A Retrospective Analysis of Energy Use and Conservation Trends: 1972-1982

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PREFACE

This document contains a detailed analysis of U.S. energy use intensities for the residential, commercial, industrial, and transportation sectors over the period 1972-1982. The data and methods used to derive the alternative estimates of energy savings in each sector are contained in a companion document, A Retrospective Analysis of Energy Use and Conservation Trends: 1972-1982, PNL-5026 App., Pacific Northwest Laboratory, Richland, Washington, January 1985.

EXECUTIVE SUMMARY

The primary objective of the research reported here is to analyze energy use trends for the entire economy and by end-use sector (residential, commercial, industrial, and transportation). In particular, an examination of energy trends was undertaken for the period 1972 through 1982 to determine the magnitude of "energy savings" attributable to: 1) changes in economic activity, 2) efficiency improvements relative to the 1972 stock (including structures and capital equipment), and 3) efficiency improvements relative to 1960-1972 trends. In addition to identifying the measures of energy savings described above, the causes of efficiency improvement relative to 1972 are explored. For example, energy savings due to efficiency improvements in the residential sector are explained by such activities as changes in household size, migration, improved shell and appliance efficiencies, and increased wood use.

For this research, Pacific Northwest Laboratory (PNL) developed a consistent methodology for analyzing energy use trends by end-use sector. Alternative measures of energy use trends (i.e., alternative base cases) were developed for the purpose of measuring energy savings. The energy use trends were calculated as the product of economic activity levels (number of households in the residential sector, square feet of floor space in the commercial sector, output in the industrial sector, and person-miles/ton-miles traveled in the transportation sector) and energy use intensities (energy use per household, energy use per square foot of commercial floor space, energy use per unit of industrial output, and energy use per mile traveled). Energy savings were then defined as differences between alternative estimates of energy use.

RESIDENTIAL SECTOR

The residential sector has consistently accounted for about 20 percent of total U.S. energy use since 1960. Total residential energy consumption increased from 14.54 quads in 1972 to 14.81 quads in 1982, peaking at 15.63 quads in 1978. Energy use per household increased rapidly between 1960-1972.

This trend, however, has reversed itself since 1972. In fact, energy use per household in 1982 was at its 1965 level of 177.3 million Btu.

We estimated that changes in economic activity (measured by the number of households) contributed to higher residential energy consumption for the entire period, 1972-1982. Such "dissavings" were due to a dramatic increase (25 percent) in the number of households over this period. This result is graphically illustrated in Figure 1. The cumulative increase in energy consumption due to changes in economic activity between 1972 and 1982 was 2.247 quads.

With respect to energy savings due to efficiency improvements (reduced energy use for household) relative to 1972, we found that:

- o Annual energy savings increased from 0.80 quads in 1974, to 1.78 quads in 1979, and to 3.24 quads in 1982 (see Figure 1).
- o Shell efficiency, household size, and wood use are the most important factors explaining decreased energy use per household relative to 1972 levels.
- o Most of the 14.76 quads of cumulative energy savings over the period can be explained by:
 - improved shell efficiency (23.1 percent)
 - changes in household size (21.7 percent)
 - increases in wood use (15.4 percent)
 - improved appliance efficiency (10.2 percent)
 - migration (2.2 percent).

When compared to an extrapolation of 1960-1972 trends in household energy use, rather than just to the 1972 value, cumulative energy savings are estimated to be much greater--44.59 quads for the period, 1972-1982 (see Figure 1). Relative to the commercial, industrial, and transportation sectors, the residential sector contributed the greatest proportion (about 44 percent) of these savings to the economy as a whole.

COMMERCIAL SECTOR

Between 1972 and 1982 the commercial sector increased its share of total U.S. energy demand from 12.8 to 15.3 percent. While total commercial energy

FIGURE 1. Estimated Energy Savings in the Residential Sector, 1972-1982

consumption increased steadily from 9.19 quads in 1972 to 10.84 quads in 1982, energy use per square foot of floor space decreased steadily from a peak of 0.252 million Btu in 1973 to 0.228 million Btu in 1982.

We estimated that annual energy savings due to reduced economic activity (i.e., decreased rate of increase in square footage of commercial floor space) increased from 0.088 quads in 1975 to 0.901 quads in 1982 (see Figure 2).

Regarding energy savings due to efficiency improvements (reduced energy use per square foot of floor space) relative to 1972, we found that:

- o Annual energy savings increased from 0.482 quads in 1974, to 0.602 quads in 1979, to 1.129 quads in 1982 (see Figure 2).
- o Of the 5.92 quads of cumulative energy savings between 1972 and 1982, 1.78 quads (or 30 percent) is explained by building retrofits (i.e., building shell thermal characteristics), including
 - caulking and weatherstripping
 - insulation (roof and wall)
 - specially treated windows (tinted, reflective, thermal)
- o Conservation actions taken in existing retail/service and educational buildings between 1972 and 1980 account for the largest portion of building retrofit energy savings, each reducing consumption by almost 0.1 quads between 1972 and 1980.

Finally, we estimated that cumulative energy savings due to decreased energy use per square foot of floor space relative to 1960-1972 trends were 21.83 quads for the period, 1972-1982 (see Figure 2).

INDUSTRIAL SECTOR

Energy consumption in the industrial sector grew steadily from 1960 to 1973. During the recession of 1974-1975, industrial energy consumption fell sharply, dropping more than 3 quads in the span of two years. Energy consumption then rose in 1976 and continued to rise through the peak capacity

FIGURE 2. Estimated Energy Savings in the Commercial Sector, 1972-1982

year of 1979. Since 1979, industrial sector energy use has declined by over 6 quads. The decline in industrial energy consumption is due, in part, to a shift away from producing energy-intensive goods.

The period 1972-1982 was a period of mixed economic growth and recession, contributing little to the expansion of the industrial sector. Annual energy savings due to changes in economic activity (i.e., changes in the rate of increase of industrial output) increased from 1.967 quads in 1974 to 8.755 quads in 1982 (see Figure 3). Cumulative energy savings due to reduced economic activity were 40.57 quads for this period.

With respect to energy savings due to improved efficiencies (i.e., changes in energy use per unit of output) relative to 1972, we find that:

- o Annual energy savings increased from 0.339 quads in 1974, to 3.420 quads in 1979, to 7.414 quads in 1982 (see Figure 3).
- o Efficiency improvements are more important in explaining energy savings than changes in the composition of industrial output.
- o Almost all (98.5 percent) of the 30.36 quads of cumulative energy savings over the period could be explained by:
 - efficiency improvements (72.9 percent, or 22.141 quads)
 - changes in the composition of industrial output (25.5 percent, or 7.748 quads)

Regarding energy savings due to decreased energy use per unit of output relative to 1960-1972 trends, we estimated that the industrial sector experienced cumulative savings of 28.26 quads for the 1972-1982 period (see Figure 3). These cumulative savings represented approximately 28 percent of the total accumulation for the whole economy for the period, 1972-1982.

TRANSPORTATION SECTOR

Energy consumed by the transportation sector increased from 16.9 quads in 1972 to 18.5 quads in 1982. Between 1972 and 1982, economic activity rose by 0.068 trillion ton-miles. Although economic activity increased 22 percent over this period, total transportation energy use expanded by only 9 percent due to improvements in both the technological and operational efficiencies of the various transportation modes. Figure 4 illustrates how energy savings due to

FIGURE 3. Estimated Energy Savings in the Industrial Sector, 1972-1982

reduced rate of increase in economic activity (i.e., person-miles or ton-miles of freight) have fluctuated during the last decade. Cumulative energy savings due to changes in economic activity were 3.901 quads between 1972 and 1982.

Improvements in the fuel efficiency of transportation modes over and above the 1972 level generated approximately 2.2 quads in energy savings in 1982. With respect to energy savings due to improved efficiencies relative to the 1972 stock, we find that:

- o Annual energy savings increased from 0.067 quads in 1974, to 1.681 quads in 1979, and to 2.152 quads in 1982.
- o Efficiency improvements are more important in explaining energy savings than shifts in the mix of fuel-efficient vehicles within the various transportation subsectors.
- o Of the 9.87 quads of cumulative energy savings observed between 1972 and 1982, 9.82 quads, or 99 percent, are explained by improvements in efficiency.

Finally, annual energy savings due to efficiency improvements relative to 1960-1972 trends increased from 0.186 quads in 1976 to 1.532 quads in 1982 (see Figure 4). Cumulatively, these savings (6.322 quads) represented about 6 percent of such savings for the total U.S. economy between 1972 and 1982.

TOTAL U.S. ECONOMY

Total energy use grew at an annual rate of 0.3 percent during the 1972-1982 period, a rate considerably lower than the 4.4 percent observed in the 1960-1972 period. Following a pattern similar to total energy used, the average annual rate of growth for real gross national (GNP) declined from 4.1 percent during the 1960-1972 period to 2.6 percent for the 1972-1982 period. While energy use per constant dollar of GNP grew at an average annual rate of 0.3 percent between 1960-1972, it later declined at an average annual rate of 2.3 percent between 1972 and 1982.

Two approaches were used to analyze energy use trends and energy savings for the whole economy: the real gross national product (or top-down) approach and the sum-of-four-sectors (or bottom-up) approach. There is general agreement between estimates of total energy use for the total U.S. economy derived

FIGURE 4. Estimated Energy Savings in the Transportation Sector, 1972-1982

for each approach. The main difference in the estimates is likely accounted for by a lack of disaggregated data which forced the exclusion of natural gas used by pipelines in the transportation sector from the bottom-up analysis.

In general, our findings for the total U.S. economy are:

- o Annual energy savings due to reduced economic activity (gross national product) ranged from negative 1.1 quads in 1973 to 11.3 quads in 1982. The cyclical nature of these savings is illustrated in Figure 5. Cumulative energy savings for this period were 45.75 quads.
- o Annual energy savings due to efficiency improvements (reduced energy use per constant dollar of GNP) from the 1972 levels to their actual levels amounted to 0.7 quads in 1973. As depicted by Figure 5, these savings grew steadily over the period and reached 13.9 quads in 1982. The industrial sector, followed by the residential and transportation sectors, accounted for most of the savings between 1976 and 1982. Cumulative energy savings due to efficiency improvements relative to 1972 levels were 60.91 quads for the period, 1972-1982.
- o Annual energy savings due to changes from trended energy use intensities to actual energy use intensities grew from 1.5 quads in 1972 to 22.1 quads in 1982 (see Figure 5). We estimated that cumulative energy savings for this period due to decreased energy use per constant dollar of GNP relative to 1960-1972 trends were 101.03 quads.

FIGURE 5. Estimated Energy Savings for Total U.S. Economy, 1972-1982

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1.0 INTRODUCTION

The oil embargo imposed on the U.S. by the Organization of Petroleum Exporting Countries (OPEC) during 1973-1974 and subsequent events have caused significant and continuing changes in the U.S. and world energy markets.

Prices of crude oil and refined petroleum products have quadrupled relative to pre-embargo levels. Prices of other fossil-based fuels have followed the general rising trend of oil prices. The traumas of the embargo--shortages, high prices, and the potential cutoffs of vital energy supplies by OPEC--have spurred energy conservation activities and investments, as well as the development of alternative and/or renewable energy resources. Reflecting the combined influence of price impacts, conservation programs, and occasional shortages, the efficiency of energy use has also increased.

The Office of Policy, Safety, and Environment (PSE) is charged with performing the necessary analytical studies to support the policy formulation and decision activities within the Department of Energy (DOE). One of the research areas of PSE is the analysis of the demand for energy and the impacts of demand on market clearing prices. With support from Energy and Environmental Analysis, Inc. (EEA) in the transportation area, Pacific Northwest Laboratory (PNL) is assisting PSE in this effort by compiling and analyzing information on historical trends of energy consumption by end-use sector.

In this chapter of the report, we outline the objectives of the study, its scope and limitations, the methodology employed, and the sources of information utilized. Chapters 2.0, 3.0, 4.0, and 5.0 contain our analyses for the residential, commercial, industrial, and transportation sectors, respectively. Chapter 6.0 synthesizes the results for all sectors to analyze economy-wide changes in energy use trends. The data which quantitatively support the text and figures in this report have been gathered together for the reader's convenience in a set of appendixes. Individuals interested in the methodological details of this analysis are urged to read the technical appendix associated with this report.

1.1 STUDY OBJECTIVES

The primary purpose of this study is to conduct a detailed analysis of historical energy use trends for the U.S. during the 1972-1982 period. This research will provide a better understanding of U.S. energy end-use patterns and trends since the Arab oil embargo. Increased understanding will enable PSE to improve its forecasts of energy demand and prices.

Specifically, the major objectives in this study were to:

1. develop a consistent approach for analyzing energy consumption trends by end-use sector
2. apply the approach to analyze the energy use trends in the residential, commercial, industrial, and transportation sectors
3. combine the results of the above four sectors to form an economy-wide analysis
4. formulate recommendations on other areas of study to further enhance DOE's capability in forecasting energy demand by end-use sector.

1.2 SCOPE AND LIMITATIONS

This study provides detailed analyses of energy consumption trends for the period 1972-1982 for the residential, commercial, industrial, and transportation sectors. A consistent approach developed as part of our study is used to perform each of the sectoral analyses. An economy-wide analysis is then undertaken on the basis of the findings from the sectoral analyses.

It should be noted that the focus of this project is to examine energy use trends and energy savings in light of: 1) the identifiable changes in both the level and mix of economic activity; 2) the improved efficiencies of the capital stock, both since 1972 and relative to 1960-1972 trends; and 3) the impacts of these changes on energy use. For example, improvements in residential building shell efficiencies may reduce residential energy consumption, or lowered economic activity in general may lead to lowered total energy use. In this project we do not attempt to analyze the economic causes (such as increased energy prices and government subsidized programs) inducing the measured changes.

Given the above scope, several qualifications should be noted. First, the electric utility sector is sometimes treated as an end-use sector in other studies and in published data. However, since electric utilities convert primary fuels into another energy form (electricity) for use by the residential, commercial, industrial, and transportation sectors, we chose not to treat electric utilities as a separate sector in this study. As a result, total energy use by each sector is measured at the primary energy level. Consequently, our measure includes the energy losses involved in converting primary fuels into electricity. The issue of primary energy versus delivered energy is discussed further in Section 1.4.

Second, although one objective of this study is to formulate recommendations for enhancing PSE's capability in forecasting energy demand by end-use sector, this study focuses on historical trends. There is no direct analysis in terms of forecasting; rather, forecasting recommendations are based on the findings regarding historical trends and lessons to be learned from these findings.

Third, the sectoral analyses are conducted at highly aggregated levels. Except for considering the geographical distribution of economic activity for households, businesses, and industries, there is no state disaggregation.

Fourth, there is no disaggregation by fuel or energy type. The only exception is the treatment of electrical losses, which is necessitated because we distinguish between primary energy and delivered energy. However, another paper by PNL (Moe et al., 1983), entitled "Electricity Use Trends in the Residential and Commercial Sectors, 1972-1982," does provide a detailed account of residential and commercial electricity use patterns.

Fifth, the analysis in the commercial sector can be improved with the use of more current data. A more recent Nonresidential Building Energy Consumption Survey (NBECS) will be available late in 1984.

1.3 METHODOLOGICAL OVERVIEW

A consistent approach for analyzing energy consumption trends by end-use sector was developed for this study. A brief overview of this approach is

provided here. A more detailed explanation of the methods used to generate the results presented in this report is contained in the Technical Appendix.

In general, our analysis proceeded in two steps. In the first phase, "energy savings" that occurred over the 1972-1982 period were calculated. In the second phase, we decomposed the estimated energy savings attributable to efficiency improvements since 1972 into meaningful subcategories.

1.3.1 Energy Savings

The first step in calculating energy savings was to establish a standard set of definitions for key concepts. These concepts were then used to determine alternative energy use base cases which could be compared with actual observed energy consumption. Energy savings were then estimated as the difference between these base cases. These concepts and definitions are fully described below.

1.3.1.1 Definitions for End-Use Sectors, Economic Activity and Energy Use Intensity

Energy is used in the various sectors for different purposes. In defining the end-use sectors, we follow the general guidelines adopted by the Energy Information Administration (1983d, pp. vii-viii):

- o Residential Sector: Energy consumed by private household establishments primarily for space heating, water heating, air conditioning, cooking, and clothes drying.
- o Commercial Sector: Energy consumed by non-manufacturing business establishments for activities similar to those of households but with the objective of serving customers to make a profit. Establishments included are motels, restaurants, wholesale businesses, retail stores, laundries, and other service enterprises, as well as health, social, and educational institutions, and energy consumed by federal, state, and local governments.
- o Industrial Sector: Energy consumed by manufacturing, construction, mining, agriculture, fishing, and forestry establishments. Energy is used by this sector for processes such as

electrolytics, machine drive, process heat, lighting and other activities in producing goods.

- o Transportation Sector: Energy consumed to move people and commodities from one location to another in both the public and private sectors. Included are military, railroad, vessel bunkering, and marine uses, as well as the pipeline transmission of natural gas.
- o Electric Utility Sector: Energy consumed by privately and publicly owned establishments that convert primary fuels into electricity primarily for resale to the other sectors.

Since the electric utility sector will not be analyzed separately, all energy losses involved in the generation, transmission, and distribution of electricity will be attributed to the remaining four end-use sectors in accordance with the electric energy used in those sectors. That is, our analysis will proceed in terms of total primary energy, rather than delivered energy. Section 1.4 discusses this issue in more detail.

Total energy use in an end-use sector is the sum of all energy types used in the sector for the various purposes noted above. A useful approach in analyzing total energy use is to relate the level of economic activity and the "energy use intensity" in the sector to total energy use in that sector:

$$\text{Total Energy Use in Sector} = (\text{Level of Economic Activity in the Sector}) \times (\text{Energy Use Intensity in the Sector})$$

The definition of the economic activity variable depends upon the sector in question. Ideally, it should be defined in such a manner that it corresponds closely to energy use. The following are the economic activity definitions adopted in this study:

- o Residential sector: Number of households
- o Commercial sector: Square footage of commercial floor space
- o Industrial sector: Value added or industrial output
- o Transportation sector: Person-miles traveled or ton-miles of freight
- o Economy-wide: Gross National Product (GNP)

Note that the selection of the economic activity variable is somewhat arbitrary. The proposed variables are selected on the basis of conceptual usefulness, feasibility, and previous work. We recognize that other variables could also be used without impairing the applicability of the framework described later in this chapter.

It should be noted that, in the case of the economy-wide analysis presented in Chapter 6.0, the basic approach involves summing the results for the individual sectors. Hence, the use of the GNP variable as the economic activity variable for the whole economy is used here for illustrative purposes and for use in comparing the results with the summing up approach.

The energy use intensities (EUI) are energy/activity ratios, intended to measure the efficiency of energy use in the sectors. Given the economic activity variables noted above, the EUI is:

- o Residential sector: Energy use per household
- o Commercial sector: Energy use per square foot of floor space
- o Industrial sector: Energy use per unit of output
- o Transportation sector: Energy use per person-mile (or ton-mile) traveled
- o Economy-wide: Energy use per constant dollar GNP

1.3.1.2 Alternative Measures of Base Case Energy Use

In order to estimate changes in energy trends a base case is needed to compare against actual observed consumption. For each end-use sector, there are several alternative measures of "base case energy use" that can be derived by varying assumptions about economic activity levels and energy-use intensities. For example, corresponding to the "business as usual case," historically observed annual economic growth rates from 1960 to 1972 can be applied to the 1972-1982 period. Alternatively, the energy-use intensities can be held constant throughout the period, trended according to historical data, or the actual EUI can be applied.

Figure 1.1 shows five lines. Line A depicts the actually observed energy use while Lines B, C, D, and E illustrate alternative measures of base-case energy use for an end-use sector. Each line is defined as follows:

Line A: observed actual energy use; actual EUI with actual activity growth

Line B: trended EUI with actual activity growth

Line C: constant 1972 EUI with actual activity growth

Line D: actual EUI with trended activity growth

Line E: trended EUI with trended activity growth (conceptually equivalent to applying the historical energy use growth rate to the base year value).

It should be noted that the relative positions of the lines shown in Figure 1.1 are illustrative only and depend upon values of trended and actual activity levels, and that of the actual, trended, or constant 1972 EUI. The positions as shown assume that the EUI during the historical period was trending downwards and that actual economic activity growth is slower than the trended growth. If any of these assumptions were to change, then the relative positions of the lines would be affected.

1.3.1.3 Concepts of "Energy Savings"

Since Lines B, C, D, and E measure the total energy that would have been consumed in a particular sector if the conditions assumed for activity levels and energy use intensities had actually occurred, the differences between these lines and Line A are different measures of "energy savings." For the purpose of this analysis, we define four concepts relating to energy savings. These concepts are summarized in Table 1.1 and are shown graphically in Figure 1.2.

1.3.2 Decomposing Energy Savings Due to Efficiency Improvements Relative to 1972

The second phase of the individual sector analysis involves further decomposition of the energy savings due to lowered EUI (shown in Figure 1.2 as the area between Lines C and A). This is equivalent to explaining the difference between the 1972 EUI and actual EUI. It should be noted that such

- Line A: Actual Energy Use (actual EUIs with actual activity growth)
 - Line B: Trended EUIs with actual activity growth
 - Line C: Constant 1972 EUI with actual activity growth
 - Line D: Actual EUIs with trended activity growth
 - Line E: Trended EUIs with trended activity growth
- (EUI: Energy Use Intensity; energy/activity ratios)

FIGURE 1.1. Alternative Measures of "Base Case Energy Use" and Actual Energy Use For an End-Use Sector

TABLE 1.1. Concepts of "Energy Savings"

<u>Concept</u>	<u>Changes In</u>		Difference Between Lines (See Fig. 1.2)
	<u>Economic Activity</u>	<u>EUIs</u>	
Economic Activity Change Savings:			
1) D-A Alternative	From trended to actual activity level	No change; actual EUIs	D-A
2) E-B Alternative	From trended to actual activity level	No change; trended EUIs	E-B
Energy Efficiency Improvements Relative to Trends	No change; actual activity level	From trended EUIs to actual EUIs	B-A
Energy Efficiency Improvements Since 1972	No change; actual activity level	From 1972 EUIs to actual EUIs	C-A

- Line A: Actual Energy Use
- Line B: Trended EUIs with actual activity growth
- Line C: Constant 1972 EUI with actual activity growth
- Line D: Actual EUIs with trended growth
- Line E: Trended EUI with trended activity growth

FIGURE 1.2. Energy Savings Measured with Lines A - E

an analysis does not provide information as to whether the estimated changes in EUI would have occurred simply because of the time trend.

Factors contributing to lowering the EUI may be grouped into the following categories:

- o changes in activity mix
- o efficiency improvement in capital stock
- o other factors including life style, operational changes in using capital equipment, the use of wood and other renewable resources, and other conservation programs.

As noted earlier, the scope of this study does not involve an analysis of the underlying causes of these changes. In particular, price effects are subsumed into the background. Note, also, that in the following discussion, many points are raised simply to facilitate considerations from the total project perspective. Feasibility, analytical questions, and other issues will be addressed in the individual sector analyses presented in the next five chapters and in the Technical Appendix. Since there were data limitations and since some factors, including behavioral responses such as turning down thermostats, are not included in the three categories analyzed, not all of the savings due to efficiency improvements could be explained. The residual--the amount of unexplained savings--varies significantly from sector to sector.

1.3.2.1 Changes in Activity Mix

Since different economic activities have different energy-use intensities, a shift in activity mix toward less energy-intensive activities would tend to lower overall EUI and result in larger energy savings. To isolate the effect of changes in activity mix, the 1972 composition of activities in each sector will be used as a base.

The potential activity mix variables for the individual sectors are as follows:

- o Residential: State or geographical distribution of households and household size.
- o Commercial: Distribution of commercial floor space by building types and by state distribution.

- o Industrial: A shift away from producing energy-intensive goods.
- o Transportation: The distribution between passenger transportation and freight, and the distribution between personal automobiles, commercial trucking, commercial aviation, marine and light trucks.
- o Economy-wide: Sum of the above four sectors.

1.3.2.2 Efficiency Improvement in Capital Stock

Efficiency improvements in the capital stock for each sector and for the economy as a whole are explained by:

- o Residential: Improved building shell efficiency and improved appliance efficiency
- o Commercial: Improved building shell efficiency and improved appliance efficiency
- o Industrial: Recent new equipment purchases as a fraction of the total capital stock. This newer vintage of capital is assumed to raise the output/energy ratio by using energy more efficiently.
- o Transportation: Fuel economy by vehicle type and vehicle age.
- o Economy-wide: Sum of the above four sectors.

1.3.2.3 Other Factors

These factors may include use of wood, energy conservation programs, curtailment activities due to voluntary action, and involuntary reductions due to shortages. To the extent possible, these factors will be separated out in the individual sector analyses.

1.4 DATA SOURCES AND MEASUREMENT ISSUES

In this section, general aspects of the data sources and measurements used in conducting the analyses for the individual sectors are explained. However, detailed data sources and qualifications of the analyses will be covered in subsequent chapters and the corresponding appendixes.

1.4.1 Data Sources

All data used in the analyses for individual sectors are provided by published data sources. For analyzing the decomposition of energy savings due to efficiency improvements relative to 1972 levels, most data are also from published materials, although additional data development was required for some data series.

Data for total energy use by sector are obtained from the Energy Information Administration's (EIA) State Energy Data System (SEDS) as reported in State Energy Data Report, 1960 through 1981 (EIA 1983d). This data source also provides data on electrical energy losses and electricity sales to the various sectors, and thus allows the derivation of delivered energy. The corresponding data for 1982 are derived from EIA's May 1983 issue of Monthly Energy Review (EIA 1983a).

Data for the economic activity variables are derived from several sources. Number of households are from the U.S. Census Bureau, as published in the Statistical Abstract of the U.S. Total square footage of commercial floor space are obtained from the F.W. Dodge Survey of Construction. Industrial production data are indirectly based on the Federal Reserve Board's index of production. Miles traveled data are from Highway Statistics. Gross national product data are from the Department of Commerce's National Income and Product Accounts of the United States.

For the economic activity mix variables, data sources include the Census of Manufactures and Annual Surveys of Manufactures, the Census of Population, and Highway Statistics.

The measures of thermal efficiency for residential and commercial buildings are derived from a combination of statistical estimation and simulation of an engineering energy use model. Such estimation and simulation are further described in the individual sector analyses in Chapters 2.0 through 5.0.

1.4.2 Measurement Issues

One major measurement issue in this analysis is whether primary energy or delivered energy should be used in the analysis of energy consumption trends in

the end-use sectors. The difference between the two measures is the loss of energy incurred in the generation, transmission, and distribution of electricity. Generally, this is reflected in the use of specific conversion factors: 3412 Btu per kWh in the case of delivered energy, and over 10000 Btu per kWh in the case of primary energy.

The analytical issue is that prices of delivered electricity, not the embodied fuels, influence consumers' fuel choices and fuel switching decisions. If the analysis is to assess the likely impacts of relative fuel prices on such fuel choices and fuel switching decisions by end-use sector, then the delivered energy approach would be appropriate. On the other hand, a complete accounting of total energy use in the economy requires the inclusion of electrical energy losses in the analysis.

The Energy Information Administration has dealt with this issue by adopting the following approach in its official statistical series on energy consumption:

- o Delivered energy in a sector includes electricity sales to the sector converted at 3412 Btu per kWh
- o Total primary energy in the sector is equal to the sum of delivered energy and estimated electrical energy losses.

The sectoral analyses that follow are based on measuring energy use in primary, rather than delivered energy units. The basis for this selection involves the fact that we are concerned with how households, business, and industry behaved. We are not dealing with economic issues involving why they behaved in a certain manner. As a consequence, we take all energy consumed into account.

2.0 RESIDENTIAL ENERGY USE

Total residential-sector energy consumption accounted for about 20 percent of total U.S. energy consumption for each of the years from 1972 to 1982. During the same period, both total residential energy consumption and energy consumption per household declined. This chapter contains an examination of possible factors contributing to the decline in residential energy use and an estimate of the extent to which these factors resulted in energy savings. This effort is an extension of the analysis done for DOE, which is described in the report, An Analysis of Changes in Residential Energy Consumption (King et al. 1982).

There are three objectives to the residential sector analysis: 1) to revise the analysis in the King et al. report according to the standardized methodology presented in Chapter 1.0, 2) to extend the prior analysis through 1982, and 3) to attempt to further explain the historical changes in residential energy use. Revisions to the earlier work will be noted as the methodology is discussed later in this chapter. The steps in the present analysis consist of the development of base-case scenarios for residential energy use and the estimation of the energy savings defined by the difference between each of the base-case measures and actual energy use.

The first section of this chapter discusses general trends in total residential energy use, energy use intensity and economic activity. Section 2.2 provides alternative measures of energy use and residential energy savings. Section 2.3 analyzes the factors contributing to residential energy savings due to efficiency improvements since 1972. Demographic-related reasons for energy savings, energy savings due to the efficiency of capital stock, energy savings due to wood use, and residual energy savings are discussed. Methodological considerations are discussed as they apply to each of the above sections.

2.1 GENERAL TRENDS IN RESIDENTIAL SECTOR ENERGY USE

Residential sector energy use has accounted for a consistent 20 percent of all energy use since 1960. For the purposes of this report, residential sector

energy use is defined as the consumption of distillate, kerosene, natural gas, liquefied petroleum gas (LPG), coal, and electricity (including distribution losses) in residences for various end uses, which include space heating and cooling, cooking, lighting, and appliances.

In keeping with the previously discussed approach, total energy consumption is calculated as the product between economic activity (number of households) and energy use intensity (the average energy use per household). Table 2.1 shows the historical trends in these factors. From 1960 to 1972, all three items increased steadily. The number of households continued to increase, at an even more rapid pace, through 1982. Energy use per household peaked at 216.1 million Btu in 1972, then decreased fairly steadily to 177.3 million Btu in 1982. The steady increase in the number of households counteracted some of the decreases in energy use per household so that total energy consumption peaked in 1978 at 15.6 quads. Total energy consumption fell from 1978 to 1981, then rose again slightly in 1982.

The decline in energy use per household that began in 1973 coincided with the Arab oil embargo and a heightened awareness of energy as a household expense. Since then, conservation awareness programs have become widespread, and conservation of energy has apparently increased. In 1974 we witnessed both higher energy prices as a result of the oil embargo and a decrease in total residential energy consumption. Decreases in total energy which occurred in 1979, 1980, and 1981 coincided with the Iranian revolution, the Iran-Iraqi war, and the decontrol of domestically produced oil. During this period a 5 percent average decrease in energy use per household took place.

2.2 ENERGY SAVINGS

Before we measured energy savings, we first estimated what energy consumption would have been if households had not reduced their use of energy. For example, if energy prices had not risen dramatically after the Arab oil embargo, household consumption of energy might have increased or leveled off instead of decreasing after 1972. Alternative estimates of residential energy use are discussed in Section 2.2.1. An analysis of energy savings immediately follows this discussion.

TABLE 2.1. Residential Energy Consumption and Number of Households for the United States, 1960-1982

Year	Annual Energy Consumption ^(a) (Quads)	Number of Households ^(b) (000)	Energy Use per Household (Million Btu)
1960	8.312	53,021.0	156.762
1961	8.606	53,689.0	160.301
1962	9.127	54,880.9	166.298
1963	9.397	55,418.6	169.559
1964	9.714	56,227.7	172.821
1965	10.147	57,300.0	177.086
1966	10.689	58,332.0	183.244
1967	11.171	58,845.8	189.835
1968	11.890	60,726.0	195.798
1969	12.744	61,805.8	206.194
1970	13.366	63,450.0	210.654
1971	13.898	64,966.8	213.925
1972	14.540	67,293.5	216.068
1973	14.637	68,737.0	212.942
1974	14.381	70,236.0	204.753
1975	14.466	71,535.0	202.223
1976	15.013	73,297.0	204.824
1977	15.218	74,601.0	203.992
1978	15.629	76,473.0	204.373
1979	15.186	78,515.7	193.414
1980	15.084	80,390.0	187.635
1981	14.598	81,968.9	178.092
1982	14.812	83,527.0	177.332

(a) Energy Information Administration (1983d).

(b) Bureau of the Census.

2.2.1 Alternative Estimates of Residential Energy Use

The methodology discussed in Chapter 1.0 is used to estimate four different scenarios of energy consumption in the residential sector under alternative sets of assumptions about economic activity and energy use intensity. Line A in Figure 2.1 represents actual residential energy consumption while the alternative scenarios are represented by Lines B through E. The formulas for calculating each of these paths are shown in Table 2.2.

TABLE 2.2. Methods for Calculating Lines A Through E

<u>Line</u>	<u>Formula</u>
A	Actual Households x Actual Energy Use Per Household
B	Actual Households x Trended Energy Use Per Household
C	Actual Households x 1972 Energy Use Per Household
D	Trended Households x Actual Energy Use Per Household
E	Trended Households x Trended Energy Use Per Household

2.2.2 Analysis of Energy Savings

In order to explain the energy savings that took place between 1972 and 1982, we examine the different measures of energy savings that result from comparing Lines A, B, C, D, and E. These alternative estimates of energy savings are presented in Table 2.3.

The faster growth rate in the number of households between 1972 and 1982, other things being equal, resulted in increased, rather than decreased, consumption of energy. We draw this conclusion by looking at the difference between Line D and Line A. Both lines use actual energy use per household, but Line D uses trended households rather than actual households. Because the trended number of households is less than the actual number of households, Line D lies below Line A, and a comparison of the two lines does not indicate energy savings, but rather an increase in consumption.

Line C uses the actual number of households, but differs from Line A in its measure of EUI. While Line A uses actual energy use per household, Line C

FIGURE 2.1. Alternative Estimates of Total Energy Use in the U.S., Residential Sector

TABLE 2.3. Alternative Estimates of "Energy Savings"
in the Residential Sector, 1972-1982

Trillion (10^{12}) Btu

<u>Year</u>	<u>E-A</u>	<u>D-A</u>	<u>C-A</u>	<u>B-A</u>
1972	0	0	0	0
1973	609	-35	-55	646
1974	1605	-74	795	1688
1975	2296	-67	990	2374
1976	2563	-152	824	2743
1977	3211	-136	901	3378
1978	3695	-232	894	3986
1979	5076	-338	1779	5537
1980	6162	-406	2286	6749
1981	7680	-401	3113	8310
1982	8547	-407	3236	9208

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

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

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

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

assumes that household energy use remains at the 1972 level. The difference between these lines measures energy savings due to changes in household energy consumption.

2.3 COMPONENTS OF RESIDENTIAL ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

The next step in this analysis is to attempt to explain the factors contributing to the conservation of energy for the study period and to determine the degree to which each factor accounted for energy savings. This analysis is illustrated graphically in Figure 2.2 by subdivisions drawn between Lines C and A in proportion to each factor's contribution to energy savings. Changes in the geographic distribution of households (migration), changes in household size, appliance efficiency, shell efficiency, the use of wood, and changes in household attitudes are the factors examined in this report. Each of these factors is described below.

2.3.1 Geographical Distribution of Households

The movement of households from the colder states of the Northeast and Midwest to the warmer Sun Belt states over the past decade has contributed modestly to the reduction in residential energy consumption. Over the entire study period, migration accounted for 2.2 percent, and from 1979 to 1982 it accounted for only 1.4 percent of cumulative energy savings due to improved efficiencies since 1972 (see Figure 2.2).

In order to measure the impact of changes in the geographical distribution of households, it was necessary to compare energy use both with and without migration. Actual energy use already includes the effects of migration, so it was only necessary to construct a scenario of what energy use would have been without migration. To create such a scenario, data showing the proportion of households in each state and the energy use per household in each state was used. For each year, national energy savings per household due to migration were defined as the difference between actual energy use per household for that year and the weighted average of the energy use per household by state for that year, where the weights were the proportion of households in the state in

FIGURE 2.2. Decomposing Estimated Energy Savings Due to Changes in Energy Use Intensity Since 1972, Residential Sector

1972. Total residential energy savings attributable to migration in a given year are then equal to savings per household multiplied by the corresponding national number of households. This methodology was taken directly from King et al. (1982). Those readers wishing a more detailed discussion are referred to that report and to the Technical Appendix.

2.3.2 Household Size

Between 1972 and 1982, the average number of persons in each U.S. household fell 10.48 percent, from 3.11 to 2.78 persons. Nearly all econometric studies of household demand for electricity have found a significant relationship between household energy use and the number of residents. The results of our analysis show that savings due to changes in household size were 21.7 percent of cumulative residential energy savings (3.209 quads) for the 1972 to 1982 period, second only to the thermal efficiency improvement factor analyzed.

Energy savings due to the change in household size are estimated by calculating the percentage difference in household size between 1972 and each of the other years in the study period, and multiplying that series by 0.3047, the estimated weighted average elasticity of household electricity and natural gas demand with respect to household size.¹ This elasticity was derived from the Residential Energy Consumption Survey (RECS) data set using data on residential electricity and natural gas use, and is assumed to be a reasonable proxy for the total energy elasticity. The product of this elasticity and the percentage change in household size vis-a-vis 1972 is an estimate of the reduction in energy use per household. Multiplying this figure by the total number of households in each year yields the estimate of total U.S. residential energy savings attributable to changes in household size, illustrated in Figure 2.2.

¹ The elasticity of Y with respect to X represents the percentage change in Y caused by a one percent increase in X.

2.3.3 Appliance Efficiency

Improvements in the energy efficiency of appliances (including furnaces and air conditioners) contributed to residential energy savings, particularly between 1976 and 1982, when annual energy savings increased from 0.030 quads to 0.427 quads. Cumulative energy savings between 1972 and 1982 were 1.511 quads.

The estimates of energy savings from increased appliance efficiency are based on Lawrence Berkeley Laboratory's version of the residential energy use model created by Oak Ridge National Laboratory (ORNL). The Oak Ridge model used in this study includes seven major appliances (space heating equipment, air conditioners, water heaters, refrigerators, freezers, ranges and ovens, and clothes dryers), and three major fuels (electric, gas, and oil). The method used is the same as that described in King et al., but the inputs to the ORNL model have been updated and extended, resulting in slightly different figures than those reported in the King study.

The general approach in using the ORNL model was to simulate residential energy use reduction in energy use by allowing only appliance efficiencies to change during the study period. The stock of appliances was held constant at 1977 levels, with efficiencies changing only through turnover of the existing stock, not through additions to the stock. With this assumption, the model generated estimates of how much energy was used by electric and non-electric appliances during the 1972 to 1982 period. These estimates were then added to obtain an estimate of total energy use by appliances that could be converted into an index of efficiency improvement. Dividing actual total residential energy use by the index yields an estimate of what total energy use would have been if appliance efficiencies had not improved.

2.3.4 Shell Efficiency

During the 1972 to 1982 period, substantial improvements were made to the thermal integrity or efficiency of U.S. homes. Many households installed wall and ceiling insulation, storm windows and doors, weatherstripping, and caulking in order to reduce the energy used for space heating and cooling. During both the entire study period and the 1979-1982 period, thermal efficiency improvements accounted for more residential energy savings than any other factors analyzed. For the 1972-1982 period, thermal efficiency saved 3.416

quads, 23.1 percent of the cumulative savings. Most of the shell improvements occurred after the Iranian revolution and subsequent oil price increases. Over sixty percent of the reported savings (2.08 quads) appeared between 1979 and 1982.

The approach used to calculate thermal efficiency-related savings involves several steps. First, the percentage increase in thermal efficiency compared to 1972 levels is estimated using a regression equation estimated based on NIECS/RECS data and aggregate U.S. data for the 1972-1982 period. The reduction in energy used for electric space heating, electric air conditioning, electric room air conditioning, and non-electric space heating is then calculated using the demand elasticity for each end-use category (also estimated from the NIECS/RECS database) and the 1972 estimated fuel use (electricity or nonelectricity). Multiplying by the number of households using each end use gives the total savings from thermal efficiency improvements for each end use. This method used to calculate thermal efficiency energy savings in the residential sector is similar to the method described by King et al. (1982), with a few exceptions. For more information, please refer to the Technical Appendix.

2.3.5 Wood Use

Wood was the major source of energy in the U.S. until the end of the 19th century. The development of low-priced petroleum fuels, coal, natural gas, and electricity led to the decline of wood as a residential sector fuel source until the 1960s and 1970s, when environmental regulations and rising fuel prices led to a reversal in the downward trend of wood use. Cumulative energy savings from wood use was 2.267 quads between 1972 and 1982.

The use of wood as an energy source varies from household to household. Some households use wood as a primary fuel, while many more use it as a secondary fuel. Other households use wood in a recreational capacity, where the aesthetics of a fireplace are desired, with little importance being attached to the produced heat. Unfortunately, the readily available data on wood consumption do not allow the separation of the three categories of wood users. The analysis here assumes that increases in wood use over the level of

use in 1972 were made at the expense of one of the six fuels contained in the composition of residential energy use given in Section 2.1. Energy savings due to increases in wood use are then equal to the difference between actual wood use for each year in the study period taken from the Energy Information Administration report, Estimates of U.S. Wood Energy Consumption from 1949 to 1981, and the 1972 wood use.

If wood use were included in the definition of residential energy use for this analysis, this section would not have been required. Because poor data on wood use did not allow inclusion in the definition of residential energy consumed, some of the reduction in published energy use per household is simply due to use of an energy source (such as wood) that is not accounted for in the published data.

2.3.6 Other Considerations

The residual category accounted for nearly 30 percent (about 4 quads) of residential sector energy savings in the 1972-1982 period. Included in this category are savings due to consumers' attitudes about conservation (e.g., turning thermostats down, closing off rooms), the effects of fuel switching to renewable energy sources (like solar power), and other unspecified factors. Values for the residual category shown in Figure 2.2 are equal to the energy savings for each year minus the savings attributed to the other five factors. The negative residual in 1978 may mean that the systematic methods used to estimate the other five factors explained more savings than actually took place, or it may be due to non-methodological reasons, such as households simply turning up their thermostats.

2.4 SUMMARY

Approximately 20 percent of total U.S. energy consumption since 1960 is attributable to the residential sector. Energy consumption in this sector increased from 14.54 quads in 1972 to 14.81 quads in 1982, peaking at 15.63 quads in 1979. Energy use per household increased sharply between 1960 and 1972. However, a rapid decline in energy use per household since 1972 has reversed the increasing trend of energy use per household observed over the 1960-1972 period.

Energy savings due to changes in economic activity (i.e., the number of households) were negative for the entire period, 1972-1982. Such "dissavings" occurred as the result of changes in the number of households, which increased dramatically (25 percent) over this period. Cumulative energy "dissavings" due to changes in economic activity in the residential sector were 2.247 quads between 1972 and 1982.

Shell efficiency, household size, and wood use are found to be important factors explaining energy savings due to changes in efficiency improvements from the 1972 levels. In fact, of the cumulative savings for the 1972-1982 period (14.76 quads) we were able to explain 23.1 percent (3.42 quads) by improved shell efficiency, 21.7 percent (3.21 quads) by household size, 15.4 percent (2.27 quads) by increases in wood use, 10.2 percent (1.51 quads) by improved appliance efficiency, and 2.2 percent (0.32 quads) by migration.

Finally, we estimate that cumulative energy savings that occur as a result of efficiency improvements relative to 1960-1972 energy consumption trends were 44.59 quads between 1972 and 1982. This measure shows substantial energy savings occurring in the residential sector due to a reversal of the rapidly increasing trend of energy consumption per household observed between 1960 and 1972.

3.0 COMMERCIAL ENERGY USE

The glass and steel skyscrapers in America's large cities are visible reminders of the U.S. economy's shift toward a service economy. In 1982, the commercial sector, which includes office buildings, schools, stores, hospitals, warehouses, and restaurants, accounted for 15.3 percent of total U.S. energy demand, as compared to 12.8 percent a decade earlier. The commercial sector's demand for electricity has been even more dramatic; about 35 percent of the total growth in electricity consumption since 1972 is attributable to this sector.

Section 3.1 of this chapter discusses general trends in total commercial energy use, energy use intensity, and economic activity for the period, 1960-1982. Alternative measures of energy use and energy savings are described in Section 3.2. In Section 3.3 we explain energy savings due to efficiency improvements relative to 1972 by building retrofits. Our findings are summarized in the concluding section.

3.1 GENERAL TRENDS IN COMMERCIAL SECTOR ENERGY USE

Major trends on energy use per square foot are shown in Table 3.1. From 1960 to 1982 total energy use per square foot rose at an annual rate of 1.8 percent per year. As Figure 3.1 illustrates, most of the growth was attributable to electricity. By 1982, total energy use per square foot had fallen slightly more than 10 percent from its 1973 peak. This decline occurred primarily in fossil fuel consumption, which was about 25 percent lower than its 1973 level. From 1974 through 1977 electricity use per square foot rose nearly as fast as it had before the embargo, but since 1978 the growth rate has averaged less than one 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 the energy use is in fact used to space condition, provide hot water, and illuminate interior space, the activity measure chosen for this study is, perhaps, the most common one--floor space measured in square feet. Since no comprehensive surveys on commercial floor space have been taken on a periodic basis, available estimates are based on a perpetual inventory accounting

TABLE 3.1 Energy Use, Commercial Floor Space,
and Energy Use Intensity in the
Commercial Sector 1960-1984

<u>Year</u>	<u>Annual Energy Consumption^(a) (10¹²BTUs)</u>	<u>Commercial Floor Space^(b) (10⁹ft²)</u>	<u>Energy Use Per Square Foot (10⁶BTUs)</u>
1960	4810	24497	.19635
1961	4901	24735	.19814
1962	5210	25576	.20371
1963	5384	26478	.20334
1964	5576	27390	.20358
1965	5946	28437	.20909
1966	6434	29527	.2179
1967	6987	30563	.22861
1968	7398	31706	.23333
1969	7899	32972	.23957
1970	8397	34052	.24659
1971	8748	35243	.24822
1972	9189	36501	.25174
1973	9547	37909	.25184
1974	9384	39190	.23945
1975	9466	40098	.23607
1976	10033	40966	.24492
1977	10184	42000	.24246
1978	10493	43244	.24264
1979	10614	44557	.23822
1980	10601	45658	.23217
1981	10641	46743	.22765
1982	10836	47529	.22798

(a) Energy Information Administration (1983c)

(b) Information Administration (1983 a&b)

FIGURE 3.1. Energy Consumption Per Square Foot in Commercial Buildings, 1960-1982

procedure using data on floorspace of newly constructed buildings. The aggregate floorspace data for this study through 1977 were taken from the Oak Ridge National Laboratory's database in their development of the Commercial Building Energy End-Use Model. Later years were estimated by PNL on the basis of additions to stock reported by the F.W. Dodge Division of McGraw-Hill and assumed retirement rates. The series resulting from this procedure was finally benchmarked to match the aggregate floorspace estimate for 1980 from EIA's Nonresidential Building Energy Consumption Survey conducted in late 1979 and early 1980.

3.2 ENERGY SAVINGS

In this section the methodology described in Chapter 1.0 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 used per square foot of floor space) are used to estimate the baseline cases--Lines B, C, D, and E. Total energy use in the commercial sector is then represented by energy use intensity multiplied by the level of economic activity. Alternative estimates of commercial energy use are presented in Section 3.2.1. Values for the various energy savings concepts are derived in Section 3.2.2.

3.2.1 Alternative Estimates of Commercial Energy Use

Graphical representations for the five measures of total commercial energy use are displayed in Figure 3.2. The lines displayed here correspond to the following definitions:

- Line A: actual energy use intensities (EUIs) with actual activity growth
- Line B: trended EUIs with actual activity growth
- Line C: constant 1972 EUI with actual activity growth
- Line D: actual EUIs with trended activity growth
- Line E: trended EUIs with trended activity growth

Line A represents actual observed energy use from 1972 to 1982. In the section immediately below, we use this information to construct alternative estimates of energy savings for the commercial sector.

FIGURE 3.2. Alternative Estimates of Total Energy Use: Commercial Sector

3.2.2 Analysis of Energy Savings

The alternative estimates of energy savings calculated by comparing the lines in Figure 3.2 are presented in Table 3.2. The difference between Line D and Line A represents energy savings due to changes in economic activity. We find that cumulative energy savings due to changes in economic activity (i.e., decreased rate of increase in square feet of commercial floor space) were 3.57 quads between 1972 and 1982. Cumulative energy savings due to efficiency improvements since breaking away from the 1960-1972 trends (Line B minus Line A) were 21.83 quads of primary energy.

Table 3.2 also shows that energy savings due to efficiency improvements relative to 1972 (Line C minus Line A) increased from 0.482 quads in 1974 to 1.129 quads in 1982. Cumulative energy savings for this measure were 5.92 quads between 1972 and 1982.

3.3 COMPONENTS OF COMMERCIAL ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

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 3.2. Among these factors are: 1) changes in the utilization of heating, ventilation, and air conditioning (HVAC) equipment (thermostat settings); 2) changes in the average efficiency of HVAC, stemming from both turnover of old equipment and improved maintenance of existing equipment; 3) changes in occupancy patterns of buildings; 4) shifts in the geographical distribution of buildings; and 5) changes in building shell thermal characteristics.

This study concentrates on the fifth factor--the changes in average building shell thermal performance resulting from conservation actions undertaken by building owners and managers. The other factors have been ignored for the present since no national survey data exists that would provide any direct estimates. This is especially true for the first three factors which deal with efficiency and utilization of HVAC equipment. Although data do exist that might lead to estimates of savings from geographical shifts in the building stock, this factor, as evidenced from the residential results, is likely to be relatively small.

TABLE 3.2. Alternative Estimates of "Energy Savings"
in the Commercial Sector, 1972-1982

Trillion (10^{12}) Btu

<u>Year</u>	<u>E-A</u>	<u>D-A</u>	<u>C-A</u>	<u>B-A</u>
1972	0	0	0	0
1973	191	-33	-4	225
1974	937	-21	482	961
1975	1473	88	628	1372
1976	1560	226	279	1306
1977	2103	327	389	1720
1978	2529	394	393	2058
1979	3188	449	602	2628
1980	4026	558	893	3294
1981	4862	684	1126	3929
1982	5594	901	1129	4332

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

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

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

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

3.3.1 Brief Overview of Methodology

This section briefly discusses the methodology used to develop estimates of savings from conservation measures aimed at the building shell. A detailed description is provided in the Technical Appendix, so only key steps in the approach will be addressed here. The level of disaggregation at which the analysis was performed is summarized in Table 3.3. The first step of the work involves the use of the Nonresidential Building Energy Consumption Survey (NBECS), conducted by EIA in 1979-80, to provide data on the percentage of building stock (square feet) that had been retrofitted since 1972.

TABLE 3.3. Characteristics of the Commercial Sector Analysis

<u>Characteristic</u>	<u>Level of Detail</u>
Retrofit Activities	1) weather stripping or caulking; 2) addition of roof or wall insulation; and 3) installation of tinted, reflective, or thermal pane windows
Building Prototypes ^(a)	1) assembly, 2) education, 3) office, (b) 4) food sales, (b) and 5) retail/service
Representative Climates ^(c)	1) Casper, 2) Denver, 3) Portland, 4) Las Vegas, and 5) Phoenix
Fuel Types	1) electric heating and 2) non-electric heating

(a) These building types comprise over sixty percent of the floorspace in the commercial sector.

(b) Both a "large" and a "small" prototype were developed.

(c) Weather tapes were only available for cities in the western U.S.

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

familiar with commercial building energy issues, provided estimates of typical specifications of pre- and post-embargo "common practice" (e.g., R-values of roof insulation) in a number of prototype 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 into estimates of energy savings, the DOE-2 engineering energy-use model was employed. For each building prototype 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 (combined with the survey results regarding the number of buildings (floor space) retrofitted by year) were then used to "backcast" actual 1979 energy use from NBECS for each building type. The difference between the estimated 1972 and actual 1979 figures provides a measure of savings due to changes in the average shell characteristics.

Next, the yearly savings from the three retrofit actions were summed, adjusted for regional differences in climate, and normalized to the 1979 consumption figures. Using the NBECS survey information and the procedure just described, the savings estimates were constructed through 1980. These estimates were extended through 1982 by means of a simple regression analysis.

3.3.2 Sample Intermediate Results

Before turning to the final results regarding energy savings, several tables showing some intermediate results may help to illustrate the methodology more clearly. The discussion in this section is limited to small retail buildings; the Technical Appendix provides similar information for all eight building prototypes used in this study.

Table 3.4 shows the extent of insulation activity as reported in the NBECS survey for the category, "small" retail/service. The "small" designation for this building type is fairly broad, covering buildings up to 50,000 square feet. The average building size is approximately 6,600 square feet.

The top panel in Table 3.4 applies to buildings heated by the major fossil fuel types (plus steam) covered by the NBECS. The first row shows the amount

TABLE 3.4. Historical Retrofit activity for
Small Retail Buildings: Insulation

Heated by: Natural Gas, Fuel Oil, LPG, or Steam

		Weather Zones					
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>Total</u>
Total Floor Space ^(a)		481.9	1,126.1	931.6	707.6	395.9	3,643.1
No. of Observations		(62)	(153)	(128)	(84)	(66)	(489)
<u>Cumulative Percentage of Insulation Retrofits</u>							
1972	0.0	0.0	0.0	2.3	0.0		0.5
1973	0.0	0.0	0.0	2.3	0.0		0.5
1974	5.2	0.3	0.8	3.0	2.5		1.8
1975	11.2	3.3	1.9	4.8	9.1		4.9
1976	15.5	4.2	8.2	4.8	11.1		7.6
1977	23.4	7.4	12.2	5.3	11.1		10.8
1978	35.5	17.4	24.2	7.2	12.7		19.0
1979	36.5	30.4	28.5	10.1	15.5		25.2

Heated by: Electricity

<u>Total Floor Space</u> ^(a)		22.3	124.4	250.3	219.7	336.5	953.3
No. of Observations		(7)	(17)	(36)	(30)	(56)	(146)
<u>Cumulative Percentage of Insulation Retrofits</u>							
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	0.0	2.3	0.8	
1974	6.8	0.0	0.0	0.0	2.3	1.0	
1975	6.8	0.0	0.0	0.0	2.3	1.0	
1976	6.8	0.0	0.0	0.0	3.4	1.4	
1977	6.8	0.0	0.5	2.0	5.3	2.6	
1978	6.8	30.7	0.8	2.1	10.6	8.6	
1979	82.4	49.3	8.5	2.8	12.0	15.5	

(a) Million Square Feet.

of square feet in each weather zone (see section 3.2) and the sum across all weather zones. The figure 3643.1 million square feet represents almost 8 percent of the floorspace in the entire commercial sector. The number in parentheses under the square footage values show the number of buildings in the survey that fall into this category. Even in the category with fewest buildings (weather zone 1) the 61 buildings in the sample should provide a reasonably accurate representation of the time pattern of insulation activity.

Although no formal statistical analysis was performed, the overall results generally support the expectation that a greater fraction of buildings in the colder zones received additional insulation. In the coldest zone, which includes cities such as Minneapolis-St. Paul, some 36.5 percent of the total floorspace received additional insulation in the wall or roof between 1972 and 1979. By comparison, 15 percent or less of the floorspace in zones 4 and 5, received more insulation.

The number of buildings that are heated with electricity is much smaller, and for some weather zones, the results are somewhat spurious due to the small sample size. This is obviously the case for weather zone 1 with only seven observations. However, for the remaining zones the sample size is probably large enough to give a reasonably reliable indication of the extent of retrofit activity. As for the buildings heated with fossil fuels, the percentage of buildings that received additional insulation was greater in zones 1 and 2 than for the warmer zones.

Two other results in Table 3.4 are of note. First the percentage of insulation activity is greater in zone 5 than zone 4, for both categories of heating systems. This result, which also occurs in a number of other building types as shown in Tables B.3 through B.26 of the Technical Appendix, may reflect insulation to reduce air conditioning loads. Second, the percentage of building floor space that received insulation is greater for the buildings (totaled across weather zones) heated by fossil fuels than for electrically heated buildings. This is generally the case for all building types and retrofit actions. This result would be expected on economic grounds as prices for oil and gas rose much faster than electricity rates during this period.

Table 3.5 shows the results of the DOE-2 simulations for the small retail prototype. As detailed in the Appendix, the small retail prototype is a single

TABLE 3.5. Simulated Energy Reductions from Retrofit Options:
Small Retail Buildings

	<u>Zone 1</u> <u>(Casper)</u>	<u>Zone 2</u> <u>(Denver)</u>	<u>Zone 3</u> <u>(Portland)</u>	<u>Zone 4</u> <u>(Las Vegas)</u>	<u>Zone 5</u> <u>(Phoenix)</u>
<u>Heated by Natural Gas or Fuel Oil</u>					
Base Specification (Kbtu/sq.ft. primary energy)	297.1	280.0	253.1	320.1	324.9
Percentage Reduction due to:					
Caulking	-3.6	-2.1	-2.1	-1.6	-0.0
Insulation	-11.3	-9.3	-7.9	-9.2	-6.9
Treated Windows	-5.7	-5.1*	-6.0	-7.2	-6.5
<u>Heated by Electricity</u>					
Base Specification (Mbtu, primary energy)	336.6*	317.2	286.7*	362.6*	368.1*
Percentage Reduction due to:					
Caulking	-7.0*	-4.1	-4.1*	-3.1*	-0.0*
Insulation	-17.4*	-14.3	-12.2*	-14.2*	-10.6*
Treated Windows	-6.9*	-6.2	-7.3*	-8.8*	-7.9*

*Imputed value (see Appendix B, Section B.3)

story building, having 6400 square feet, and using a package single zone air conditioner with heating. Roof insulation is assumed to be changed from R-7 to R-19; wall insulation was installed at an R-7 level. Caulking was assumed to reduce infiltration by 40 percent and single pane windows were replaced by double pane. With these specifications, the percentage changes in energy consumption are simulated to relatively modest changes, all but one less than 10 percent. The weather zones are ordered from highest to lowest heating load, and vice versa, for cooling. Portland, Oregon represents the most moderate weather zone with an expected total consumption of 253 Kbtu per square foot. For caulking and insulation, the percentage reductions are higher in cities with higher heating (or significantly higher cooling) requirements.

The percentage reductions are greater for buildings heated by electricity than for buildings heated directly by gas or oil. This result stems largely from the fact that in an electric based heating system, where electricity is measured in source or primary Btus, the energy required for heating accounts for a larger percentage of total building energy use than in an alternative system. That is to say that electricity is a less efficient (not necessarily in an economic sense) method of space heating once the losses for generation and transmission are accounted for. As a result, the retrofit measures which affect the heating loads equally have a greater relative impact on total energy use in those buildings heated with electricity. Many of the figures in the bottom panel of the table are imputed, rather than directly obtained from the DOE-2 model. The Appendix provides a detailed description of the imputation procedure.

3.3.3 Final Results

From the engineering and survey results described above, a time series of energy consumption was constructed for each building type. Each series was benchmarked so that total 1979 consumption agreed with the NBECS survey (electricity was adjusted to a primary Btu basis, however). Details of the procedure can be found in the Technical Appendix.

The time series results are shown in Table 3.6. Retail and service buildings are estimated to account for the largest proportion of savings between 1972 and 1980, falling by nearly 0.1 quads in that period. On a

TABLE 3.6. Constructed Annual Energy Use by Building Type
(Quads, Primary Btu)

	<u>Assembly</u>	<u>Education</u>	<u>Food Sales</u>	
1972	.708	.949	.810	
1973	.708	.949	.810	
1974	.707	.948	.809	
1975	.707	.942	.808	
1976	.705	.934	.802	
1977	.701	.921	.798	
1978	.693	.909	.790	
1979	.682	.884	.775	
1980	.661	.858	.765	
Percent Change, 1972-80	-6.7	-9.5	-5.6	
	<u>Office</u>	<u>Retail/Service</u>	<u>Total Energy Used</u>	<u>Annual Savings, 1972 base</u>
1972	2.133	1.367	5.967	--
1973	2.133	1.367	5.967	0.0
1974	2.132	1.366	5.962	-.005
1975	2.129	1.362	5.947	-.020
1976	2.126	1.356	5.923	-.044
1977	2.123	1.341	5.884	-.083
1978	2.114	1.331	5.837	-.130
1979	2.099	1.300	5.741	-.226
1980	2.082	1.269	5.636	-.331
1981			5.561*	-.406
1982			5.428*	-.539
Percent Change, 1972-80	-2.4	-7.2	-5.5	

* Extrapolated by regression equation

percentage basis, educational buildings show the greatest decline, almost 10 percent over the study period. Educational buildings are generally "shell dominated" in that they generally have a greater wall to floor space ratio than most other building types and they generally do not have high internal loads. Thus, the retrofit options from the DOE-2 model display sizeable percentage reductions. This same phenomenon also applies, to a lesser extent, to assembly buildings.

Office buildings, on the other hand, generally generate significant internal heating loads, which explains why some offices need air conditioning in certain portions of the building even during the winter months. This is reflected in the methodology here. Offices are estimated to have reduced consumption resulting from retrofits only between 2 and 3 percent.

Over the five building types analyzed, the estimated percentage reduction is 5.5 percent between 1972 and 1980. Translated into savings, this amounts to about one third of a quad.

In order to extend the savings estimates through 1982, a simple regression equation was estimated with fuel prices as the independent variable. The results for 1981 and 1982 should therefore be viewed very cautiously. Although price increases can be viewed as the primary driving force behind the conservation actions considered, the timing of the actions bears only a loose relationship to the changes in fuel prices. For instance, the 1977-78 change in real fuel prices was the lowest in the post-embargo period. Yet, it is in this period (1977 and 1978) that retrofit activity seems to have accelerated.

Using the estimates of savings resulting from retrofits shown in Table 3.6, a simple decomposition of the historical total savings "wedges" is shown in Figure 3.3. The only plausible explanation for the behavior of the residual energy savings component is that there exists considerable short-run price and income elasticities for energy in the commercial sector as a whole. In the 1974-1975 period, with rapidly rising energy prices and declining economic activity, building managers apparently attempted to reduce the utilization of HVAC equipment. This effect seems to lessen as the recovery proceeded and energy price rises moderated. The residual energy savings falls to a post-embargo low of 0.26 quads in 1978. The short-run measures again seem to be responsible for the subsequent dramatic increase in the component, leading to

FIGURE 3.3. Decomposing Estimated Energy Savings Due to Changes in Energy Use Intensity Since 1972, Commercial Sector

0.7 quads in 1981. The 1982 drop to 0.6 quads may simply reflect an overestimate of the retrofit component (C-X), stemming from the simplicity of the regression model described above. However, it is plausible that it also reflects the short-run price response; in real terms, prices actually fell in 1982 by several percent. Only additional work, as described in the next section, may provide a clearer picture of the relative influences of these factors since 1980.

3.4 SUMMARY

The current study has initiated an explanation of energy savings observed in the commercial sector. This section summarizes our findings and seeks to put into perspective the limitations of the current analysis and also suggests some further approaches by which a decomposition of energy savings may be performed.

Between 1972 and 1982, the commercial sector increased its share of total U.S. energy demand from 12.8 to 15.3 percent. While total commercial energy consumption increased steadily from 9.19 quads in 1972 to 10.84 quads in 1982, energy use per square foot of floor space decreased steadily from a peak of 0.252 million Btu in 1973 to 0.228 million Btu in 1982.

Energy savings due to efficiency improvements relative to 1972 increased from 0.482 quads in 1974 to 1.129 quads in 1982. Cumulatively, these savings were 5.92 quads for the period, 1972-1982. Of the cumulative savings, 1.78 quads (30 percent) are explained by improved building shell thermal characteristics (i.e., caulking and weatherstripping, insulation, and specially treated windows).

As more fully discussed in the Technical Appendix, the commercial-sector analysis has at least three serious limitations. The first is a lack of survey data, which forced us to develop "common practice" assumptions regarding the magnitude of retrofit actions. The reader is therefore cautioned that although we believe the average results reasonably reflect the range of savings, great significance should probably not be placed on the specific results by building type. The second limitation is that service stations, warehouses, hospitals, public buildings, hotels and motels were not included in the analysis. Although some additional savings could be explained if these building types

were included, a significant level of effort would be required to do so. The final limitation was the need to extrapolate aggregate savings for the 1979 to 1982 period.

Some of these limitations could be overcome with further analysis. For example, preliminary statistics from the second NBECS, which covers the period 1978 to 1983, are scheduled for release later in 1984. Unfortunately, the new survey does not ask the year in which the activity took place. Consequently, only savings through 1983 could be computed. Even so, this information would greatly improve our confidence in the assessment of 1979 to 1982 consumption trends.

4.0 INDUSTRIAL ENERGY USE

Energy use in the industrial sector of the economy has changed dramatically since 1972. At the same time that relative energy prices were rising sharply, many other events were simultaneously occurring: price controls were being eased, requirements for pollution abatement investments were being promulgated, multinational companies were shifting production to lower-cost countries, and the U.S. began to change the way energy was imported. These factors have triggered both a shift in the composition of output produced by the industrial sector and an increase in the efficiency of energy use.

This chapter will first describe the changes in energy use patterns that have occurred, and indicate the extent of energy savings. A second section will then indicate what might have occurred if trends over the period 1960-1972 continued unabated. A third section then decomposes the industrial sector energy savings due to efficiency improvements (relative to 1972) into two components--one component that resulted from shifts in the composition of output, the other from increases in the efficiency of energy use. The last section in this chapter summarizes the findings of our industrial-sector analysis.

4.1 GENERAL TRENDS IN INDUSTRIAL SECTOR ENERGY USE

Energy consumption in the industrial sector grew steadily from 1960 until 1973 with only one decline during the mild recession of 1970. During the recession of 1974-75, industrial energy consumption fell sharply, dropping more than three quads in the span of two years. Energy consumption then rose in 1976 and continued to rise through the peak capacity year of 1979. Since 1979, industrial sector energy use has declined by over 10 quads. This sharp decline resulted in part from the decline in output in 1980 and 1982. But energy use declined more rapidly than output; indeed, in 1982, industrial energy use was at approximately the same level as in 1967, although output was more than 25 percent greater.

Industrial sector output, as measured by inflation adjusted gross national product (GNP) originating in agriculture, mining, construction and manufacturing, grew from 1960 to 1969 without interruption (see Table 4.1). After the

TABLE 4.1. Energy Use, Value Added and
Energy Use Intensity in
Industrial Sector 1960-1982

<u>Year</u>	<u>Annual Energy Consumption^(a) (10¹²Btus)</u>	<u>Value Added (GNP) (Billions of 1972 Dollars)</u>	<u>Energy Use Per Constant 1972 Dollar Value Added (10³Btus)</u>
1960	20359	263.5	77.262
1961	20446	264.1	77.417
1962	21243	280.7	75.678
1963	22176	299.1	74.142
1964	23498	315.8	74.408
1965	24477	339.6	72.076
1966	25785	357.3	72.165
1967	26004	357.3	72.781
1968	27199	374.8	72.569
1969	28409	383.9	74.002
1970	28997	367.9	78.818
1971	28962	379	76.417
1972	30219	406.3	74.376
1973	31842	439.9	72.385
1974	30899	420	73.569
1975	28568	393.9	72.527
1976	30395	425.1	71.5
1977	31149	450.6	69.127
1978	31490	473.1	66.562
1979	32645	484.9	67.324
1980	30653	464.7	65.963
1981	29292	479.7	61.064
1982	26025	449.6	57.885

(a) Energy Information Administration (1983c)

(b) U.S. Department of Commerce (1981, 1982 and 1983)

mild recession in 1970, industrial sector GNP increased through 1973. The recession of 1974-75 had a severe impact on the industrial sector, with GNP declining by more than 10 percent from 1973 to 1975. Thereafter until 1979, industrial sector GNP grew steadily, then declined in 1980, recovered somewhat in 1981, but fell again in 1982. The final three years of this topsy-turvy decade have reduced industrial sector output only 7.3 percent from the 1979 peak, considerably less than the two-year decline in the mid-1970's. A decade of mixed growth and recession has contributed little to the expansion of the industrial sector--in 1982, industrial sector GNP was only 10.7 percent higher than in 1972.

With an increase in industrial sector GNP and a reduction in energy use, it is clear that industrial sector energy intensity has declined substantially. The decade from 1972 to 1982 has seen energy intensity decline in 8 of ten years, with a net decline in energy use per dollar of GNP of over 21 percent. This decade is in marked contrast to the period 1960-1972, when energy intensity fluctuated up and down, with a slight downward trend. In the 12 years from 1960 through 1971, energy intensity increased in 6 years and declined in 6, with a peak in 1979 of 78,818 Btu per inflation adjusted dollar (Btu/\$) of output. In 1982, this energy requirement had declined to 58,185 Btu/\$ of output. These energy intensity statistics, along with industrial sector GNP and total energy use numbers, are shown in Table 4.1.

4.2 ENERGY SAVINGS

This section provides a summary of alternative estimates of industrial sector energy use and energy savings. Actual energy use is shown as Line A in Figure 4.1 along with four projections labeled Lines B through E.

Line E is the forecast constructed by projecting the trend of economic growth over the period 1960-72, then multiplying this trend by the trended energy intensity over the same period. It is predicated on the assumptions that industrial sector GNP would grow at the rate of 3.6 percent per year and that energy intensity would continue to decline at a rate of 0.1 percent per year. If these two assumptions had been realized, the industrial sector would have used 44 quads of energy to produce nearly \$600 billion of product at 1972

FIGURE 4.1. Alternative Estimates of Total Energy Use, Industrial Sector

prices. Instead, the industrial sector used 26 quads to produce nearly \$450 billion of output.

Line D alters the assumption about energy intensity, but retains the assumption of trended growth in output. It is constructed as if GNP had continued its trend but energy intensity had followed its actual path. In this case, the \$600 billion of output would have required 34.8 quads to produce in 1982--9.2 quad less than if trended energy intensity growth had persisted.

Lines B and C are constructed using actual growth of industrial GNP rather than trended GNP, but make slightly different assumptions about energy intensity. Line C assumes that energy intensity remained constant at the level that occurred in 1972--74, 376 Btu per dollar of output. Line B, on the other hand, assumes that the trend in energy intensity had continued its modest historic decline. These lines are almost identical during the first several years for two reasons: 1) the 1972 level of energy intensity coincidentally falls almost exactly on the trend line, so they start at nearly the same points; and 2) the rate of decline in energy intensity is so small as to be hardly noticeable until the decade is nearly over. Because of these two factors, these lines provide nearly the same information in the industrial sector.

If the 1972 energy intensity level prevailed (74,376 Btu/\$), the modest growth over the period 1972-1982 would have required 7.4 quads more energy than actually used. A continuation of the 1960-1972 decline in energy intensity would have reduced energy consumption by only 0.4 quads more than would have been used if there had been no change from the 1972 level. This clearly indicates that the decline in energy intensity has been a major factor in the decline in industrial energy use.

Table 4.2 shows the estimated energy savings derived from subtracting Line A from Lines B, C, D and E.

4.3 COMPONENTS OF INDUSTRIAL ENERGY SAVINGS DUE TO EFFICIENCY IMPROVEMENTS RELATIVE TO 1972

The difference between actual energy use (Line A in Figure 4.1) and energy use that would have resulted if energy intensity remained at 1972 levels

TABLE 4.2. Alternative Estimates of "Energy Savings"
in the Industrial Sector, 1972-1982

Trillion (10^{12}) Btu

<u>Year</u>	<u>E-A</u>	<u>D-A</u>	<u>C-A</u>	<u>B-A</u>
1972	0	0	0	0
1973	139	-661	876	817
1974	2235	1967	339	252
1975	5761	5033	729	619
1976	5172	3959	1222	1073
1977	5700	3296	2365	2174
1978	6688	2906	3697	3463
1979	6910	3434	3420	3145
1980	10328	5992	3910	3612
1981	13167	5889	6386	6045
1982	17965	8755	7414	7063

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

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

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

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

(Line C) has been decomposed into two major components: that portion of savings attributable to changes in the efficiency of energy use and that portion due to the change resulting from a shift in industrial output from relatively energy-intensive goods to less energy-intensive goods. This section explains the decomposition and provides estimates of the change in energy use attributable to efficiency improvement and to changes in the composition of output. A graph of the decomposition is presented in Figure 4.2. The details of the methodology are contained in the Technical Appendix.

There are many factors that may result in a change in energy intensity in the industrial sector. These have been subsumed under the two categories--shift in mix and changes in efficiency--because they are indicative of the consequences rather than the causes. The causes--such as higher relative energy prices, the potential for interrupted supplies, fiscal and environmental policies--will bring about changes in the structure of the industrial sector, but sorting out the separate effects of each one of these many factors is an extremely complex task, beyond the scope of the current analysis. There are more direct ways of measuring the consequences of the interaction of all these factors. Consider first the shift in output mix.

Rising energy prices, pollution abatement legislation, and many other factors have increased the costs of producing some goods and services. These higher costs have been reflected in the prices of the final goods and services sold. But since some industrial firms use more energy in the production of their goods than other industries, these increases in costs will not fall equally on all producers, and therefore the relative prices of final goods will change. Consumers, subject to a different array of relative prices, will alter their decisions about which goods to purchase. Concurrently, producers will try to economize on the use of more expensive inputs into the production process, hence changing the purchased inputs (which, for the most part, are simply outputs of other firms) into production. Thus, as a consequence of price increases, both producers and consumers will change their purchases, which, in turn, will result in a change in the industrial mix of goods produced.

This shift in production can be measured in various ways. Appropriate to this particular analysis is a comparison of an energy weighted measure of

FIGURE 4.2. Decomposing Estimated Energy Savings Due to Changes in Energy Use Intensity Since 1972, Industrial Sector

output to the more familiar output measure which is weighted by value added (its dollar contribution to GNP). A research effort by Marlay (1983) has recently been completed and provides these energy weighted measures of industrial output. The ratio of these energy weighted output indexes relative to the value added indexes provides a metric of the energy that would have been used to produce the actual level of output if the industry mix had remained constant. To calculate the additional energy that would have been required if industrial production had not shifted, the actual energy used is simply multiplied by the ratio of the energy weighted output index to the value-added weighted output index. The difference between actual energy used and the energy that would have been required if the industrial mix had not changed is the estimated savings due to a change in industrial composition.

The next step in the decomposition is to determine what fraction of the remaining difference can be explained by economic variables i.e., increases in efficiency. A reasonable set of explanatory variables would include the fraction of recent investment relative to the total stock of equipment and capacity utilization in addition to the relative price of energy. The difference between Line C and the amount of energy the industrial sector would have used if no shift in output mix had occurred is then regressed against these explanatory variables. The "explained" difference is shown in Figure 4.2.

4.4 SUMMARY

If GNP originating in the industrial sector had increased during the 1972-1982 period at the same rate it did in the period 1962-1972, the value of output in the industrial sector measured in inflation adjusted 1972 dollars would have increased \$150 billion more than the \$450 billion that was actually produced. This reduced output was the result of two major factors: an economy-wide slowdown in growth and a shift in production from energy-intensive sectors to other sectors.

If the industrial sector had produced that additional \$150 billion of output, even at actual levels of energy intensity that prevailed in 1982, there would have been an additional energy requirement of 8.7 quads, or 33 percent. If the 1960-1972 trend in the reduction of energy use per dollar of industrial GNP had continued, this additional output would have required nearly 18 quads

(about 70 percent) more energy than the 26 quads actually used by the industrial sector.

If the 1972 energy intensity level had prevailed (74,376 Btu/\$), the modest growth over the period 1972-1982 would have required 7.4 quads (28 percent) more energy than actually used. A continuation of the 1960-1972 decline in energy intensity would have reduced energy consumption by only 0.4 quads. Clearly the decline in energy intensity has been a major factor in the decline in industrial energy use.

The difference between actual energy use and energy use that would have resulted if energy intensity had remained at 1972 levels has been decomposed into two major components--that portion attributable to changes in efficiency in the use of energy and the change that results from a change in industrial mix. This decomposition suggests that, over the three years 1980-1982, shifts in product mix account for about 30 percent of the decline in energy use, while increases in efficiency account for about 70 percent of the decline.

5.0 TRANSPORTATION ENERGY USE

The pattern of energy consumption in the transportation sector has undergone a substantial change since 1972. The oil price shocks and the oil supply disruptions of 1973-1974 and 1978-1980 triggered improvements in the efficiency of vehicle use as well as short-run curtailments in travel. In addition, corporate average fuel economy standards, environmental regulations, and market place demands for improved fuel economy have stimulated significant changes in the technological efficiency of the motor vehicle fleet.

This chapter describes the changes in energy use patterns that have occurred in the transportation sector. A second section presents an assessment of what transportation energy use might have been had trends over the period 1960-1972 continued unabated. The total transportation energy savings due to efficiency improvements (relative to 1972) are then disaggregated to show the effects of two components: 1) increases in the technological efficiency of motor vehicles and 2) shifts in the mix of fuel-efficient vehicles within the various transport modes.

The reader should note that this chapter focuses on the total transportation energy use and conservation. This was evaluated by aggregating fuel use and activity data on six transportation subsectors: railroads, commercial shipping, commercial trucks, air transport, passenger cars, and light-duty trucks. (Pipelines were not included since insufficient time series data were available.) For analyses of conservation trends in each of these individual subsectors (and a discussion of the total transportation-sector methodology), the reader is referred to the Technical Appendix.

5.1 GENERAL TRENDS IN TRANSPORTATION ENERGY USE

Transportation energy use grew from 10.2 quads in 1960 to 17.8 quads in 1973 at an average annual rate of 4.4 percent. During the Arab oil embargo and oil price shock of 1973-1974, energy use dropped 2.4 percent but then rose to reach a new peak of 20.0 quads in 1978. Since 1978, transportation energy use has declined about 1.6 quads (7.8 percent). By 1982, transportation energy use had fallen back to about the same level as in 1976, even though total activity was almost 10 percent higher.

Transportation-sector activity (measure in total ton-miles) closely paralleled the growth in energy use in the period 1960 to 1973. Total activity peaked in 1973 and then dropped about 2 percent over the following two years as a result of the Arab oil embargo and subsequent recession. After 1975 and 1978, activity resumed a steady growth of about 5.2 percent per annum before peaking at an historical high of 380 billion ton-miles in 1979. Since 1979, total activity has declined slightly--dropping about 3.6 percent by 1982--as a result of the economic recession of 1980-1982 (see Figure 5.1).

Between 1972 and 1982, transportation activity rose 22 percent while energy demand increased by only 9 percent. It is clear, therefore, that there has been a substantial reduction in energy use intensity. In fact, from 1972 to 1982, energy use intensity dropped by a total of 10.4 percent or an annual average of 1.1 percent. This is more than double the 0.5 percent average yearly rate of decline in energy use intensity experienced in the 1960-1972 time period.

5.2 ENERGY SAVINGS

Figure 5.2 shows total energy use and energy savings in the transportation sector over the 1972-1982 time period. In 1982, transportation energy use is almost 17 percent (3.73 quads) below that which would have occurred had trends in energy use intensity and activity continued at historical rates of change (line E minus line A). Improvements in the technological and operating efficiency of transport over and above the 1972 level account for net energy savings of 2.1 quads in 1982 (line C minus line A). After accounting for continuation of the underlying trend in the reduction of energy use intensity observed in the 1960-1972 time period, the energy savings attributable to the "marginal" improvements in efficiency in the 1970s drop to 1.5 quads in 1982 (line B minus A).

Reduced levels of activity also significantly contribute to energy savings in the transportation sector. In 1982, activity dropped 10 percent below that implied by the continuation of historical trends and yielded savings of 2.1 quads (line D minus line A). Had the comparison been made assuming the

FIGURE 5.1. Energy, Activity and Efficiency in Transportation

FIGURE 5.2. Energy Use in the Transportation Sector

continuation of historical trends in energy use intensity, activity savings in 1982 would have been even higher--on the order of 2.2 quads (line E minus line B). This is attributable to the higher energy use intensities implied by the continuation of historical trends.¹

These savings have fluctuated over the past ten years. In 1978, for example, total gross energy savings were negative (-0.12 quads), due primarily to a surge in activity levels. Decomposition of these "negative" savings shows nevertheless that decreases in energy use intensity reduced total energy consumption by about 1.3 quads below what it would have been had no improvements in efficiency occurred since 1972.

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

As indicated previously, improvements in the fuel efficiency of transport modes over and above the 1972 level produced total net energy savings of 2.2 quads in 1982. There are several factors that have contributed to the growth in fuel efficiency since 1972. These include: 1) changes in vehicle maintenance and use (i.e., driver behavior) patterns; 2) technological improvements to new vehicles; and 3) changes in the mix of vehicles in the fleet. Due to the diversity of transport modes and the wide range in the consistency and coverage of available sources of data, it is not possible to evaluate the components of fuel efficiency improvement at the total transportation-sector level. Nevertheless, the aggregation of the components of fuel efficiency in the three major subsectors for which data are available (automobiles, light trucks and commercial aircraft) should provide at least a rough illustration of the trends at the total transportation level.

¹ For the purpose of this study, savings due to activity changes in each of the transportation subsectors are highlighted using trends in actual energy use intensity as the basis of measurement (line D minus line A). However, to show the effect of using trended energy use intensities to measure fuel savings from activity changes, the delta between line E and line B also is presented (but not discussed).

Table 5.1 shows the components of the total net reduction in transportation energy use which are attributable to 1) improved technological efficiency of transportation and 2) shifts in the mix of fuel-efficient vehicles within the various transport subsectors. A third component, labeled "other," incorporates the residual element of unexplained "savings" from transport modes not included in the analysis (i.e., commercial trucking, rail, coastal shipping). In addition, factors such as changes in driver behavior and improved vehicle maintenance which could not be quantified in detail also are included.

TABLE 5.1. Components of the Total Net Reduction
in Transportation Energy Use

(Trillion Btu)

<u>Year</u>	<u>Total</u>	<u>Efficiency</u>	<u>Mix</u>	<u>Other</u>
1972	0	0	0	0
1973	-98	-76	46	-68
1974	67	-124	39	152
1975	-200	-46	147	-301
1976	426	191	199	36
1977	679	572	217	-110
1978	1292	973	243	76
1979	1681	1371	216	95
1980	1817	2055	237	-475
1981	2053	2297	278	-522
1982	2152	2604	259	-711

Total = total net energy savings (line C minus line A)

Efficiency = savings due to improved technical and
operating efficiency

Mix = savings due to shifts in activity mix

Other = residual component of unexplained savings

Table 5.1 shows that changes in the mix of vehicles in use contributed the majority of the identifiable total net fuel savings from efficiency improvements in the early and mid-1970s. In fact, cumulative savings due to technological changes were negative through 1975, indicating a continuing decline in the overall fleet fuel efficiency of transport modes. (The fuel

efficiency of the car fleet, in particular, declined through 1974 before beginning an upturn.) However, commencing with the automobile and light-truck fuel economy standards in 1978 and 1979 and the impacts of sharp increases in fuel prices in 1979, technological improvements far outweighed the effects of shifts in mix on fuel efficiency. In 1982, for example, technological improvements in transportation efficiency accounted for about 91 percent (or 2.6 quads) of the identified components of the total net reduction in transportation energy use. Changes in mix contributed energy savings of 0.3 quads while other components contributed negative energy savings of 0.71 quads in 1982. Had this last component been absent, the combined effects of improvements in efficiency and mix would have been to increase the actual total net reduction in 1982 transportation energy use by an additional 33 percent.

5.4 SUMMARY

Change in transportation fuel uses are governed by two major factors: activity levels and energy use intensity. Had both of these variables continued to follow historical trends established prior to 1972, total transportation energy use in 1982 would have been more than 17 percent (3.7 quads) higher than what actually occurred. Reduced growth rates in activity levels significantly contributed to these savings. If total transportation activity (ton-miles) had continued along historical 1960-1972 trends, but in conjunction with actual levels of energy intensity, there would have been an additional energy requirement of 2.1 quads (11 percent of actual consumption) in 1982.

If the 1972 energy use intensity had prevailed, the growth in activity between 1972 and 1982 would have required 2.2 quads (12 percent) more than the 18.5 quads actually consumed in 1982. A continuation of the 1960-1972 trend of declining energy use intensity would have reduced this requirement by only 0.6 quads (29 percent)--a clear indication of the significant improvements in efficiency which occurred after 1972.

The energy savings attributable to reductions in energy use intensity since 1972 have been decomposed into two major components: 1) improvements in technological efficiency of transport and 2) shifts in the mix of efficient vehicles in use in the various transport modes. This disaggregation suggests

that about 91 percent of the decline in energy use in 1982 can be attributable to improvements in technological efficiency while shifts in the mix of in-use vehicles account for the remaining 9 percent.

6.0 ECONOMY-WIDE ENERGY USE

For the analysis conducted in this study, the economy has been subdivided into four sectors: residential, commercial, industrial, and transportation. Following the general approach described in Chapter 1.0, the trends and alternative estimates of total energy use and the decomposition of energy savings due to changes in energy use intensities have been explored in detail in the four previous chapters for the residential, commercial, industrial, and transportation sectors, respectively.¹ Results from these chapters are combined to analyze energy use in the total economy. We refer to the approach of summing up the four sectors as the bottom-up, or sum-of-four-sectors, approach.

In contrast, an alternative approach is to take real gross national product (GNP) as the activity variable and use it to derive the energy use intensities. The sectoral analysis procedure explained in Chapter 1.0 is then followed to estimate the alternative energy use estimates of Lines B, C, D, and E. This is termed top-down, or real GNP, approach. Both approaches are tried and the results are compared.

Section 6.1 explains the general trends with respect to total energy use, real GNP growth, and energy use intensity. Section 6.2 then presents and discusses the alternative estimates of total energy uses and the associated energy savings estimates. Section 6.3 provides a discussion involving all four sectors. Two qualifications should be noted at the beginning:

- o Due to a lack of disaggregated data, pipeline use of natural gas was excluded from the transportation analysis. Therefore, total energy use derived from the sum of the four sectors can be expected to be somewhat lower than the total economy energy use derived directly from the State Energy Data System (Energy Information Administration, 1983c).

¹ Note that the electric utility sector is not separately treated. Hence, energy uses of the four sectors are measured in terms of primary energy instead of delivered energy. As discussed in Chapter 1.0, primary energy use in a sector is equal to the sum of delivered energy use and estimated energy losses associated with the electricity delivered to that sector.

- o Because of the different levels of detail and sophistication involved in decomposing energy savings due to changes in energy use intensity since 1972 for the individual sectors, a decomposition analysis for the total economy would involve diverse assumptions and methodologies if we were to sum results for the four sectors. Hence, such an exercise is not attempted in this report.

6.1 GENERAL TRENDS IN ECONOMY-WIDE ENERGY USE

Table 6.1 presents data on total economy-wide energy use, real GNP, and the derived energy use per constant 1972 dollar GNP for the period 1960 through 1982. Total energy use grew at an annual rate of 0.3 percent during the 1972-1982 period, considerably lower than the 4.4 percent observed in the 1960-1972 period. From 1960 to 1974, total energy use grew consistently, without interruption, reaching a high of 74.6 quads. It fell by 5 percent to 70.7 quads in 1975 and then grew to 78.9 quads in 1979. After that, total energy use declined every year. In 1982, it amounted to 70.8 quads, approximately 10 percent lower than the 1979 high.

Real GNP exhibited a pattern similar to the economy-wide energy use. The average annual rate of growth for real GNP declined from 4.1 percent during the 1960-1972 period to 2.6 percent for 1972-1982 period.

Energy use intensity in thousand Btu per constant 1972 dollar GNP initially fell from 59.8 in 1960 to 56.9 in 1966 and then rose to 61.6 in 1970. Since then, it has declined consistently. By 1982, it reached 48.0 thousand Btu, a drop of 22 percent from the 1970 level. During the 1972-1982 period, energy use per constant dollar GNP fell by 2.3 percent annually, compared to the annual 0.3 percent for the 1960-1972 period.

6.2 ALTERNATIVE ESTIMATES OF TOTAL ENERGY USE AND ENERGY SAVINGS

Figure 6.1 shows the alternative estimates of energy use for the economy using the sum-of-four-sectors (bottom-up) approach. The five lines correspond to:

TABLE 6.1. Energy Use, Real GNP, and Energy Use Intensity in the Total Economy, 1960 - 1982

<u>Year</u>	<u>Annual Energy Use (10^{12} Btu)(a)</u>	<u>Real Gross National Product (Billions of 1972 dollars)(b)</u>	<u>Energy Use Per Constant 1972 dollar GNP (10^3 Btu)</u>
1960	44084	737.2	59.799
1961	44727	756.6	59.116
1962	46802	800.3	58.481
1963	48605	832.5	58.385
1964	50776	876.4	57.937
1965	52989	929.3	57.02
1966	55992	984.8	56.856
1967	57892	1011.4	57.239
1968	61323	1058.1	57.956
1969	64529	1087.3	59.348
1970	66828	1085.6	61.559
1971	68300	1122.4	60.851
1972	71628	1185.9	60.4
1973	74602	1255	59.444
1974	72755	1248	58.297
1975	70709	1233.9	57.306
1976	74509	1300.4	57.297
1977	76335	1371.7	55.65
1978	78186	1436.9	54.413
1979	78903	1483.3	53.194
1980	76022	1480.7	51.342
1981	74014	1510.1	49.013
1982	70842	1477	47.963

(a) Energy Information Administration, (1983c).

(b) U.S. Department of Commerce, (1981, 1982, and 1983).

FIGURE 6.1. Alternative Estimates of Total Energy Use: Sum of Four Sectors

- Line A: actual EUIs with actual activity growth
- Line B: trended EUIs with actual activity growth
- Line C: constant 1972 EUIs with actual activity growth
- Line D: actual EUIs with trended activity growth
- Line E: trended EUIs with trended activity growth

Since there is general agreement between the results from the sum-of-four-sectors and the real GNP (top-down) approaches, a graph of the real GNP results would look very similar to Figure 6.1. In fact, the differences by line are as follows:

(%)	<u>Line</u>	<u>Range of Difference</u>
	A	- .7 to -1.1
	B	-1.4 to 0.4
	C	-1.1 to -5.7
	D	- .5 to -4.2
	E	- .6 to -3.9

The differences in Line A are primarily due to the exclusion by Energy and Environmental Analysis, Inc., of natural gas used by pipelines for gas transmission purposes (a transportation end use). Table 6.2 shows that the difference in Line A (Col. 4) is almost exclusively accounted for by this item (Cols. 3 and 5).

Table 6.3 provides the estimates of "energy savings" corresponding to a comparison of Line A and Lines B, C, D, and E. Several aspects are noted:

- o Annual energy savings according to the "business as usual" case (Line E) grew from 0.5 quads in 1973 to 35.8 quads in 1982.
- o Annual energy savings due entirely to changes from trended economic activity growth to actual activity growth ranged from a negative 1.1 quads in 1973 to 11.3 quads in 1982.
- o Annual energy savings due to changes in sectoral energy use intensities from their 1972 levels to the actual levels amounted to 0.7 quads in 1973. This savings estimate grew consistently over the years to reach 13.9 quads in 1982.

TABLE 6.2. Accounting for Differences of Total Energy Use
Data Between Sum-of-Four-Sector Approach and Real
GNP Approach, Line A Only

Trillion (10^{12}) Btu

Year	Transportation Sector			Diff. In Total Energy (4)	Natural Gas Used In Trans- porta- tion (5)
	EEA (1)	SEDS (2)	Differ- ence (3)		
1972	16910	17680	770	770	787
1973	17850	18577	727	726	743
1974	17420	18091	671	671	685
1975	17630	18209	579	579	595
1976	18420	19068	648	648	559
1977	19260	19785	525	524	543
1978	20040	20574	534	534	539
1979	19680	20457	777	778	612
1980	19060	19685	625	624	650
1981	18840	19482	642	643	658
1982	18480	19065	585	687	607

Col. (1): Energy and Environmental Analysis, Inc. (EEA), excludes pipeline use of natural gas from total transportation use data reported by SEDS.

Col. (2): State Energy Data System (SEDS) includes pipeline use of natural gas.

Col. (3): Col. (2) - Col. (1)

Col. (4): Difference between total energy use as reported in SEDS and the sum of four sectors in this analysis.

Col. (5): Natural gas used for transportation purpose as reported in SEDS.

TABLE 6.3. Alternative Estimates of "Energy Savings":
Sum of Four Sectors, 1972-1982

Trillion (10^{12}) Btu

<u>Year</u>	<u>E-A</u>	<u>D-A</u>	<u>C-A</u>	<u>B-A</u>
1972	0	0	0	0
1973	467	-1050	719	1533
1974	5217	2354	1683	2856
1975	10254	6168	2146	3998
1976	9738	4267	2751	5308
1977	11139	3252	4334	7634
1978	12794	2103	6277	10393
1979	15968	3154	7482	12517
1980	22497	6791	8906	14944
1981	28493	7395	12678	19743
1982	35849	11318	13931	22105

E-A: Energy savings due to differences from trended to actual activity levels and from trended energy use intensities (EUIs) to actual EUIs.

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

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

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

- o Annual energy savings due to changes from the trended EUIs to actual EUIs grew from 1.5 quads in 1973 to 22.1 quads in 1982.

Table 6.4 provides a sectoral decomposition of the economy-wide energy savings due to EUI changes from the 1972 levels. Since 1976, the industrial sector accounted for over 40 percent of the estimated savings according to Line C. The residential and transportation sectors each represented between 15 and 25 percent of total savings; the commercial sector accounted for a somewhat smaller portion (less than 10 percent) of the estimated savings.

6.3 CROSS-SECTORAL RESULTS

This section provides a short discussion of the results across the end-use sectors by comparing the relevant annual growth rates. Table 6.5 compares the average annual rates of growth for economic activity, energy use intensity, and total energy use in the U.S. economy for the 1960-1972 and 1972-1982 periods. In general, we find that:

- o Growth in total energy use in the U.S. economy slowed considerably during the two periods under comparison. Instead of the 4.4 percent annual rate during the 1960-1972 period, total energy use grew at a 0.3 percent rate during 1972-1982.
- o All four sectors showed patterns similar to the total economy. The industrial sector actually showed a negative growth rate during the latter period.
- o Underlying the slower growth in total energy use by all sectors during the 1972-1982 period, as compared to the 1960-1972 period, are lowered growth of the respective activity variables and lowered energy use intensities in all sectors, with the exception of the residential sector for the economic activity variable. The annual growth rate of the economic activity variable falls from 3.5 to 2.7 percent for the commercial sector; from 3.6 to 1.5 percent for the industrial sector; and from 4.8 to 2.0 percent for the transportation sector. In contrast, the growth rate of households increased from 1.9 to 2.3 percent; growth rates of EUIs in the residential and commercial sectors

TABLE 6.4. Estimated Energy Savings Due to Changes
In EUIs From the 1972 Levels, by Sector

Trillion (10^{12}) Btu

Year	Resi- den- tial	Com- mer- cial	In- dus- trial	Trans- por- tation	Sum of 4 Sectors
1972	0	0	0	0	0
1973	-55	-4	876	-98	719
1974	795	482	339	67	1683
1975	990	628	729	-201	2146
1976	824	279	1222	426	2751
1977	901	389	2365	679	4334
1978	894	393	3697	1293	6277
1979	1779	602	3420	1681	7482
1980	2286	893	3910	1817	8906
1981	3113	1126	6386	2053	12678
1982	3236	1129	7414	2152	13931

TABLE 6.5. Average Annual Rate of Economic Activity, Energy Use Intensity,
and Total Energy Use in the U.S., 1960-72 and 1972-82
(%)

Sector	Economic Activity		Energy Use Intensity		Total Energy Use	
	1960-72	1972-82	1960-72	1972-82	1962-72	1972-82
Residential	1.9	2.3	2.9	-1.9	4.9	.3
Commercial	3.5	2.7	2.4	-1.0	6.0	1.7
Industrial	3.6	1.5	-.1	-2.2	3.5	-.7
Transportation	4.8	2.0	-.5	-1.1	4.3	.9
Total Economy	4.1	2.6	+.3	-2.3	4.4	.3

turned from positive in the earlier period to negative in the latter period. The decline in the EUIs for industrial sector and the total economy accelerated during the 1972-1982 period from those of the 1960-1972 period.

6.4 SUMMARY

Total energy use for the economy as a whole grew at an annual rate of 0.3 percent during the 1972-1982 period, a rate considerably lower than the 4.4 percent observed in the 1960-1972 period. While energy use per constant dollar of gross national product grew at an average annual rate of 0.3 percent between 1960 and 1972, it experienced a negative growth rate of 2.3 percent between 1972 and 1982.

Two approaches were used to analyze total energy use trends and total energy savings for the U.S. economy: the real gross national product approach (or top down approach) and the sum-of-four-sectors approach (or bottom up approach). In general, estimates from both approaches are in agreement. The main difference between the estimates are likely explained by the exclusion of natural gas used by pipelines in the sectoral analysis of the transportation sector.

Using the bottom-up approach, we find that annual energy savings due to changes in economic activity ranged from negative 1.1 quads in 1973 to 11.3 quads in 1982. Cumulatively, these savings were 46.14 quads for the 1972-1982 period. Annual energy savings due to efficiency improvements from their 1972 levels were 0.73 quads in 1973 and grew steadily to 13.9 quads in 1982. The industrial sector, followed by the residential and transportation sectors, accounted for most of the savings between 1976 and 1982. Finally, annual energy savings due to efficiency improvements relative to 1960-1972 trends grew from 1.5 quads in 1972 to 22.1 quads in 1982. Cumulatively these savings represented approximately 101 quads for the 1972-1982 period.

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