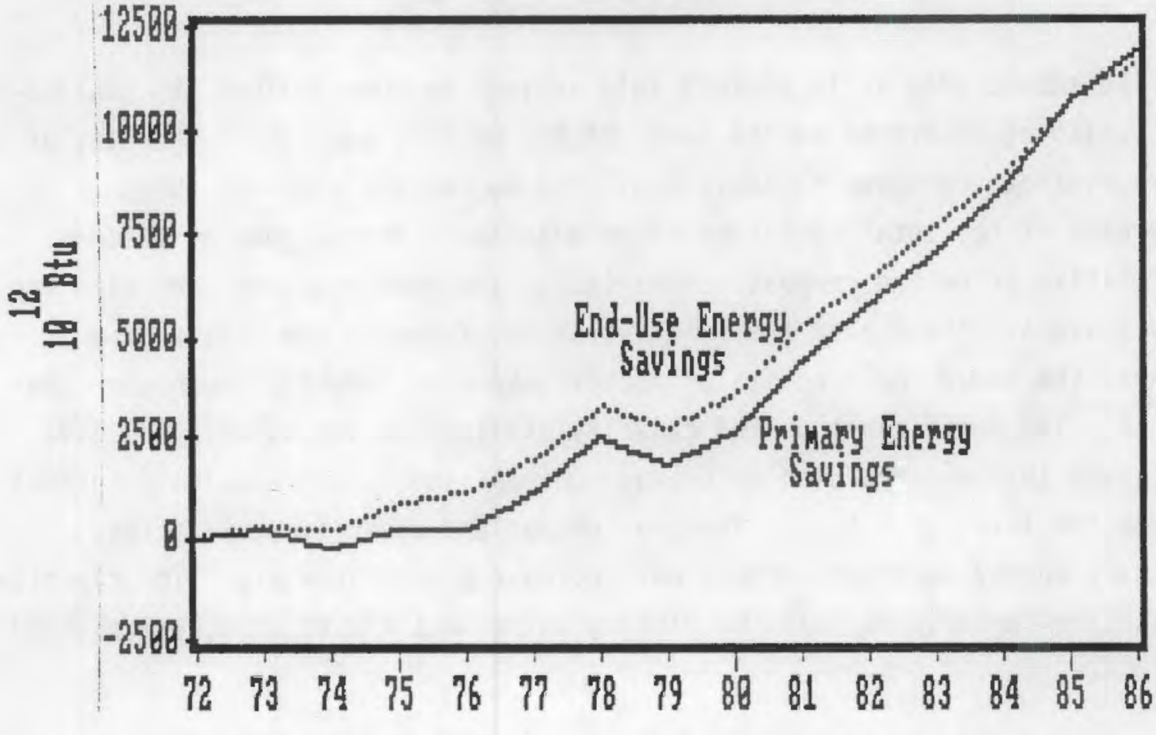

FIGURE D.1. End-Use and Primary Energy Savings

TABLE D.2. Differences Between Primary End-Use Energy

obs	DIF	DIF2
1972	2.699219	2.699219
1973	288.5391	290.3496
1974	-157.4883	170.3008
1975	239.9297	859.2617
1976	293.6191	1116.170
1977	1148.830	1950.189
1978	2494.731	3277.701
1979	1830.172	2699.690
1980	2622.801	3540.539
1981	4382.988	5181.170
1982	5785.070	6272.549
1983	7005.350	7581.512
1984	8492.711	8794.799
1985	10673.81	10692.34
1986	11915.52	11564.39

The second step is to regress this savings measure against the explanatory variables described in the text, RELPR, GPORAT, and CU.[a] Results of the regression are shown in Table D.3. The regression explains about 92 percent of the total variation after adjustment for degrees of freedom. The relative price and composition variables are highly significant with the correct signs: the higher the relative price of energy the greater the savings; the lower the fraction of energy-intensive industry the higher the savings. The coefficient on the capacity utilization variable is positive, suggesting that some portion of energy consumption may be relatively insensitive to the level of output. Thus, as output and capacity utilization increase, energy consumption does not increase proportionately. The capacity utilization variable may also be picking up product mix effects not captured by GPORAT.

(a) One of the exploratory regressions used NIISEC, the measure of new capital investment, in the place of CU. Unfortunately, this variable, intended to capture the effect of the introduction of new technology on energy savings, was neither significant nor of the proper sign. Apparently, more intensive analysis at an industry level would be required to adequately represent this effect.

TABLE D.3. Regression Output for Energy Savings

LS // Dependent Variable is CA2
Date: 12-14-1988 / Time: 12:08
SMPL range: 1960 - 1986
Number of observations: 27

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	10141.123	5661.1641	1.7913495	0.086
RELPR	24.240755	3.8841747	6.2409023	0.000
GPORAT	-1866.4340	274.76112	-6.7929337	0.000
CU	155.90014	48.601098	3.2077494	0.004

R-squared	0.919713	Mean of dependent var	2599.743
Adjusted R-squared	0.909241	S.D. of dependent var	3455.355
S.E. of regression	1040.969	Sum of squared resid	24923178
Durbin-Watson stat	0.727682	F-statistic	87.82421
Log likelihood	-223.7402		

Although the regression performs quite well, it is interesting to see how the forecast values for energy savings compare to the actual energy savings. Figure D.2 shows actual energy use, constant 1972 EUI energy use, and the forecast values of the regression (added to actual energy use). These estimated savings track actual savings in the sense that they peak at the same time and the level is about the same. There are several notable exceptions: the regression under-forecasts in 1973-74 and again in 1986. The model also over-forecasts in 1979 and 1980.

The third step is to decompose the savings by holding some of the variables constant at their 1972 levels, then forecasting the savings based only on the movement of the other variables. The first forecast generated (E1) is due to changes in relative prices alone; GPORAT and CU are held at their 1972 levels. E1 is constructed by adding predicted savings from the regression model to actual energy use. A second forecast, labeled E2, is generated by allowing both RELPR and GPORAT to assume their actual values.

The final step in the decomposition is the normalization process. In this procedure, the regression forecast (E2) is divided by constant EUI energy use (C2 in Table D.1) to construct a new variable, Z. Then E1 and E2

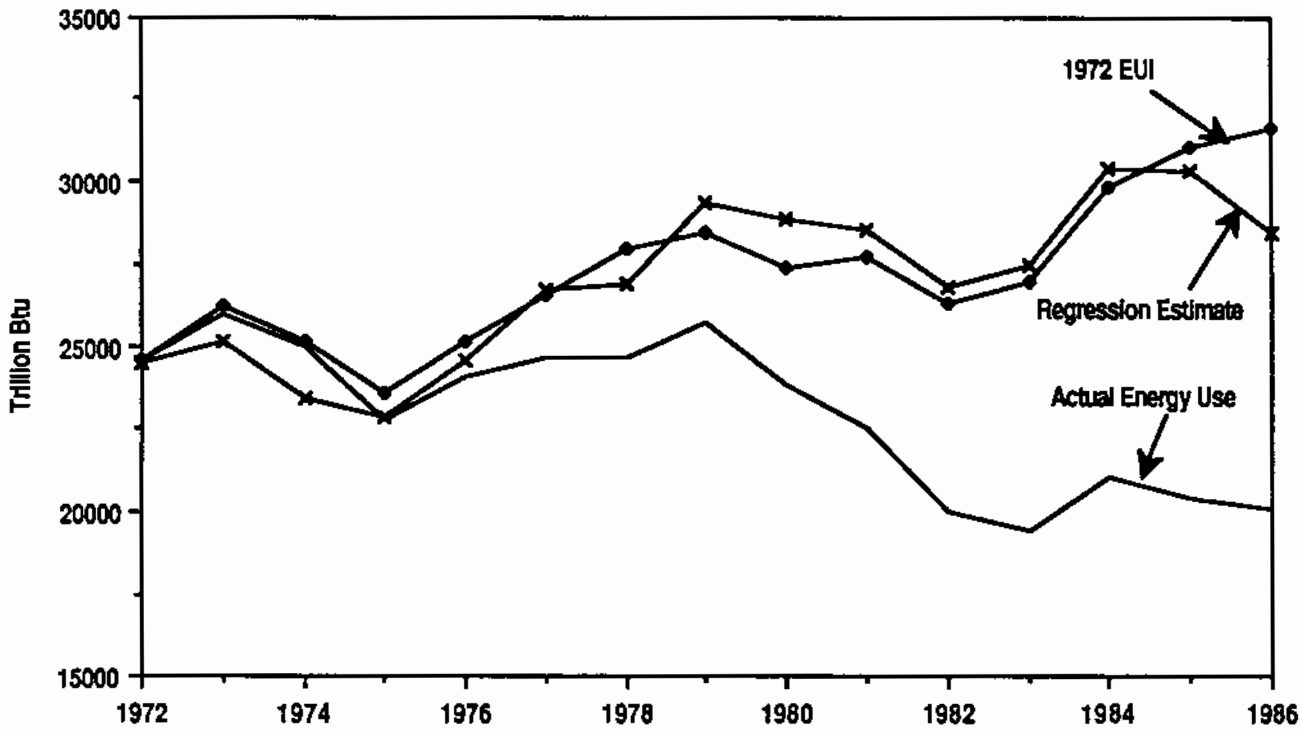

FIGURE D.2. Regression Estimates of Energy Savings

are transformed by multiplying them by Z, generating new variables EE1 and EE2, respectively. The results are shown in Table D.4.

The estimated effects of each variable are determined by subtraction. The conservation or price effect (PEFFECT) is computed by subtracting actual energy use from EE1. The difference between EE2 and EE1 is the compositional effect (CEFFECT). Finally, the difference between the constant-EUI consumption (C2 in Table D.1) and EE2 is the impact from capacity utilization (UEFFECT). These effects are shown in Table D.5. The effects were reordered to facilitate the presentation in the area graph in Figure 5.6.

D.5 COMPARISON WITH PREVIOUS RESULTS

A number of differences between the current study and the one published in 1985 make it difficult to provide a straightforward comparison of decomposition results. The industrial sector decomposition in 1985 was done using

TABLE D.4. Raw and Normalized Decomposition Variables

obs	E1	EE1	E2	EE2	Z
1972	24513.37	24620.93	24513.37	24620.93	1.004388
1973	25950.90	27050.31	24495.08	25532.82	1.042365
1974	25746.55	27549.09	23436.72	25077.55	1.070011
1975	23848.04	24629.54	24445.22	25246.30	1.032770
1976	25404.42	25973.02	25464.16	26034.10	1.022382
1977	26481.66	26364.26	26928.42	26809.04	0.995567
1978	26687.87	27699.05	26706.74	27718.63	1.037889
1979	28389.70	27491.36	29025.76	28107.30	0.968357
1980	27768.80	26285.06	29417.63	27845.78	0.946568
1981	27093.36	26344.78	29220.85	28413.49	0.972370
1982	24997.19	24554.32	28724.85	28215.93	0.982283
1983	24320.74	23855.30	28886.66	28333.83	0.980862
1984	25824.34	25333.12	30801.26	30215.37	0.980978
1985	24966.10	25588.98	30743.69	31510.71	1.024949
1986	23268.54	25645.10	28886.53	31836.89	1.102136

TABLE D.5. Savings Impacts of Explanatory Variables After Normalization

obs	UEFFECT	CEFFECT	PEFFECT
1972	0.470703	0.000000	-0.470703
1973	729.6504	-1517.490	1075.311
1974	89.98828	-2471.539	2549.090
1975	-1616.932	616.7617	1856.840
1976	-848.0898	61.08008	1900.420
1977	-216.7695	444.7793	1719.260
1978	266.7090	19.58008	2988.352
1979	300.1797	615.9414	1780.459
1980	-438.2402	1560.719	2415.061
1981	-676.1602	2068.711	3785.580
1982	-1905.969	3661.609	4514.020
1983	-1351.080	4478.529	4451.102
1984	-340.9492	4882.250	4250.219
1985	-412.0801	5921.731	5179.281
1986	-202.6699	6191.791	5571.799

the primary energy savings; this study uses end-use energy. More importantly, the 1985 study used a methodology developed by Robert Marlay to identify the component of the savings attributable to efficiency changes; this study assumes that efficiency changes are a result of behavioral changes, the major motivation for which is relative price changes. Finally, the numbers are not reported directly in the earlier report, although a graph of the results is provided.

Offsetting these difficulties, there are two things that make comparison possible. The residual error in 1982 is near zero in both studies, so the decomposition for some components can be compared directly for these two years. The second thing that makes comparison possible is the use of similar variables--a measure of the change in the energy-intensive composition of industry: GPORAT in the current study, RIVE in the 1985 study. To generate the numbers that are comparable with the 1985 study, RELPR was held constant at their 1972 values, then energy savings was forecast. The results of this forecast provide a wedge comparable to the 1985 wedge labeled "change in industrial composition."

In the 1985 study, the saving attributable to compositional shifts in 1982 was 2.8 quads out of a total of 7.8 quads and total primary energy use of 26.0 quads. The compositional effect accounted for 10.7 percent of total energy in the 1985 study and 36 percent of total savings. Comparison with the current study is complicated by the explicit treatment of capacity utilization. For 1982, the year of the worst post-war recession, low operating rates tended to increase energy consumption nearly two quads. In the parlance of these studies the low utilization resulted in negative savings. As a result the positive impacts of price and compositional change add to <u>more</u> than 100 percent of the savings. To provide some measure of comparability we can look only at the contributions of these two positive effects relative to each other. Using this approach, compositional impacts are about 45 percent of the total positive impacts.[a]

Thus despite substantially different methodologies and the use of different explanatory variables, the results are reasonably similar in 1982. Compositional impacts make up a slightly greater percentage of the combined impact of conservation and compositional change in the current study. Some

---

(a) From Table D.4, the impact of compositional change is 3,661 TBtu and the impact of conservation or prices is 4,514 TBtu in 1982. Compositional change is 45 percent of the total.

of the negative impact associated with capacity utilization may actually include product mix changes. If we could determine exactly what percentage of this effect that might be attributed to this factor, the results would tend to be even closer.

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