Chapter 1

Energy Use in Buildings: Past, Present, and Future

Box I-A--Chapter Summary

Energy issues are of continuing policy concern, due to the crucial role played by energy in environmental quality, economic vitality, and national security. In recent reports OTA has suggested that energy efficiency is a critical component of a comprehensive policy framework to further these issues. This report addresses energy use and efficiency in U.S. buildings, which account for over one-third of U.S. energy consumption.

Energy use in buildings has grown in the last 20 years. Sheer increases in numbers underlie much of this growth-more people, more households, and more oftices. Increased service demand—--more air conditioning, more computers, larger houses----has contributed as well. However the application of improved technology has moderated this growth. Energy efficient building shells, appliances, and building designs have lowered energy intensity in residences (energy use per household per year) and stabilized energy intensity in the commercial sector (energy use per square foot per year).

Building energy use in the future will be driven by technological change but will be influenced by other factors as well, including population and economic growth, changes in household six, changes in lifestyle, and migration patterns. The complexity and interactions of these factors make it difficult to predict accurately future levels of building energy use, however OTA estimates that, in a "business-as-usual" scenario (that is, assuming no policy change), building energy use will continue to grow at a moderate pace, reaching roughly 42 quads by 2015. An alternative perspective, assuming all energy efficient technologies with a positive net present value to the consumer are implemented, suggests that building energy use could actually decrease to 28 quads by 2015. Although predicted savings estimates are extremely uncertain, there is general agreement that the technical and economic potential for savings is considerable.

Contents

Boxes

Chapter 1

Energy Use in Buildings: Past, Present, and Future

INTRODUCTION: THE POLICY CONTEXT

Recent events have once again brought energy issues to the forefront of national policy debate. In 1991 the Persian Gulf War and its effects on world oil markets seized world attention. The same year, the administration released a National Energy Strategy,[1] and numerous legislative options are being considered by Congress in its wake. This renewed interest in energy, however, is different from the prevailing concerns of the 1970s when fears about oil price and availability were triggered by the major oil supply disruptions of 1973 and 1979.

In the 1990s, concerns about U.S. energy production and use are broader, longer term, and more complex.[2] In 1990, prior to the Persian Gulf War, pressing energy concerns related to environmental quality-including regional issues of urban air quality, acid rain, and nuclear waste, as well as global issues such as the role of fossil fuels in climate change. Indeed, the Clean Air Act Amendments of 1990 are among the most significant energy-related national legislation in recent years.

The Persian Gulf War returned energy security to the national policy agenda after a decade of absence, but even the nature of energy security concerns has changed.[3] Concerns about U.S. reliance on imported oil, which has risen steadily from 22 percent of total oil use in 1970 to 42 percent in 1990 and is expected to rise to 62 percent by2010,4 has as much to do with the role of oil imports in the U.S. trade deficit as with the concerns over supply reliability or price volatility.

The role of energy in economic production is also changing as the structure of the U.S. economy changes. For many years, the conventional wisdom held that energy use and gross domestic product (GDP) were immutably linked, moving in lock step. We learned from the energy shocks of the 1970s, however, that ingenuity and innovation can substitute for energy supply when the price is right. When energy prices rise, people respond over time by shifting their market basket of purchases and by developing more efficient ways to provide energy services. The energy consumed per unit of GDP fell 2,4 percent per year between 1972 and 1985, mostly due to improved energy efficiency (figure 1-1).[5] This steady drop in energy intensity also reflects changing patterns of consumer demand, a shifting balance of imports and exports for both energy and nonenergy goods, and a changing market basket of goods produced and consumed in the United States.

Understanding these trends is essential to grasp the complex interdependence of energy with broader national issues of economic vitality, national security, and environmental quality.[6] Indeed, a critical lesson of the 1970s and 1980s is that energy policy must integrate with these three *issues,* and in recent reports OTA has suggested several policy goals that address these issues, including limiting oil import dependence, improving international competitiveness of U.S. goods and services, and addressing both

[1] U.S. Department of Energy, *National Energy Strategy: Powerful Ideas for America,* 1st ed. (Washington, DC: February 1991).

[2] The changing nature of U.S. energy policy concerns is addressed in U.S. Congress, Office of Technology Assessment, *Energy Technology Choices: Shaping Our Future,* OTA-E-493 (Washington DC: U.S. Government Printing Office, July 1991).

[3] Energy security and oil import issues are addressed in U.S. Congress, Office of Technology Assessment, *U.S. Oil Import Vulnerability:* The *Technical* Replacement *Potential*, OTA-E-503 (Washington, DC: U.S. Government Printing Office, October 1991).

[4] Data arc total net imports of petroleum as a percent of total U.S. consumption. Historical data from U.S. Department of Energy, Energy Information Administration *Annual Energy Review 1990, DOE/EIA-0384(90)* (Washington, DC: May 1991), p. 129. Forecast from U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1992, DOE/EIA-0383(92)* (Washington, DC: January 1992), p. 3, reference case.

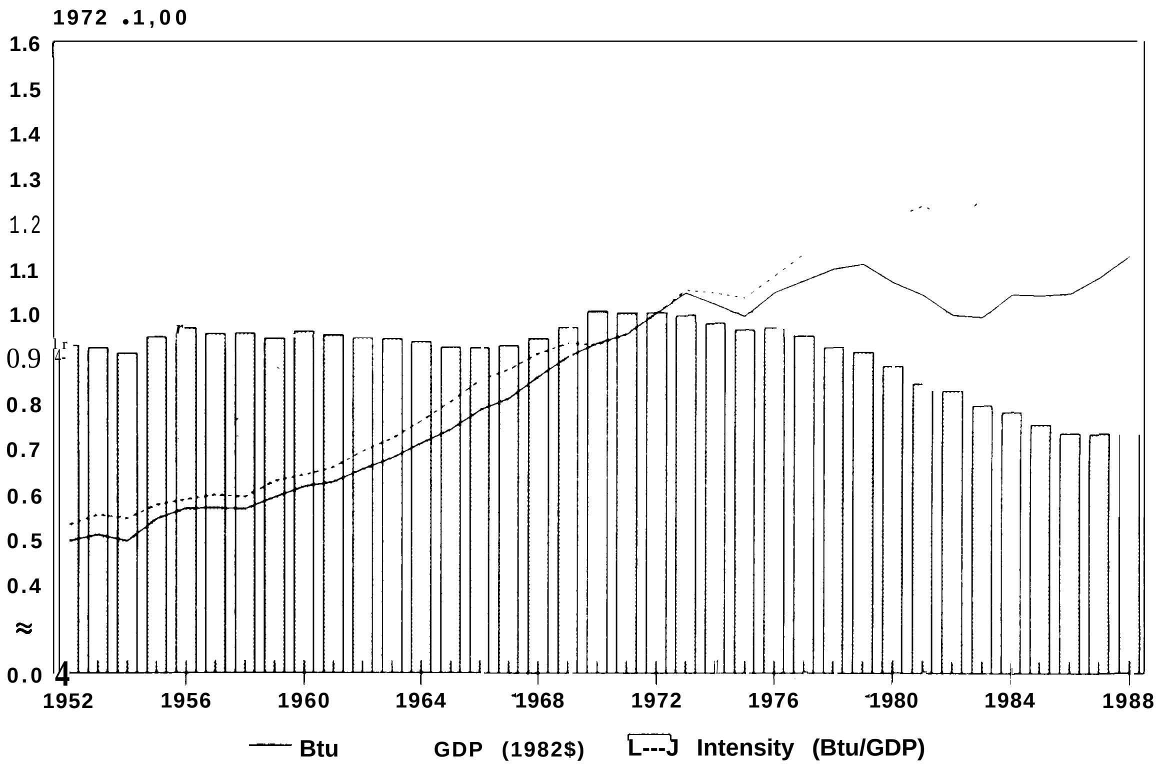
[5] About two-thirds of the reduction in energy use per unit of GDP was due to energy efficiency improvements, and the remaining one-third was due to structural changes in the economy. U.S. Congress, Office of Technology Assessment, Energy *Use and the U.S. Economy*, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

6 These relationships arc discussed in more depth in John H. Gibbons, Director, U.S. Congress, Office Of Technology Assessment, "Energy Policy Context for the 1990s: Considerations for a National Energy Strategy, ' testimony before the House Committee on Energy and Commerce, Subcommittee on Energy and Power, Feb. 20, 1991; and Peter D. Blair, Program Manager, Energy and Materials Program, Office of Technology Assessment, "Considerations for National Energy Policy, " testimony before the House Committee on Banking, Finance, and Urban Affairs, Subcommittee on Economic Stabilization, Oct. 17, 1991.

local and global environmental concerns.[7] In virtually all of this work, energy efficiency is shown to be a critical component of a comprehensive policy to further these goals and is a focus of this report.[8]

This report addresses energy use and efficiency in U.S. buildings. Energy use in buildings accounts for an increasing share of total U.S. energy consumption: 27 percent in 1950, 33 percent in 1970, and 36 percent in 1990.[9] At present, buildings account for over 60 percent of all electricity used in the United States and almost 40 percent of all natural gas.[10] Other OTA reports, recently completed or in preparation, address energy use and efficiency in

Figure I-I—Index of U.S. Energy Use, Gross Domestic Product (GDP), and Energy Intensity



Energy use (Btu) and economic growth (GDP) grew in parallel from 1952 to 1971, causing the energy intensit y (Btu/GDP) to be relatively flat. After 1971, GDP continued to grow, but energy use stayed relatively constant, resulting in a decline in the energy intensity until 1986. Due to an increase in energy use after 1985, the energy intensity stayed level from 1986 to 1988.

SOURCE: U.S. Congress, Office of Technology Assessment, Energy *Use and the U.S.* Economy, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990), p. 2.

7 These policy goals are addressed in more detail in U.S. Congress, Office of Technology Assessment *U.S. Oil Import Vulnerability: The Technical Replacement Potential,* OTA-E-503 *(Washington* DC: U.S. Government Printing Office, October 1991); and U.S. Congress, Office of Technology Assessment *Energy Technology Choices: Shaping Our Future, OTA-E-493 (Washington DC:* U.S. Government Printing Office, July 1991).

8 The goal of improving energy efficiency stems in part from a recognition that energy is used not for its own sake but to supply energy "services" (e.g., lighting, heating, and transportation). Thinking in terms of energy services, rather than only energy supplies, provides a context for understanding the appropriate role of energy efficiency, as efficiency may be able to supply the needed services at a lower economic and environmental cost.

9 Industry (37 percent) and transportation (27 percent) account for the rest. Data include energy losses in the conversion and transmission of electricity. U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990,* DOE/EIA-0384(90) *(Washington DC: May 1991),* p. 13.

10 Ibid., pp. 173, 215.

other sectors of the economy, including the Federal Government,[11] industry, transportation, and the role of electric and gas utilities in efficiency .12

A recent OTA study has shown that the use of cost-effective, commercially available technologies could reduce total building energy use by about one-third by 2015, relative to a' 'business-as-usual' baseline .13 The use of these technologies would save money and in addition would reduce the environmental damage associated with energy production. However, the buildings sector presents some distinct policy challenges for capturing these savings. For example, buildings in the United States are technically complex; the building industry is decentralized and fragmented; and buildings are subject to a mix of Federal, State, and local requirements that can frustrate or even discourage improvements in energy efficiency. The nature of buildings, with occupants that are often not owners, creates market imperfections that can be difficult to overcome. Finally, past Federal efforts to improve building energy efficiency have a mixed record, and tools for measurement and evaluation of energy savings are imperfect.

This report assesses technologies for improving energy efficiency in buildings, discusses why these technologies are not widely used, and offers policy options for encouraging their use. Several questions are explored:

- How much energy could be saved through the use of energy efficient technologies? (chapter 1)
- What specific technologies are available, and what are their cost and performance characteristics? (chapter 2)
- What prevents the widespread use of these technologies? (chapter 3)
- What policies have been used in the past to encourage efficiency, and how well have they worked? (chapter 4)
- What policy options are available to the U.S. Congress to encourage greater energy efficiency? (chapter 5)

The remainder of this chapter discusses recent trends in building energy use and the factors affecting this use. The future of energy use in buildings is then discussed from two perspectives: the likely future of building energy use, and what that future could be if energy efficient technologies were used more widely.

ENERGY TRENDS AND CHANGES SINCE 1970

Energy use in U.S. buildings has increased steadily-from about 22 quadrillion British thermal units (quads) in 1970 to about 30 quads in 1989.[14] Several factors have contributed to this growth, while others have acted to constrain it. Understanding these factors illuminates the role of technology in building energy use. (These factors also provide some insight into the efficiency of U.S. buildings relative to other countries-see box l-B.)

The Residential Sector

In 1989, residential buildings used 16.8 quads of energy at a cost of $104 billion dollars[15]-the majority in the form of electricity, followed by natural gas and oil. Space heating is responsible for almost half of total energy use, followed by water heating, refrigerators and freezers, space cooling, and lights (figure 1-2). In the last 20 years, residential energy use increased at an average annual rate of about 1.2 percent (figure 1-3). More recently (1985-89), this growth accelerated to an annual average rate of 2.1 percent. The major factors contributing to this growth include a growing population, shrinking household size (people per household) leading to a greater number of households, and increasing demand for energy-intensive services such as air conditioning (table l-l).

11 U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government by Good Example?, OTA-E-492* (Washington, DC: U.S. Government Printing Office, February 1991).

12 Reports covering these other sectors are forthcoming.

13 U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991). This and other estimates of the savings potential are discussed in detail in this chapter.

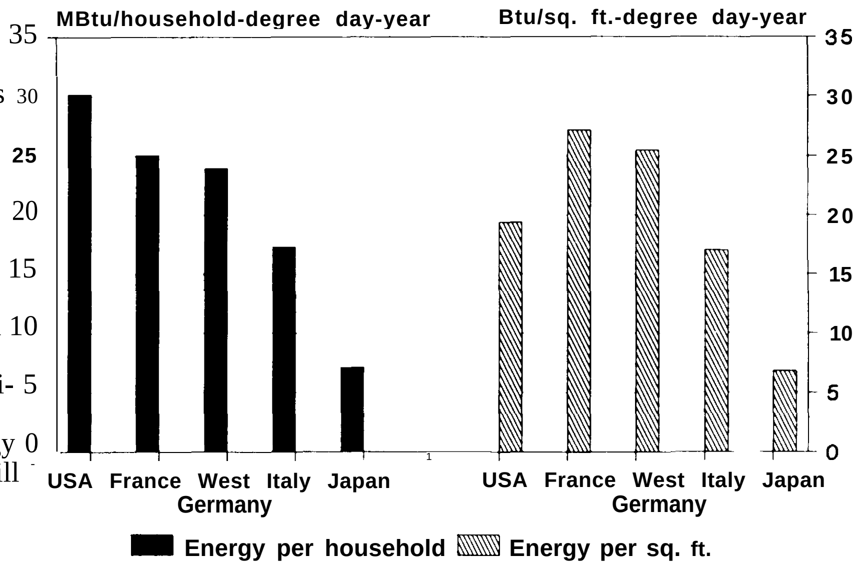
14 Source is OTA 1992, see app. 1-B. A quad is 10^{15} Btus, worth about $5.7 billion at today's prices for energy used in buildings.

15 Source is OTA 1992, see app. 1-B. This includes energy used for space heating, space cooling, hot water heating, arid various appliances, but excludes energy used for transportation. Throughout this report, electricity is converted to energy (Btu) units using a primary conversion factor that includes generation losses. See app. 2-C for a discussion of energy conversion issues.

Box 1-B—International Comparisons of Energy Efficiency in Buildings

International comparisons of energy use can be a useful way to *examine* energy use and energy efficiency, however care must be taken to-consider all the factors that might account for differences among countries. In the residential sector, for example, climate, household size, floor space, indoor temperature, and appliance saturation can all be as or more important in determining total household energy use than the thermal properties of homes or the efficiencies of their appliances.[1] As a result, simply calculating the average household energy use among different nations will not always provide a useful measure of relative efficiency.

Figure 1-B-1—Residential Energy Use in Five Countries



The bars on the left show residential energy use per household, while the bars on the right show residential energy use per square foot of living space. The effects of climatic differences have been removed.

NOTE: Includes losses associated with electricity generation.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Indicators of Energy Efficiency: An International Comparison,* SR/EMEU/90-02 (Washington, DC: July 1990), pp. 11-12.

A simple example illustrates this point. After adjusting for climatic differences, consumption data indicate that the United States uses more energy per household than France, Germany, Italy, or Japan (see figure 1-B-1), which-might at first glance suggest that U.S. households are less efficient. However, energy use *per unit of floor space in the* United States is actually lower than in France or Germany (see figure 1-B-1).[2] And although Italy and Japan use less energy per unit of residential floor space than the United States, these countries generally have lower indoor temperatures and use central heating less than the United States,[3] factors that may account for most of the differing consumption levels.

As this example suggests, international comparisons of energy efficiency should be viewed with caution and, where possible, the variables and assumptions underlying such comparisons should be understood. Differences may indeed stem from differing energy efficiencies but may also be related to temperature settings, appliance saturation, and other, nontechnical factors that influence energy use.

1 See L. Schipper, A. Ketoff, and A. Kahane, "Explaining Residential Energy Use by International Bottom-Up Comparisons," *Annual Review of Energy 1985* (Palo Alto, CA: Annual Reviews, Inc., 1985), vol. 10, pp. 341405.

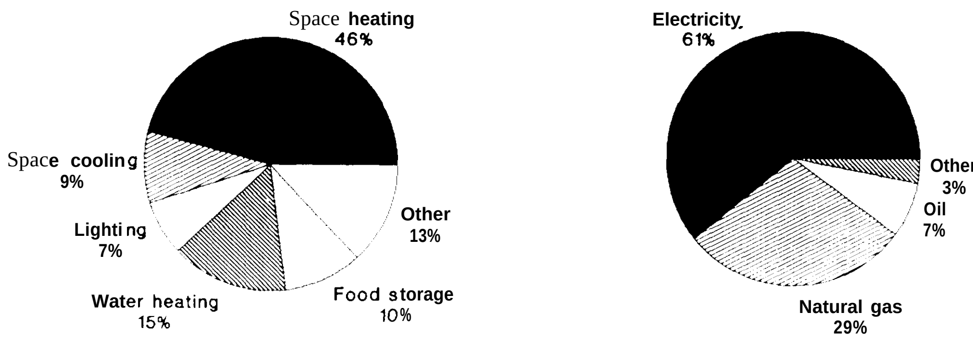
2 U.S. Department of Energy, Energy Information Administration, *Indicators of Energy Efficiency: An International Comparison* SR/EMEU/90-02 (Washington, DC: July 1990), pp. 11-12.

3 L. Schipper, A. Ketoff, and A. Kahane, "Explaining Residential Energy Use by International Bottom-Up Comparisons," *Annual Review of Energy 1985 (Palo* Alto, CA: Annual Reviews, Inc., 1985), vol. 10, pp. 352-353.

The U.S. population increased by 45 million people from 1970 to 1990.[16] At the same time the average number of people per household dropped considerably, from 3.24 in 1970 to 2.68 in 1990 (figure 1-4). The combined effect of these two factors was an almost 50 percent increase in the number of households in just two decades. As each household requires space conditioning, hot water, and other energy services, these changes drove the growth in energy use in the residential sector.

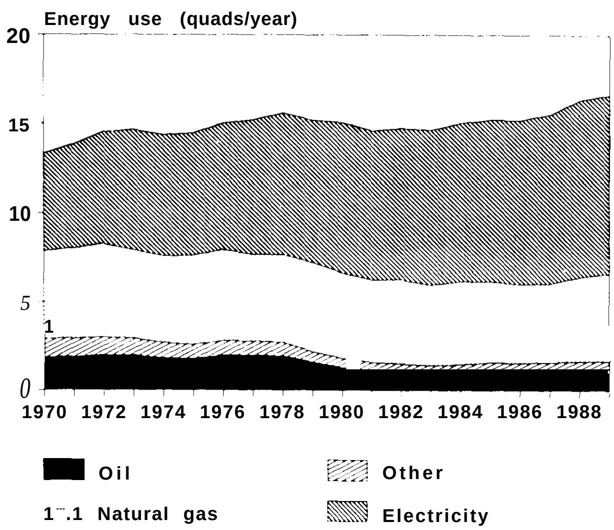
16 U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1991* (Washington, DC: 1991), p. 7.

Figure 1-2—Residential Sector Energy Use by End Use and Fuel Type, 1988



NOTE: Includes energy losses associated with electricity generation (see app. 2-C).
SOURCE: Office of Technology Assessment, 1992 (see app. I-B).

Figure 1-3—Residential Sector Energy Use by Fuel Type, 1970-89



NOTE: Includes energy losses associated with electricity generation (see app, 2-C).
SOURCE: U.S. Department of Energy, Energy Information Administration, *State* Energy Data Report: Consumption Estimates, 1960-1989, DOE/EIA-0214(89) (Washington, DC: May 1991), p. 24.

Table I-I—Major Factors Influencing Residential Energy Use

Factors causing an *increase* in consumption:
Larger population—more households
Fewer people per household-more households
Increased demand for energy-intensive services
Factors causing a *decrease* in consumption:
New housing more efficient than existing stock
New appliances more efficient than existing stock
Retrofits to existing housing
Migration to the South and West
More multifamily units
Factors causing fluctuations in consumption:
Occupant behavior, changes in thermostat settings
Fuel shifts-more electricity and less oil, changes in wood use
Price changes

SOURCE: Office of Technology Assessment, 1992.

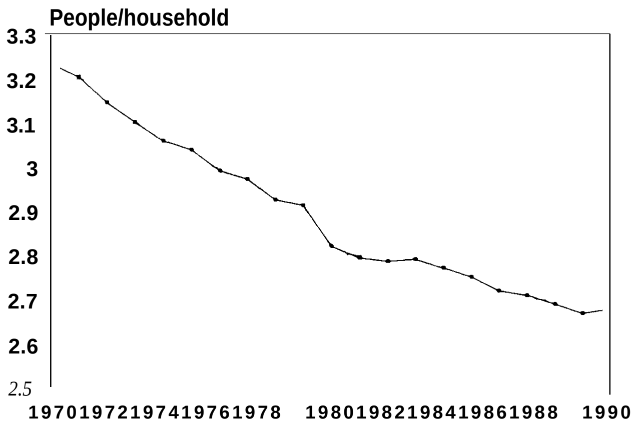
Increased demand for particular energy-intensive services also contributed to the growth in residential energy use. The popularity of central air conditioning has grown, and it is now routinely installed in over three-fourths of new single-family homes.[17] Increasing market penetration of energy-intensive appliances such as clothes dryers is also contributing to increased energy use.[18] And there is some evidence that residences are becoming larger as well, requiring more energy for space heating and cooling.[19] At present almost all households have space heating of *some* kind, water heating, and at least one refrigerator. Over 90 percent of existing households have color TVs, about three-fourths have clothes washers, about two-thirds have clothes

17 In 1970 about one-third of new single-family homes had central air conditioning; by 1990 this figure reached 76 percent. Pacific Northwest Laboratory, *Residential and Commercial Data Book—Third Edition*, PNL-6454 (Richland, WA: February 1988), p. 3.28; U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990*, C25-9013 (Washington, DC: June 1991), p. 4.

18 In 1982 60 percent of households had clothes dryers; by 1987 this had climbed to 66 percent. US. Department of Energy, Energy Information Administration, *Housing Characteristics 1982*, DOE/EIA-0314(82) (Washington, DC: August 1984), p. 69; U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87) (Washington DC: May 1989), p. 83.

19 The average new single-family house in 1986 had 1,825 square feet of floor space, by 1990 this was up to 2,080 square feet. The same trend occurred in new multifamily units as well—from an average of 911 square feet of floor space in 1986 to 1,005 square feet in 1990. U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990*, C25-9013 (Washington, DC: June 1991), pp. 33,40.

Figure 1-4--Changes in Household Size, 1970-90

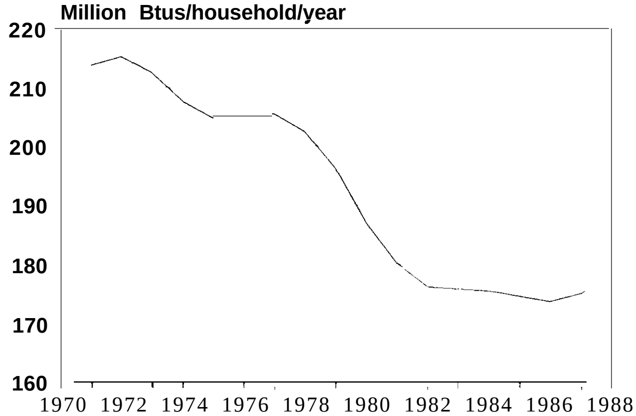


From 1970 to 1990the average household size dropped from 3.24 people to 2.68 people.

NOTE: Y-axis not set to zero.

SOURCE: Office of Technology Assessment, 1992 (see app. I-B).

Figure 1-5-Energy Use Per Household Dropped From 1970 to 1985, But Increased From 1985 to 1988.



NOTE: Three-year moving average shown. Y-axis not set to zero. Includes energy losses associated with electricity generation (see app. 2-C).

SOURCE: Office of Technology Assessment, 1992 (see app. I-B).

dryers, and about one-third have central air conditioning.[20]

Although total residential energy use increased from 1970 to 1989, energy intensity-energy consumption per household per year-actually *decreased by 15* percent in the same period (figure 1-5). Several factors contributed to this intensity drop, but improved technology and building practices were key: older houses were retrofit to improve energy efficiency, newer houses make greater use of energy-efficient building practices, and the energy efficiency of equipment in homes has improved dramatically.

Considerable effort has been made to improve the energy efficiency of the existing building stock. National retrofit data are scarce but, by one estimate, from 1983 to 1988 about 26 million owner-occupied U.S. households added storm windows and/or doors, and 17 million added insulation.[21] Careful evaluations of retrofit efforts have shown that energy savings are often substantial.[22] New houses benefited from greater use of energy efficient techniques. For example, new houses built in 1985 were better

Table 1-2-Changes in Construction Practices for New Single-Family Detached Homes

	1973	1985
Average R-value[a] of insulation		
Ceiling	14.4	26.9
Exterior Wall	10.0	12.5
Floor	4.0	10.2
Window type (percent)		
Single-pane	60	19
Double- or triple-pane	40	81

[a] R.value is a measure of resistance to heat flow. A higher R-value means a better insulating value,

SOURCE: Adapted from S. Meyers, "Energy Consumption and Structure of the U.S Residential Sector: Changes Between 1970 and 1985," *Annual Review of Energy* 1987 (Palo Alto, CA: Annual Reviews, Inc., 1987), vol. 12, p. 90.

insulated and had more energy efficient windows than those built in 1973 (table 1-2).

Residential equipment is now more energy efficient as well. The typical new gas furnace sold in 1975 had an efficiency of 63 percent; by 1988, this increased to 75 percent. The efficiency gains in appliances were even greater-the typical new

20 u.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87) (Washington, DC: May 1989), pp. 77-79, 83. As noted previously, however, over three-fourths of new single-family homes have central air conditioning.

21 U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for t& United States in 1985*, H-150-85 (Washington, DC: December 1988), p. 98; U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in 1987, H-150-87* (Washington, DC: December 1989), p. 120; U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in 1989,* H150/89 (Washington DC: July 1991), p. 122.

22 See, for example, S. Cohen, C. Goldman, and J. Harris, *Measured Energy Savings and Economics of Retrofitting Existing Single-Family Homes: An Update of the BECA-B Database*, LBL-28147 (Berkeley, CA: Lawrence Berkeley Laboratories, February 1991), vol. 1.

Table 1-3-New and Existing Housing Types

Structure	Percent of existing households, 1987	Percent of new units started, 1988a
Single-family detached	62	
Single-family attached	5	(include~~above)
Multifamily: 2 to 4 units	11	3
Multifamily: 5+ units	16	18
Manufactured (mobile) home	6	15

ªPrivately owned only.

NOTE: Mobile home data are "placed for use."

SOURCES: Existing: U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in 1989*, H-1 50/89 (Washington, DC: July 1991), p, 34. New: U.S. Department of Commerce, Bureau of the Census, Statistical *Abstract of the United States: 1991* (Washington, DC: 1991), pp. 720, 722.

refrigerator sold in 1990 used less than half as much electricity as a comparable unit sold in 1972.[23]

Other factors acted to dampen total energy demand in residences, although their effects were minor. There was a slight shift in the types of homes—the share of single-family homes in the United States shrank slightly from 68.7 percent in 1982 to 66.5 percent in 1987.[24] This means slightly lower heating and cooling requirements, as multifamily units have fewer exterior walls. However, single-family detached homes remain the most common type of housing unit (table 1-3). There has been a slight migration to the South and West in recent years,[25] which has probably decreased space heating needs and increased space cooling needs. The overall effect of this migration is thought to be a small net decrease in energy use.[26]

Several other factors affected residential energy use, although the direction of their effect was either unclear or variable in recent years. Examples include occupant behavior, shifts in fuel types, and energy prices.

The behavior of building occupants can significantly influence energy use. One measure of behavior in residences is the thermostat setting. There is some evidence that heating thermostat settings decreased from 1973 to 1981, increased slightly to 1982, were flat from 1982 to 1984, and then increased again from 1984 to 1987.[27] The impacts of these shifts on energy use are difficult to determine, but higher heating thermostat settings clearly mean more energy for space heating, all else being equal. Broader behavioral factors, such as the fraction of time spent on leisure activities, the trend toward two-career families, and economic shifts from manufacturing to service, may have affected energy use in buildings as well (box 1-C).[28]

The fuel mix of residential energy use has changed as well. Electricity has become increasingly prevalent for both space and water heating, while oil's share of the space heating market has dropped sharply.[29] In 1970, electricity supplied 41 percent of residential energy; by 1988, this had climbed to 61 percent.[30] Yet this trend toward greater electrification maybe changing; electricity's share of the space heating market in new single-family homes dropped sharply in recent years, from 49 percent in 1985 to 33 percent in 1990. Natural gas' share jumped from

23 See ch. 2 for sources and definitions.

24 Includes single-family detached houses and mobile homes. U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1982*, DOE/EIA-0314(82) (Washington, DC: August 1984), p. 17; U.S. Department of Energy, Energy Information Administration *Housing Characteristics 2987,* DOE/EIA-0314(87) (Washington DC: May 1989), p. 18.

25 In 1970, 52 Percent of homes were in the Northeast and Midwest; by 1983 this had fallen to 47 percent. S. Meyers, "Energy Consumption and Structure of the U.S Residential Sector: Changes Between 1970 and 1985, " *Annual Review of Energy 1987* (Palo Alto, CA: Annual Reviews, Inc., 1987), vol. 12, p. 87.

26 L. Schipper, R. Howarth, and H. Geller, "United States Energy Use From 1973 to 1987: The Impacts of Improved Efficiency, " *Annual Review of Energy 1990* (Palo Alto, CA: Annual Reviews, Inc., 1990), vol. 15, p. 482.

27 S. Meyers,' 'Energy Consumption and Structure of the U.S. Residential Sector: Changes Between 1970 and 1985," *Annual Review of Energy 1987* (Palo Alto, CA: Annual Reviews, Inc., 1987), vol. 12, p. 92; U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987,* DOE/EIA-0314(87) (Washington DC: May 1989), p. 3.

28 These factors are discussed in U.S. Congress, office of Technology Assessment, Technology *and the American Economic Transition,* OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988); also L. Schipper, *Energy Use and Changing Lifestyles,* EPRI CU-7069 (Palo Alto, CA. Electric Power Research Institute, November 1990).

29 The efficiency implications of this shift depend on the technologies used to convert energy into heat. An electric heat pump, for example, is of comparable efficiency to an oil-fired furnace, if one accounts for electricity generation losses. An electric resistance heater, however, is much less efficient than an oil furnace, if one accounts for electricity generation losses.

30 Primary equivalent. Source is OTA 1992 (see app. 1-B).

Box I-C-Technology and Behavior: Effects on Building Energy Use

This assessment focuses on technical means to improve the efficiency of energy use in buildings. Technology, however, is not the only determinantt of building energy use. Human behavior-how people operate equipment, how many children they bear, where they reside, and so on-can strongly influence building energy use as well.

In recent years, there has been increased interest in learning how human variables affect energy use in buildings. A major stimulant of this interest was the emerging uncertainty in electrical utility planning. Whereas electricity demand had increased at a fairly steady 7 percent per year from 1950 to 1973, increased prices, appliance saturation, and other factors slowed this increase to 1 to 2 percent per year.[1] An annual rate of 1 to 2 percent represents a doubling time of anywhere from 70 to 35 years, and therefore considerably greater uncertainty than the decadal doubling rate of earlier years. With saturation, patterns of equipment use-rather than the steady growth of new demand introduced by their acquisition-became a primary factor in determining energy demand. And equipment use is a function of human behavior.

Human behavior can be studied on two significantly different levels: the observable behavior of people and the underlying values and attitudes that drive those behaviors. Our understanding of both is imperfect, as is our ability to predict exactly how and when they will change. It is difficult to quantify and compare the contributions of family size, time spent cooking, work habits, and the myriad other behaviors that jointly affect residential energy use. Nor can we predict when, and how strongly, people will be motivated to conserve or stop conserving energy in buildings, beyond the expectation that rather gross changes, such as a steep rise in energy prices, will significantly influence behavior. Despite our limited understanding, it is clear that human behavior and values contribute substantially to variations in building energy consumption. The following paragraphs provide supporting evidence.

Major influences on household energy use are family size, income, average length of daily occupancy, and whether both household heads are employed; all but the last of these influences tend to increase energy use.[2] Although larger families consume more residential energy than smaller ones, this relationship reverses when calculated on a per capita basis.[3] Other relevant factors are the ages of family members and whether or not there are children. Elderly singles, most of whom are not employed, tend to use more residential energy than younger singles, most of whom are employed and spend less time at home.[4]

One estimate of the importance of behavioral differences in residential energy use comes from a careful study that examined variation in winter natural gas consumption of 205 townhouses in Princeton, New Jersey. Physical features-such as the position of the townhouse (end or non-end unit), the number of bedrooms, and the amount of insulated glass-accounted for 54 percent of the variation in energy use. Differences in occupant behavior were associated with much of the remaining 46 percent variation.[5]

In the future, many factors will affect human behavior and its influence on energy demand in residential and commercial buildings. A number of demographic trends are expected to influence future demand but in uncertain ways. For example, the "graying" of the U.S. population will continue; the proportion of those older than 65 is projected to grow from about 12 percent today to about 20 percent by the year 2030.[6] However, the elderly of tomorrow may be different than the elderly of today in terms of health, activity levels, and other characteristics, which could substantially alter their influence on building energy demand.

---

1 L. Schipper, S. Bartlett, D. Hawk, and E. Vine, *Energy Use and Changing Lifestyles*, EPRI CU-7069 (Palo Alto, CA: Electric Power Research Institute, November 1990), p. 1-1.

2 P. Gladhart, B. Morrison, and B. Long, "HOW@@ Energy, " in P. Gladhart, B. Morrison, and J. Zuiches, *Energy and Families* (E. Lansing, MI: Michigan State University Press, 1987), p. 131.

3 L. Schipper, S. Bartlett, D. Hawk, and E. Vine, "Linking Life-Styles and Energy Use: A Matter of Time?' *Annual Review of Energy 1989*, (Palo Alto, CA: Annual Reviews, Inc., 1989), vol. 14, p. 304.

4 Ibid., p.305.

5 R, Socolow (editor), *Saving Energy in the Home: Princeton's Experiments at Twin Rivers* (Cambridge, MA: Ballinger Publishing Company, 1978), pp. 227-228.

6 Population Reference Bureau, *America in the 21st Century: Governance and Politics* (W-01+ DC: Population Reference Bureau, rnc., 1990), p. 3.

The number of households is growing faster than the U.S. population. Household growth is expected to continue to outpace population growth, although by a slower rate than before.[7] Thus, the trend toward smaller households is expected to continue, which in the past has been associated with increased per capita residential energy demand.

As a final example, changes in the ethnic composition of the U.S. population could affect residential and commercial building energy demand but the potential effect is unknown. Due to immigration and differential fertility, the proportion of minorities in the U.S. population has been increasing steadily. In 1980, *about* **20** *percent* of Americans were black Hispanic, or Asian. By 2030, these groups are projected to represent 38 percent of the U.S. population.[8]

The future contribution of behavioral and demographic variables on energy use is unclear. In the absence of better understanding, it maybe prudent for policies to focus on technology, where the links to energy use are better understood. Nevertheless, it is important to recognize that policies affecting behavioral and demographic variables (such as changes in the tax treatment of child care, which could change the incentives for two-career households) could have important effects on future energy use in buildings.

[7] Ibid., pp. 4, 12.

[8] Ibid., p. 5.

44 to 59 percent in the same period.[31] Wood use for space heating has fluctuated; in 1978, 2.5 percent of U.S. households reported that their main heating fuel was wood, and this increased to 7.5 percent in 1984, but then dropped down to 5,6 percent by 1987.[32]

The price of energy underlies many of the changes discussed above. There is little agreement on exactly how energy prices and energy costs influence efficiency. There is general agreement that, all else equal, higher prices are an incentive for more efficiency, but the exact relationships between price, cost, and efficiency are not understood. The expectation of future price increases maybe as important as the actual current price, especially in influencing consumer decisions on capital investments. Price changes may substantially change short-term behavior; for example, the changes in residential thermostat settings discussed above may have been so influenced. However, the longer term impacts on capital equipment selection decisions are unclear. As shown in figure 1-6, energy prices in the residential sector increased during the period 1975 to 1985, in most cases faster than the consumer price index (CPI), but have dropped or held steady since then.

The Commercial Sector

Commercial buildings used 12.9 quads of energy at a cost of $68 billion in 1989.[33] About two-thirds of this energy was in the form of electricity. Space heating, lighting, and space cooling were the principal end uses (figure 1-7). Today, commercial buildings are used for diverse functions, but the predominant ones are retail/service, office, warehouse, assembly, and education. Figure 1-8 details commercial building square footage and energy use by function. Note that the most energy-intensive uses (those with the greatest energy consumption per square foot) are offices, health care, and food.

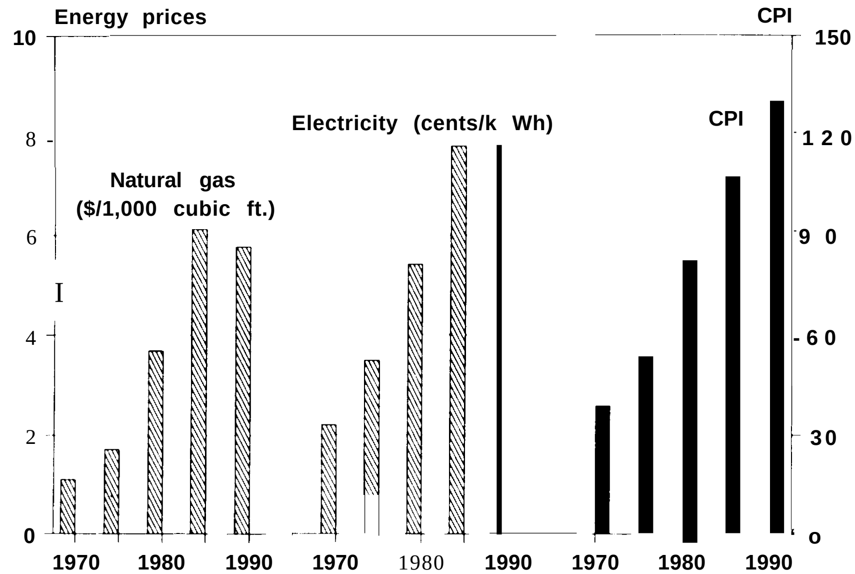
Energy use in the commercial sector has increased rapidly since 1970--at an average annual rate of 2.3

[31] The same trend occurred in multifamily homes—67 percent of new multifamily units had electric space-heating systems in 1985, dropping to 53 percent in 1990. U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1989*, C25-8913 (Washington DC: July 1990), pp. 20, 39; U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing.'* 2990, C25-9013 (Washington DC: June 1991), pp. 20,39.

[32] U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87) (Washington, DC: May 1989), p. viii.

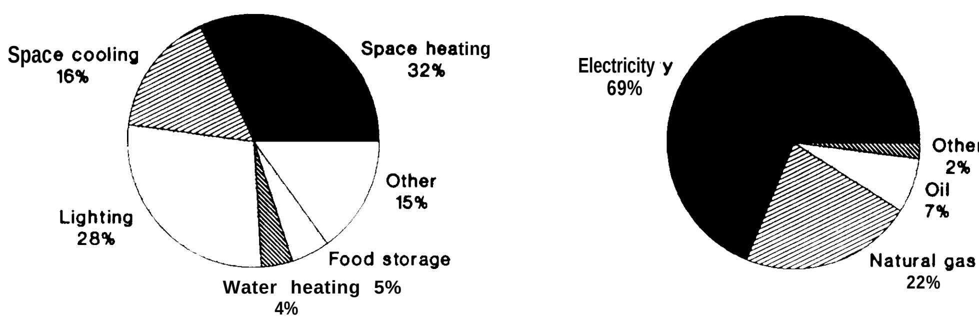
[33] Source is OTA 1992; see app. 1-B. The commercial sector is difficult to define but can be thought of as encompassing all buildings that durable products are not made in and that people do not live in. This includes energy used in offices, stores, schools, churches, and hospitals but excludes energy used in factories and apartment buildings.

Figure 1-8-Energy Prices in the Residential Sector Rose From 1970 to 1985, Then Dropped From 1985 to 1990



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990,* DOE/EIA-0384(90) (Washington, DC: May 1991), pp. 179, 225; U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1991* (Washington, DC: 1991), p. 476.

Figure 1-7—Commercial Sector Energy Use by End Use and Fuel Type, 1988

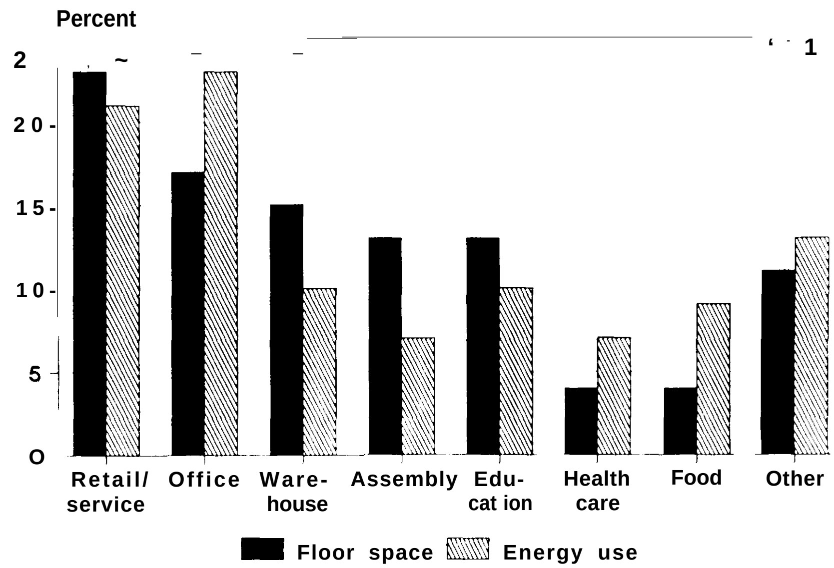


NOTE: Includes energy losses associated with electricity generation (see app. 2-C).
SOURCE: Office of Technology Assessment, 1992 (see app. l-B).

percent (figure l-9).[34] As in the residential sector, a number of factors contributed to this growth (table 1-4), the most important being the rapid growth in new commercial buildings. The stock of commercial buildings, as measured by total square footage, grew more than 50 percent from 1970 to 1989 (figure 1-10). Heating, cooling, and lighting these new buildings has considerably increased energy consumption in the commercial sector. Furthermore many of these new buildings are offices, retail/service buildings, and other commercial buildings that are, on average, relatively energy intensive (i.e.,

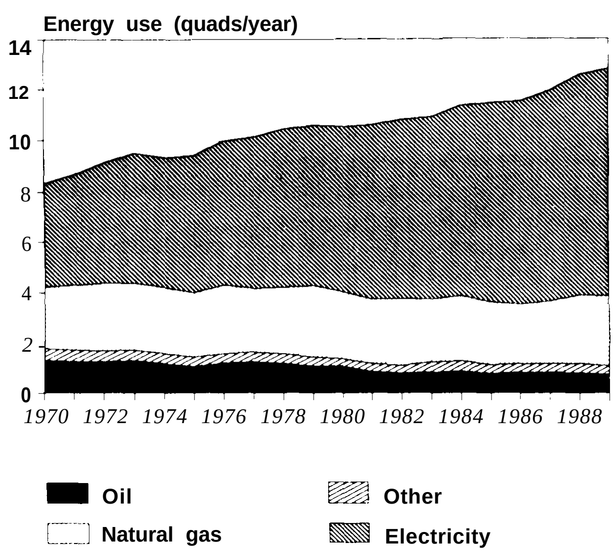
[34] Source for consumption data is OTA 1992; see app. l-B. Note that GNP grew even more quickly in the same period—at average annual rates between 2.8 and 2.9 percent, in constant dollars. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1991* (Washington DC: 1991), p. *433.*

Figure 1-8-Breakdown of Energy Use and Square Footage by Commercial Building Type, 1986



SOURCE: U.S. Department of Energy, Energy Information Administration, *Commercial Building Consumption and Expenditures 1986,* DOE/EIA-0318(86) (Washington, DC: May 1989), p. 29.

Figure 1-9-Commercial Sector Energy Use by Fuel Type, 1970-89



NOTE: Includes energy losses associated with electricity generation (see app. 2-C).

SOURCE: U.S. Department of Energy, Energy Information Administration, *State Energy Data Report: Consumption Estimates, 1960-1989,* DOE/EIA-0214(89) (Washington, DC: May 1991), p. 25.

Table 1-4-Major Factors Influencing Commercial Building Energy Use

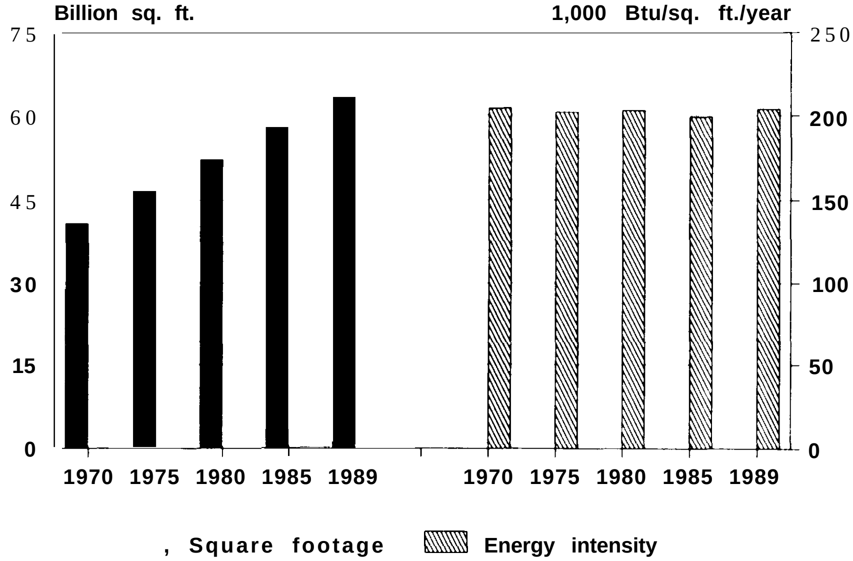
Factors causing an increase in consumption:
More buildings
More service demand-such as space cooling and office equipment
Factors causing a *decrease* in consumption:
New buildings more efficient
New appliances more efficient
Retrofits to existing buildings
Factors causing fluctuations in consumption:
Fuel shifts-more electricity and less oil
Price changes

SOURCE: Office of Technology Assessment, 1992.

requiring more energy use per square foot per year) as compared to the sector as a whole (figure 1-8). Increased demand for energy-intensive services has further increased commercial building energy use. Most commercial buildings constructed in the past 20 years were built with air conditioning, while many older commercial buildings were not. There has been rapid growth in the use of computers and related electronic office equipment-in 1984 there were about 1.8 million personal computers in use in businesses; by 1989 this had climbed to 14.0 million.[35]

[35] U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1990* (Washington, DC: January 1990), p. 95 1. For the commercial sector as a whole, however, office equipment is still a small energy user, accounting for only 3 to 4 percent of total commercial-sector electricity use. See ch. 2.

Figure I-l O-The Stock of Commercial Buildings (as measured by total square footage) Has Grown Rapidly, But the Energy Intensity (energy use per square foot per year) Has Held Steady.



SOURCE: U.S. Department of Energy, Energy Information Administration, *State Energy Data Report: Consumption Estimates, 1960-1969,* DOE/EIA-0214(89) (Washington, DC: May 1991), p. 25; D. Belzer, Pacific Northwest Laboratories, personal communication, September 19, 1991.

Despite growth in the number of energy-intensive buildings (e.g., offices and stores) and increases in air conditioning and other equipment, energy *intensity* (energy use per square foot per year) actually stayed flat in the commercial sector from 1970 to 1990 (figure 1-10). As in the residential sector, improved technology has helped to dampen the growth in commercial building energy use. New commercial buildings use improved windows and shells, more efficient space conditioning equipment, and better lighting systems. For example, commercial buildings constructed from 1980 to 1989 made greater use of ceiling and wall insulation, multipane and reflective windows, and shadings or awnings compared to buildings constructed in earlier years.[36] Computer hardware and software improvements allowed for more use of computer-aided building design and analysis methods. In addition, the energy efficiency of the existing building stock has been improved through retrofits (table 1-5).

Table 1-5-Commercial Building Retrofits

Action	Percent of floor space[a]
Energy management system.	12
Efficient light ballasts..	24
Ceiling insulation.	20
Weatherstrip/caulk.	22

[a]The percent of all commercial building floor space for which the associated action was added after construction, as of 1986.

SOURCE: U.S. Department of Energy, Energy information Administration, Characteristics of Commercial Buildings *1986,* DOE/EIA-0246(86) (Washington, DC: September 1988), p. 24.

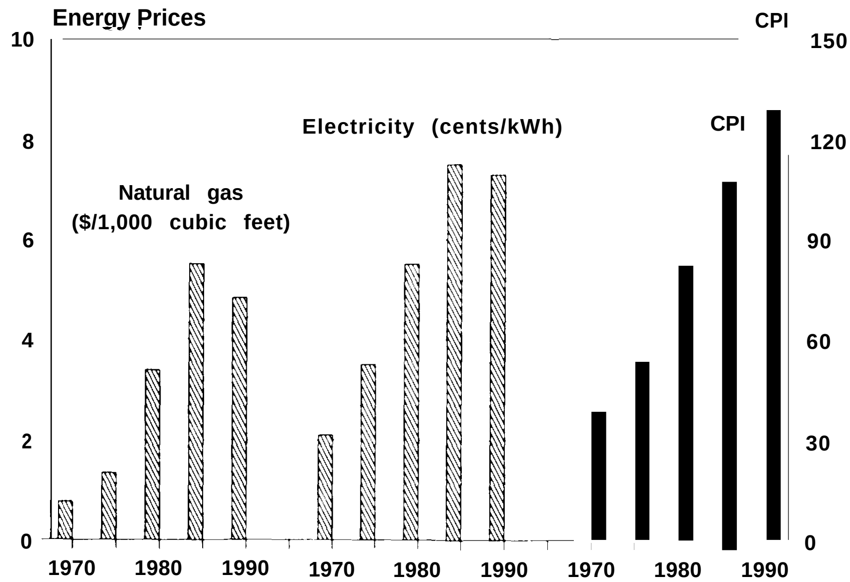
Several other factors have influenced energy use in commercial buildings. Electricity has replaced oil and natural gas to a considerable extent.[37] As in the residential sector, a greater share of new commercial building construction has been in the South and West,[38] which may have led to a slight net increase in energy consumption due to an increased need for

36 U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989,* DOE/EIA-0246(89) (Washington, DC: June 1991), p. 202.

37 In 1970, 49 percent of energy used in commercial buildings was in the form of electricity; by 1988 this had increased to 69 percent (primary equivalent, see app. 2-C). Source is OTA 1992; see app. l-B. The efficiency implications of this shift depend on the technologies used (see footnote 29 above).

38 U.S. Department of Energy, Energy Information Administration, *Characteristics of Commercial Buildings 1989,* DOE/EIA-0246(89) *(Washington DC:* June 1991), p. 42. Commercial buildings tend to need more energy for space cooling and less for space heating than residential buildings; therefore this geographic shift would be more likely to increase overall consumption in commercial buildings than in residential buildings.

Figure 1-1 l—Energy Prices in the Commercial Sector Rose From 1970 to 1985, Then Dropped From 1985 to 1990.



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990,* DOE/EIA-0384(90) (Washington, DC: May 1991), pp. 179, 225; U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1991* (Washington, DC: 1991), p. 476.

space cooling. Finally, energy prices in the commercial sector increased from 1970 to 1985 but dropped after that (figure 1-1 1).

Summary

Energy use in both the commercial and residential sectors has grown in the last 20 years. Sheer increases in numbers underlie much of this growth—more people, more households, and more offices. Increased service demand-more air conditioning, more computers, larger houses—has contributed as well. However, the application of improved technology has moderated this growth. Better building shells (windows and insulation), better appliances (furnaces, air conditioners, refrigerators), and better building design have lowered energy intensity in residences (energy use per household per year) and stabilized energy intensity in the commercial sector (energy use per square foot per year).

BUILDING ENERGY USE IN THE NEXT 20 YEARS: THE ENERGY SAVINGS POTENTIAL

Where Are We Headed?

As in the past, building energy use in the future will be driven by technological change but will be influenced by other factors as well, including population and economic growth, changes in household size, changes in lifestyle, and migration patterns. The complexity and interactions of these factors make it difficult to predict accurately future levels of building energy use. Nevertheless, it is useful to project these levels under different conditions *to illumin*ate potential policy issues.

One way to consider future energy use is in terms of *intensity* (defined as energy use per household per year in residential buildings, and energy use per square foot per year in commercial buildings). As discussed above, since 1970 residential intensity dropped and then increased (figure 1-5), while commercial intensity stayed relatively constant (figure 1-10). OTA has modeled future intensity levels in terms of scenarios-projections of possible futures, based on differing assumptions about future levels of intensity and other factors. Uncertainties in household size and new commercial building construction rates make it difficult to specify precisely the levels of future consumption; however assuming that recent historical trends continue-specifically that commercial sector intensity remains flat, and that residential sector intensity drops slowly—yields a residential consumption of 18.9 quads per year in 2010 and a commercial sector consumption

297-936 0 - 92 - 3 : QL 3

of 19.9 quads per year in 2010. A complete description of the model used to build the scenarios is in appendix l-A.

The scenarios presented here can be compared to those made by other groups. Figures 1-12 and 1-13 show the OTA estimates, as well as those by five other groups (see appendix 1-C for a detailed table and sources for these other estimates). The simple mathematical average of these consumption scenarios is 20.2 quads for the residential sector and 18.5 for the commercial sector. This is not to say that the mathematical average is the ''correct' number, for all the estimates may be wrong; but the average does provide a single number summarizing the different estimates. While there is a range of estimates, there is reasonable agreement on future business-as-usual consumption in 2010; the difference between the average and the outlier (i.e., the estimate farthest from the average) is less than 16 percent for both sectors.[39]

Where Could Technology Take Us?

The preceding discussion summarized different forecasts of building energy use in a business-as-usual assumption. An alternative method of forecasting future energy use is to consider what energy use could be if greater use was made of energy efficient technologies. At one extreme is the true technical potential-i. e., the energy savings that would result from maximum use of all technologies, regardless of cost. From a policy perspective, however, it is more useful to consider the energy savings resulting from optimal use of all cost-*effective* technologies.

Estimating cost-effective savings is a difficult task. Technology is just one of many factors affecting energy use, and the effects of technological change may be masked by population increases, demographic shifts, and other factors. Technology is not stagnant; costs, performance, and efficiencies change as technology is improved and refined. The diversity of the building stock, climatic variations, and uncertainty over future fuel costs all make estimates of technical and economic potential for energy savings a very uncertain exercise. Furthermore, defining ''cost-effective" can be problematic. There are several measures of cost-effectiveness, including the cost of conserved energy (CCE), net present value, and payback (these terms are defined in appendix 2-B). One can consider different perspectives, such as the consumer, the utility, and society as a whole. Finally one can vary the values of inputs to these definitions, notably the discount rate. There is little agreement on the best measure, perspective, or assumptions to use in projecting energy use.

Nevertheless, it is useful to review estimates of the energy savings that could result from greater use of cost-effective technologies, recognizing the effects of different definitions of cost-effective. If there is general agreement that a significant gap between the business-as-usual forecasts and the cost-effective forecasts exists, then one may reasonably conclude that the market is not performing optimally and that policy change may be appropriate. Alternatively, if there is general agreement that there is little or no gap between the two forecasts, then policy intervention may not be appropriate.

Previous work by OTA has estimated that energy use in buildings could be reduced about one-third by 2015, relative to a business-as-usual scenario, through the use of technologies with a positive net present value to the consumer.[40] Adjusting this model's results to the projected business-as-usual consumption discussed above yields a 2015 cost-effective consumption of about 27.7 quads per year (figure 1-14). This is about a 2 quad *decrease* from 1989 to 2015,[41]

Numerous other estimates of this savings potential have been made:

- A modeling effort by the Energy Information Administration,[42] conducted as part of the National Energy Strategy, estimated the business-

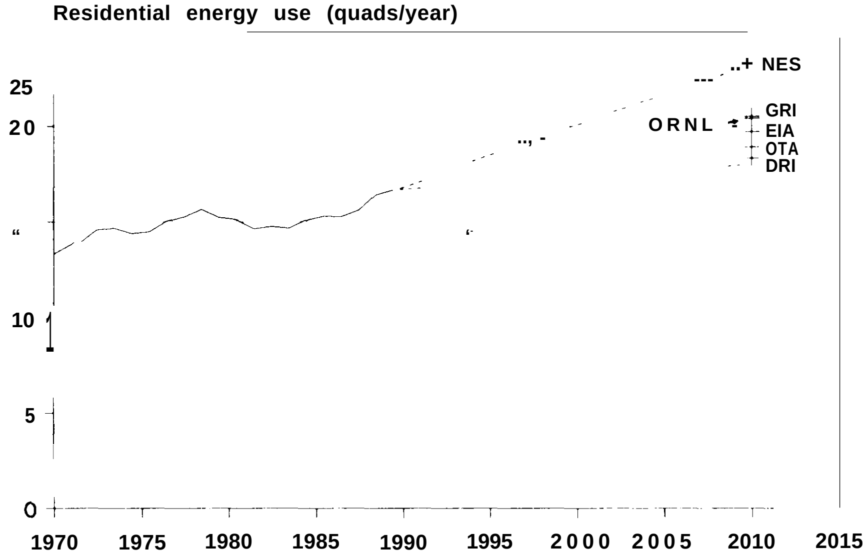
39 Much of these differences can be traced to different assumptions—for example, the National Energy Strategy estimates assume that GNP grows at an average annual rate of 2.9 percent from 1990 to 2010, while the DRI study assumes a rate of 2,3 to 2,0 percent in the same period. See app. 1-C for sources.

40 Based on an OTA model described in U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases, OTA-O-482* (Washington, DC: U.S. Government Printing Office, February 1991), app. A, pp. 313-326. This model assumes full penetration of all cost-effective technologies and a 7 percent real discount rate.

41 The ''bus~ess+.+usu~' estimates discussed above were recalculated for 2015, yielding 19.4 quads per year (residential) and 22.1 quads per year (commercial). The one-third reduction, therefore, corresponds to a 13,8 quad savings in 2015.

42 The Energy Information Administration (EIA) is an independent statistical and analytical agency within the U.S. Department of Energy @E)"

Figure I-12—Residential Energy Use in 2010: Comparison of Different Business-as-Usual Forecasts

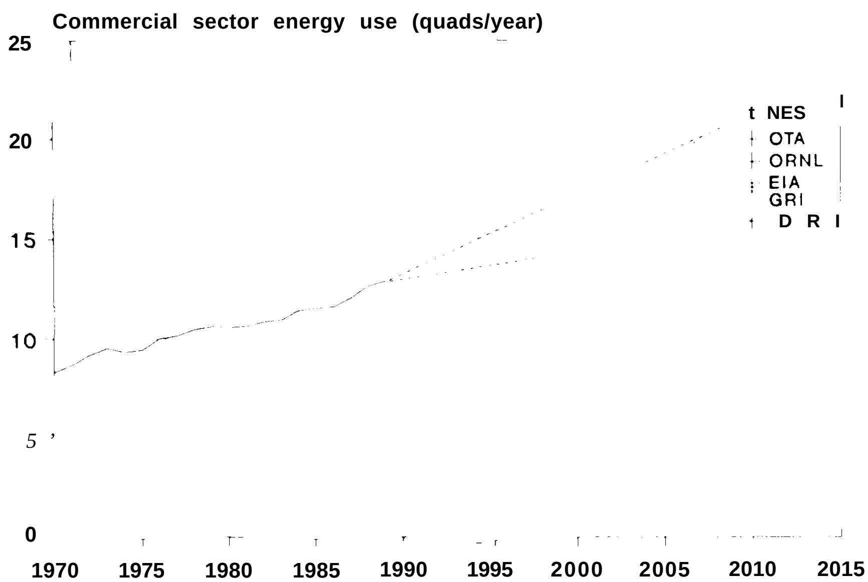


KEY: DRI = Data Resources, Inc., EIA = Energy Information Administration, GRI = Gas Research Institute, NES = National Energy Strategy, ORNL = Oak Ridge National Laboratory, OTA = Office of Technology Assessment.

NOTE: Includes losses associated with electricity generation (see app. 2-C).

SOURCE: Office of Technology Assessment, 1992 (see app. 1 -C).

Figure I-13-Commercial Sector Energy Use in 2010: Comparison of Different Business-as-Usual Forecasts

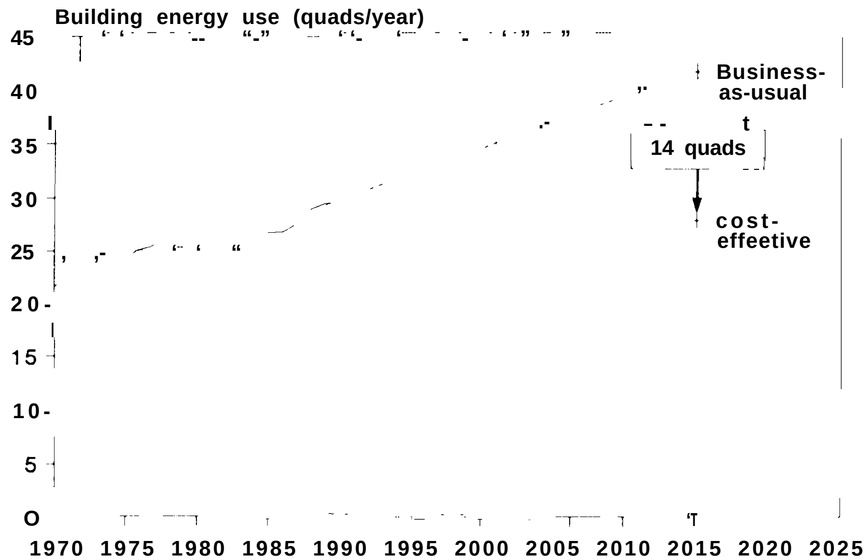


KEY: DRI = Data Resources, Inc., EIA = Energy Information Administration, GRI = Gas Research Institute, NES = National Energy Strategy, ORNL = Oak Ridge National Laboratory, OTA = Office of Technology Assessment.

NOTE: Includes losses associated with electricity generation (see app. 2-C).

SOURCE: Office of Technology Assessment, 1992 (see app. 1 -C).

Figure I-14-Building Energy Use: Two Possible Futures



NOTE: Business-as-usual is OTA's estimate of future consumption without policy change. Cost effective is OTA's estimate of future consumption if all energy efficient technologies with a positive net present value are implemented. There is considerable uncertainty in both estimates. See text for details. Includes losses associated with electricity generation (see app. 2-C).

SOURCE: Office of Technology Assessment, 1992.

as-usual and cost-effective (see table 1-6 for definition) levels of energy use in buildings in 2010. This study estimated that, relative to the predicted business-as-usual 2010 consumption, 13 percent of energy used in buildings could be saved with cost-effective technologies, and that 26 percent of energy could be saved with technically feasible, but not necessarily cost-effective technologies (table 1-6).[43] These estimates are at the low end of the range of cost-effective savings found in other studies, probably due in part to conservative assumptions concerning building shell retrofits.[44]

- A recent study by the National Academies examined the energy and carbon savings potential in the residential and commercial sectors.[45] The study examined a range of supply curves[46] and examined in depth data from the Electric Power Research Institute (EPRI). The Academies' analysis of the EPRI data found an aggregate electricity savings potential of 45 percent in existing buildings at a cost of conserved energy of less than or equal to 7.5 cents per kWh.[47] Natural gas and oil savings of 50 percent in existing buildings were claimed, at a cost of less than $5.63 per MBtu.[48] These results are not directly comparable to those of

43 The EIA notes that costs for the technical Potential case may not be prohibitive, due to the economies of scale resulting from large production runs and cost reductions from R&D. U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential.' Supporting Analysis for the National Energy Strategy,* SR/NES/90-02 (Washington, DC: December 1990), p. 7.

44 The EIA assumes that pre-1975 residential buildings yield a 16 percent reduction in heating service demand and a 4 percent reduction in cooling service demand in the "high conservation" case by 2030, while OTA assumes a 20 percent savings by 2010 in the "moderate" case. Ibid., p. 6; U.S. Congress, Office of Technology Assessment *Energy Technology Choices: Shaping Our Future, OTA-E-493* (Washington, *DC:* U.S. Government Printing Office, July 1991), p. 130.

45 The National Academies are the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). The report is "Policy Implications of Greenhouse Warming,' Report of the Mitigation Panel, prepublication manuscript, National Academy Press, Washington DC, 1991.

46 A supply curve is a graphical method Of summarizing the costs and energy savings potential of energy efficient technologies.

47 Sensitivity analyses feud the 45 percent savings at discount rates of 3,6, and 10 percent. ''Policy Implications of Greenhouse Warming," Report of the Mitigation Panel, prepublication manuscript, National Academy Press, Washington, DC, 1991, ch. 3, p. 3-3 and table 3.7 (chapter dated 613/91).

48 Ibid.

Table 1-6—Forecasts of Building Energy Use by the Energy Information Administration

Sector	Energy Use (quads/year)			
	1990	2010 Business-as-usual	2010 Cost-effective	2010 Technical potential
Residential. . .	10.7	11.7	10.2	8.3
Commercial. .	6.8	8.7	7.5	6.8
Total.	17.5	20.4	17.7	15.1

NOTE: Does not include losses associated with electricity generation.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy,* SR/NES/90-02 (Washington, DC: December 1990). Business-as-usual forecast assumes "current government policies and programs remain in effect" (p. 56). Cost-effective forecast is the "high conservation excursion," and assumes "full penetration of cost-effective, energy efficient technologies and other conservation measures" where "cost-effectiveness is defined as an energy savings investment that generates a positive net present value." (p. 59). A 10 percent discount rate is assumed (p. 68). Technical potential is the "very high conservation excursion," and assumes that the most efficient technologies are installed when in-place units fail. There is no premature scrapping of capital equipment in either case (p. 3).

OTA or the Energy Information Administration (EIA). This study assumes a "frozen efficiency' baseline; in other words no allowance is made for efficiency improvements expected to occur under existing economic and political conditions. However the specific measures proposed in the Academies' study appear to fall somewhere in between the OTA moderate and tough scenarios, suggesting that the Academies' measures would yield savings of from 20 to 38 percent in 2010, relative to a business-as-usua1 scenario. A separate OTA analysis of all energy-using sectors found that the Academies' results, when forecasted relative to a base case, yielded results comparable to OTA's moderate scenario .49

- A study entitled *America's Energy Choices* estimated the energy savings resulting from greater use of technologies for which the additional frost cost is less than the cost of new supply, at both existing supply prices and those estimated by including environmental and security costs in energy supply prices. Relative to reference consumption in 2010, estimated energy savings were 28 and 37 percent.[50]
- Several other studies have examined energy savings for specific fuels, sectors, or geographic regions. A comprehensive analysis of electricity use in U.S. residences, for example, found that 37 percent of residential electricity could be saved by 2010 at a cost below that of supplying the electricity.[51] A comprehensive study of electricity use in Michigan estimated that a 29 percent savings by 2005 would be ''achievable' at a reasonable cost.[52] A study of electricity use in New York State found that present day consumption could be reduced by 34 percent in the residential sector and 48 percent in the commercial sector at a cost below that of supplying the electricity .53

The results of some of these studies are summarized in table 1-7. The results vary widely, as do the analytical techniques, assumptions about cost and performance, and definitions of cost-effectiveness.

49 See John Andelin, Assistant Director, U.S. Congress, Office of Technology Assessment, testimony before the House Committee on Science, Space, and Technology, July 17, 1991.

50 The 28 percent savings is under the ''Market' scenario, defined as, "making use of cost-effective energy-efficiency and renewable energy technologies, assuming market penetration rates, and with no accounting for environmental or security costs beyond those embodied in current trends and policies. " The 36 percent savings corresponds to the "Environment" scenario, which includes additional technologies, "to the extent justified by the environmental and security costs of fossil fuels, and assuming more rapid penetration rates." *America's Energy Choices,* Executive Summary (Cambridge, MA: The Union of Concerned Scientists, 1991). A 3 percent real discount rate is assumed. Savings estimates include losses in electricity generation and exclude solar and geothermal energy. *America's Energy Choices,* Technical Appendixes (Cambridge, MA: The Union of Concerned Scientists, 1991), pp. A-1, G-4 to G-7.

51 That is, with a cost of conserved energy (CCE, see app. 2-B for definition) below 7.6 cents/kWh. The baseline is a' 'frozen efficiency' one, which does not give credit for efficiency improvements that would result from naturally occurring efficiency improvements (it does, however, exclude from the baseline predicted savings resulting from future appliance efficiency standards). A 7 percent real discount rate is assumed. J. Koomey, C. Atkinson, A. Meier, J. McMahon, S. Boghosian, B. Atkinson, I. Turiel, M. Levine, B. Nordman, P. Chan, *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector, LBL-30477* (Berkeley, CA: Lawrence Berkeley Laboratory, July 1991), pp. 35-36.

52 Calculations are relative to a ''business as usual'' baseline. The "achievable' potential assumes the use of commercially available technologies and aggressive conservation programs. F. Krause, J. Brown, D. Connell, P. DuPont, K. Greely, M. Meat, A. Meier, E. Mills, B. Nordman, *Final Report: Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector,* Volume 1: Executive Summary, LBL-23025 (Berkeley, CA: Lawrence Berkeley Laboratory, April 1988).

53 Conservation measures With a cost of saved electricity below 7 cents/kWh are included. Costs are for technology and titillation only, and do nOt include marketing and other implementation costs. Interestingly, however, adding a 50-percent implementation "penalty' to the cost of saved energy for these measures would *still* allow savings of 32 percent (residential) and 41 percent (commercial). A 6-percent discount rate is assumed. American Council for an Energy-Efficient Economy (ACEEE), ''The Potential for Electricity Conservation in New York State, ' published by the New York State Energy Research and Development Authority (NYSERDA), report 89-12, September 1989, pp. S-5, S-6.

Table 1-7-Summary of National Cost-Effective Savings Estimates

Source	Percent savings relative to baseline	Year	Coverage	Definition of cost-effective
Office of Technology Assessment. . .	33	2015	Residential/commercial all fuels	Positive net present value
National Academies.		1986	Existing buildings	
	45		Electricity	CCE less than or equal to 7.5 cents/kWh
	50		Gas and oil	CCE less than or equal to $5.63/MBtu
Energy Information Administration. . .	13	2010	Residential/commercial all fuels	Positive net present value
Union of Concerned Scientists.	28	2010	Residential/commercial all fuels	CCE less than cost of supply “Market” scenario
Lawrence Berkeley Laboratory.	37	2010	Residential electricity	CCE less than 7.6 cents/kWh

NOTE: Results are not directly comparable. See text for sources and limitations. CCE - cost of conserved energy.

SOURCES: See text.

As discussed above, the Academies’ results appear to fall between the OTA moderate and tough scenarios, corresponding to 20 and 38 percent savings, respectively. The EIA savings estimate of 13 percent is lower than the OTA moderate scenario, due in part to their more conservative assumptions concerning shell retrofits. While there is considerable uncertainty in all of these modeling efforts, there is general agreement that, despite gains made to date, there remain significant opportunities for increased energy efficiency in U.S. buildings through the use of cost-effective technologies.[54]

The gap between what appears to be cost-effective and what is actually used suggests that there maybe a role for Congress in ensuring that cost-effective efficiency improvements are implemented. There are many benefits of such actions, the most important being they save both energy and money. Furthermore, calculations of cost-effectiveness discussed above generally do not incorporate environmental and other externalities, and doing so would most likely increase the gap between cost-effective and actual energy use. overcoming barriers to wider use of these technologies may require direct policy actions, as the existence of barriers suggests that current market conditions will not result in optimal use of cost-effective energy efficiency opportunities.

The remainder of this report focuses on the critical question of *implementation* of energy efficient technologies. Chapter 2 takes a closer look at the technologies themselves, with a focus on their availability, costs, and other attributes. Chapter 3 examines how the markets function, with a focus on why energy efficient technologies are often not used despite their apparent cost-effectiveness. Chapter 4 reviews past Federal efforts to encourage energy efficiency in buildings, and Chapter 5 distills the analyses of the first four chapters in a discussion of policy issues and options for Congress.

54 The studies discussed above use a variety of definitions of cost-effective. Although the sw@ potential varies by the specific definition used, by most definitions it is clear that a considerable potential exists for saving energy through greater use of technologies with positive net benefits. However, some argue that these studies calculate costs incorrectly, and that there is little evidence of market imperfections that would yield such a potential. W. David Montgomery, “The Cost of Controlling Carbon Dioxide Emissions, ’ Charles River Associates Inc., Washington, DC, December 1991.