I-24785

DOE/CE-0140

260
2/5/86

M.L.R. (1)

(24)

DR-1527-X

Overview of Building Energy Use and Report of Analyses - 1985

Buildings and Community Systems

October 1985

Prepared for the

Office of Buildings and Community Systems
U.S. Department of Energy

DOE/CE-0140
Dist. Category UC 95d

DOE/CE--0140

DE86 005856

Overview of Building Energy Use and Report of Analyses - 1985

Buildings and Community Systems

October 1985

Prepared for the

Office of Buildings and Community Systems
U.S. Department of Energy
Washington, D.C. 20585

MASTER

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This report presents the results of work performed by many persons in the U.S. Department of Energy, at several national laboratories, and by several contractors. The report was assembled by Dr. Marjorie Schnader and Jerome Lamontagne of Brookhaven National Laboratory. Acknowledgement is made of substantial assistance received from Pacific Northwest Laboratory, particularly from Dr. David Belzer, Mr. Bill Flynn, and Ms. Aileen Bohn. Dr. Fred Abel, U.S. Department of Energy, Office of Buildings and Community Systems, is the Program Manager.

Inquiries relating to this report should be addressed to Mr. Jerome Lamontagne.

PREFACE

The U.S. Department of Energy (DOE) Office of Buildings and Community Systems (BCS) encourages increased efficiency of energy use in the buildings sector through the conduct of a comprehensive research program, the transfer of research results to industry, and the implementation of DOE's statutory responsibilities in the buildings area. The planning and direction of these activities require the construction and maintenance of database and modeling capability, as well as the conduct of analyses.

This report summarizes the results of data development and analytical activities undertaken on behalf of BCS during 1985. It provides historical data on energy consumption patterns, prices, and building characteristics used in BCS's planning processes, documents BCS's detailed projections of energy use by end use and building type (the Disaggregate Projection), and compares this forecast to other forecasts. Summaries of selected recent BCS analyses are also provided.

1. EXECUTIVE SUMMARY

1.1 Overview

This report performs several functions. First, it serves as a consistent source of historical data on energy consumption patterns, prices, and building characteristics for use as input to BCS's research and development (R&D) planning and program planning processes. The data include the most current information available. Second, the report documents BCS's Disaggregate Projection of residential and commercial energy consumption, which supplies detailed forecasts of energy use by end use and building type to aid in the prioritization of R&D programs supported by BCS. This disaggregate forecast is also compared to other forecasts. Third, summaries of selected recent BCS analysis activities are provided.

1.2 Buildings and Community Systems' Objectives

The goal of the Office of Buildings and Community Systems (BCS) is to increase the efficiency of energy use in the buildings sector, thereby contributing to the reduction of U.S. dependency on foreign energy sources and minimizing the consumption of scarce domestic energy supplies. Ancillary benefits include improved electric load management capability, reduced environmental pollution, and significant cost savings to consumers. This goal is pursued through a comprehensive research program, the transfer of research results to the building industry, and the implementation of DOE's statutory responsibilities in the buildings area.

Specific objectives are to:

- Advance the scientific understanding of how energy is used in buildings and how increased efficiency may be achieved;
- Accelerate the introduction of a new generation of energy-efficient, cost effective space heating, cooling, water heating, lighting and other building equipment;
- Encourage the use of cost-effective district heating and cooling and other energy-efficient community energy systems;
- Support the development and introduction of voluntary standards for the design of new energy-efficient residential and commercial buildings and mandatory standards for new federal buildings;
- Maintain and update scientific test procedures for major home appliances and implement the Federal appliance standards legislation;
- Transfer R&D results to the private sector.

Direction of the activities necessary to achieve the above objectives requires an understanding of historical energy use and current trends, as well as the development and maintenance of appropriate databases and analytical tools.

1.3 Trends in Energy Use

The years from 1973 to 1984 taught us that energy demands change when energy prices change. This may seem obvious now, but during the 1970's there was a strong and vocal contingent who believed that energy demand could not (or would not) decline enough to stem the rise in oil imports and prices. This view has been shown to be incorrect; energy imports in the United States are no higher than they were in 1973 and world crude oil prices have declined from the peak levels reached in 1980.

The hazards of forecasting energy prices and demands based on current trends should be apparent from the experiences of the 1970's. While oil prices and imports have declined from their peaks, there is no guarantee that these developments will continue. The behavioral component of demand reduction may prove easily reversible.

After decades of increasing use (pausing during recession years), total U.S. primary energy consumption declined during the 1973-1975 period and again following 1979. In 1984, however, the brief downward trend reversed, due primarily to increased industrial consumption associated with economic recovery. In spite of this, less energy was used in 1984 than in 1973. This reversal has been due to a variety of factors, including price-induced conservation and efficiency improvements, and changes in the structure and composition of economic activity. Industrial energy use peaked in 1979 and has declined substantially since, while transportation, residential, and commercial use have remained relatively constant since the mid-1970's. Industrial energy use accounted for 43.1% of total use in 1970, but only 37.8% in 1984; over the same period, the share used by the residential and commercial sectors grew from 32.7% to 37.8%.

Energy use by the residential and commercial sectors in absolute terms has grown slowly over the past decade, while both the number of households and commercial building floorspace have grown substantially. The number of households has increased by 25% since 1973, while residential energy consumption (including electricity generation losses) rose by only 2%. During the same period, commercial floorspace increased by 36%, while commercial energy consumption grew 16%. Average residential energy use has fallen from 214 to 177 million Btu per household per year from 1973 to 1984, a decline of 17%. During the same time period, commercial energy consumption fell from 253 to 216 thousand Btu per square foot per year, a reduction of 15%. The intensity of direct fossil energy use has declined substantially over time in both the residential and commercial sectors, while electricity has become increasingly important.

An important question to consider at this time is: what will happen to energy demand if oil prices remain stable or continue to decline as they have recently? Will energy conservation trends be reversed? Will we again become vulnerable to energy supply shocks - dependent upon insecure sources of crude oil to maintain both our production capabilities and our quality of life at home? The answers will depend to a large extent upon how much we invest now in energy efficient capital in the various energy using sectors.

1.4 Forecasts of Residential and Commercial Energy Use

BCS requires detailed forecasts of energy use in the residential and commercial sectors to aid in establishing program directions and in the prioritization of individual projects. While other organizations provide forecasts of energy supply and demand, none of these has sufficient end-use detail for BCS's needs. Consequently, BCS has supported the development of forecasts of residential and commercial energy use disaggregated by end-use and building type. The input assumptions used in generating these forecasts are generally consistent with those used in producing other contemporaneous DOE forecasts.

The BCS Disaggregate Forecast shows moderate growth in residential sector primary energy use (15.3 to 19.4 quads) and substantial growth in commercial sector primary energy use (11.2 to 17.9 quads) from 1984 to 2010. Both sectors experience a decline in the relative importance of space heating, while air conditioning, water heating, and other uses increase in relative importance in the residential sector, and air conditioning and other uses increase in relative importance in the commercial sector. Due to substantial growth in the size of the commercial sector, all end-uses show absolute increases over time. Shifts in the mix of end-uses and growth in the use of electricity for space heating lead to an increase of approximately 60% in electricity use from 1984 to 2010, while natural gas and fuel oil use remain relatively stable.

Other forecasts are also reviewed and compared to the BCS forecast of residential and commercial energy use. The general consensus among the forecasts surveyed is that energy consumption in the buildings sector will increase on the order of one to two percent per year over the next decade, after essentially showing little or no growth since 1978. Although energy intensities are projected to continue to decline, this effect is more than offset by continued growth in the number of households and in the stock of commercial floorspace. The majority of forecasts show that electricity's share of total fuel consumption continues to grow. On an absolute basis, most predictions indicate that the growth of electricity use between 1984 and 2000 in the residential and commercial sectors will be at least 2 percent per year.

The projected increasing reliance upon electricity in the building sector has important implications for research and development strategy. The benefits of R&D expenditures in the buildings sector by the federal government have largely been evaluated in terms of energy savings of fossil fuels. This approach has been based on the need to reduce dependence upon foreign oil supplies; a direct reaction to the events of the 1970's. The forecasts produced by the end-use models, as well as by other forecasting organizations, indicate that increasing benefits may be obtained from those technologies which reduce electricity consumption.

1.5 Summaries of Selected Studies

A broad range of studies are conducted to develop data required to support analysis, maintain and enhance modeling capabilities, estimate the effects of federal standards and other programs, and to assess the potential impacts of R&D projects. The highlights of several studies are outlined below.

In order to respond to inquiries from Congress, private concerns, and other government agencies and Department of Energy Offices, BCS has developed the Buildings Energy Accounting System (BEAS) data base. BEAS provides a single source of statistics for many of BCS's data requirements; the database contains current and historical statistics on residential and commercial sector energy consumption and prices, characteristics of the U.S. buildings stock, forecasts of energy consumption and prices, and energy savings estimates for BCS's programs. The majority of the quantitative information presented in this report was provided by BEAS.

The Buildings Energy-Use Compilation and Analysis (BECA) data base provides detailed data on the energy performance of buildings designed or retrofitted to be energy efficient. These data are analyzed to evaluate the performance and cost-effectiveness of the energy-efficiency features. Documentation of the energy savings and cost-effectiveness of energy conservation techniques in actual buildings is necessary to identify successful measures and complement computer simulations and engineering calculations. Identification of data sources, data collection, and the development of analytical techniques to measure and compare energy performance are conducted on a continuing basis; analysis to date shows a wide range of energy use in new buildings designed to be energy-efficient, and considerable scatter in energy savings and cost-effectiveness results for retrofitted buildings.

A better understanding of the factors and decision processes which determine consumers' conservation behavior is basic to effective policy design. A review of studies which address consumer decision processes with respect to energy consumption and conservation investment was conducted, which established that while behavior has been analyzed from a variety of disciplinary perspectives, no single study has utilized a comprehensive approach. An integrated framework for modeling consumer behavior has been defined which includes the impacts of fuel costs, socio-demographic characteristics, personal norms for conservation, household attitudes, and the role of uncertainty.

During the past several years, BCS has supported studies of residential energy use and its underlying structure in the major OECD countries. Recently this work was expanded to include the commercial buildings sector. The goals of the work have been to 1) establish the data base of energy use in homes and buildings in OECD countries; 2) analyze the components of changes in energy use since 1973, particularly the permanence of these changes; 3) extend this analysis through econometric work as well; 4) analyze the relationship between government conservation programs and actual savings in the residential sector; 5) evaluate techniques or policies from overseas that may be relevant to the United States. This work has uncovered several new technologies that appear promising for the U.S. (e.g., the exhaust-air heat pump for domestic hot water), and has developed an understanding of the role of policy in conservation in other countries which may be applied to the U.S.

The Residential and Commercial Energy Models play a central role in many of the analyses conducted by BCS; the models are updated periodically to include newly available information. A major project was undertaken to update the commercial model's data base, using information available from a number of sources including 1) the 1979 EIA Nonresidential Building Energy Consumption Survey, 2) DOE 2.1 simulations performed to support the update of the ASHRAE Commercial Building Standards, 3) DOE 2.1 simulations run to study the energy impacts of commercial retrofits for DOE's Office of Policy, Planning and Analysis, 4) California Energy Commission's 1978 survey, and 5) metered end use data for a small sample of restaurants gained through a joint DOE-National Restaurant Association project. The residential model was also updated to include recent or improved information on housing starts and stocks, appliance prices, efficiencies, retirements, and energy price projections.

Analyses were conducted to estimate the potential economic impacts of the proposed Federal Commercial Building Energy Conservation Standard and the effects of implementing minimum efficiency standards for appliances. The proposed Commercial Building Energy Conservation standard was estimated to provide net benefits to the nation on the order of several hundred million dollars (largely in fuel savings). In terms of conventional economic indicators, such as GNP, price level, and employment, the economic impacts were found to be so small as to be insignificant.

Appliance efficiency standards defined through previous analysis were set aside based on a U.S. Court of Appeals decision in July of 1985, which also mandated that new analysis of standards be performed. Analysis to comply with the Court of Appeals decision has been initiated but not completed; thus, it is not possible at this time to specify the total social benefits and costs of different levels and timing of standards. However, the previous analysis estimated that the net present value of the consumer benefits alone associated with the levels for appliance standards proposed by DOE in 1980 would total $5 to $10 billion (in 1985 dollars), and that the standards would reduce future energy demand growth in the residential sector. The products yielding the largest estimated benefits in energy savings from standards are water heaters, refrigerators, freezers, and central air conditioners. The benefits of standards on central air conditioners depends critically on the value of peak power, a factor that has not yet been completely assessed.

Analysis was also performed to assess the economic impacts of a variety of conservation programs on electric utilities and their customers. Findings of the analysis are preliminary, but indicate that approximately 50% of investor-owned utilities have a significant incentive to pursue conservation programs in the current environment.

BCS has also developed a methodology for quantifying the impacts on the future energy system of various conservation research programs. Estimates of market potential, market penetration and energy savings on a per unit basis for innovations are derived from the responses of program managers to questionnaires; these are combined with estimates of market sizes (e.g., commercial and residential activity by building type, number of installations by end-use, fuel shares) from economic simulation models to estimate potential future energy savings.

2. OVERVIEW OF PAST AND CURRENT ENERGY USE

All figures and tables in this section are derived from information contained in the Buildings Energy Accounting System (BEAS), with the exception of Table 2.4, wich was developed using information from the Energy Administration's 1984 Annual Energy Review.

2.1 Energy Consumption

2.1.1 Total Primary Energy Use

U.S. energy consumption by end-use sector over time is shown in Figure 2.1, below. After decades of increasing use (pausing during recession years), total energy consumption declined during the 1973-1975 period and again following 1979. In 1984, however, the brief downward trend reversed, due primarily to increased industrial consumption associated with economic recovery. In spite of this, less energy was used in 1984 than in 1973. This reversal has been due to a variety of factors, including price-induced conservation and efficiency improvements, and changes in the structure and composition of economic activity. Industrial energy use peaked in 1979 and has declined substantially since, while transportation, residential, and commercial use have

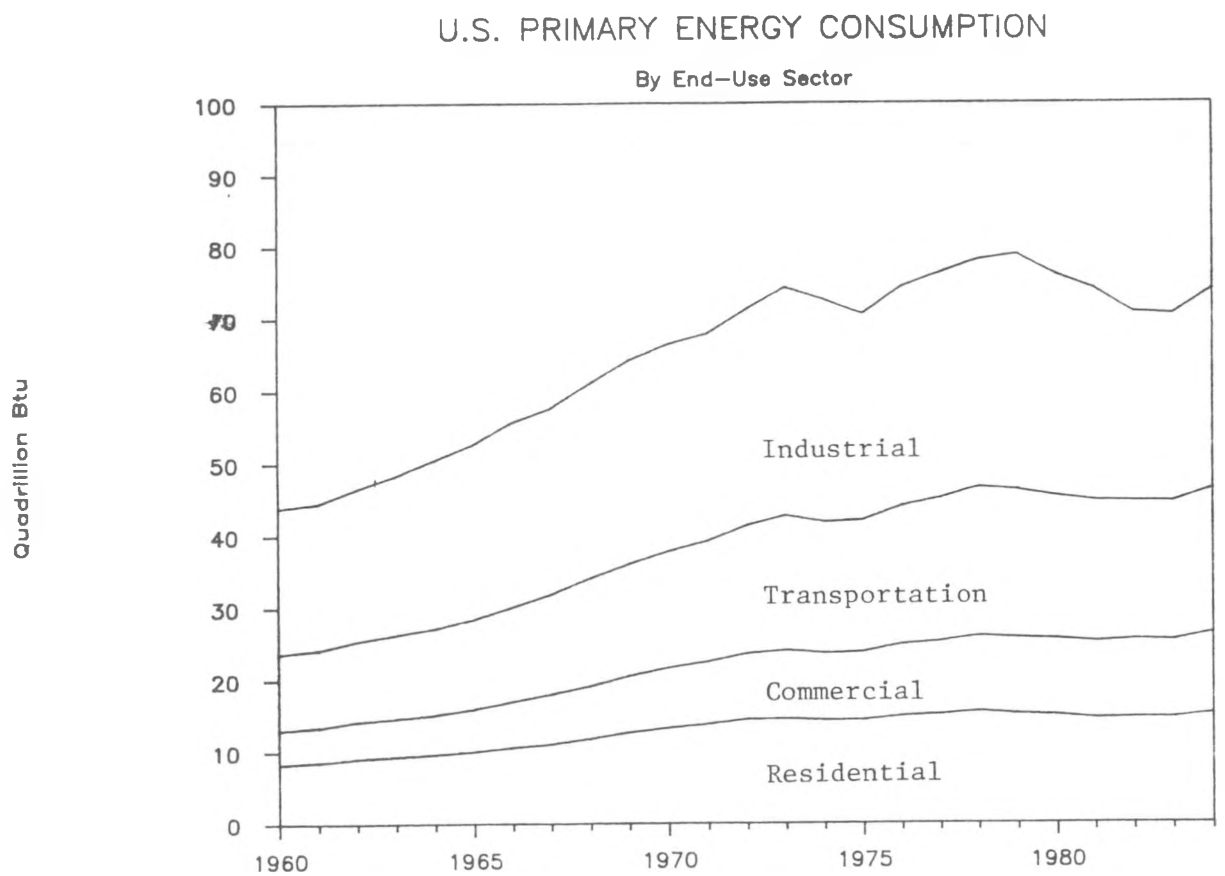


Figure 2.1

remained relatively constant since the mid-1970's. Industrial energy use accounted for 43.1% of total use in 1970, but only 37.8% in 1984; over the same period, the share used by the residential and commercial sectors grew from 32.7% to 37.8%.

2.1.2 Residential and Commercial Energy Use (Aggregate)

Energy use by the residential and commercial sectors in absolute terms has stabilized over the past decade, while both the number of households and commercial building floorspace have grown substantially. The number of households has increased by 25% since 1973, while residential energy consumption (including electricity generation losses) rose by only 2% (Figure 2.2). During the same period, commercial floorspace increased by 32%, while commercial energy consumption grew 18% (Figure 2.3).

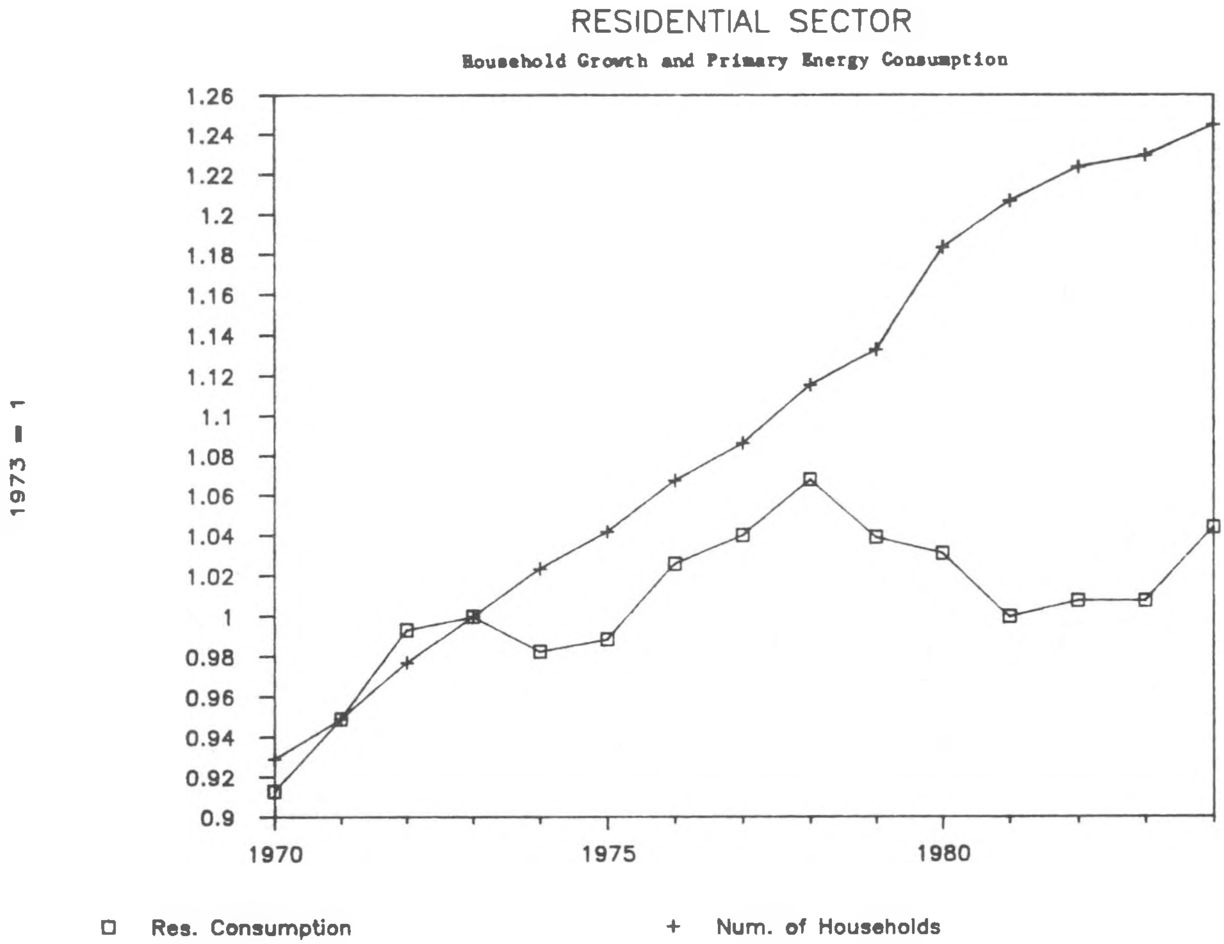


Figure 2.2

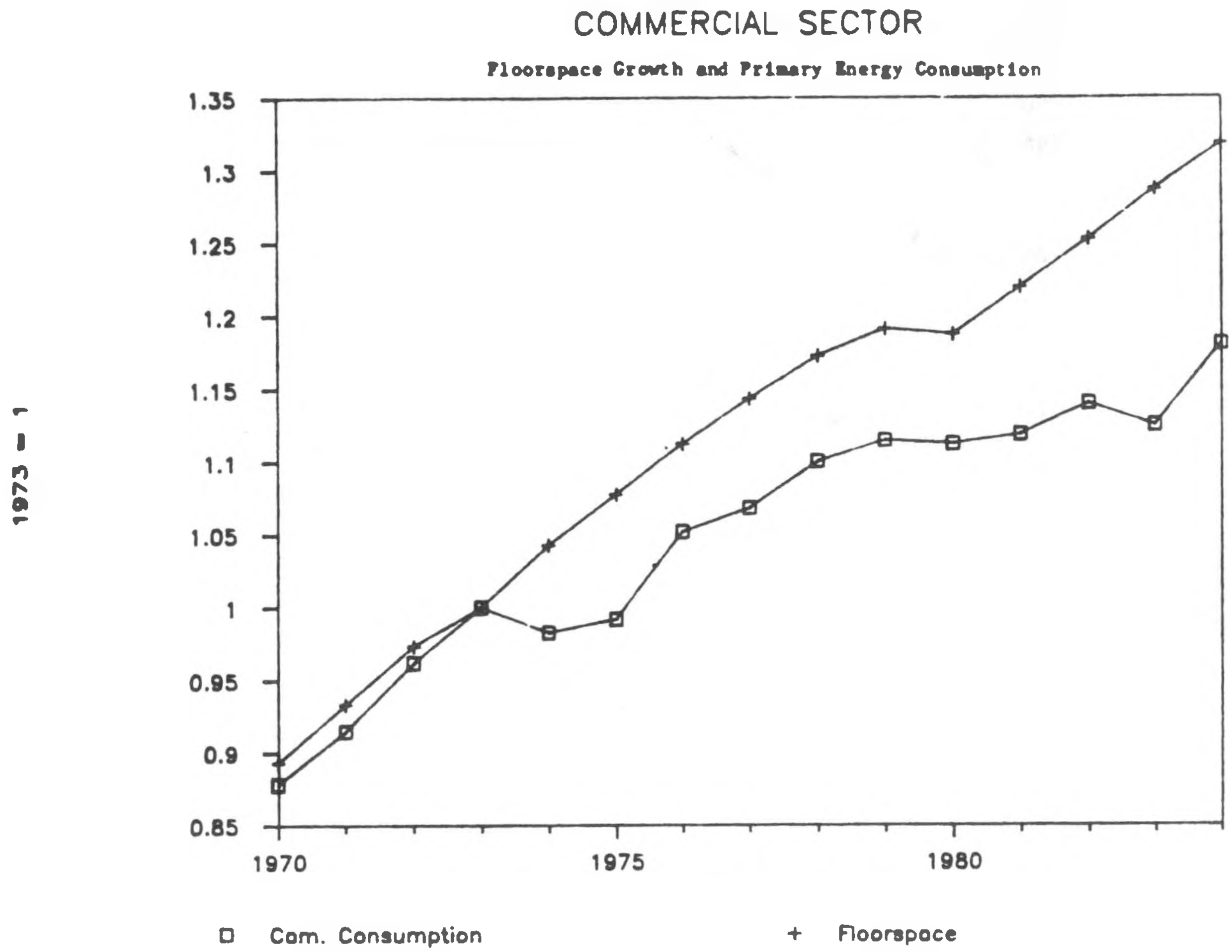


Figure 2.3

Aggregate energy intensities over time for the residential and commercial sectors are shown in Figures 2.4 and 2.5. Average residential energy use has fallen from 214 to 177 million Btu per household per year from 1973 to 1984, a decline of 17%. During the same time period, commercial energy consumption fell from 253 to 226 thousand Btu per square foot per year, a reduction of 11%.

Figures 2.4 and 2.5 also show the trend toward electrification in the buildings sector. The intensity of direct fossil energy use has declined substantially over time in both the residential and commercial sectors, while electricity (shown here including generation losses) has become increasingly important.

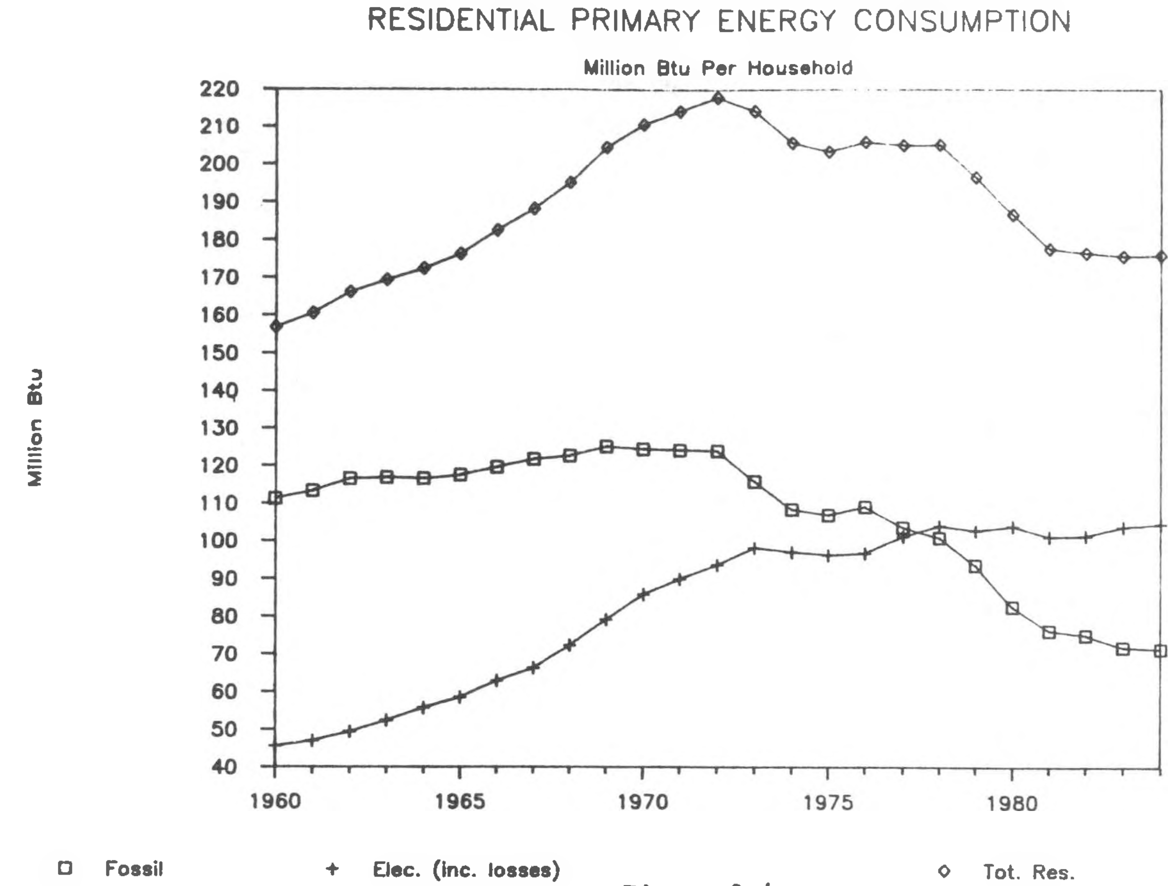


Figure 2.4

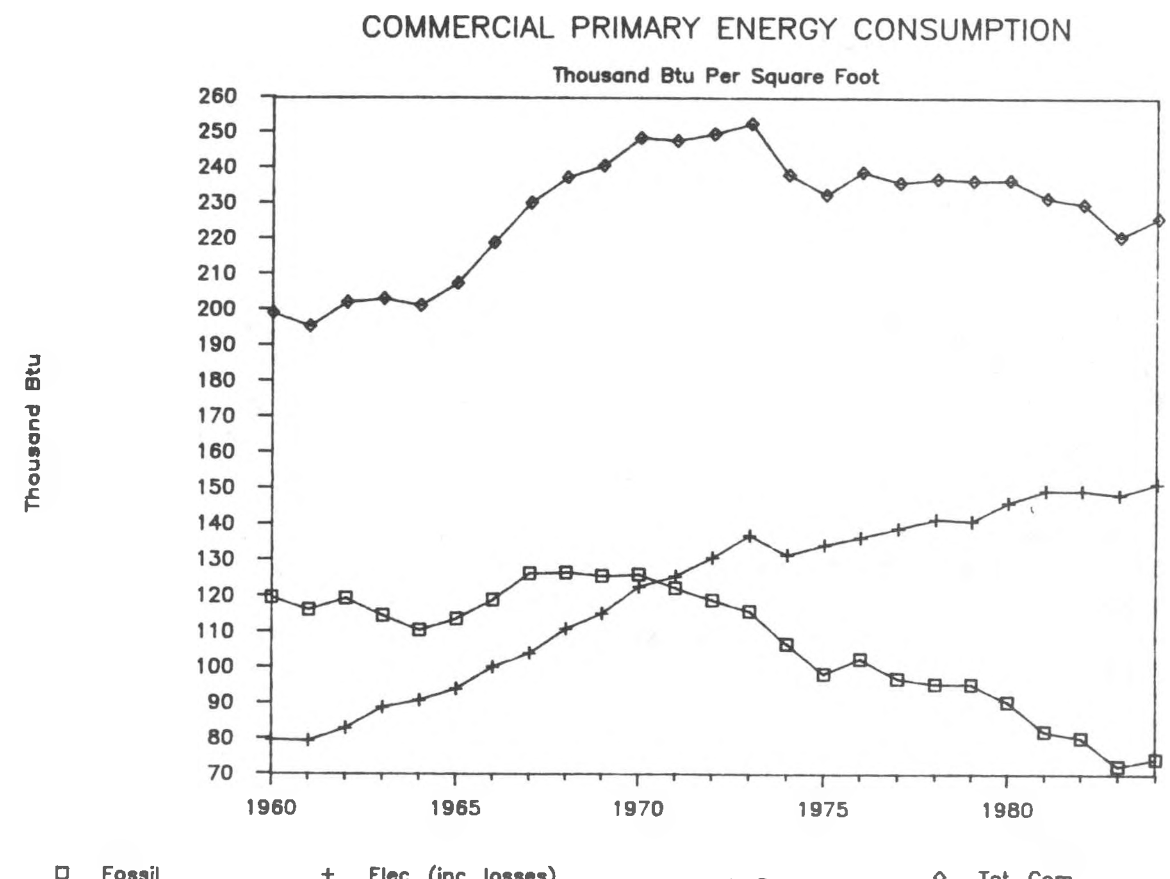


Figure 2.5

Residential and commercial energy consumption by fuel form are shown in more detail in Figures 2.6 and 2.7. For the time period considered here, natural gas has been the dominant fuel in both sectors. Electricity has displaced oil as the second most important fuel on an end-use basis, while coal has not held significant market share during the period considered.

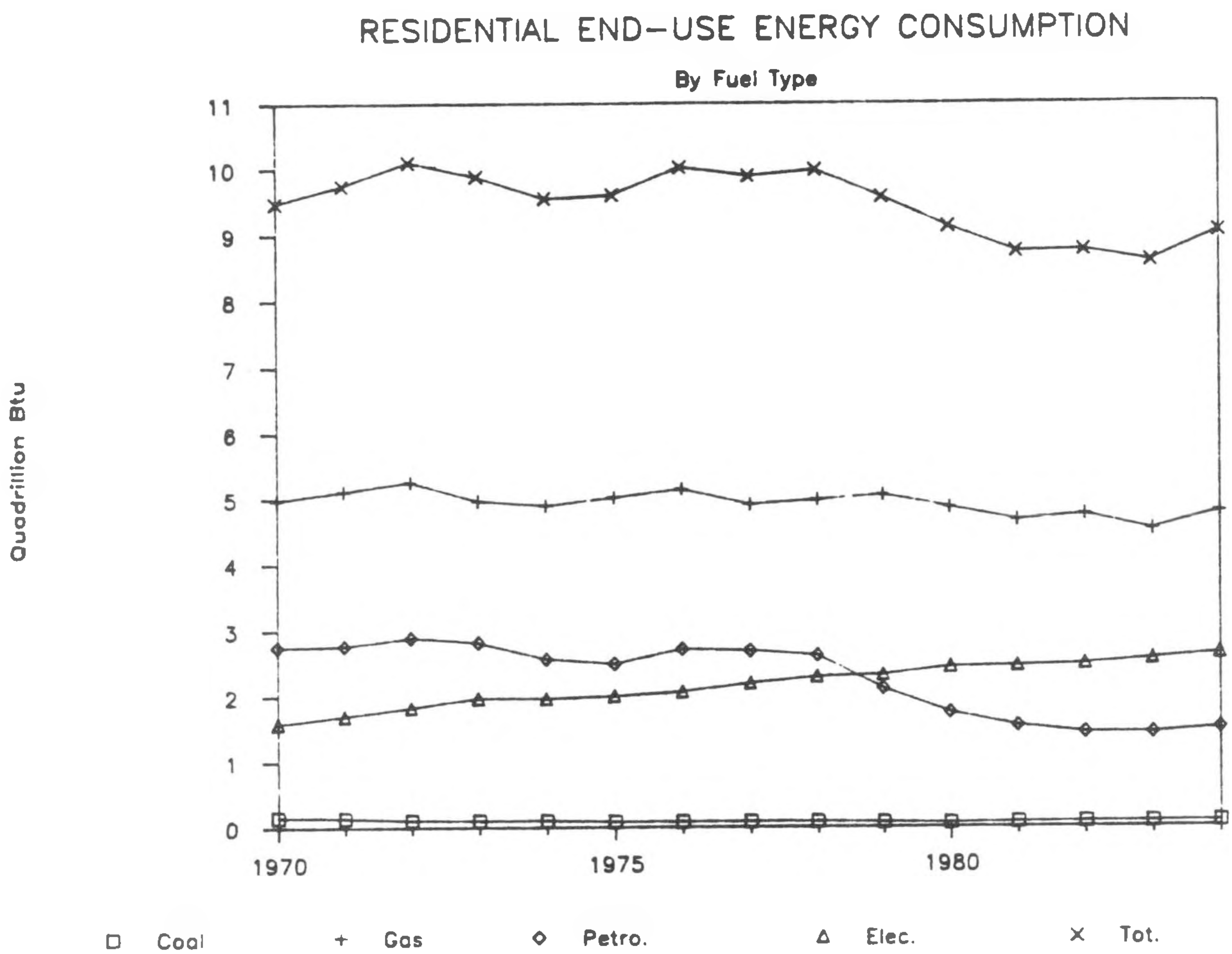


Figure 2.6

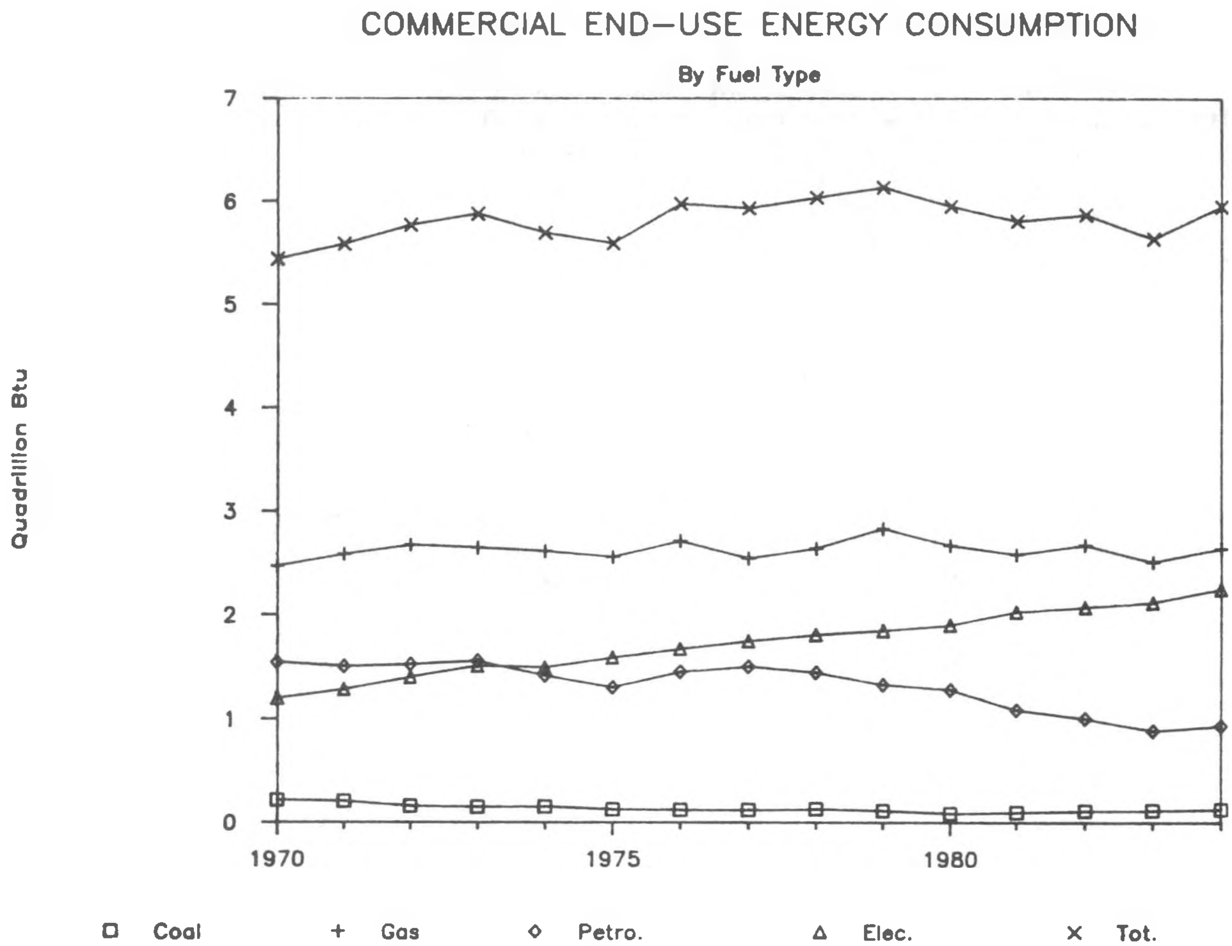


Figure 2.7

2.1.3 Residential and Commercial Energy Use by Function

The most current available estimates on energy use by function for the residential and commercial sectors are given in Table 2.1. Space heating is the most important end-use for both sectors, followed by water heating and other uses in the residential sector and lighting and ventilation in the commercial sector.

2.2 Energy Prices

Increases in energy prices have been a principal driving force behind the improvements in energy efficiency and productivity responsible for declining energy intensities in the residential and commercial sectors. Figures 2.8 through 2.11 show energy prices over time to both the residential and commercial sectors. From 1973 to 1983, both sectors experienced average fuel price increases of approximately 15% per year in current dollars, and 7%

Table 2.1. Primary Energy Consumpton by Fuel Type
1983 Data for Commercial and Residential Buildings[1]

	Electricity[2]	Gas	Oil	Other[3]	Total	Percent
	(Quadrillion Btu's)					
RESIDENTIAL SECTOR						
Space Heating	1.66	2.94	1.01	.34	5.90	40.3
Water Heating	1.46	.80	0.09	.06	2.38	16.2
Refrigerators	1.32				1.32	9.0
Lighting	1.02				1.02	6.9
Air Conditioners	1.13				1.13	7.6
Ranges/Oven	.56	.25		.03	0.84	5.7
Freezers	.46				.46	3.1
Other	1.10	.53			1.63	11.1
TOTAL	8.71	4.52	1.08	0.43	14.74	100.0
COMMERCIAL SECTOR						
Space Heating	.89	1.95	.81	.12	3.77	35.2
Lighting	2.67				2.67	24.9
Air Conditioning	1.10	.11			1.21	11.3
Ventilation	1.35				1.35	12.6
Water Heating	.27	.24	.08		0.59	5.5
Other	.92	.21			1.13	10.5
TOTAL	7.20	2.51	.89	.12	10.72	100.0
TOTAL RESIDENTIAL AND COMMERCIAL CONSUMPTION 1983	15.91	7.03	1.97	0.55	25.46	100.0

[1]Totals for residential and commercial consumption for electricity, gas, and oil are from the EIA State Energy Data Report. Distribution between sectors and end-uses is based on the LBL Residential Energy Model and the PNL Commercial Energy Model. The latest period for which data are available is 1983.

[2]Represents the Btu value of primary energy inputs in the production of electricity (11,500 Btu/kWhr).

[3]Primarily propane and coal. Excludes an estimated .8 quads of energy from wood fuel in the residential sector.

per year in constant dollars. Electricity prices increased the most in absolute terms during this period (residential, \$13.65 current dollars per million Btu, \$6.16 constant dollars; commercial, \$13.38 current dollars per million Btu, \$6.20 constant dollars). Fuel oil prices experienced large increases on a percentage basis (residential, 133%, commercial 143%, in constant dollars), as did natural gas (residential, 129%, commercial, 190%, in constant dollars).

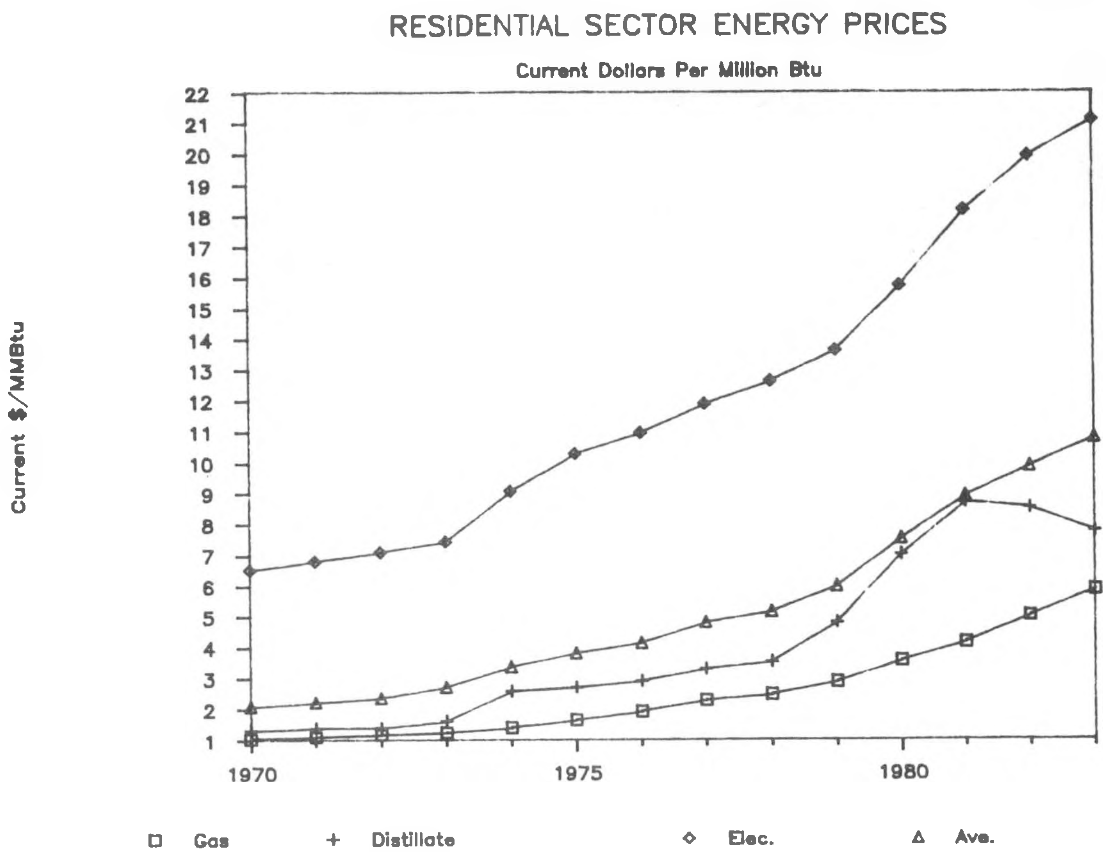


Figure 2.8

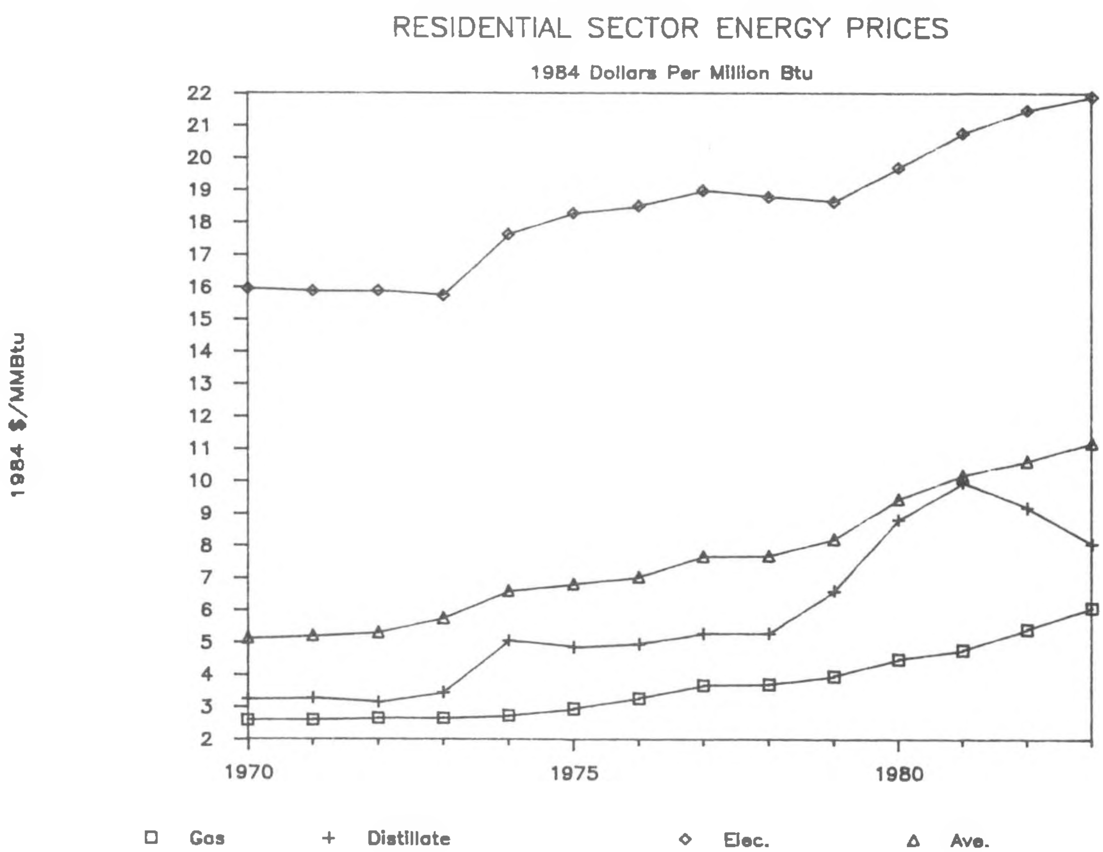


Figure 2.9

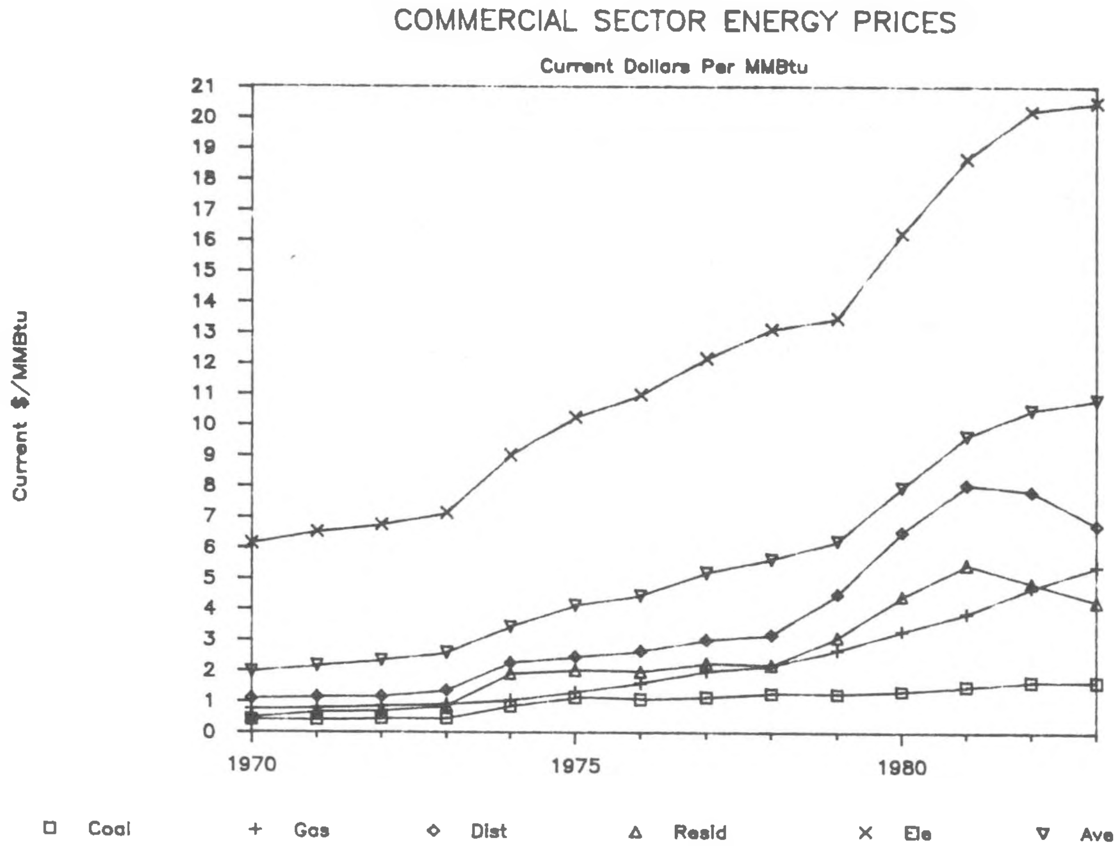


Figure 2.10

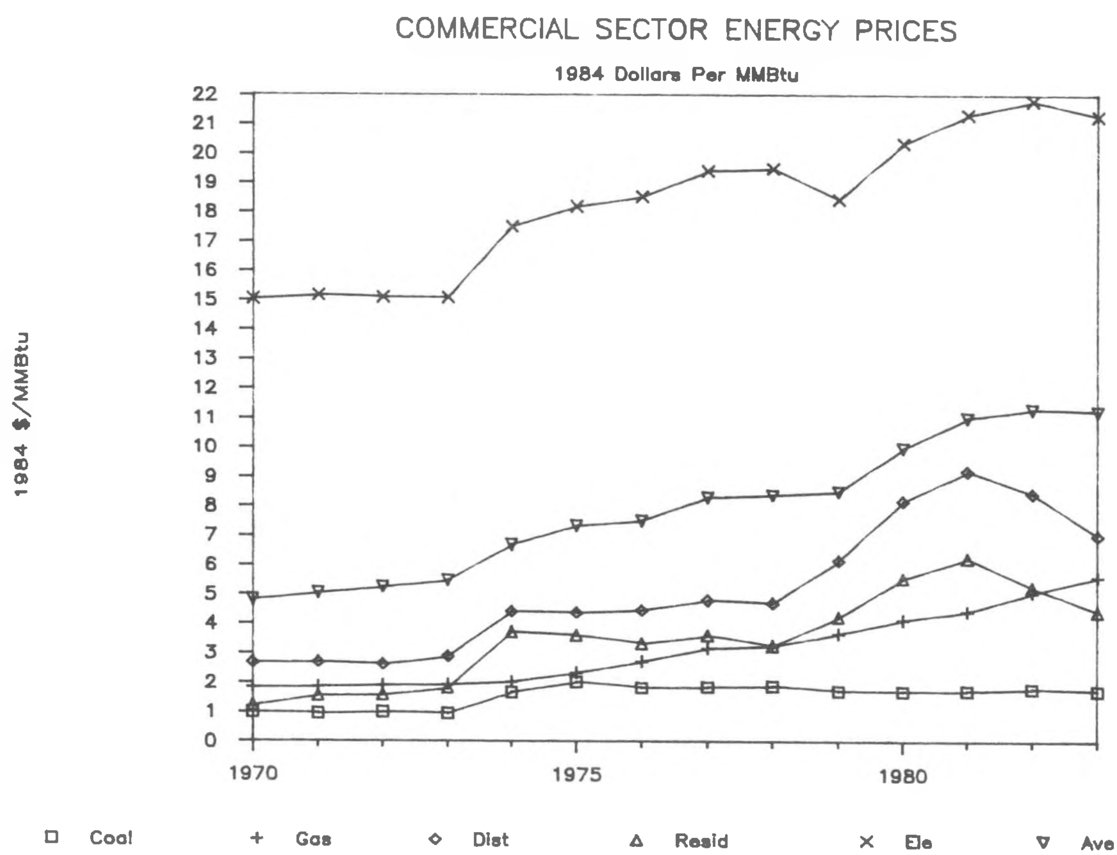


Figure 2.11

2.3 Buildings Capital Stock

2.3.1 Residential Sector - Space Conditioning

Heating fuel types used in the existing housing stock (as of 1981) are summarized in Table 2.2. Natural gas is the most widely used fuel (55%), followed by electricity and fuel oil.

Space heating fuel types for new homes show a significant divergence from the mix for existing dwellings. Since 1970, the fraction of new single-family homes heated with electricity has increased from 28% to 49%; the shares for natural gas and oil have fallen from 62% to 43% and 8% to 2% respectively (Figure 2.12). For new multi-family units, electricity's share is almost 70% (Figure 2.13).

Table 2.2

RESIDENTIAL SECTOR HOUSE HEATING FUEL BY HOUSING TYPE
Total U.S. Stock, 1981
(Number of Units, in Thousands)

	Total U.S.		Single Family		Multi-Family		Mobile Home or Trailer	
All Occupied Housing Units...	83,175		59,916		22,389		3,871	
HOUSE HEATING FUEL	#	% of Total	#	% of SF	#	% of MF	#	% of MH
Utility Gas.......	46,083	55	33,225	58	11,462	51	1,396	36
Bottled, Tank, or LP Gas.......	4,165	5	3,033	5	91	.4	1,041	27
Fuel Oil, Kerosene	14,494	17	9,223	16	4,727	21	553	14
Electricity.......	15,486	19	9,000	16	5,712	26	774	20
Coal or Coke......	361	.4	325	1	32	.1	3	.07
Wood.............	1,894	2	1,734	3	53	.2	107	3
Solar Heat........	18	.02	14	.02	4	.01	-	-
Other Fuel........	84	.1	20	.04	63	.3	1	.03
None..............	589	1	341	1	244	1	5	.1

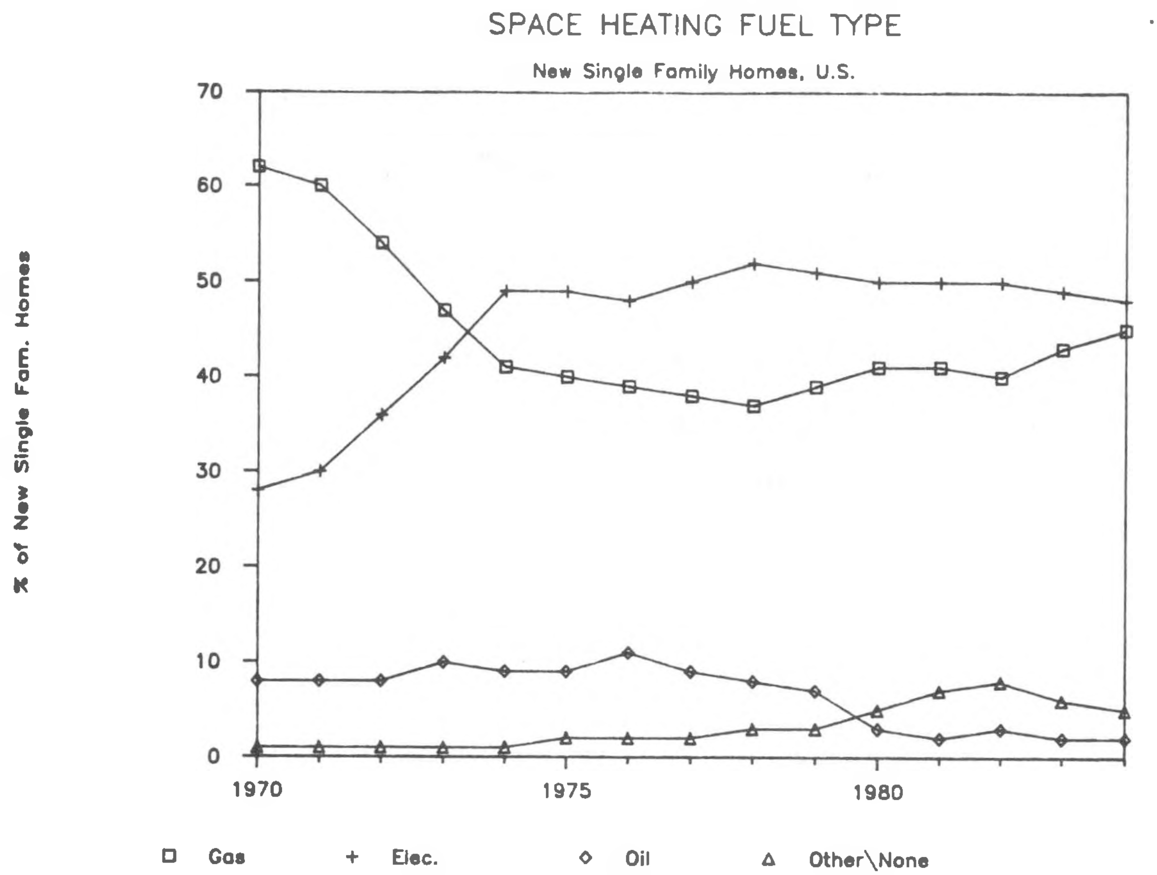


Figure 2.12

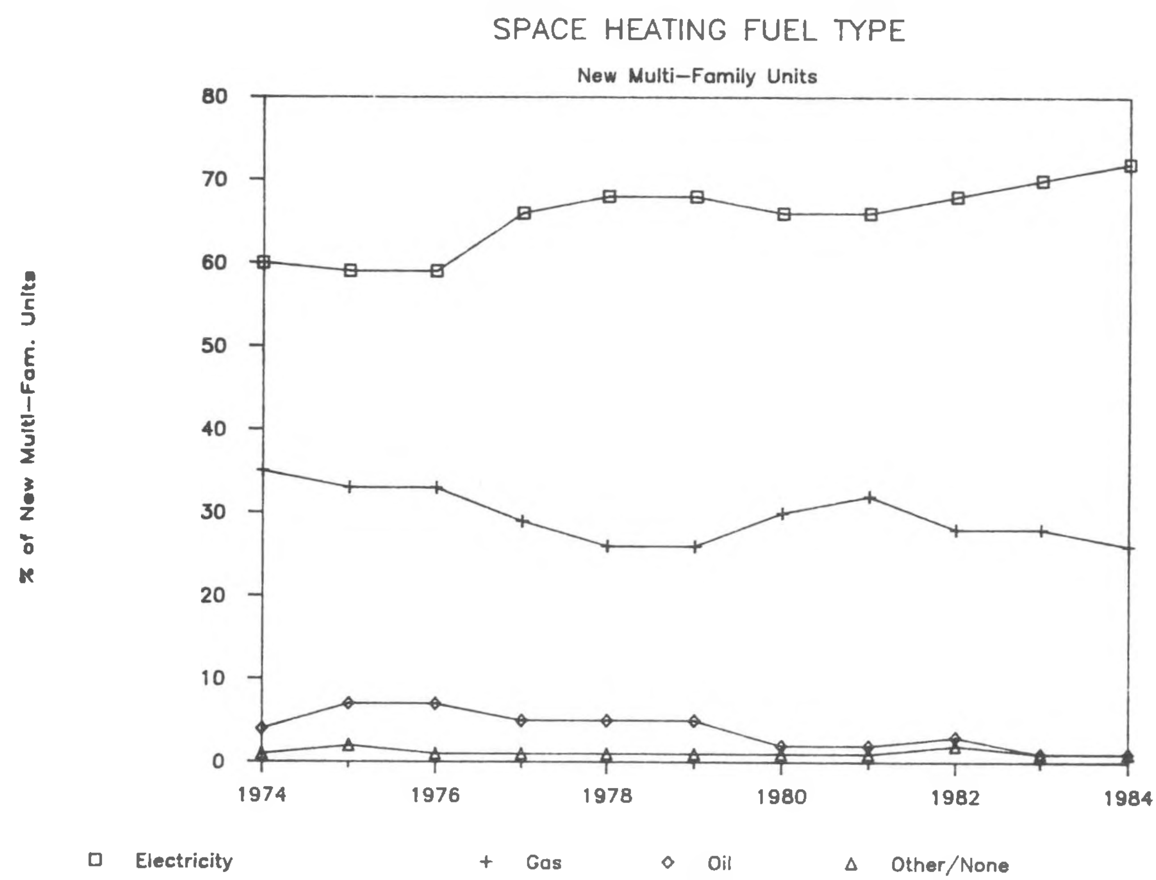


Figure 2.13

Approximately 27% of the existing housing stock has central air conditioning, while 57% has some air conditioning equipment (Table 2.3). Over 65% of new single family homes have air conditioning equipment installed, as do over 85% of new multi-family units (Figure 2.14).

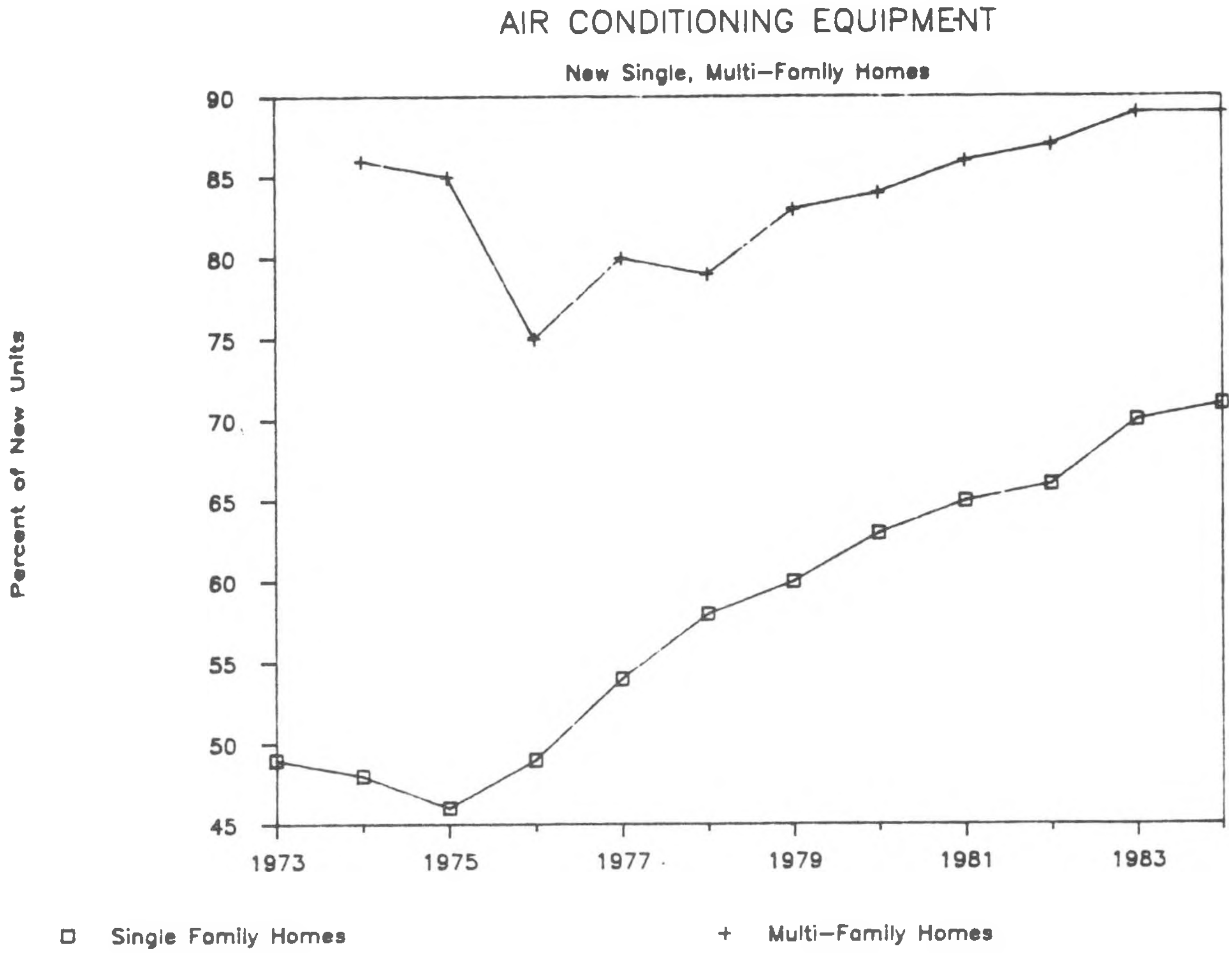


Figure 2.14

The increasing electrification of the residential sector mentioned earlier is accounted for in part by the dominance of electricity for space heating in new homes and the high degree of market penetration of air conditioning in new dwellings.

Table 2.3

RESIDENTIAL SECTOR AIR CONDITIONING EQUIPMENT BY HOUSING TYPE
Total U.S. Stock, 1981
(Number of Units, in Thousands)

	Total U.S.		Single Family		Multi-Family		Mobile Home or Trailer	
All Occupied Housing Units...	83,175		59,916		22,389		3,871	
AIR CONDITIONING EQUIPMENT	#	% of Total	#	% of SF	#	% of MF	#	% of MH
With Air Conditioning	47,470	57	33,000	58	12,101	54	2,369	61
Room Units..........	24,621	30	16,735	29	6,683	30	1,203	31
1	16,170	19	10,292	18	4,888	22	991	26
2	6,256	8	4,602	8	1,453	6	201	5
3	1,578	2	1,311	2	259	1	8	.2
4	429	.5	361	.6	64	.3	3	.1
5 or more.........	188	.2	168	.3	20	.1	-	-
Central System......	22,848	27	16,265	29	5,418	24	1,166	30
With No Air Conditioning........	35,705	43	23,916	42	10,287	46	1,502	39

2.3.2 Residential Sector - Appliance Saturation Levels

Table 2.4 shows estimates of the quantities and saturation levels in U.S. households for various appliances. All households have an electric or gas range, while 99% have refrigerators, 85% have color televisions, and 72% have clothes washers. 36% have dishwashers, and 21% have microwave ovens (up from 8% in 1978).

Table 2.4

HOUSEHOLD APPLIANCE SATURATION LEVELS, 1978-1982

	Million Households		Percentage of Households	
Appliance	1978	1982	1978	1982
Total Households.............	76.6	83.8	100	100
Type Appliances				
Electric Appliances				
Television Set (Color).....	NA	71.0	NA	85
Television Set (B/W).......	NA	38.9	NA	47
Clothes Washer.............	57.4	60.4	75	72
Range (Stove-Top or Burners)............	40.7	44.7	53	53
Microwave..................	6.0	17.3	8	21
Clothes Dryer..............	34.5	37.9	45	45
Separate Freezer...........	27.0	31.0	35	37
Dishwasher.................	26.5	30.3	35	36
Gas Appliances				
Range (Stove-Top or Burners)...........	36.9	39.0	48	47
Clothes Dryer.............	11.0	12.2	14	15
Refrigerators				
One or More...............	76.4	83.5	100	99
Air Conditioning (A/C)				
Central...................	17.6	23.3	23	28
Individual Room Units.....	25.1	25.3	33	30

2.3.3 Residential Sector - Appliance Efficiencies

Available time-series data for appliance efficiencies are shown in Table 2.5. While the data are incomplete, consistent efficiency gains over time are indicated for the appliance groups considered here. In some cases (e.g., refrigerators and freezers), these improvements are substantial.

Table 2.5

Appliance	Source	SHIPMENT WEIGHTED ENERGY FACTORS (SWEF) 1972	1975	1976	1977	1978	1979	1980	1981	1982
Gas Central Space Heater (AFUE %)	CS-179	62.7	N/A	N/A	N/A	63.6	N/A	65.9	N/A	N/A
	Lennox	N/A	65.0	65.0	65.1	65.5	66.3	66.6	67.0	N/A
	Carrier	N/A	N/A	N/A	N/A	65.1	66.3	66.7	66.5	N/A
Oil Central Space Heater (AFUE %)	CS-179	73.6	N/A	N/A	N/A	75.0	N/A	76.0	N/A	N/A
Room Air Conditioner (EER)	CS-179	6.2	N/A	N/A	N/A	6.8	N/A	7.0	N/A	N/A
	AHAM	6.0	N/A	N/A	N/A	6.7	N/A	7.0	7.1	N/A
Central Air Conditioner (SEER)	CS-179	6.7	N/A	N/A	N/A	7.0	N/A	7.8	N/A	N/A
	Lennox	N/A	6.2	6.9	7.0	7.0	7.1	7.1	7.7	8.2
	ARJ	6.7	N/A	7.1	7.2	7.4	7.5	7.6	7.6	7.9
Electric Water Heater (Percent)	CS-179	79.8	N/A	N/A	N/A	80.8	N/A	81.3	N/A	N/A
Gas Water Heater (Percent)	CS-179	47.4	N/A	N/A	N/A	48.2	N/A	51.2	N/A	N/A
Refrigerator (Cu.Ft./kwH/Day)	CS-179	4.2	N/A	N/A	N/A	5.7	N/A	5.7	N/A	N/A
	AHAM	3.8	N/A	N/A	N/A	5.0	N/A	5.6	6.1	N/A
Freezer (Cu.Ft./kwH/Day)	CS-179	8.1	N/A	N/A	N/A	10.1	N/A	10.8	N/A	N/A
	AHAM	7.3	N/A	N/A	N/A	9.9	N/A	10.9	11.3	N/A

2.3.4 Commercial Sector - Building Types

There are approximately 4 million commercial buildings in the U.S., with about 50 billion square feet of floor space. The distribution of buildings by type is shown in Figure 2.15 (number of buildings) and 2.16 (square feet). By both measures, retail sales/service buildings is the largest category, followed by office buildings. Some categories are far more important on a floor space basis than on a numerical basis (e.g., education buildings).

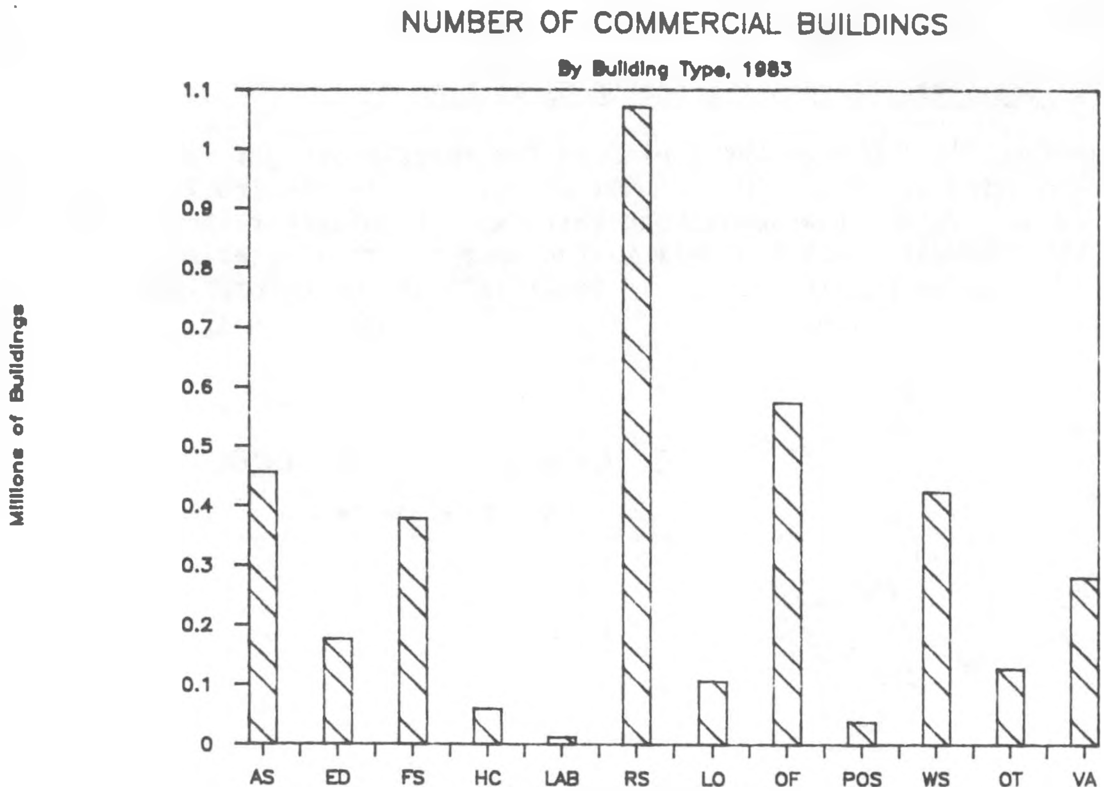
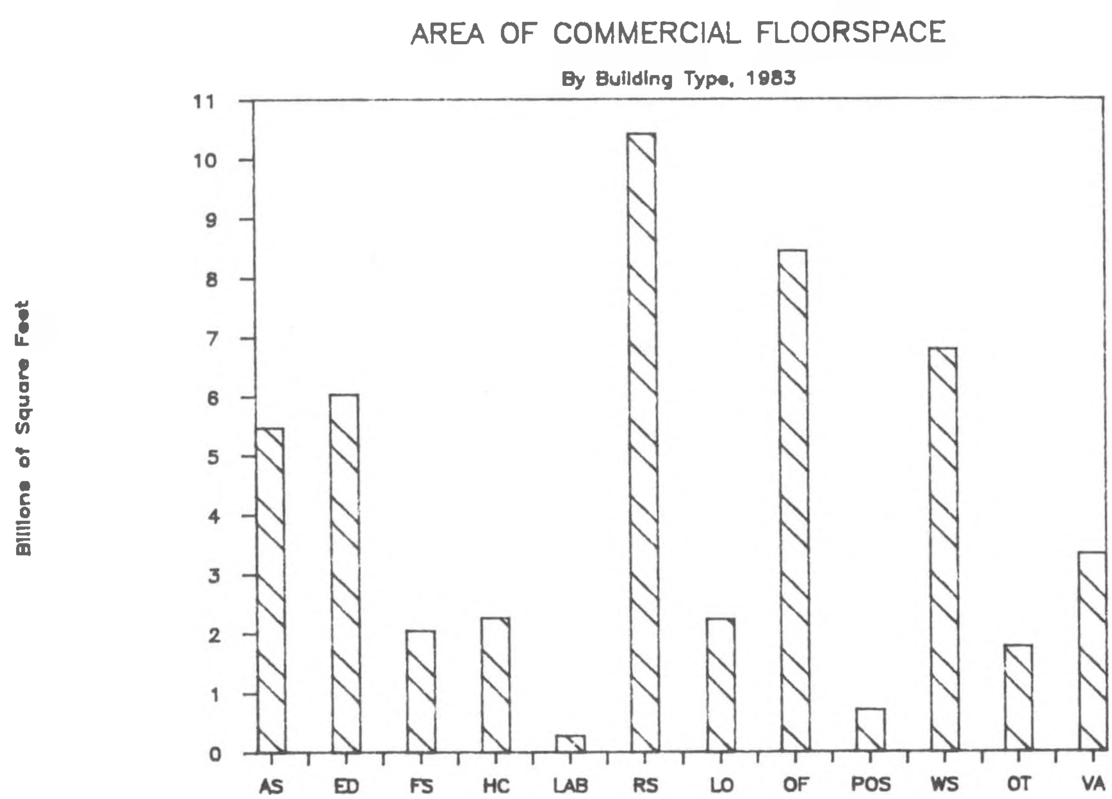


Figure 2.15



Key for Figs. 2.15 and 2.16: AS - Assembly, ED - Educational, FS - Food Sales/Service, HC - Health Care, LAB - Laboratory, RS - Retail Sales/Service, LO - Lodging, OF - Office, POS - Public Order and Safety, WS - Warehouse, OT - Other, VA - Vacant.

Figure 2.16

2.3.5 Commercial Sector - Space Conditioning

Natural gas is the dominant fuel used for space heating in the commercial sector, accounting for slightly over 50% of heated area (Figure 2.17). Electricity and oil are the second and third most important fuels. There is considerable regional variation; oil is the most important fuel in the Northeast, while electricity is nearly as significant as natural gas in the South and West.

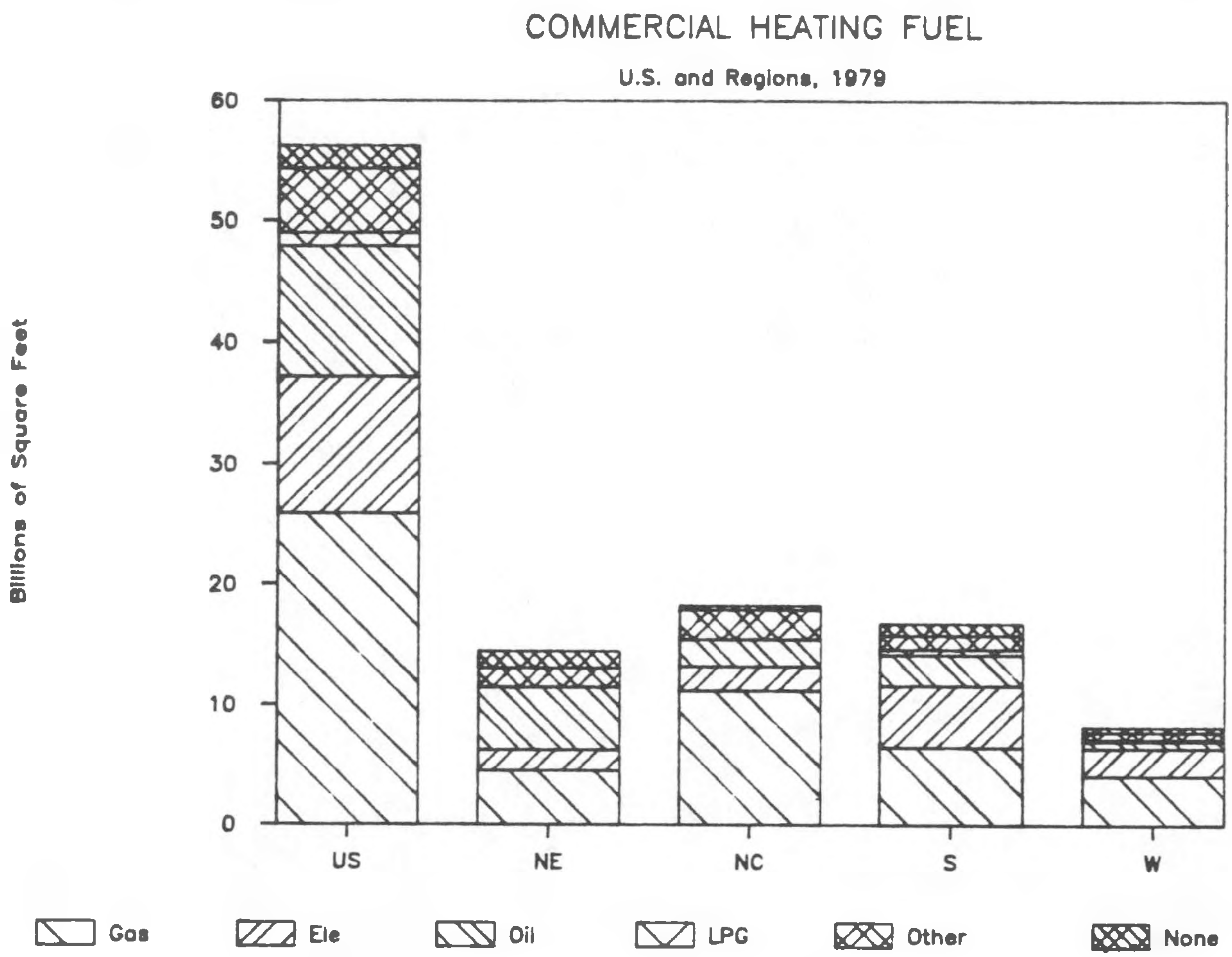


Figure 2.17

Approximately 50% of total commercial square footage is heated by forced air heating systems, with the balance split equally between radiant and combination systems (Figure 2.18). As with heating fuel, there is considerable regional variation. About 4% of total commercial square footage was not heated.

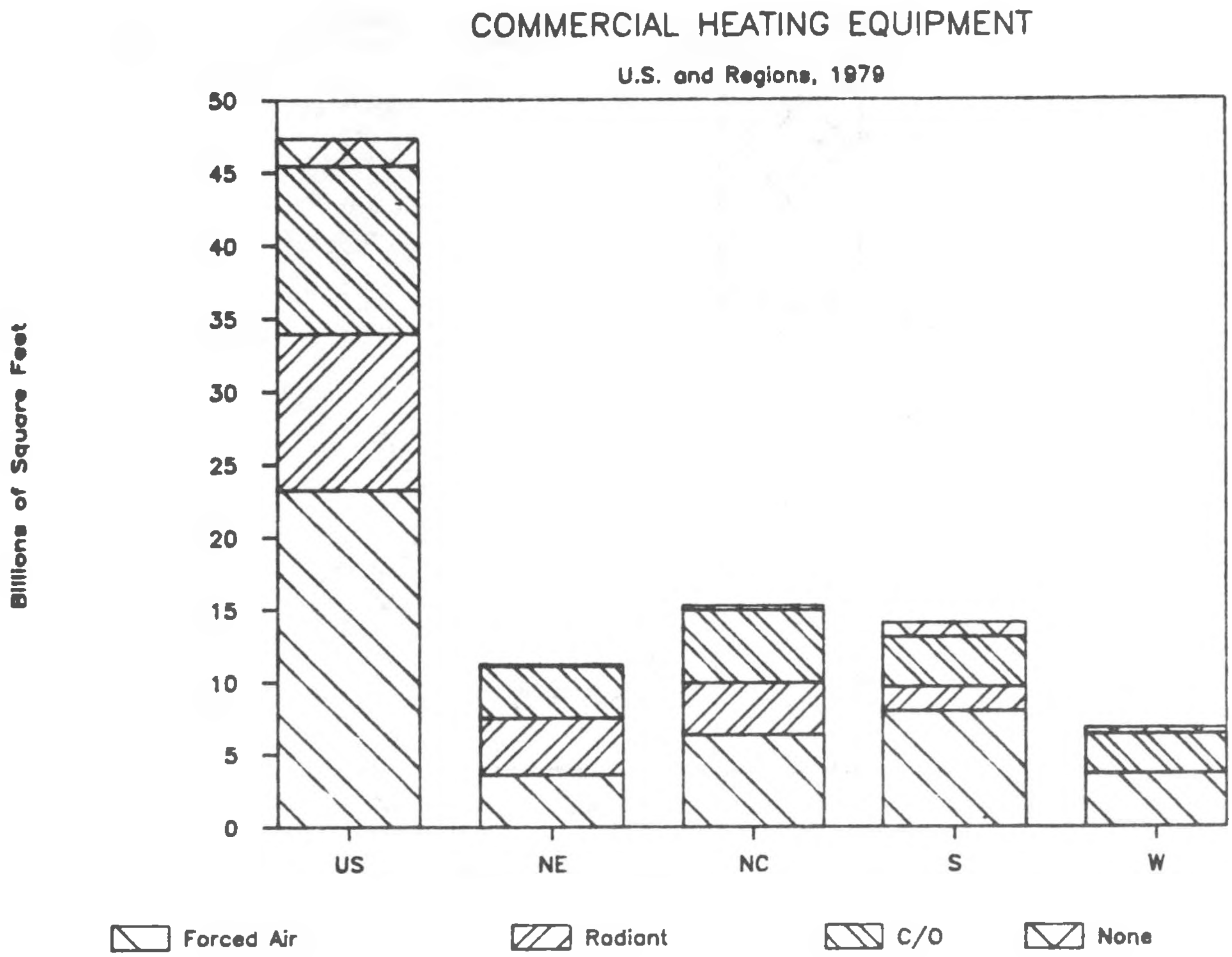


Figure 2.18

The majority (66%) of commercial buildings in the U.S. are air conditioned (Figure 2.19). The South has the highest percentage of air conditioned buildings (75%), while the West has the lowest (45%). Electricity is the most important air conditioning fuel in all regions.

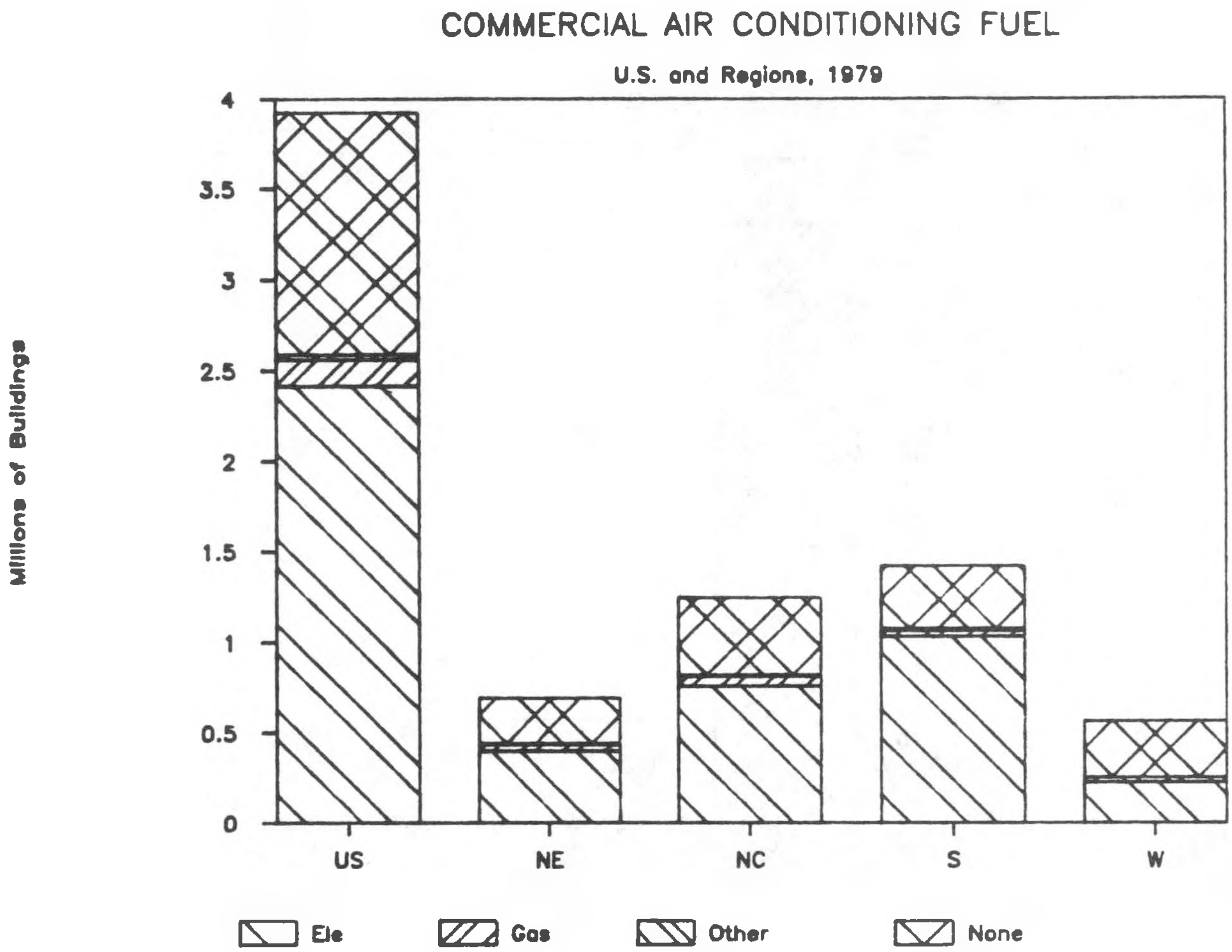


Figure 2.19

3. BUILDINGS SECTOR FORECASTS

3.1 The BCS Disaggregate Projection of Energy Use

3.1.1 Rationale

BCS requires detailed forecasts of energy use in the residential and commercial sectors to aid in establishing program directions and in the prioritization of individual projects. While other organizations provide forecasts of energy supply and demand, none of these have sufficient end-use detail for BCS's needs. Consequently, BCS has supported the development of forecasts of residential and commercial energy use disaggregated by end-use and building type. The input assumptions used in generating these forecasts are generally consistent with those used in producing other contemporaneous DOE forecasts.

3.1.2 Methodology and Assumptions

A disaggregate projection of residential and commercial energy consumption was prepared with the national Residential and Commercial Energy Models. Both models were originally developed at Oak Ridge National Laboratory in the late 1970's. The residential model has been improved and is currently maintained by Lawrence Berkeley Laboratory, and provides forecasts of energy use by ten end uses, four fuel types, and three building types (single family, multi-family and mobile homes). An improved version of the commercial model, with an expanded number of end uses and more thorough treatment of heating efficiency and fuel choice, is maintained by Pacific Northwest Laboratory.

The disaggregated forecasts of energy use by end use and building type provided by these models facilitate the prioritization of buildings R&D programs within BCS. However, for broad planning in conjunction with the transportation and industrial programs divisions within DOE's Office of Conservation, BCS also employs forecasts provided by the DOE's Office of Policy, Planning and Analysis (PPA). These forecasts are generated by the WOIL/Fossil National Energy Model. To the extent feasible, the end-use models used similar assumptions as employed by PPA in the baseline WOIL/Fossil forecast used by the Office of Conservation for its 1987 Multi-Year Plan. Although the forecasts are generally similar, there are differences in the growth rates over sub-periods and in the fuel shares. The disaggregate forecasts, as such, should thus not be interpreted as official BCS forecasts, to be contrasted to the more aggregate forecasts produced by the WOIL/Fossil model. Rather, they should be analyzed for the information they can provide about how the detailed pattern of energy use may be expected to change over the next several decades. Comparison of the disaggregate forecast with other forecasts prepared by PPA and other groups, both inside and outside of DOE, will be discussed later in this report.

3.1.3 The Disaggregate Forecast

Table 3.1 shows the disaggregate projections of total energy use per household along with the key driving variables used in their development. Primary energy consumption per household is projected to decline only slightly throughout the remainder of the decade, as real energy prices are expected to remain fairly stable. In the 1990's fossil fuel prices are projected to rise sharply and electricity prices are assumed to increase about one percent per year. These price increases are expected to accelerate the decline in energy use per household (an estimated decline of five percent from 184 million Btu per household in 1984 to 173 million in 2000). Beyond 2000, total primary energy consumption per household drops only slightly. As real electricity prices are assumed to remain relatively constant, the continuing trend toward greater electricity use nearly offsets the drop in direct fossil use per household over this period.

Table 3.2 presents the disaggregate projections of total primary energy consumption in the commercial sector, accompanied by the projections of fuel prices and building stock. A basically similar pattern to the residential sector is exhibited with regard to the forecast trends in commercial sector energy intensity, here measured by energy use per square foot. Stable or falling prices until the early 1990's are expected to result in stability in energy use per square foot. Beyond 1990, rising energy prices accelerate pressure on building designers and managers to reduce energy consumption. Energy use per square foot is projected to fall continuously after 1990, although the rate of decline slows after 2000 as electricity price increases moderate. In spite of these reductions in intensity, total energy use in the commercial sector is expected to grow significantly between 1984 and 2010 as total commercial floorspace grows by nearly 77 percent.

Table 3.3 presents the disaggregate forecast by fuel type through the year 2010. Continuing historical trends, electricity increases its share throughout the forecast period. In terms of primary energy, the electricity share is projected to increase from 62 percent in 1984 for the buildings sector as a whole to 75 percent in 2010. The increase in the electricity share in the residential sector is projected to be larger than for the commercial sector, due largely to the number of new homes with electric heating. Direct consumption of gas and oil are expected to decline in absolute terms by 2010, although the decline for gas is relatively modest.

The relative shares of building energy use between the residential and commercial sectors are also expected to change, consistent with the trends observed in the 1970's. The commercial sector comprised 42 percent of building energy use in 1984; in 2010 nearly half (48 percent) is projected to be used in the commercial sector. The disparity in the growth in total energy use between these sectors is primarily a function of the difference in the growth of the number of households (38 percent) and in the assumed growth of commercial floorspace (77 percent). This disparity in growth is consistent with historical experience; from 1960 to 1984, the number of households increased by 60%, while commercial floorspace increased by 112%.

The disaggregate projection details of primary energy use by end-use are shown in Table 3.4. Space heating declines significantly in relative importance in both the residential and commercial sectors, although it increases 0.5 quads from its 1984 level of absolute consumption (6.2 quads) by 2010 in the residential sector, and increases substantially in the commercial sector (4.0 to 5.4 quads) over the same period. This results from the interaction of increasing efficiency and overall sectoral growth; for the commercial sector, growth more than offsets efficiency gains, while in the residential sector, the two are approximately in balance.

In contrast to space heating, the fraction of primary energy consumption used for air conditioning is expected to grow for both the residential and commercial sectors. Both sectors experience significant increases in absolute energy use for air conditioning from 1984 to 2010, from 1.1 to 2.1 quads for the residential sector, and from 1.3 to 1.9 quads for the commercial sector.

Water heating increases both its relative and absolute importance in the residential sector (from 16 to 18% and 2.5 to 3.4 quads, 1984 to 2010). In the commercial sector, its relative importance remains almost constant, while consumption almost doubles in absolute terms (0.6 to 1.0 quads, 1984 to 2010). Ventilation in the commercial sector also exhibits relative stability but absolute growth (1.4 to 1.9 quads, 1984 to 2010).

Energy use for lighting, cooking, refrigerators, and freezers in the residential sector shows little relative or absolute change, with small increases in lighting and cooking. Increased use of convenience and leisure appliances in the residential sector shows up in the "other" category; this end-use is expected to nearly double between 1984 and 2010, from 1.7 to 2.8 quads.

Water heating, cooking, and refrigeration maintain their relative shares of commercial energy use across the time horizon considered here, and together account for 1.5 quads by 2010. Lighting maintains its share of commercial energy use at 25% (2.8 to 4.5 quads) from 1984 to 2010, while other (e.g., office and medical equipment) uses increase from 8 to 13% (0.9 to 2.4 quads).

In summary, the BCS Disaggregate Forecast shows moderate growth in residential sector primary energy use (15.3 to 19.4 quads) and substantial growth in commercial sector primary energy use (11.2 to 17.5 quads) from 1984 to 2010. Both sectors experience a decline in the relative importance of space heating, while air conditioning, water heating, and other uses increase in relative importance in the residential sector, and air conditioning and other uses increase in relative importance in the commercial sector. Due to substantial growth in the size of the commercial sector, all end uses show absolute increases over time. Shifts in the mix of end uses and growth in the use of electricity for space heating lead to an approximate doubling of electricity use from 1984 to 2010, while both natural gas and fuel oil use remain relatively stable.

3.2 Comparison of Forecasts

In the following sections, the disaggregate projection presented in section 3.1.3 is compared with other available forecasts prepared by the groups both in and outside of DOE. The forecasts reviewed include a draft of the 1985 National Energy Policy Plan as contained in the 1987 Multi-Year Plan from DOE's Office of Conservation (CE); the 1984 Annual Energy Outlook from the Energy Information Administration (EIA); the Energy Review from Data Resources, Inc. (DRI); the Energy Analysis Quarterly from Chase Econometrics (Chase); the Long-Term Forecast from Wharton Economic Forecasting Associates

(Wharton); the Audubon Energy Plan from the National Audubon Society (Audubon); the GRI Baseline Projection from the Gas Research Institute; and the Total Energy Resource Analysis from the American Gas Association (AGA). The forecasts for total primary consumption for both the residential and commercial sectors are shown in Table 3.5.

3.2.1 Overview of Forecasted Consumption for the Buildings Sector

All of the forecasts reviewed predict increases in residential and commercial sector energy consumption over the next three decades. Much of the increase in these sectors is based on assumed growth in several primary determinants of energy demand, specifically the number of households for the residential sector and the stock of floorspace for the commercial sector.

In 1995, the residential and commercial consumption estimates in the forecasts reviewed range from 27.5 to 33.9 quadrillion Btu (quads). (See Table 3.5). Given the Energy Information Administration's estimated 1984 buildings sector consumption of 26.5 quads, increases in energy consumption in the residential and commercial sectors over the next decade are forecast to be just over two percent per year using the high range of these predictions.

In the year 2000, forecasts of primary energy consumption in the residential and commercial sectors range from 28.5 to 35.7 quads, with 32.9 quads the average of the forecasts. The disaggregate forecast for the year 2000 places energy consumption in the buildings sector at 32.5 quads. Based on the EIA estimate for consumption in 1984, the forecasted consumption for the year 2000 represents, on average, a 24 percent increase in the amount of primary energy consumed in these sectors. Using available information from the forecasts, the commercial sector is predicted to show the most growth. The average of the forecasts for 2000 for the commercial sector is about 32 percent higher than the EIA estimate for consumption in the commercial sector in 1984, while the average for the residential sector indicates an increase of 19 percent. The BCS Disaggregate forecast is close to the average of the other forecasts for the residential sector for 2000 (17.5 vs 18.1 quads), and identical for the commercial sector (14.8 quads).

As shown in Table 3.5, four forecasts provide predictions to the year 2010; the disaggregate projection, the draft 1985 NEPP, NEPP IV and DRI. According to these forecasts, by the year 2010 primary energy consumption by residential and commercial consumers is expected to reach at least 36 quadrillion Btu. This represents almost a 40 percent increase over the primary energy consumption in the buildings sector in 1984. The commercial sector is expected to continue to experience higher growth. Averaging the four forecasts to 2010, commercial sector consumption grows almost two percent per year faster than the residential sector for the decade 2000-2010.

3.2.2 Forecasts of Energy Consumption by Fuel Type

Table 3.6 provides a disaggregation of primary energy consumption in the buildings sector by fuel type. An analysis of the forecasted figures shows that consumption of electricity is expected to increase dramatically by the end of the century. In the year 2000, most forecasters predict that electricity consumption on a primary energy basis will be in the 23 to 24 quad range compared to an estimated 16.4 quads consumed in 1984. This implies at least a 35 percent increase in the use of electricity by the buildings sector in the next 16 years.

The level of consumption of natural gas and oil in the year 2000 will be similar to the 1984 levels according to most forecasters. Natural gas consumption is predicted to be in the seven to eight quad range in 2000. Consumption of natural gas in the buildings sector was approximately seven quads in 1984. Oil consumption in 2000 is predicted to be about two to three quads as compared to three quads estimated in 1984. Coal and other fuels will continue to account for less than seven percent of the total primary energy consumption in the buildings sector according to the forecasters in the year 2000.

The American Gas Association has the only prediction that varies significantly from the outputs of other models. A.G.A. sees a modest increase in electricity consumption in the buildings sector and an increase of two quads in natural gas use by the year 2000. Consumption of other fuels is forecasted to continue near 1984 levels according to A.G.A.

3.2.3 Forecast Assumptions

Forecasted energy consumption in the buildings sector is dependent principally on assumptions concerning world oil prices, real GNP, end-user energy prices, and the size of building stock. Table 3.7 contains a listing of these assumptions for the forecasts reviewed.

World oil prices in the recent forecasts range between $33 and $44 per barrel (1984$) for the year 2000. The one outlier is the National Audubon Society forecast which contains an assumption that the world oil price in the year 2000 will be $75 per barrel (1984$). The National Audubon Society's end-use energy prices are also comparatively high. As indicated in Table 3.5, the National Audubon Society has one of the lowest forecasts for buildings sector energy consumption for the year 2000, consistent with its assumptions for comparatively high energy prices.

A fuel-by-fuel comparison of end-use reveals another unique pattern in forecasted data. The American Gas Association assumes relatively high electricity prices and low prices for other end-use fuel types. This pattern may account for the lower forecasted consumption of electricity noted earlier.

The economic growth assumptions of the forecasts reviewed vary only slightly (2.4% to 2.8% annual growth). In the year 2000, real GNP is forecasted to be around $2.5 trillion (1972$). In 1984, real GNP was $1.6 trillion (1972$).

In the forecasts reviewed, assumptions concerning the size of the building stock are tabulated in terms of the number of households for residential sector and square feet of commercial floorspace for the commercial sector. The year 2000 forecasts for the number of households (or housing units) range between 103 and 116 million units which is 21 to 36 percent larger than the current number of households. The American Gas Association forecasts the number of residences to be 84.6 million units at the end of the century. According to their data, this is a 20 percent increase over the 1984 level.

Available information indicates that the forecasters believe that commercial floorspace will increase anywhere from 27 to 96 percent over current levels. As shown in Table 3.7, two private industry groups, the National Audubon Society and GRI, forecast a significantly larger stock of floorspace by the year 2000.

3.2.4 Energy Intensity

Energy intensity, defined in the residential sector as energy consumption per household and in the commercial sector as the ratio of energy consumption to square feet of floorspace, is an important basis for comparing the output of the energy models. Table 3.8 contains a listing of the forecasted energy intensities.

In the residential sector, most forecasters see a reduction in energy consumption per household from the 1984 estimated level of 184 MMBtu per household. For the year 2000, the forecasts for residential energy intensities range from 149 to 195 MMBtu per household. GRI's figures for the year 2000 indicate an increase in energy consumption per household. The inclusion of renewables in the GRI forecast may, in part, be the cause of the increase in the energy intensity.

Most of the calculations for energy intensities in the commercial sector (column two of Table 3.8) also show an overall decline. The energy intensity estimated for 1984 was 244 thousand Btu per square foot. According to the BCS Baseline, CE/BCS, EIA, the National Audubon Society and GRI forecasts, energy consumption per square foot of commercial floorspace ould decrease anywhere from six to 36 percent by 2000. (It should be noted that these numbers are not directly comparable due to incompatible assumptions concerning existing floorspace.) NEPP IV, one of the older forecasts, actually predicts a slight increase in the energy intensity of the commercial sector.

3.2.5 Conclusion

The general consensus among the forecasts surveyed is that energy consumption in the buildings sector will increase on the order of one to two percent per year over the next decade, after essentially showing little or no growth since 1978. Although energy intensities are projected to continue to decline, this effect is more than offset by continued growth in the number of households and in the stock of commercial floorspace.

The majority of forecasts show that electricity's share of total fuel consumption continues to grow. On an absolute basis, most predictions indicate that the growth of electricity use between 1984 and 2000 in the residential and commercial sectors will be at least 2 percent per year.

The projected increasing reliance upon electricity in the buildings sectors has important implications for research and development strategy. The benefits of R&D expenditures in the buildings sector by the federal government have largely been evaluated in terms of energy savings of fossil fuels. This approach has been based on the need to reduce dependence upon foreign oil supplies; a direct reaction, of course, to the events of the 1970's. The forecasts produced by the end-use models, as well as by other forecast organizations, indicate that increasing benefits may be obtained from those technologies which reduce electricity consumption.

Table 3.1. Disaggregate Forecast: Projected Total Energy Consumption and Key Driving Variables: Residential Sector

Prices (1984 $/MMBtu)	1980	1984	1990	2000	2010
Electricity	18.75	19.62	19.84	22.05	22.54
Gas	4.49	6.00	5.77	8.18	11.72
Fuel Oil	8.78	7.70	7.38	10.41	14.62
Income per household (index, 1977 = 1.00)	1.034	1.110	1.307	1.550	1.830
Households (millions)	79.8	83.0	89.1	102.6	114.4
Total Energy Use-Primary (quadrillion Btu)	15.1	15.3	15.9	17.5	19.4
Energy Use Per Household-Primary (million Btu)	189	184	178	172	170

Table 3.2. Disaggregate Forecast: Projected Total Energy Consumption and Key Driving Variables: Commercial Sector

Prices (1984 $/MMBtu)	1980	1984	1990	2000	2010
Electricity	18.44	21.10	21.04	23.34	23.90
Gas	3.66	5.45	4.87	7.20	13.04
Fuel Oil	6.17	6.99	7.47	10.76	15.33
Building Floor Stock (Billion sq. ft.)	44.7	49.7	55.5	69.3	88.1
Total Energy Use- (Quadrillion Btu)	10.6	11.2	12.4	14.8	17.9
Energy Use Per Sq. Ft. (Thousand Btu)	237	226	223	214	203

Table 3.3. Disaggregate Forecast: Projected Energy Consumption by Fuel Type
(Quadrillion Btu, Primary Energy)

	1980 (act.)	1984 (est.)	1990 (proj.)	2000 (proj.)	2010 (proj.)
Residential & Commercial					
Electric	14.9	16.4	18.8	23.0	28.2
Gas	7.6	7.5	7.2	7.2	7.2
Oil	2.7	2.1	1.8	1.6	1.5
Other	0.5	0.5	0.5	0.5	0.5
Total	25.7	26.5	28.3	32.3	37.4
Residential					
Electric	8.4	8.9	10.0	11.8	14.1
Gas	4.9	4.8	4.6	4.6	4.4
Oil	1.4	1.2	0.9	0.7	0.6
Other*	0.4	0.4	0.4	0.4	0.3
Total	15.1	15.3	15.9	17.5	19.4
Commercial					
Electric	6.5	7.5	8.8	11.2	14.1
Gas	2.7	2.7	2.6	2.6	2.8
Oil	1.3	0.9	0.9	0.9	0.9
Other	0.1	0.1	0.1	0.1	0.1
Total	10.6	11.2	12.4	14.8	17.9

*Primarily Propane

Table 3.4. Disaggregate Forecast: Primary Energy By End-Use Building Sector

	1980		2000		2010	
	QBtu	%	QBtu	%	QBtu	%
Sector/Function						
Residential						
Space heating	6.2	41	6.6	38	6.9	35
Air conditioning	1.1	7	1.7	10	2.1	11
Water heating	2.5	16	3.1	17	3.4	18
Lighting	1.0	7	1.1	7	1.2	6
Cooking	0.9	6	.9	5	1.0	5
Refrigerators	1.3	9	1.2	7	1.3	7
Freezers	0.5	3	0.5	3	0.5	3
Other	1.7	11	2.4	13	2.8	15
	15.3	100	17.7	100	19.4	100
Commercial						
Space heating	4.0	36	4.8	33	5.6	30
Air conditioning	1.3	11	1.7	11	1.9	12
Ventilation	1.4	12	1.6	11	1.9	11
Water heating	0.6	5	0.9	6	1.0	6
Lighting	2.8	25	3.6	24	4.3	25
Cooking	0.1	1	0.2	1	0.2	1
Refrigerators	0.2	2	0.2	2	0.3	2
Other	0.9	8	1.8	12	2.7	13
	11.2	100	14.8	100	17.5	100

Table 3.5. Forecasts of Energy Consumption by End-Use Sector
(Quadrillion Btu. Including Losses)

SECTOR Forecasting Organization	YEAR 1980	 1984	 1990	 1995*	 2000	 2010
RESIDENTIAL & COMMERCIAL						
Disaggregate	25.7	26.5	28.3	-	32.3	37.4
CE/BCS	26.9	28.0	31.1	-	34.8	37.6
NEPP IV (1)	26.9	-	32.8	33.9	35.7	38.8
EIA (1)	-	27.1	30.3	32.8	-	-
DRI (1)	-	25.6	29.2	-	32.8	35.6
Chase	-	25.9	28.4	30.8	33.1	-
Wharton	-	26.2	29.8	32.5	-	-
Audubon (1,2)	-	-	-	-	30.2	-
GRI (1)	-	-	31.2	-	35.5	-
AGA	-	24.8	25.9	27.5	28.5	-
- RESIDENTIAL						
Disaggregate	15.1	15.3	15.9	-	17.5	19.4
CE/BCS	16.3	16.1	18.3	-	19.7	20.8
NEPP IV	16.3	-	18.6	19.2	19.8	20.3
EIA (1)	-	15.2	16.6	17.8	-	-
DRI (1)	-	15.0	16.5	-	17.3	17.3
Chase	-	15.3	16.8	17.9	18.7	-
Wharton	-	15.0	16.9	18.1	-	-
Audubon	-	-	-	-	15.8	-
GRI (1)	-	-	18.1	-	20.2	-
AGA (1)	-	13.8	14.3	14.7	15.0	-
- COMMERCIAL						
Disaggregate	10.6	11.2	12.4	-	14.8	17.9
CE/BCS	10.6	11.9	12.8	-	15.1	16.8
NEPP IV	10.6	-	14.2	14.7	15.9	18.5
EIA (1)	-	11.8	13.7	15.0	-	-
DRI (1)	-	10.6	12.7	-	15.5	18.3
Chase	-	10.6	11.7	12.9	14.4	-
Wharton	-	11.2	12.9	14.4	-	-
Audubon	-	-	-	-	14.4	-
GRI (1)	-	-	13.1	-	15.3	-
AGA (1)	-	11.0	11.6	12.8	13.5	-

(1) These forecasts have been modified to include electrical generation losses based on ratios of direct electricity sales to electricity losses. Data for these ratios were obtained from the State Energy Data Report published by the Energy Information Administration of the Department of Energy in May 1984.

(2) The forecast for electrical generation losses in the year 2000 was allocated to the residential, commercial and industrial sectors based on an average for such allocations in other models.

Sources: Disaggregate obtained from October 1985 runs of end-use models maintained by the Pacific Northwest Laboratory and the Lawrence Berkeley Laboratory; CE/BCS from U.S. DOE Office of Energy Conservation, FY 1987 Energy Conservation Multi-Year Plan; NEPP IV from U.S. DOE Office of Planning, Policy and Analysis, Energy Projection to the Year 2010 (Washington, D.C., 1983); EIA from U.S. DOE Energy Information Administration, Annual Energy Outlook 1984, "Middle Scenario", (Washington D.C., 1985); DRI from Data Resources Inc., Energy Review (Lexington, Mass., Spring 1985); Chase from Chase Econometrics, Energy Analysis Quarterly, (Bala Cynwyd, Pa., Third Quarter 1983); Wharton from Wharton Econometric Forecasting Associates, Wharton Long-Term Forecast (Philadelphia, Pa., June 1985); Audubon from the National Audubon Society, The Audubon Energy Plan (New York, N.Y., July 1984); GRI from the Gas Research Institute, 1984 GRI Baseline Projection of U.S. Energy Supply and Demand (Chicago, Ill., October 1984); AGA from the American Gas Association, AGA-TERA Base Control 1985-I (Arlington, Va., March 1985).

Table 3.6. Forecasts of Energy Consumption by Fuel Source in Buildings (Quadrillion Btu, Including Losses)

SECTOR Forecasting Organization	1984					1995					2000					2010				
	Gas	Oil	Ele.	Other	Total	Gas	Oil	Ele.	Other	Total	Gas	Oil	Ele.	Other	Total	Gas	Oil	Ele.	Other	Total
RESIDENTIAL/COMMERCIAL																				
DISAGGREGATE(1)	7.5	2.1	16.4	0.5	26.5						7.2	1.6	23.0	0.5	32.3	7.2	1.5	28.2	0.4	37.4
CE/BCS (2)	7.4	2.6	16.7	1.3	28.0						7.1	3.0	22.5	2.2	34.8	6.7	2.6	25.4	2.9	37.6
NEPP IV (2,3)						8.2	2.9	20.7	2.0	33.8	8.0	2.2	23.1	2.4	35.7	7.2	1.3	26.9	3.5	38.9
EIA (3)	7.4	2.6	16.9	0.2	27.0	7.3	2.8	22.6	0.2	32.8										
DRI (3)	6.8	2.5	16.1	0.2	25.6						6.7	2.3	23.6	0.2	32.7	6.5	2.0	26.7	0.4	35.6
Chase	7.5	2.5	15.7	0.2	25.9	7.0	2.5	21.0	0.3	30.8	7.0	2.7	23.1	0.3	33.1					
Wharton					26.2					32.5(4)										
Audubon (2,3)															30.2					
GRI (2,3)											7.8	2.0	23.8	1.9	35.5					
AGA (2,3)	7.1	3.6	13.7	0.4	24.8	8.8	3.8	14.5	0.4	27.5	9.1	3.8	15.1	0.5	28.5					
- RESIDENTIAL																				
DISAGGREGATE(1)	4.8	1.2	8.9	0.4	15.3						4.6	0.7	11.8	0.4	17.5	4.4	0.6	14.1	0.3	19.4
CE/BCS (2)	4.7	1.6	8.7	1.1	16.1						4.3	1.6	12.1	1.7	19.7	3.7	1.2	14.0	1.9	20.8
NEPP IV (2,3)						5.2	1.8	10.9	1.3	19.2	5.1	1.3	11.9	1.5	19.8	4.6	0.8	12.9	2.0	20.3
EIA (3)	4.7	1.5	8.9	0.1	15.2	4.6	1.5	11.7	0.1	17.8										
DRI (3)	4.4	1.5	9.0	0.1	15.0						3.8	1.4	12.0	0.1	17.3	3.5	1.2	12.6	0.1	17.3
Chase	4.9	1.5	8.8	0.1	15.3	4.4	1.6	11.9	0.1	17.9	4.2	1.6	12.8	0.1	18.7					
Wharton	4.6	1.6	8.8	-	15.0					18.1(4)										
Audubon															15.8					
GRI (2,3)											4.3	0.9	13.6	1.4	20.2					
AGA (2,3)	4.6	1.3	7.5	0.3	13.8	5.0	1.2	8.2	0.2	14.7	5.1	1.1	8.6	0.2	15.0					
- COMMERCIAL																				
DISAGGREGATE(1)	2.7	0.9	7.5	0.1	11.2						2.6	0.9	11.2	0.1	14.8	2.8	0.9	14.1	0.1	17.9
CE/BCS (2)	2.7	1.0	8.0	0.2	11.9						2.8	1.4	10.4	0.5	15.1	3.0	1.4	11.4	1.0	16.8
NEPP IV (2,3)						3.0	1.1	9.9	0.7	14.7	2.9	0.9	11.2	0.9	15.9	2.6	0.5	13.9	1.5	18.5
EIA (3)	2.7	1.0	8.0	0.1	11.8	2.7	1.3	10.9	0.1	15.0										
DRI (3)	2.4	1.0	7.1	0.1	10.6						2.8	0.9	11.6	0.1	15.5	3.0	0.8	14.2	0.3	18.3
Chase	2.6	1.0	6.9	0.1	10.6	2.7	0.9	9.2	0.2	12.9	2.8	1.1	10.3	0.3	14.4					
Wharton					11.2					14.4(4)										
Audubon															14.4					
GRI (2,3)											3.5	1.1	10.2	0.5	15.3					
AGA (2,3)	2.5	2.2	6.2	0.1	11.0	3.8	2.5	6.3	0.2	12.8	4.0	2.6	6.6	0.2	13.5					

(1) From energy models maintained by Lawrence Berkeley Laboratory and Pacific Northwest Laboratory, October 1985.

(2) Renewables are included in "other." (Other is primarily propane.)

(3) These forecasts have been modified to include electrical generation losses based on ratios of direct electricity sales to electricity losses. Data for these ratios were obtained from the State Energy Data Report. U.S. DOE/EIA, April 1985.

(4) 1994 estimate.

(5) Sources: Disaggregate obtained from October 1985 runs of models maintained by the Pacific Northwest Laboratory and the Lawrence Berkeley Laboratory; CE/BCS from U.S. DOE Office of Energy Conservation, FY 1987 Energy Conservation Multi-Year Plan, NEPP IV from U.S. DOE Office of Planning, Policy and Analysis, Energy Projection to the Year 2010 (Washington, D.C., 1983); EIA from U.S. DOE Energy Information Administration, Annual Energy Outlook (Washington, D.C., 1985); DRI from Data Resources Inc., Energy Review (Lexington, Mass., Spring 1985); Chase from Chase Econometrics Energy Analysis Quarterly, (Bala Cynwyd, PA., Third Quarter 1983); Wharton from Wharton Econometric Forecasting Associates, Wharton Long-Term Forecasts (Philadelphia, Pa., June 1985); Audubon from the National Audubon Society, The Audubon Energy Plan (New York, N.Y., July 1984); GRI from the Gas Research Institute 1984 GRI Baseline Projection of U.S. Energy Supply and Demand, Chicago, Ill., October 1984); AGA from the American Gas Association, AGA-TERA Base Case 1985-I (Arlington, VA., March 1985).

Table 3.7. Forecast Assumptions for the Year 2000[1]

	Date of Forecast/ Scenario Name	World Oil Price (1984$/Barrel)	Real GNP (Billions 1972$)	Residential Energy Prices (1984$/MMBtu) Elec.	Residential Oil	Residential Gas	Commercial Energy Prices (1984$/MMBtu) Elec.	Commercial Oil	Commercial Gas	Number of Households (Million Units)	Square Feet of Commercial Floorspace (Billion Square Feet)
Disaggregate[2]	October 1985	$43.57	$2,574.8	22.05	10.41[3]	8.18	23.34	10.76[3]	7.20	102.6	69.3
CE/BCS	May 1985/ Scenario B	$43.57	$2,574.8	22.05	10.41[3]	8.18	21.91	9.74[3]	7.74	—	72.4
NEPP IV	Oct. 1983/ Scenario B	$61.68	$2,438.8	25.87	13.96[3]	9.97	27.47	12.89[3]	9.34	116.0	60.0
DOE/EIA	Jan. 1985/ Scenario A	$40.00[4]	$2,206.0[4]	19.37[4]	10.11[4]	9.07[4]	19.75[4]	8.30[4]	8.34[4]	104.1[4,5]	66.3[4]
DRI	Spring 1985	$36.59	$2,500.1	24.45	9.63[3]	11.40	21.20	9.63[3]	10.05	112.0[5,6]	—
Chase	Sept. 1983/ Moderate Growth	$40.88	$2,506.5	19.21	9.67[3]	10.02	19.21	9.67[3]	9.36	—	—
Wharton	June 1984/ Long-Term Forecast	$37.55[7]	$2,084.7[7]	29.99[7]	10.85[7]	8.21[7]	—	—	—	114.3[7]	—
National Audubon Society	July 1984/ Conventional Model	$74.98	$2,335.2	32.96	14.33[3]	10.00	32.96	14.33[3]	10.00	106.0[5]	92[6]
GRI	Oct. 1984/ Baseline	$40.64	$2,470.0	21.22	8.97[3]	8.37	21.22	8.97[3]	7.99	103.7[5]	83.0[6]
AGA	Mar. 1985/ Base Case	$32.56	$2,084.7[7]	25.97	9.23[3]	6.01	25.80	8.84[3]	5.68	84.6[8]	—
1984 Data		$27.44[9]	$1,639.0[10]	22.16[11]	7.87[3,11]	5.88[11]	21.48[11]	7.87[3,11]	5.53[12]	85.01[13]	47.1[14]

(1) Dollar values are deflated to 1984$ based on real GNP price deflators contained in the forecast or are inflated to 1984$ based on the GNP price deflators for final sales contained in the Economic Report of the President, Council of Economic Advisors, February 1985, p. 237.
(2) From end-use models maintained by Lawrence Berkeley Laboratory and Pacific Northwest Laboratory, October 1985.
(3) Distillate only.
(4) 1995 data.
(5) Number of occupied housing units.
(6) Calculated based on information contained in forecast documentation.
(7) 1994 estimates.
(8) Number of residences.
(9) Average FOB Cost of Crude Oil Imports, Monthly Energy Review, U.S. DOE/EIA, April 1985, p. 91.
(10) Economic Report of President, Council of Economic Advisors, February 1983, p. 234.
(11) Monthly Energy Review, U.S. DOE/EIA, April 1985, pp. 99-101.
(12) Quarterly Review of Statistics, American Gas Association, fourth quarter 1984.
(13) Current Population Report Series, U.S. Bureau of Census, p. 20, July 1985 estimate of number of households for 1984.
(14) From baseline forecast, see Table 3.2.

Table 3.8. Forecasts of Energy Intensities[1] for the Year 2000

	MMBtu/ Household	% Change Per Year	Thousand Btu/ Square Foot	% Change Per Year
Disaggregate	172.2	-0.4[4]	213.6	-0.3[4]
CE/BCS	---	---	289.0	-1.1[4]
NEPP IV	170.7	-0.6[5]	265.0	-2.1[5]
EIA	171.0[2]	-0.1[6]	226.2[2]	-0.2[6]
DRI	154.5[2]	-0.9[4]	---	---
Chase	---	---	---	---
Wharton	158.2[3]	-0.1[7]	---	---
Audubon Society	149.0	Unknown	156.5	Unknown
GRI	194.8	+0.1[8]	184.3	-1.2[8]
AGA	177.3	-0.9[4]	---	---

(1) Primary energy use.
(2) 1995 estimate.
(3) 1994 estimate.
(4) Between 1984 and 2000.
(5) Between 1985 and 2000.
(6) Between 1984 and 1995.
(7) Between 1984 and 1994.
(8) Between 1983 and 2000.

4. SELECTED STUDIES

The activities summarized in this section were performed on behalf of BCS at several National Laboratories under the direction of (or by) the individuals listed below:

David Belzer, Pacific Northwest Laboratory (PNL):

- 4.1.1 Building Energy Accounting System (BEAS) (Aileen Bohn)
- 4.2.2 Update of the Commercial Energy Model (David Belzer)
- 4.3.1 Economic Analysis of Federal Commercial Building Standards (Joseph Roop)
- 4.3.4 R&D Project Appraisal (William Flynn)

Alan Meier, Lawrence Berkeley Laboratory (LBL):

- 4.1.2 Building Energy-Use Compilation and Analysis

Terry Dinan, Oak Ridge National Laboratory (ORNL):

- 4.1.3 Consumer Decision Process with Regard to Energy Use and Conservation Investment

Lee Schipper, Lawrence Berkeley Laboratory:

- 4.1.4 Building Energy Conservation in Other Countries

Mark Levine, Lawrence Berkeley Laboratory:

- 4.2.1 Update of the Residential Energy Model (James McMahon)
- 4.3.2 Appliance Standards Analysis (Henry Ruderman)
- 4.3.3 Impacts of Energy Conservation Programs on Electric Utilities (Edward Kahn)

The summaries contained in this section were provided by the above persons or members of their staffs associated with specific projects (as indicated); further information on these studies may be obtained by contacting them.

4.1 Data Development

4.1.1 Buildings Energy Accounting System (BEAS)

The Office of Buildings and Community Systems (BCS) of the U.S. Department of Energy (DOE) requires data to respond to inquiries from Congress, private concerns, other government agencies and DOE offices and to include in publications such as the Annual Operating Plan and the Multi-Year Plan. In addition, information is needed for special studies being performed within BCS and for briefings conducted by BCS officials.

In 1984, the Residential and Commercial Buildings Data Book was published in order to provide a single source of statistics for many of BCS's data requirements. The 1984 Data Book contained current and historical statistics on residential and commercial sector energy consumption and prices along with data on the characteristics of the U.S. building stock. In 1985, the concept of a database was expanded into the Buildings Energy Accounting System (BEAS), which in addition to the type of information contained in the 1984 Data Book, is to contain forecasts of consumption and prices, energy savings estimates for each of BCS' programs, and data required for and obtained from special BCS studies.

BEAS will be available on floppy disks for use in the IBM PC. A user's manual and documentation for the BEAS database will be included with the floppy disks. Hard copies of some of the information contained in BEAS will be published in the 1985 version of the Residential and Commercial Buildings Data Book.

BEAS will have three parts; the core dataset, the core database, and the auxiliary database. The core database and the auxiliary database will each contain detailed datasets, while the core dataset will be a singular entity containing data that are most often referenced.

The core database, the largest section of BEAS, is intended to provide a compilation of all available data pertinent to energy consumption in the residential and commercial sectors. This information includes data on energy prices, consumption, building characteristics, major fuel-consuming equipment, and energy savings as a result of BCS projects. These datasets are designed to be detailed and will contain, for example, regional disaggregations of data and historical information that predates 1973.

The core dataset, designed to contain the most frequently referenced data will essentially be a subset of some of the information found in the core database. The core dataset will provide only national statistics. Energy consumption and prices by sector and by fuel type will be part of the information included in the core dataset.

The auxiliary database will provide descriptions and sources of additional series of data concerning the buildings sector which have not been included in the core dataset or core database.

4.1.2 Buildings Energy-Use Compilation and Analysis (BECA)

The Buildings Energy-Use Compilation and Analysis (BECA) data base project was started five years ago by the Buildings Energy Data group at Lawrence Berkeley Laboratory, in an attempt to address the need for measured data on the energy performance of buildings designed or retrofitted to be energy efficient. Most energy-related investment decisions and evaluations of programs to increase energy efficiency in buildings have been based on predictions of the energy savings and costs associated with proposed conservation measures. Documentation of the energy savings and cost-effectiveness of energy conservation techniques implemented in actual buildings is necessary to complement computer simulations and engineering calculations.

There are currently six BECA data compilations:

- BECA-A: new, low-energy residential buildings
- BECA-B: retrofitted residential buildings
- BECA-CN: new commercial buildings designed to be energy-efficient
- BECA-CR: retrofitted commercial buildings
- BECA-D: residential water-heating systems
- BECA-V: validation of computer loads models

Each of the building data bases contains energy consumption data plus building and occupancy characteristics.

Findings To Date

These data bases currently contain over 1000 entries, representing over 40,000 buildings and appliances. Results to date have underscored both the importance and the difficulty of understanding energy performance in real buildings. In general, the new buildings in our sample are using less energy than stock averages, and most of the retrofitted buildings show decreased energy consumption following implementation of conservation measures. There is, however, a wide range of energy use in new buildings designed to be energy-efficient, and considerable scatter in energy savings and cost-effectiveness results for retrofitted buildings.

In addition to identifying data sources and collecting building data, much of our effort to date has focused on developing analytic techniques to measure and compare energy performance. We are learning what data are necessary to evaluate indicators of energy performance.

Residential Buildings. The new homes in the BECA-A compilation incorporate energy-design strategies, including passive solar, active solar, superinsulation, and earth-sheltering. The energy consumption of each house is normalized to account for differences in floor area, climate, and heat produced by appliances and the occupants. (A few active people produce as much heat as a small electric heater.) Indicators of the thermal performance of the homes which enable comparison among the buildings in the sample are derived from regression of the outside temperature and fuel consumption. Submetering furnace consumption and collection of inside temperature data have proven to be vital for valid calculation of these performance indicators, the "k value" (a heat-loss factor) and "balance temperature" (the lowest outdoor temperature at which no space heating is required).

Most of the new homes in BECA-A are energy-efficient compared to conventional new housing stock. As a group, earth-sheltered homes perform the best, with passive solar homes a close second. The superinsulated homes are the preferred design in very cold climates. The extra cost of energy-efficiency features in passive and superinsulated homes is quickly recovered in lower utility bills, although the exact payback time depends on the local utility prices. Some of the best houses do not need a furnace until the outside temperature drops below 40^{o}F. The active solar homes are a poorer investment, but still have an acceptable payback time where electricity prices are above 5.7 cents/kWh.

Retrofits of shell and/or heating systems in residences are covered in the BECA-B compilation. Shell retrofits typically involve adding insulation, replacing windows, or reducing air infiltration. Shell retrofits typically reduce the heating load that is met by the furnace. Figure 4.1 shows the range in fuel savings among houses that had similar retrofit measures installed. Part of the wide range in energy savings is due to variation in operating conditions and in the quality of the retrofit. Poorly trained contractors, for example, often leave gaps in the insulation. The retrofits had short payback times in about three-quarters of the retrofits compiled. A combination of shell and system retrofits appears to be twice as cost-effective as shell measures alone. Most of the research has been directed towards saving space heating energy; there are very few investigations of retrofits to save cooling energy.

Commercial Buildings. Evaluation of performance indicators for commercial buildings is currently at a less sophisticated level, due to the lack of instrumented monitoring of commercial buildings, and the diversity of this sector. We currently use annual energy intensity (total energy consumption/floor area) and peak electric demand (also normalized by floor area) as indicators of building energy performance. Initial results from the new commercial data base (BECA-CN) show that the buildings are performing better than stock averages, but often not as well as design predictions. See Figure 4.2 for the distribution of resource energy consumption of the offices in the data base. Some of the offices with the highest energy intensities are operated long hours and have computer facilities.

The median simple payback is only one year for the retrofits implemented in commercial buildings in the BECA-CR compilation. The most common retrofit measures involve "low cost" HVAC (heating, ventilating, air conditioning) system operations and maintenance, and lighting.

Most buildings in the commercial compilations include only whole-building metered consumption. Additional end-use consumption data and details of building operation are required to understand the scatter in energy use and discrepancies between predicted and actual consumption. Variations in operating schedules, occupancy conditions, and weather complicate comparisons among buildings, with a group of average buildings or code levels, or between pre- and post-retrofit periods. Where available, we collect detailed data on occupancy schedules, process loads (including the increasingly prevalent office computers), weather conditions, etc. in an effort to develop additional performance indicators, or standardization techniques to normalize energy consumption for these factors. End-use monitoring of commercial buildings has been rare, but projects underway should supply high-quality data during the next year. In addition, we are investigating the use of energy management system data-logging capabilities as a low-cost monitoring technique.

Peak electric demand has become a major concern for the commercial building sector and many demand-control and load-management strategies are implemented in the buildings. We are collecting electricity load profiles, time-of-use data, and utility billing schedules to incorporate indicators of electric power performance into evaluations of commercial building performance.

Water Heating and Model Validation. In addition to the buildings data bases, we compile measured energy data for residential water heating systems (BECA-D) and we compile validations of building load programs against measured performance (BECA-V). Results from BECA-V show that many models predict energy use within 20% of the actual value. The accuracy of the prediction appears to depend on such factors as who performed the simulation (authors of the model are most successful) in addition to the validity of the formulas used in the calculations.

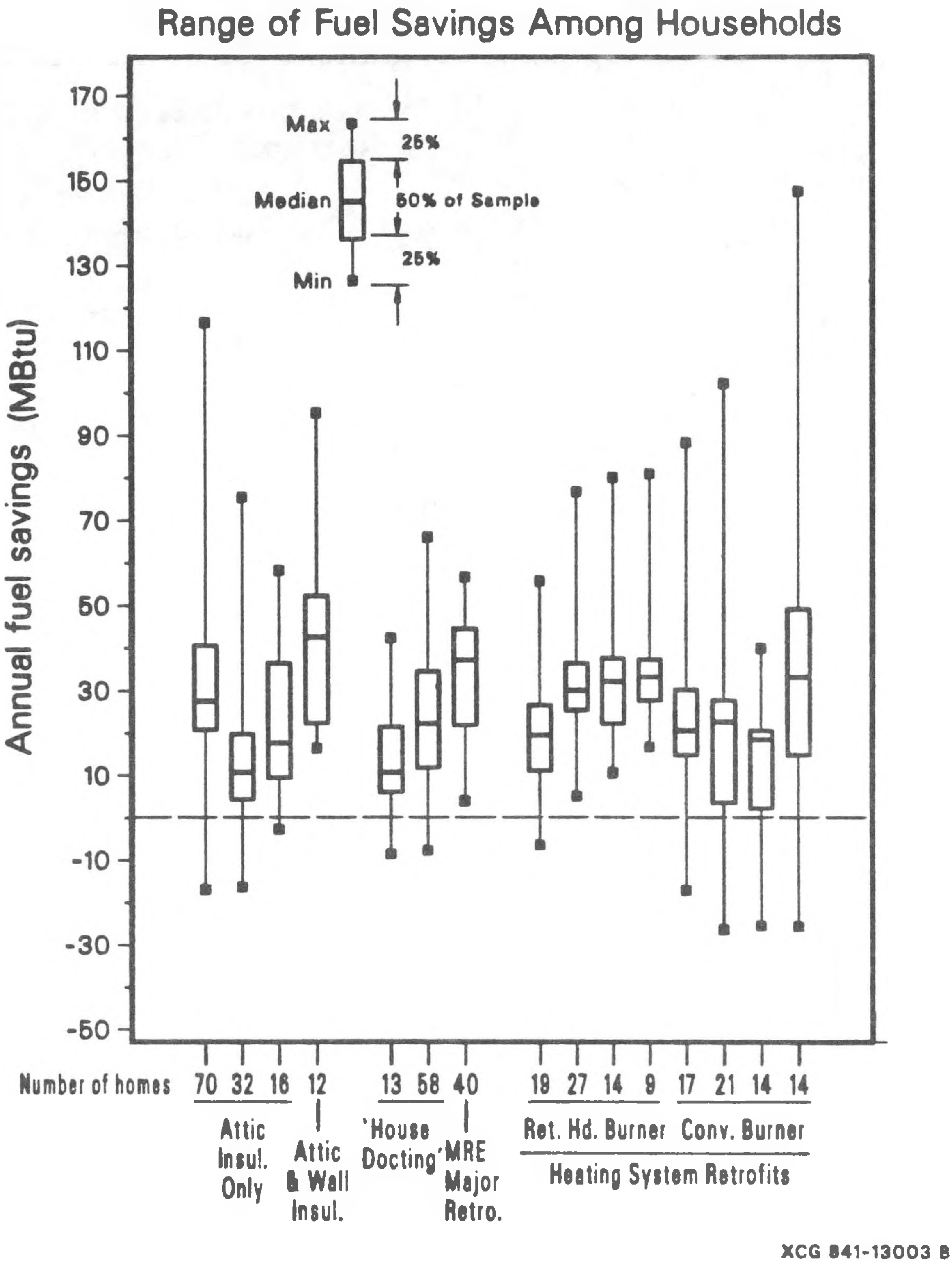


Figure 4.1 Range in annual fuel savings among households installing similar measures. The site label, number of homes in the project, and type of measure are listed below each distribution. In most cases, the savings apply to space heating only, except for the heating system retrofits and the house-doctor experiments where consumption includes all end uses of the space heating fuel. For the middle 50 percent of the homes, the spread in savings is typically ± 70% of the median.

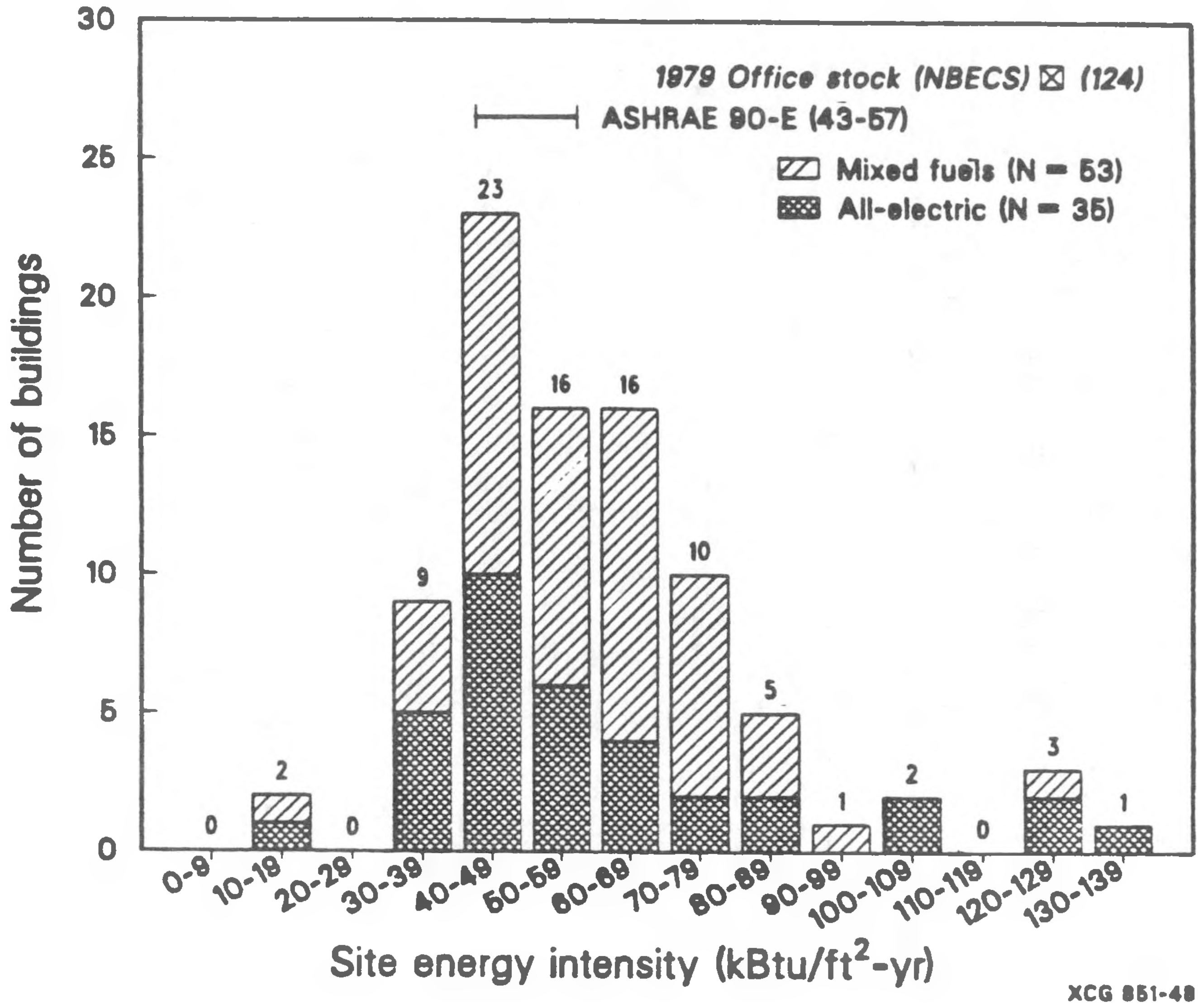


Figure 4.2

Actual site energy intensity for new office buildings in BECA-CN. The distribution for all-electric and mixed-fuel buildings are similar. Over 60% use between 40 to 70 kBtu/ft^2-yr. The average U.S. office stock (EIA, 1981) and the proposed ASHRAE 90-E values for large offices are included for reference.

4.1.3 The Consumer Decision Process With Regard To Energy Use and Conservation Investment

The purpose of this study is to assist the DOE Office of Building and Energy Research and Development (BERD) by reviewing current and completed studies that address consumer decision processes with respect to energy consumption and conservation investment. The motivation for undertaking such a review is a belief that a prerequisite for effective policy design is a sound understanding of what factors and decision processes underlie consumers' conservation behavior. The literature review consists of two levels of specificity. First, an extensive search was conducted to collect and classify relevant literature. Second, a detailed review of a subset of the collected articles was undertaken. In this state, the theoretical and empirical findings concerning the consumer decision process are examined.

Numerous studies have examined the factors which influence consumers' energy using and investment behavior. Economic optimizing models have provided a theoretical framework for predicting consumer behavior. These models are based on the assumptions that consumers seek to maximize a conceptual artifact known as a "utility function" subject to a budget constraint. By assuming that consumers seek to maximize utility subject to a budget constraint (even if they don't calculate the utility maximizing choice mathematically) and assuming a form for the utility function, information about consumer preferences can be inferred. Many studies have utilized this technique to derive information about consumers' discount rates, i.e., the reduction in annual operating cost which is required to induce the consumer to invest $1. These studies have taken useful steps toward establishing the relationship between discount rates and several socioeconomic factors. Substantial evidence exists which reveals a negative relationship between consumer discount rates and household income and also between consumer discount rates and ownership status; i.e., high income consumers and homeowners are more willing to undertake conservation investments than low income consumers and renters. The relationship between discount rates and other socioeconomic factors is less clear and serves as an area for future investigation.

Attitudinal models have analyzed the correlation between consumer attitudes and conservation behavior. A consensus among these studies is that there is a poor correlation between conservation behavior and general attitudes such as a concern for or belief in the energy crisis; however, there is a significant correlation between specific conservation behavior and specific attitudes towards health and comfort, and feelings of a personalized responsibility to conserve.

Energy investments are characterized by uncertainty. Uncertainty concerning future energy prices and actual performance of energy efficiency increasing investments leads to uncertainty about the savings resulting from a given investment. Uncertainty about the introduction of new technologies and innovations and the future prices of currently existing technologies complicate the decision of whether to invest in a technology now, or whether to "wait and see." The impact of uncertainty on conservation investment behavior has been overlooked in many previous studies; however, general findings on the effect of risk and uncertainty on decision making have revealed that this may be an important factor affecting consumers' conservation investment decisions. Future research aimed at understanding the impact of uncertainty on consumers conservation investment decisions may aid policymakers in their ability to both predict and promote conservation behavior.

In addition to examining the factors which affect conservation behavior, several studies which examine potential barriers to conservation behavior were reviewed. These barriers include income, lifestyle, and information constraints, as well as constraints arising from the uncertainty and risk associated with conservation investments. A discussion of methods of overcoming these barriers is provided along with a review of the effectiveness of previous programs designed to promote conservation behavior.

The literature review revealed a need to develop a comprehensive framework for examining consumer energy conserving behavior. While energy using and conservation investment behavior have been analyzed and modeled from a variety of disciplinary perspectives and empirical techniques, no single study has utilzed a comprehensive approach. Based on the findings of the review, the factors which should be included in modeling conservation behavior are illuminated, and an integrated framework for modeling consumer behavior is suggested. The suggested framework simultaneously examines the impact that fuel prices, capital equipment costs, socio-demographic characteristics, personal norms for conservation, and specific household attitudes have on conservation behavior. In addition, the framework includes the role of uncertainty in influencing investment behavior. The suggested framework includes an examination of the process by which energy using and conservation investment decisions are made, as well as the factors which influence these decisions. Previous research has focused mainly on investigating the factors influencing decisions; however, significant improvements in policy effectiveness may be obtained from understanding the process underlying conservation decisions.

The review also revealed a need for improved data. Current studies are limited by the absence of panel data on conservation actions, and by sparse household level data collection on attitudes and norms toward conservation, measures of risk perception about conservation investments, socioeconomic characteristics, and energy consumption and investment behavior.

Finally, the literature review revealed little on the factors and processes underlying conservation investment in the commercial sector. Initiating data colleciton and basic research in this area is necessary in order to formulate effective conservation policies for the commercial sector.

4.1.4 Building Energy Conservation in other Countries

During the past several years, the Energy Analysis program at LBL has been following residential energy use and its underlying structure in the major OECD countries, with support from BCS and from the Swedish Council for Building Research. Recently this work was expanded to include the commercial buildings sector. The goals of the work have been to 1) establish the data base of energy use in homes and buildings in OECD countries; 2) analyze the components of changes in energy use since 1973, particularly the permanence of these changes; 3) extend this analysis through the econometric work as well; 4) analyze the relationship between government conservation programs and actual savings in the residential sector; 5) evaluate techniques or policies form overseas that may be relevant to the United States.

Since official data covering these sectors are almost non-existent, the group was forced to build up understanding and a data base as well from the bottom up. Thus we collected and analyzed data on the building stocks, heating fuel choices, unit consumption, electric and gas appliances, prices, incomes, conservation programs and other components of the residential energy use picture.

Our work led us to examine total energy use by fuel and purpose for the period 1960 - 1983, with emphasis on the period after the 1973 oil price shock. We then disaggregated this total by fuel and purpose for a variety of key years.

In most countries (Canada, US, W. Germany, France, Sweden, Denmark, UK), energy use fell somewhat through 1975, led by decreased space heating, then recovered to prior levels. Primary energy use continued to grow because of increased electric appliance ownership, and in the case of Norway and Sweden, growing popularity of electric heating. The second oil shock (1979) unleashed a torrent of energy conservation activity, however, which through 1983 had not been erased. Oil use per home fell dramatically in every country, both because of deep reductions in heating use and through increased use of wood or even electricity as a secondary fuel. Electricity use per home for appliances virtually ceased to grow, as more new, efficient appliances entered the stock. Gas use per home stopped growing in countries where growth had been strong (France, Germany, Holland), and declined markedly in the US and Canada.

The continued increase in electricity use for space heating — most notable in Norway and Sweden but also important in France, Canada, and the US -- accounted for much of the increase in primary energy use per dwelling, although electric heating in each country became more efficient as new homes with tight shells entered the stock.

Because oil led the decline in residential energy use, we examined home heating oil in great detail. For seven major OECD countries, (Canada, Denmark, France, W. Germany, Norway, Sweden, and the US), home oil decreased by 32% between 1972/3 and 1981/2, for a savings of about 1 million barrels per day (50 million tonnes of oil equivalent (MToe) per year). One fourth of these savings was caused by reductions in the number of homes heated with oil, the rest in reductions in oil use per oil heated home. During that time, however, the size and central heating penetration in these homes increased significantly, so these figures underestimate the real conservation efforts made to date. About 45% of the total oil savings (through 1982) are permanent, while the rest could be reversed with a continued slide in oil prices, although it is likely that most of the savings will remain and probably increase.

All countries experienced steep price increases for heating oil in 1973/4 and again in 1979-81, causing the drop in oil use, which by 1982 had amounted to a real flight in most countries. The share of oil in final residential energy use fell from between 53% and 71% (Canada, Denmark, France, Germany, Sweden) in 1972/3 to as little as 30% in Canada, 36% in Sweden and 40% in France by 1983. The shares in Germany and Denmark remained somewhat higher. The shares in the US and Norway were always lower than in these other countries; the U.S. still has the lowest dependence on oil (and LPG) in the residential sector.

Although data are preliminary, it appears that the pace of conservation is slowing, because oil use per oil-heated home, corrected for yearly climate variations, did not fall in 1983 over 1982, and may have increased slightly in a few countries. While there is some danger that oil users may be losing interest in reducing their oil bills, momentum for "off oil", i.e., conversions to other fuels, is strong in every country.

By 1983 the near term effects of the 1979/80 price shock appeared to have worn off. However we have not yet seen any dramatic upturn in energy intensities. Gas, electricity, and district heating continue to fight for the heating market abandoned by oil; electric appliances continue to improve, and consumers appear to have gained a permanent awareness of the economic benefits of efficient energy use. Intensity of gas use for heating appears to be falling slowly but steadily in Holland, the United Kingdom, and the U.S., the three countries with the highest dependence on gas.

What role have policies played in all of these changes? Active, forcing policies governing use in existing homes have been almost non-existent. New building codes have come into force in most OECD countries, but almost always following the most economic practices already in place, rather than forcing new practices. Only in the US does it appear that practices lag behind what appears otherwise to make economic sense. When these practices are required, (such as for some kinds of Federal financing), they are usually far tighter than when not required. In Sweden, a complex system of building codes linked to financial support for builders and buyers (in place since the early 1960s) clearly stimulated the building industry to produce far more efficient homes than anywhere else. The extra costs incurred were automatically financed through normal home financing channels. This led to practices that were on average better than what was required by codes, with average R factors in 1983 of R-25 for walls and R-40 for roofs. Similarly the retrofit grant program in Sweden, also administered by a key group that was in place long before 1973, raised the rate of investment in insulation and other practices to nearly 2/3 of the stock of single-family dwellings and half the apartments, figures not matched yet by any other country.

In other OECD countries the impact of policies is less clear. This is because energy savings came about mainly through rapid reductions in energy intensities for heating fuels, principally oil. Denmark, W. Germany, France, and the US are important examples. In Holland, the reduction in gas heating use has been gradual, in part because of the National Insulation Program, which will eventually reach most of the eligible dwellings. In Denmark and France programs in the mid-1980s appear to be replacing the "quick and dirty" savings won in 1979/81 with more permanent savings through better building shells and equipment. In our judgement, these programs are increasing the rate of investment in retrofit substantially over what it would otherwise be, aiding households in finding more comfort at lower cost. Thus we find that while conservation programs and policies had only a minor effect in the 1970s, they are bearing fruit in the 1980s in most countries in Europe. In all these countries, new homes heated by gas or electricity, and new electric appliances are considerably more efficient than older, with little pressure from codes necessary. Improvements in appliances in the US appear to be less than those in other countries.

Our work has uncovered several new technologies that appear promising for the United States. Of these, the most dramatic is the exhaust-air heat pump for domestic hot water, now outfitting half of the new single-family dwellings stock in Sweden. This small device uses the stream of 20°C air exhausted with a small fan from very tight houses to provide roughly half of the energy required for domestic hot water. If the home uses a hydronic space heating system, surplus heat from the heat pump can also heat the home. Other promising technologies from Europe include bivalent (two-fueled) heat pumps, condensing gas furnaces, and multi-fuel boilers that use oil (or gas), wood, and electricity, depending on which is more advantageous to use. Finally, electric appliances have become more efficient in every country, judging from catalogs from most of the important manufacturers (Philips, Electrolux, Mitsubushi). Equally important, the market has absorbed these devices, perhaps even more so than in the United States, as evidence from Danish, German, and Japanese authorities suggests. Indeed, many await an invasion of very efficient appliances from Japan, which has had high electricity prices to stimulate technical developments, and a set of guidelines to challenge industry to produce more efficient appliances for the domestic market.

The most dramatic technology, however, is the wooden house itself. Factory crafted houses from Sweden (with some from Norway and Denmark as well) have the best thermal performance of any production houses in the world, at minimal extra cost. In our study we found that houses built in Sweden in the late 1970s and early 1980s generally performed as expected. We also found that with the exchange rates of 1984/5, these houses could be profitably exported to the US. More important, the Swedish factory crafting techniques could incude a wave of low-cost thermal comfort for new US homes. As of May, 1985, about 300 Swedish homes were planned for various developments, mostly in the Eastern US, and an advanced home from Denmark was assembled at the Brookhaven National Laboratory.

4.2 Model Maintenance

4.2.1 Update of the Residential Energy Model

Background

Energy consumption in residences accounts for 20% of total energy and 35% of electricity used in the United States today. Over time, the amount of energy consumed to provide a particular service will change, due to both technological changes in the energy-using equipment and behavioral changes. The mix of fuels consumed also changes; recently, households have increased their electricity consumption and decreased consumption of fossil fuels. For these reasons, an understanding of the components of residential energy consumption and the effects of policies on them is important.

Computer models for projecting residential energy consumption at the end-use level have been in existence since the 1970's. The LBL Residential Energy Model is derived from the ORNL residential energy forecasting model developed by Hirst and Carney. The LBL model, while retaining the structure of the original ORNL model, has had significant improvements made in both data and algorithms, as discussed later.

The LBL model combines engineering information (costs and efficiencies of products available for purchase) and economic formulations (elasticities of demand separated into fuel choice, efficiency choice, and usage decisions) to provide simulations of future energy consumption at the end-use level. This approach considers the problem at a sufficient level of disaggregation to utilize engineering information without neglecting the important economic determinants of market behavior. The model now includes: representation of recent equipment efficiency trends; new techniques for forecasting future appliance efficiencies and annual appliance replacements; and explicit representation of heat-pump space-conditioning systems. The resulting forecasts give improved agreement with recently reported energy consumption and provide lower estimates of future energy consumption.

Recent Results

The data used by the model have been updated in several areas:

1. Housing starts/stocks. The 1980 Census gives higher estimates of the housing stocks than previous surveys, and shows an increase in the fraction of dwelling units in multifamily dwellings, at the expense of single family houses. At the same time, the construction forecast has been revised downward.

2. Energy cost projections. The last decade has seen dramatic changes in expectations regarding energy costs. For that reason, the assumed energy price projections have been altered repeatedly to keep abreast of changes in the market.

3. Income projections. The expected increases in real income were previously based on per capita estimates. The older estimates were optimistic, and have not been borne out by recent experience. In addition, the definition of the input variable has been changed to income per household. Currently, we assume 1.2%/year real growth in income per household after 1985.

4. Engineering Analysis. We developed a new aggregation procedure for combining data for different classes of products, e.g., manual defrost and frost-free refrigerators. This method was designed to extract as much information as possible, yet simplify the representation to a single curve for each product type.

5. Recent efficiency trends. We have included in the model the significant changes in design that have been reported by trade associations. Projections of future efficiencies are based upon the observed efficiencies and an analysis of the decision processes in the market since 1972.

Model Specification Changes

We made changes in the method of projecting future energy consumption in several key areas:

1. Efficiency of new appliances. The market behavior algorithm has been replaced. The original formulation was theoretical, since data on appliance efficiencies were not available. Recent work at LBL using data made available during the Department of Energy analysis of proposed Consumer Product Efficiency Standards indicates that the original formulation, assuming an inverse relationship between energy price and unit energy consumption, forecasts higher efficiency improvements than observed in the market in the past 10 years. Appliance efficiencies have improved, and for certain products not by as much as had been forecast. On the whole, the tradeoff between operating cost and purchase cost by purchasers of appliances has not changed over time. Increases in energy costs have been reflected in the operating costs of appliances, and efficiencies (and presumably purchase costs) have increased. But, in most cases, the efficiency increases have only kept pace with rising energy costs, and do not yet indicate any change in the market decision-making process toward placing more emphasis on energy conservation. The details of the analysis of market behavior regarding efficiency choice are reported elsewhere.

2. Appliance retirements. The original formulation used an exponential retirement function, equivalent to retiring each year a constant percentage of the existing appliances of each age. We found data on retirement functions that give the percent of appliances that retire during each year after original purchase. The use of a vintaging approach achieves two purposes: 1) it eliminates the erroneous early retirement of young appiances; (Retirements in early years of the projection are therefore lower in the new method.) 2) it captures the wave-like rise and fall of replacement sales, reflecting the aging of units purchased during peak economic and housing construction periods.

3. Energy use of retiring appliances. The old method accounted for the energy use of retiring appliances by retiring the energy use of the average unit in stock at the time. This was inaccurate, since units of several ages retire in any given year and the older retirees are likely to consume more energy (be less efficient) than newer models. In the new model, the retirees retain the unit energy consumption appropriate for their vintage.

4. Appliance Price Deflators. Another new feature is the ability to adjust the real purchase price of equipment each year of the forecast. Changes in the real price per unit may occur as technologies for the manufacture of a product evolve, or as economies of scale are realized. Different changes in the real price over time may be applied to different products and fuel types.

5. Explicit treatment of heat pumps. The old model subsumed heat pumps under electric central space heating and central air conditioning. The market shares of heat pumps were determined indirectly, using an old formulation to forecast the saturation of electric central space heating systems. The model has been revised to consider heat pumps as an explicit technology option for heating and cooling, and the new market share elasticities are under development.

6. Distribution of efficiencies. Early analyses of appliance efficiency standards assumed the 1978 distribution (number of shipments in each range of efficiencies) to be static for all time. In the LBL model, the 1978 distribution of efficiencies is moved each year in the standards case so that the average efficiency agrees with the base case projection. The new method has the advantages that: 1) the distribution of efficiencies changes in a way consistent with the change in the average efficiency; 2) the efficiency level in the standards case is a function of the standard level and a distribution that changes (toward more efficient products) over time; 3) standards can be applied to individual classes of appliances.

7. Graphical output. We added the capability of obtaining graphical output for most of the key outputs. The pictorial presentation, as opposed to tabular, facilities analysis of large amounts of data, and is particularly useful when analyzing trends over time or the difference between two scenarios.

4.2.2 Update of the Commercial Energy Model

The Commercial Sector Energy Model was developed by Oak Ridge National Laboratory in 1977-78 to predict energy consumption by end use in the the commercial sector. The model has been used by BCS and others within DOE in evaluating various energy conservation policy options, including building standards, Federal Conservation Grant programs, energy conservation building standards, increased building shell and equipment R&D funding, and end use alterations resulting from changes in fuel prices.

In 1984 Pacific Northwest Laboratory began a major project to update the model's data base, using information available from a number of sources including 1) the 1979 EIA Nonresidential Building Energy Consumption Survey (NBECS), 2) DOE 2.1 simulations performed to support the update of the ASHRAE Commercial Building Standards, 3) DOE 2.1 simulations run to study the energy impacts of commercial retrofits for DOE's Office of Policy, Planning and Analysis, 4) California Energy Commission's 1978 survey, and 5) metered end use data for a small sample of restaurants gained through a joint DOE-National Restaurant Association project.

The use of this data provided information to determine, 1) share of floorspace served by specific end use and fuel type for each commercial sector, 2) energy consumption per square foot by end use, fuel type and sector, and 3) floorspace stocks by building type and vintage. These estimates were derived for twelve building types, eight end uses and three fuel types.

In the development of floorspace fractions, three end-uses were assumed to have 100 percent floorspace saturations: ventilation, lighting, and miscellaneous electric. Floorspace saturations for refrigeration were assumed to be the same as those reported by the California Energy Commission from its 1978 survey results. The remaining floorspace fractions were derived from information contained in the NBECS survey. These estimates are based upon an algorithm that determines the proportion of the building stock in each sector which has a specific end use present and which fuel combinations are used for each end use.

Energy Use Indexes (EUI) are based upon several sources listed previously. Of the twelve commercial sectors, restaurant EUI's represent the only estimates that are based upon metered data. The remaining estimates were derived from a series of DOE 2 simulation runs and the ASHRAE standards work carried on at PNL. All of the EUI's were then calibrated to match aggregate energy use by fuel type contained in the NBECS survey.

From analysis of the NBECS data set, energy use per square foot varies widely from building to building. Thus, in a number of cases, the building specifications used in the available DOE 2 simulation runs show total energy intensities (total site Btu/sq.ft) that differ sharply from the "mean" intensity computed from NBECS. For restaurants, metered data was gathered from seven apparently typical fast food and full service restaurants in the mid-Atlantic region. Even here, however, the intensity of this (admittedly small) sample was about double that of the national average from NBECS. Work is continuing to attempt to reconcile the differences between the engineering and statistical-based information.

Work was also undertaken to revise the floorspace estimates by building type. The 1979 EIA survey revealed substantially more commercial floorspace in the U.S. than estimated by previous studies; approximately 40 percent higher than the figure used in the original end-use model. For the 12 building types, there was an estimated 43 billion square feet of floorspace in the U.S. in 1979. Floorspace additions from the original model database, based on information from F. W. Dodge, were adjusted to match the estimates by vintage (pre-1920, 1921-45, 1946-1960, 1961-1970, 1971-1973, and 1974-1979), reported by EIA in the 1979 survey. These adjustments were predicated on the type of floorspace depreciation (i.e. building demolitions) function used in the original ORNL model, a logistic function with a 60-year half life. The 1983 NBECS will provide more direct evidence on the magnitude and shape of the floorspace depreciation function. This information will be incorporated into the model as soon as it becomes available, now scheduled for late 1985.

The update work is incorporated in the BCS Disaggregate Forecast of commercial energy consumption presented in Section 3 of this report.

4.3 Impact Analysis

4.3.1 Economic Analysis of the Federal Commercial Building Standard

The Federal Commercial Building Energy Conservation Standard, currently being promulgated by DOE under legislative mandate, has been under development since the late 1970's. Legislative changes since the 1976 Energy Conservation Standards for New Buildings Act have altered the focus of the standards program and the research that supports it. In its most recent version, the standard has been developed in conjunction with ASHRAE's (American Society of Heating, Refrigeration and Air Conditioning Engineers) revision of Standard 90A, that applies to all new commercial buildings.

Analysis of the proposed standard conducted at Pacific Northwest Laboratory included an examination of the separate components of commercial buildings -- shell efficiency, lighting, glazing, HVAC systems, etc. -- to determine what changes would both improve energy efficiency and be cost effective. The analysis was conducted for ten different commercial building types at eight different locations around the U.S. The energy performance of each of the commercial buildings was simulated for a variety of components. Based on this simulation, the life-cycle cost of the building was calculated. Configurations with the lowest life-cycle costs were then analyzed for energy savings and net benefits were calculated by comparing them to current practice. An unexpected result of this analysis was the finding that improving the shell efficiency of the building allows the downsizing of HVAC equipment in most cases, thus reducing equipment costs enough to offset the increased costs of improving shell efficiency.

When the building analysis was completed, an economic analysis was undertaken to determine the effect of imposing the commercial building standard on all new Federal construction. This was done by first identifying five of the sites as representative of different regions of the country. Then regional forecasts of commercial building construction were used to determine the amount of Federal construction that would be undertaken for each of the building types in each region. These construction forecasts were used to weigh the annual life-cycle capital and operations and maintenance costs and fuel savings for each buildng type to arrive at a national estimate of the costs and benefits of imposing the standard. The net benefits were then discounted over the life of the buildings to arrive at an estimate of the total impact of imposing the standard. The results indicated that total benefits would amount to \$165 million, of which \$142 million is fuel savings and \$23 million is from reduced operating and capital expenses.

This measure of the total impact of imposing the standard was then used as input into a macroeconomic model of the U.S. economy to determine the major economic effects of imposing the standard. This analysis indicated that on no industry was the effect as much as one-tenth of one percent, measured in terms of output changes. At the national level, the measured effects were even smaller on a percentage basis. Similarly, employment effects were too small to be significant, although the model indicated that employment might rise slightly. These results were obtained even though the analysis was slanted to exaggerate the effect of imposing the standard, by assuming that the discounted effect of the standard applied in a single year.

After the analysis was conducted, the standard was modified by ASHRAE and subsequently was incorporated into the standard being promulgated by DOE. Although the current verison of the standard is quite different from the one analyzed, the effect on energy consumption is very similar. Energy consumption is reduced by 10-25 percent, depending on the building type and location. The unexpected consequences of the earlier version of the standard -- tightening the envelope allowed down sizing of the HVAC equipment, thus offsetting the increased capital cost of the tighter envelope -- still holds. In simulating the energy savings of applying the standard to different buildings, the energy savings will be somewhat different, as will be the costs. Preliminary simulations indicate, however, that the net benefit will be of the same order of magnitude as from those analyzed earlier.

In summary, the proposed standard is estimated to provide net benefits to the nation on the order of several hundred million dollars. In terms of conventional economic indicators, such as GNP, price level, and employment, the economic impacts are so small as to be insignificant.

4.3.2 Appliance Standards Analysis

Background

The Lawrence Berkeley Laboratory (LBL) is managing the federal effort to analyze the impacts of appliance energy efficiency standards. The analysis is required by Congressional legislation, which mandates both the establishment of appliance standards and an update of the efficiency standards within five years of initial promulgation and periodically thereafter.

The significance of appliance standards from a national perspective is twofold: (1) standards are one of the few federal policies that have the potential to increase energy efficiency in buildings, and (2) standards cover products that include residential heating and cooling equipment which account for almost 30% of U.S. buildings sector energy demand.

LBL has convened a review group, called the Appliance Standards Analysis Review Group (ASARG). ASARG has recommended a research agenda that will provide a thorough evaluation of the impacts of standards. Both the ASARG report and a multi-year research plan prepared by the LBL staff are available from LBL and DOE.

Recent Results

The analysis process has produced results in a variety of areas:

1. Overall Framework

The overall framework used in previous analyses of appliance efficiency standards appears adequate to the task; however, components of the analytic structure need major overhaul, and integration among the parts of the analysis needs to be strengthened. In particular, any new analysis should contain:

- an extension of the engineering analysis to include advanced designs of higher efficiency;
- a new approach to the assessment of manufacturer impacts that involves both the study of distribution of impacts throughout the industries and simulated business planning for selected "typical" firms;
- new data to assess consumer decision-making on appliance efficiency choice at the household level;
- assessment of effects of state, other federal (especially the Federal Trade Commission labeling program) and utility programs on appliance efficiency choice.

2. Engineering and Cost Analysis

The engineering analysis defines both cost and efficiency of appliances and heating and cooling equipment. This analysis thus provides the basic information about the maximum efficiency gains that can be achieved in products in the marketplace and the cost of the improved products.

Preliminary surveys suggest that the estimates of manufacturing cost of efficiency improvements obtained in the late 1970s approximate current costs (updated for inflation). However, for central air conditioners and heat pumps, data indicate that the markup in prices to the final consumer increases as the efficiency of the product increases. This higher markup serves as a barrier to the purchase of more efficient equipment, because of the relatively high incremental cost of the more efficient products. Further research is underway to determine the reasons for the increase in markup with efficiency for these two products and to investigate pricing policies for other products.

3. Market Behavior

The assessment of consumer behavior includes the study of factors influencing product and efficiency choice and usage of appliances and heating and cooling equipment. These are issues crucial to the assessment of appliance standards. If market forces alone serve to induce the manufacture and sale of efficient products, then efficiency standards are not needed. On the other hand, if significant imperfections in the market result in sales of inefficient products, federal standards provide one mechanism to increase efficiency. The analysis to date has dealt with market choice of energy efficiency in the aggregate (Ruderman, Levine and McMahon, 1984). The conclusions are:

- for all major appliances (except air conditioners), market forces lead to underinvestments in energy efficiency. (Investments in efficiency with a payoff in less than one year are foregone by most purchasers for amost all appliances);

- in spite of rising energy prices, greater consumer awareness of energy problems, and active state and utility programs to promote appliance efficiency, the analysis shows very little change in the market decision process (payback periods on energy efficiency are roughly constant, 1972-1981).

It has been suggested that consumers will increase their usage of efficient appliances so much that standards will fail to reduce energy demand. LBL has reviewed past studies of "usage" elasticities (Henly, Reid, and Ruderman, 1985) and has concluded that:

- most studies of the phenomenon use data of such low statistical reliability that it is impossible to determine whether the "usage" elasticity leads to a large, small or negligible effect;

- recent analyses show that the usage effect is likely to be relatively small (in the range of 3 to 25 percent).

Equipment choice is also an important determinant of residential energy use. Recent work has focused on the study of factors influencing the choice of residential heat pumps, a product that reduces energy use for space heating by 30-50 percent compared with most electric heating alternatives. Major conclusions to date are:

- heat pumps have captured about 50% of the electric heating market in new houses (25% of total market);

- this is surprising in light of unfavorable economics of heat pumps as compared to gas furnaces/central air conditioners.

The major reasons for the success of heat pumps in the market are the historical unavailability of natural gas, active utility marketing/preferential rates, and good marketing infrastructure among heating subcontractors and others. This means that a serious, complex effort is required to forecast heat pump sales.

4. Overall Impact Assessment

Appliance efficiency standards defined through previous analysis were set aside based on a U.S. Circuit Court of Appeals (District of Columbia) decision in July of 1985, which also mandated that new analysis of the proposed standards be performed. Analysis to comply with the Court of Appeals decision has been initiated but not completed; thus, it is not possible at this time to specify the total social benefits and costs of different levels and timing of standards. However, the previous analysis estimated that the net present value of the consumer benefits alone associated with the levels for appliance standards proposed by DOE in 1980 would total \$5 to \$10 billion (in 1985 dollars), and that the standards would reduce future energy demand growth in the residential sector. The products yielding the largest estimated benefits in energy savings from standards are water heaters, refrigerators, freezers, and central air conditioners. The benefits of standards on central air conditioners depends critically on the value of peak power, a factor that has not yet been completely assessed.

4.3.3 Impacts of Energy Conservation Programs on Electric Utilities

Background

Electric utilities have the potential to play a crucial role in promoting programs that encourage efficient use of energy in buildings. Electricity currently accounts for 60 percent of the total energy use in residential and commercial buildings, in terms of resource energy. The utility industry has a vast infrastructure for dealing directly with consumers of electricity.

The LBL program is designed to assess economic impacts of a variety of conservation programs on utilities and their customers. Because the evaluation methodologies of most utilities fail to account for the load shape impacts of end use conservation programs, the project has particularly emphasized load shape. The basic purpose is to carry the load shape research from the technical all the way to the economic and financial analysis. In this way, a more complete assessment of impacts of conservation programs can be achieved. The end result of the effort is the demonstration of conservation programs that can produce benefits not presently accounted for as a function of the energy supply, demand, and economic conditions of utilities. In this way, a larger segment of the utility industry may be able to perceive more accurately the impacts of conservation programs. The analysis approach also identifies those utilities for which selected or most conservation programs do not yield economic benefits.

The research is divided into three tasks: (1) overview of the electric utility industry, (2) development and testing of an hourly residential end use model, and (3) economic case studies of residential energy conservation programs.

Recent Results

The overview of the utility industry has gathered and interpreted statistical data for the 85 investor owned utilities (IOUs) that represent 90 percent of the sales by IOUs. The interpretation has focused on the development of indicators that relate to potential utility interest in energy conservation programs. The indicators include a variety of variables relating to (1) energy supply/demand balance and marginal costs of new supply, (2) ratemaking factors affecting the magnitude of revenue losses resulting from conservation programs, and (3) institutional factors, particularly the role of regulatory commissions and their decisions that affect risk and return on investments in new supply and end-use programs.

The findings of the analysis are still preliminary (Yen-Wood, Kahn, Chan, and Levine, 1985). The present interpretation of the indicators suggests that in the current environment somewhat more than 50% of IOUs (representing more than 50 percent of sales) have a significant incentive to pursue conservation programs. This percentage is likely to remain steady or to grow somewhat over the next ten years, although the specific utilities with incentives to promote conservation will change. Approximately 15 to 25 percent of IOUs by sales have strong disincentives to promote conservation programs, largely because of the availability of large amounts of power at marginal costs significantly below average costs. The remaining utilities have indicators showing mixed impacts of conservation programs; much more detailed analysis is needed to determine the types of conservation programs and the economic circumstances under which conservation policies make economic sense for them.

While these results are preliminary and subject to change as the data gathering and interpretation continue, they do tend to emphasize the importance of assisting selected utilities in developing and implementing conservation programs. With careful targeting, a DOE program to encourage utility conservation programs may increase the utility role in improving the energy efficiency of buildings.

The second task has involved development and testing of the LBL hourly demand model. The model is of particular importance, as the load shape impact plays a major role in determining economic impacts of conservation programs for many utilities. The major issue of the past year has been the accuracy of the load shape model in characterizing hourly residential loads of different utilities. The model was extensively tested against four years of residential hourly load data from the Detroit Edison Company (DECO). Very good agreement between model results and measured data were obtained (Verzhbinsky, Ruderman, and Levine, 1984). When the model was applied to the Pacific Gas and Electric Company (P.G.&E.) service area, significant discrepancies were observed between models results and measured data for air conditioner usage. Good agreement between model results and measured data was achieved by recognizing that the lower humidity in the P.G.&E. service area led to higher thermostat settings than assumed in the model (which was developed from hourly load profiles obtained in humid regions).

Thus, although further testing and additional hourly load data are needed, the hourly demand model appears to yield good estimates of the residential load shapes by end use.

The third task involves the detailed financial and economic analysis of impacts of conservation programs on specific utilities. Two utilities case studies have been completed, DECO and P.G.&E. (Kahn, Pignone, Eto, McMahon, and Levine, 1984). Three others (Virginia Electric Power Company, Nevada, and Texas Electric Utilities) are underway. The DECO results indicate that no conservation program is likely to be beneficial for DECO for many years, largely because of the availability of large amounts of low-cost power. Nonetheless, if DECO is to avoid a repeat of the serious financial problems of over-capacity, research on energy conservation programs can contribute significantly to better decisions affecting supply and demand in the future.

For P.G.&E. and its customers, a variety of (but not all) conservation programs yield beneficial impacts. Of particular interest is a program to promote high efficiency air conditioners. Such a program has very desirable load shape impacts and could yield a net present bvenefit to the utility and its consumers of several hundred million dollars. The analysis of the efficient air conditioner program demonstrated the critical role of load shape impacts of conservation programs. The air conditioner program exhibited a benefit twenty times as great per Btu saved as a program effecting no change in load shape.

Additional case studies will accomplish at least two objectives: (1) they will permit the generalization of results to a wide range of utilities in the nation, and (2) they will demonstrate the types of conservation programs that make the best economic sense for utilities and their customers facing different economic circumstances and having different physical environments.

4.3.4 R&D Project Appraisal

The Office of Buildings and Community Systems (BCS) is responsible for the conduct of R&D to improve scientific knowledge in the buildings sector. As in any dynamic environment, however, the changing state of technology, the level of public awareness, and changing economic conditions in the buildings sector necessitate ongoing assessment of public policy prescriptions. To meet this necessity and to fulfill its system analytic functions, BCS has conducted through Pacific Northwest Laboratory (PNL) an initial appraisal of its office-wide R&D projects. The project appraisal will help enable BCS to identify and select current and proposed projects that best contribute to fulfilling BCS's objectives, given the existing and projected buildings sector environment, and is a major component of research strategy development.

A methodological framework was developed to help ensure that the project level information obtained and subsequent information developed had a common base. The appraisal was conducted in four steps: the first step selected 69 projects for inclusion in the appraisal; the second step identified the criteria for the evaluation of individual projects; the third step developed and administered a questionnaire to obtain project level data from program managers; and the fourth step developed and applied methods and assumptions for calculating the energy impacts of the projects.

The result of the R&D project appraisal effort was a bottom-up approach to estimating energy savings for all of the projects in BCS by identifying the relevant market for improved technologies developed by BCS, the likely penetration the technologies would obtain, and the likely per unit energy savings expected from the R&D. Energy savings estimates were developed for the year 2000, as well as cumulative savings from the time of market entry to the year 2000. The Federal cost to achieve these savings was also estimated, and qualitative factors such as the likelihood of success of the projects and the level of barriers to commercialization of the projects were evaluated.

The project appraisal effort represents a major achievement in collecting detailed information for specific projects and research activities within BCS. It is particularly significant that the information collected and the energy savings estimates developed were done in a consistent framework in order to facilitate comparisons across projects. Previous efforts in this regard did not adequately relate cost and savings estimates to specific projects. The impacts of generic technologies were estimated through the use of simulation models, but project managers could not measure the effects that any particular project or groups of projects had on the total estimated impact.

The availability to project managers of the type of data collected for the project appraisal will better enable them to assess the relative merits among their own projects as well as among all other BCS projects. This type of assessment can facilitate changes in research direction in response to changing technology or market conditions, improving the benefits to be gained from the expenditure of Federal dollars. It also allows project managers to identify areas of synergy within the BCS portfolio of R&D projects. Designing

R&D projects that support or cooperate with other R&D projects in BCS also increases the benefits to be gained from a given expenditure of funds.

☆U.S. GOVERNMENT PRINTING OFFICE: 1986-461-208:20249