Trends in Energy Use in Commercial Buildings—Sixteen Years of EIA's Commercial Buildings Energy Consumption Survey

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ABSTRACT

The Commercial Buildings Energy Consumption Survey (CBECS) collects basic statistical information on energy consumption and energy-related characteristics of commercial buildings in the United States. The first CBECS was conducted in 1979 and the most recent was completed in 1995. Over that period, the number of commercial buildings and total amount of floorspace increased, total consumption remained flat, and total energy intensity declined. By 1995, there were 4.6 million commercial buildings and 58.8 billion square feet of floorspace. The buildings consumed a total of 5.3 quadrillion Btu (site energy), with a total intensity of 90.5 thousand Btu per square foot per year. Electricity consumption exceeded natural gas consumption (2.6 quadrillion and 1.9 quadrillion Btu, respectively). In 1995, the two major users of energy were space heating (1.7 quadrillion Btu) and lighting (1.2 quadrillion Btu). Over the period 1979 to 1995, natural gas intensity declined from 71.4 thousand to 51.0 thousand Btu per square foot per year. Electricity intensity did not show a similar decline (44.2 thousand Btu per square foot in 1979 and 45.7 thousand Btu per square foot in 1995).

Two types of commercial buildings, office buildings and mercantile and service buildings, were the largest consumers of energy in 1995 (2.0 quadrillion Btu, 38 percent of total consumption). Three building types, health care, food service, and food sales, had significantly higher energy intensities. Buildings constructed since 1970 accounted for half of total consumption and a majority (59 percent) of total electricity consumption.

Introduction

The Commercial Buildings Energy Consumption Survey (CBECS) is conducted by the Energy Information Administration (EIA), the energy statistics and analytical organization within the U.S. Department of Energy. The CBECS provides basic statistical information on energy consumption and expenditures for commercial buildings in the United States and data on energy-related characteristics of these buildings. Because energy use is most closely associated with characteristics of buildings rather than occupants, the CBECS presents statistics for commercial *buildings* rather than for commercial *establishments*, the entity used in many business surveys. The CBECS is a national-level sample survey of commercial buildings and their energy suppliers. The survey collects information on physical characteristics of buildings, building use and occupancy patterns, equipment use, conservation features and practices, and types and uses of energy in buildings. The 1995 CBECS was the sixth in a series of surveys covering the commercial sector. The first survey was conducted in 1979; surveys were then conducted triennially beginning in 1983. Future CBECS will be conducted on a quadrennial cycle, with the next CBECS scheduled for 1999. The buildings characteristics data were published in detailed tables in a series of EIA reports (EIA 1981, EIA 1988, EIA 1991, EIA 1994a, and EIA 1997). The consumption and expenditures data were published in detailed tables a second series of reports (EIA 1983a, EIA 1983b, EIA 1989, EIA 1992, EIA 1995a, EIA 1998a, and EIA 1998b). CBECS data are also available as

micro-data files in ASCII and dBASE formats. These files contain records containing building characteristics, energy consumption, and expenditure information for each of the sampled buildings in the surveys. The micro-data files for the 1992 and 1995 CBECS are available for downloading on EIA's website (www.eia.doe.gov).

Survey Methodology

The CBECS survey design has remained essentially the same over the past sixteen years. It is conducted in two major data collection stages: a Building Characteristics Survey and an Energy Suppliers Survey. The first stage, the Building Characteristics Survey, collects information about selected commercial buildings through voluntary personal interviews with the buildings' owners, managers, or tenants. The second stage, the Energy Suppliers Survey, obtains data concerning the building's actual consumption of energy and expenditures for energy from records maintained by energy suppliers.

The target population for CBECS consists of all commercial buildings in the United States with more than 1,000 square feet of floorspace. A commercial building is defined by CBECS as an enclosed structure with more than 50 percent of floorspace devoted to activities that are neither residential, industrial, nor agricultural. For the 1995 CBECS, a representative sample of 6,639 buildings was chosen and building characteristics interviews were completed at 5,766 buildings, for a response rate of 87 percent. The commercial buildings population sampled in 1995 differed slightly from that sampled in previous CBECS. Two types of buildings that were previously included were excluded—indoor enclosed parking garages and commercial buildings on multibuilding manufacturing facilities. The two previous CBECS (1989 and 1992) can be adjusted to match the building universe of the 1995 survey. Earlier CBECS cannot be adjusted as accurately because complete information on multibuilding facilities was not collected.

The sample design for the CBECS is a multistage area probability cluster sample design supplemented by a list sample of "large" buildings, recently constructed buildings, and "special" buildings (Federal Government buildings and post offices; hospitals; and college and university buildings). The area sample portion of the design is a sample from the broad spectrum of commercial buildings. This portion uses a four-stage cluster sampling design, a method that involves sampling progressively smaller geographic areas. The supplemental list sample provides an oversample of "large" buildings to ensure adequate coverage of buildings that are significant energy users. Similarly, for recently constructed buildings, the area sample is used to provide a sample from the broad spectrum of new buildings and the supplemental list sample provides an oversample of "large" new buildings. A more detailed discussion of survey methodology can be found in the "How the Survey Was Conducted" section in the Appendices of any of the CBECS data reports (e.g., EIA 1995a).

Sampling Error

Since the purpose of the CBECS is to publish estimates of population values, the CBECS sample is designed so that survey responses can be used to estimate characteristics of the entire stock of commercial buildings in the United States. The method of estimation is to calculate basic sampling weights (base weights) that relate the sampled buildings to the entire stock of commercial buildings. In statistical terms, a base weight is the reciprocal of the probability of selecting a building into the sample. A base weight can be explained as the number of actual buildings represented by a sampled building, e.g., a sampled building that has a base weight of 1,000 represents itself and 999 similar (but unsampled)

buildings in the total stock of buildings. Then, to reduce the bias from unit nonresponse in the survey statistics, the base weights of respondent buildings are adjusted upward, so that the respondent buildings represent not only themselves and the buildings they were chosen to represent, but also nonrespondent buildings and the buildings they were chosen to represent.

The estimates are based on reported data from representatives of a randomly chosen subset of the entire commercial building population (with more than 1,000 square feet of floorspace), consequently the estimates always differ from the true population values. One source of the difference between the estimated values and the actual values is sampling error, the random difference between the survey estimate and the population value that occurs because the survey estimate is calculated from a randomly chosen subset of the entire population. The sampling error averaged over all possible samples would be zero, but since there is only one sample for each CBECS, the sampling error is nonzero and unknown for the particular sample chosen. However, the sample design permits sampling errors to be estimated. Because of sampling error, it is important to note that CBECS estimates should not be considered as definite point estimates, but as estimates with some associated error in each direction. In published CBECS tables, the relative standard error is given for each estimate, which can be used to calculate the approximate standard error and the 95-percent confidence range for each estimate. (Figures 1 through 4 show estimates and 95-percent confidence ranges).

End-Use Consumption Estimation Methodology

The energy consumption data provided by the energy suppliers are for total consumption within the commercial buildings. Estimates for major end uses can be calculated by disaggregating total energy consumption into end-use consumption by using several approaches—engineering simulations, statistical modeling, or a hybrid approach known as statistically adjusted engineering (SAE). CBECS end-use estimates were developed using the SAE approach. The initial engineering estimates were provided by the Facility Energy Decision Screening (FEDS) system, a building energy simulation model. The CBECS building characteristics data and weather data were then used to create FEDS estimates for the sampled buildings and those estimates were modified to match the observed CBECS consumption data using statistically-derived coefficients to adjust the FEDS engineering estimates. Details on the end-use consumption methodology can be found in (EIA 1994b) and in the methodology section that accompanies the 1995 end-use consumption data posted on the EIA website (www.eia.doe.gov/emeu/cbecs/cbec-eu2.html).

Major Trends in the Commercial Buildings Sector

Total Buildings and Floorspace

In 1979, there were an estimated 3.7 million commercial buildings and 50.0 billion square feet of floorspace in the United States (see EIA 1995b, for discussion of adjustment of 1979 CBECS data for sampling undercount). By 1992, the number of buildings had increased 30 percent to 4.8 million and the amount of floorspace had increased 36 percent to 67.9 billion square feet (both statistically significant increases) (Figures 1 and 2). Between 1989 and 1995 there were no significant changes in the estimates of number of buildings or amount of floorspace (the 1989 and 1992 estimates were adjusted to match the 1995 building definition, as shown in Figures 1 and 2) . In 1995, there were an estimated 4.6 million buildings and 58.8 billion square feet of floorspace.

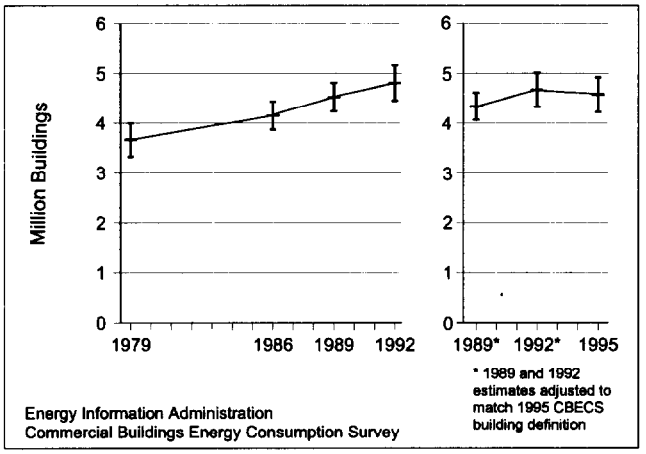

Figure 1. Total Commercial Buildings, 1979 to 1992 and 1989 (adjusted) to 1995.

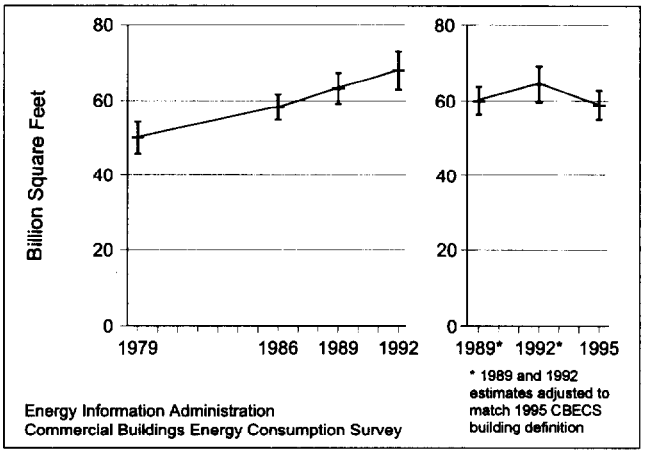

Figure 2. Total Commercial Floorspace, 1979 to 1992 and 1989 (adjusted) to 1995.

Total Energy Consumption and Intensity

The CBECS collected from energy suppliers the amount of energy consumed for the following major sources: electricity, natural gas, fuel oil, and district heat. Total consumption for the major sources showed no significant changes from 1979 to 1992 or from 1989 (adjusted) to 1995 (Figure 3). All consumption data presented in the following sections, unless otherwise noted, is for site energy consumption. Site energy is the energy consumed directly by the end uses in the building. Primary energy includes energy consumed in the production and delivery of energy products. Electricity, of the major energy sources, has the greatest disparity between site and primary energy—a greater amount of energy is used to generate and transmit electricity than in the production and generation of the other major sources. Primary energy consumption in commercial buildings is discussed in the 1995 CBECS data report (EIA 1998b).

The increase in floorspace combined with no change in consumption is reflected in the total energy intensity trend (Figure 4). The total energy intensity (consumption per square foot of floorspace per year) showed a decline of 25 percent from 1979 to 1992 (from 114.0 thousand Btu per square foot to 85.5 thousand Btu per square foot).

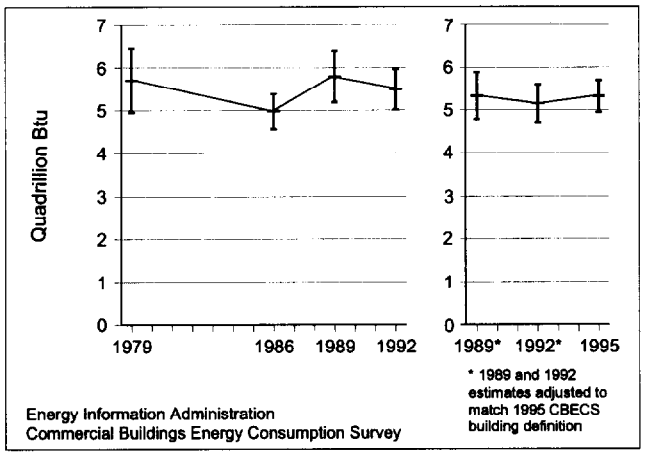

Figure 3. Total Site Energy Consumption, 1979 to 1992 and 1989 (adjusted) to 1995.

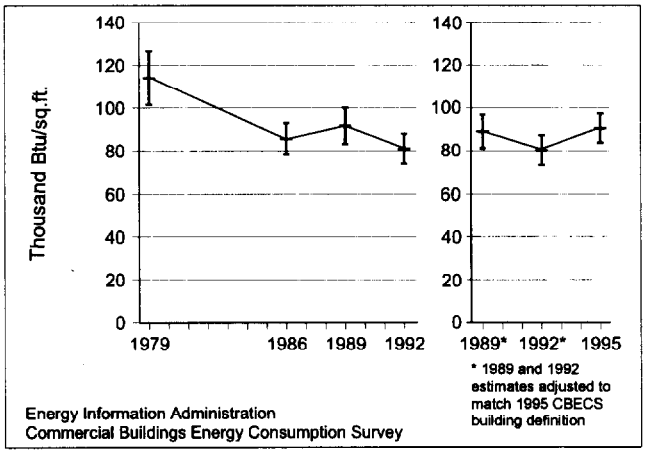

Figure 4. Total Site Energy Intensity, 1979 to 1992 and 1989 (adjusted) to 1995.

Total Energy Consumption and Intensity by Energy Source

Electricity and natural gas consumption exceeded the other major sources across the period 1979 to 1995. In 1995, electricity consumption was 2.6 quadrillion Btu, greater than natural gas consumption at 1.9 quadrillion Btu—together they accounted for 86 percent of total consumption (Figure 5). Neither energy source showed a significant change across the period.

Consumption for fuel oil and district heat were each less than one quadrillion Btu across the period, with district heat 0.5 quadrillion Btu by 1995, and fuel oil 0.2 quadrillion Btu. Both fuel oil and district heat showed a significant change from 1979 to 1992—total fuel oil consumption declined 65 percent while district heat consumption increased 88 percent.

The energy source-specific intensities (the intensities for only those buildings that used each source) for the four sources were quite different from each other (Figure 6). Natural gas and fuel oil intensities showed significant declines from 1979 to 1992; natural gas declined 32 percent and fuel oil declined 66 percent. Both electricity and district heat showed no significant changes (the apparent increase for district heat was not statistically significant because of the large standard errors associated with this source). The flat trend of electricity, in contrast to the decline for natural gas and fuel oil, reflected the increased use of electricity for additional end uses (e.g., space heating, office equipment).

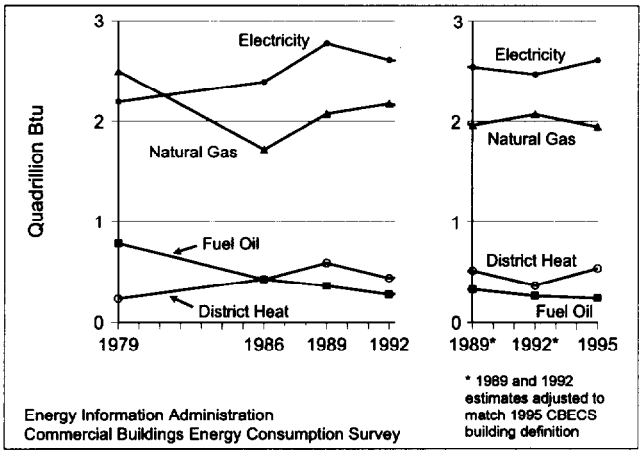

Figure 5. Site Energy Consumption by Source, 1979 to 1992 and 1989 (adjusted) to 1995.

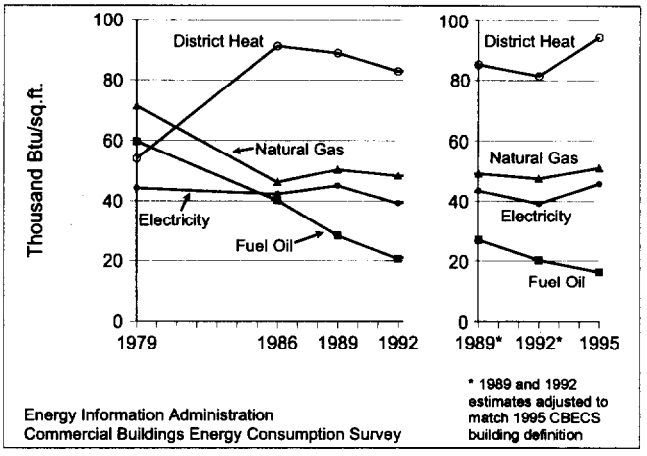

Figure 6. Site Energy Intensity by Source, 1979 to 1992 and 1989 (adjusted) to 1995.

Major Trends in Energy-Related Building Characteristics

End Uses

Many of the energy end uses in commercial buildings were energy source-specific, in particular end uses dominated by electricity (e.g., office equipment, lighting). There were, however, two major end uses for which the four sources competed—space heating and water heating. Over the period 1979 to 1995, the use of electricity for space heating (primary or secondary use) significantly increased from 25 to 38 percent of total floorspace (Figure 7). (That percentage is total floorspace of buildings with electric space heating divided by total floorspace of all buildings.) Over the same period, fuel oil use declined from 21 percent to 11 percent of floorspace. The use of natural gas and district heat remained constant, with natural gas the most used source for space heating at about 55 percent of floorspace. There were no

changes in the primary sources for space heating over the period 1986 to 1995 (data were not collected in 1979). Natural gas far exceeded the other sources as the primary space heating source (Figure 8) at about 50 percent of floorspace. Comparison of Figures 7 and 8 shows that if natural gas, fuel oil, or district heat, were used for space heating, then that source was also the primary space heating source. Electricity, in contrast, was often used as a secondary source—in 1995, 38 percent of floorspace used electricity for space heating, but only 23 percent used it as the primary source.

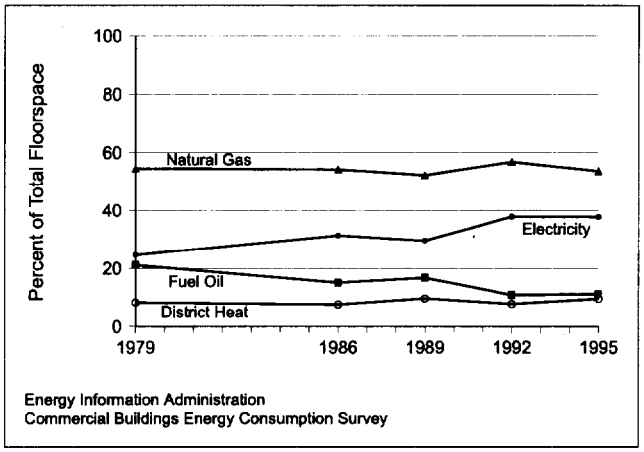

Figure 7. Energy Sources Used for Space Heating (Primary or Secondary), 1979 to 1995.

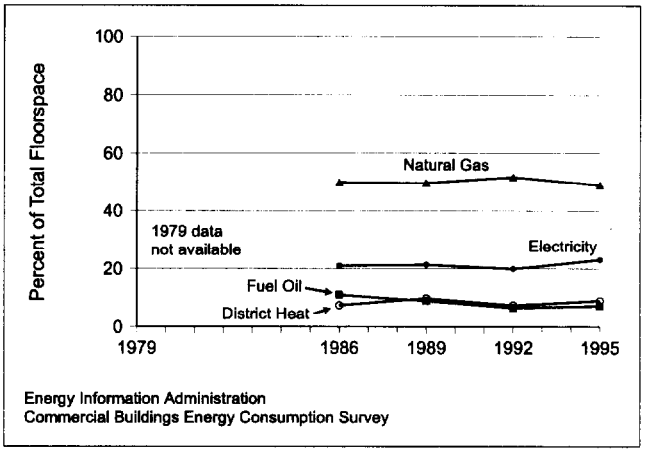

Figure 8. Energy Sources Used for Primary Space Heating, 1986 to 1995.

Natural gas and electricity were the most used sources for water heating (Figure 9), with natural gas at just over 40 percent of floorspace and electricity at just under 40 percent. Both fuel oil and district heat were used for less than 10 percent of floorspace in commercial buildings. The split of sources remained about the same from 1979 to 1995.

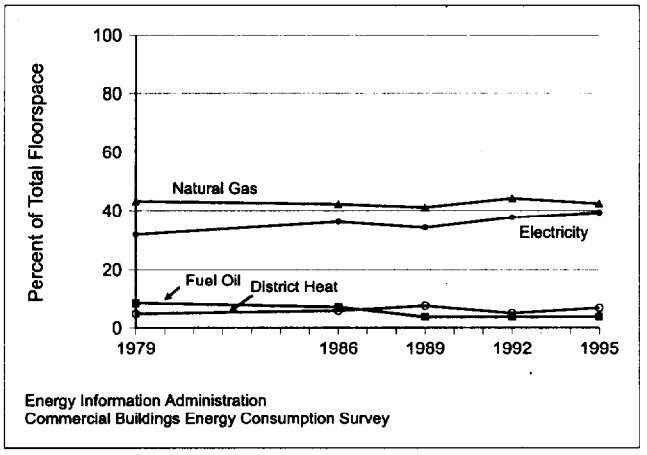

Figure 9. Energy Sources Used for Water Heating, 1979 to 1995.

Conservation Features

CBECS collected specific information on conservation features and practices for the three most recent CBECS only, but several features showed significant increases in use over that relatively short

time frame. Two types of building shell conservation increased in use from 1989 to 1995—exterior or interior shading or awnings (from 41 to 63 percent of floorspace) and storm or multiple window glazing (from 38 to 49 percent). The most used building shell conservation feature was roof or ceiling insulation, at 79 percent of floorspace in 1995. All of the other shell features exceeded 40 percent by 1995 (Figure 10).

Information on specific types of lighting and HVAC conservation were collected by the 1992 and 1995 CBECS (Figure 11). Three of the lighting features showed large increases in percentages of use—specular reflectors (from 22 to 31 percent of floorspace), natural lighting (5 to 11 percent), and occupancy sensors (from 5 to 10 percent).

Maintenance of HVAC systems was very widely practiced in commercial buildings (73 percent of floorspace in 1995). HVAC systems that had an economizer cycle (systems that can use outside air for cooling) were used for 28 percent of floorspace and variable air-volume (VAV) systems were used for 22 percent of floorspace (Figure 11).

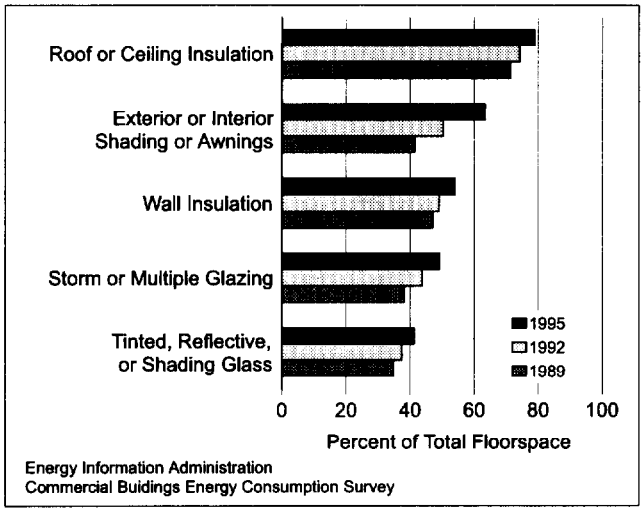

Figure 10. Building Shell Conservation Features Used, 1989 to 1995.

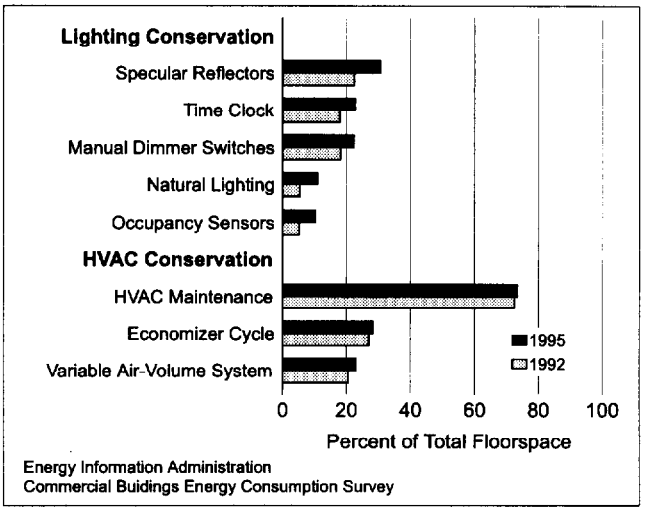

Figure 11. Lighting and HVAC Conservation Features Used, 1992 to 1995.

End-Use Consumption and Intensity—1995 CBECS

In 1995, energy consumption for each of the major end uses in commercial buildings was dominated by either natural gas or electricity with two exceptions, space heating and water heating, both of which consumed substantial amounts of fuel oil and district heat energy (Figure 12). Those two sources combined for 29 percent of space heating consumption and 30 percent of water heating consumption.

The three predominant end uses in commercial buildings (both consumption and intensity) were space heating, lighting , and water heating (Figures 12 and 13). Total consumption for both space heating and lighting was greater than 1 quadrillion Btu (1.7 quadrillion and 1.2 quadrillion Btu, respectively). The conditional space heating intensity (the intensity for buildings with space heating) was 38.3 thousand Btu per square foot and the lighting conditional intensity was 21.0 thousand Btu per square foot.

Lighting was the greatest consumer of electricity in commercial buildings (1.2 quadrillion Btu), followed by cooling (0.3 quadrillion Btu) and office equipment (0.3 quadrillion Btu). Conditional electricity intensity for lighting (23.8 thousand Btu per square foot of buildings with lighting) greatly

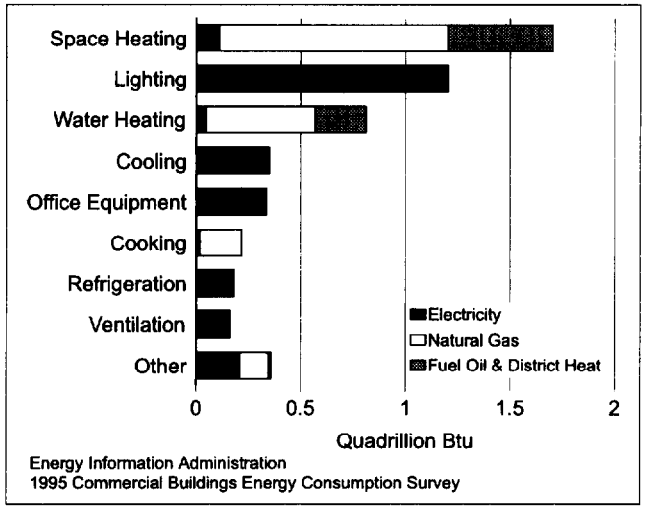

Figure 12. Site Energy Consumption by End Use, 1995.

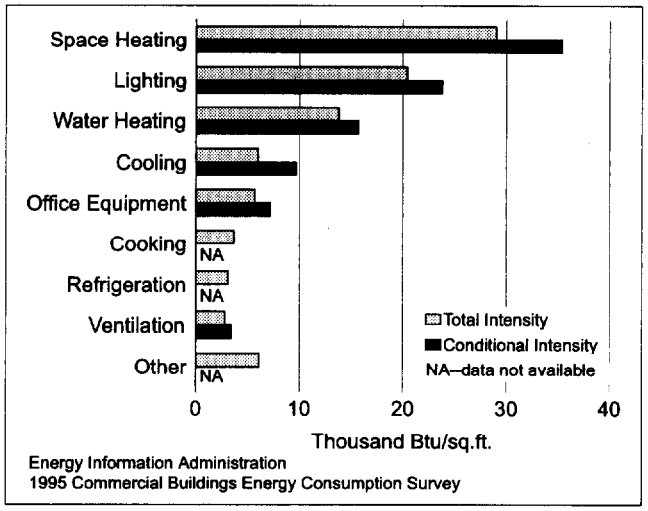

Figure 13. Total and Conditional Site Energy Intensity by End Use, 1995.

exceeded that of the other electricity end uses (Figure 14). Cooling intensity was next greatest at just over 10 thousand Btu per square foot of cooled floorspace. When site electricity consumption is expressed as *primary* electricity consumption, lighting consumption was 3.6 quadrillion Btu and lighting was the largest end use (space heating expressed as primary energy was 1.9 quadrillion Btu).

The three major end uses for natural gas were space heating (1.1 quadrillion Btu), water heating (0.5 quadrillion Btu), and cooking (0.2 quadrillion Btu). The conditional natural gas intensity for space heating (38.3 thousand Btu per square foot of heated floorspace) was substantially greater than that of water heating (21.0 thousand Btu per square foot of buildings with water heating), the next most intense natural gas end use (Figure 15).

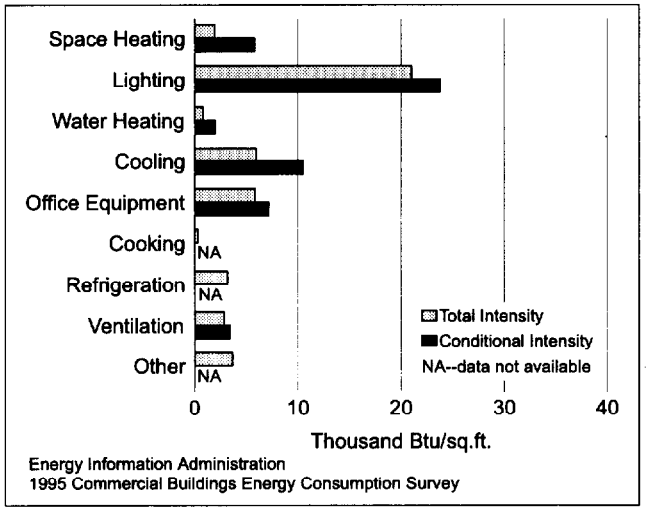

Figure 14. Total and Conditional Site Electricity Intensity by End Use, 1995.

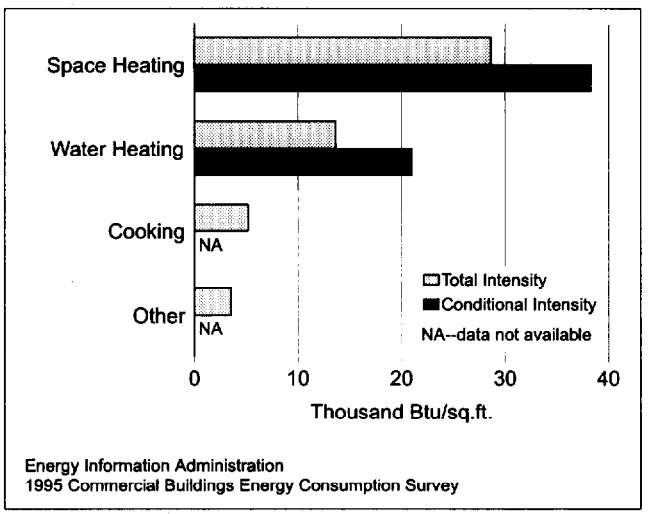

Figure 15. Total and Conditional Natural Gas Intensity by End Use, 1995.

Energy Consumption and Selected Major Building Characteristics—1995 CBECS

Principal Building Activity

Office buildings and mercantile and service buildings had the greatest total consumption of all building types (2.0 quadrillion Btu, 37 percent of total consumption) (Figure 16). Three building types, health care, food service, and food sales, had energy intensities that were significantly greater than any other building types—all three exceeded 213 thousand Btu per square foot, more than twice the average intensity for all buildings (Figure 17). Electricity and natural gas intensities for two of the types, health care and food service, were much higher than average, but the third type, food sales, had higher than average intensity for electricity only (Figures 18 and 19).

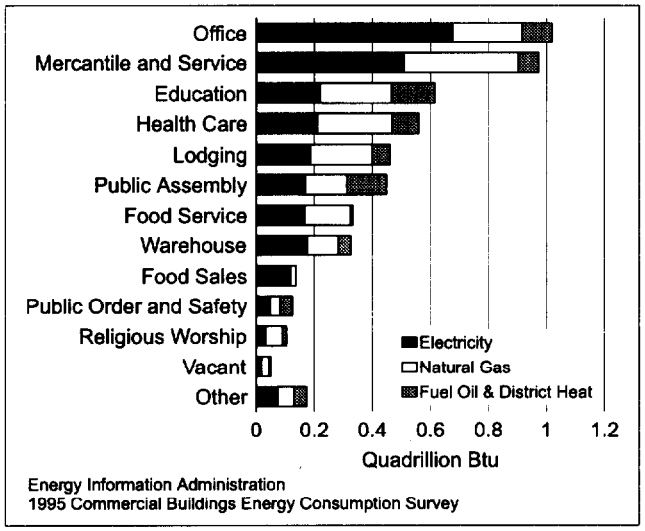

Figure 16. Site Energy Consumption by Principal Building Activity, 1995.

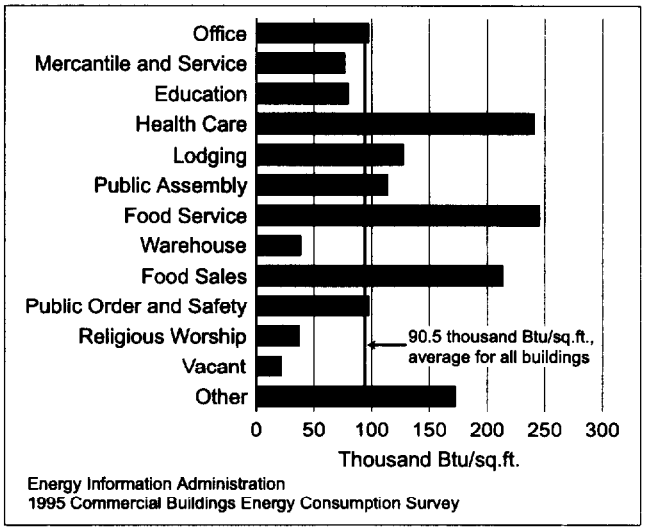

Figure 17. Total Site Energy Intensity by Principal Building Activity, 1995.

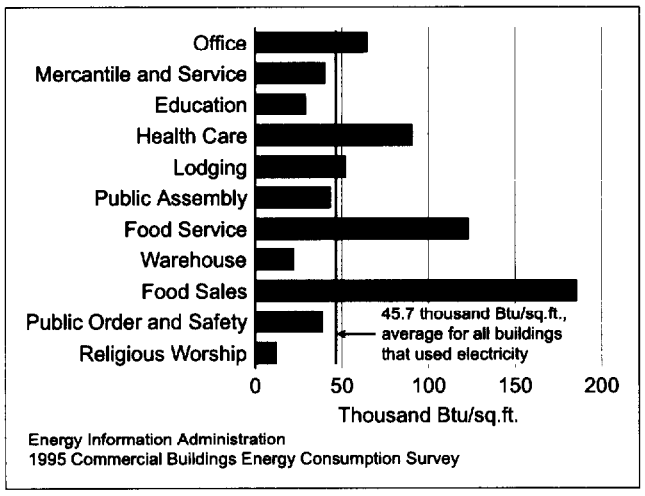

Figure 18. Site Electricity Intensity by Principal Building Activity, 1995.

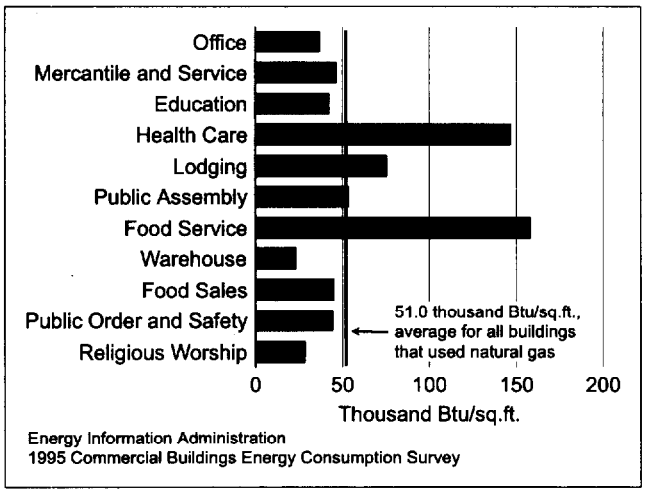

Figure 19. Natural Gas Intensity by Principal Building Activity, 1995.

Year Constructed

Fifty percent of total energy was consumed in commercial buildings constructed after 1970, buildings that comprised 48 percent of total floorspace (Figure 20). A relatively greater amount of total electricity was consumed in those buildings (59 percent of total electricity) compared to natural gas (43 percent of total natural gas). Electricity intensities were significantly greater in newer buildings than in older buildings (less than 36 thousand Btu per square foot for buildings constructed before 1960, and greater than 54 thousand Btu per square foot for those constructed since 1970) (Figure 22). The proportionally greater consumption of electricity and the higher electricity intensities in newer buildings were consistent with increased use of additional electricity end uses in newer buildings. There were no significant differences for either total or natural gas intensities across the year constructed categories (Figures 21 and 23).

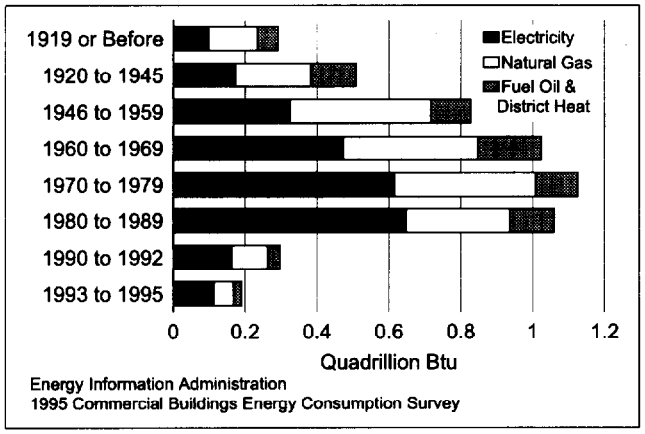

Figure 20. Site Energy Consumption by Year Constructed, 1995.

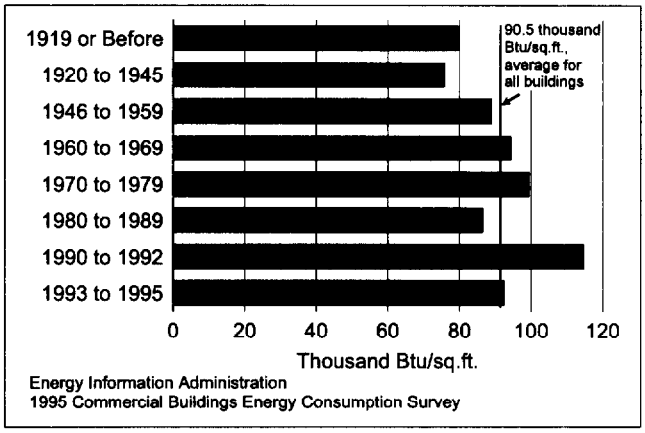

Figure 21. Total Site Energy Intensity by Year Constructed, 1995.

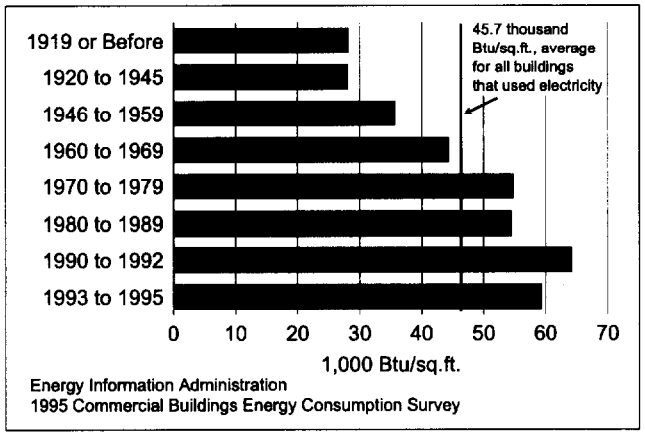

Figure 22. Site Electricity Intensity by Year Constructed, 1995.

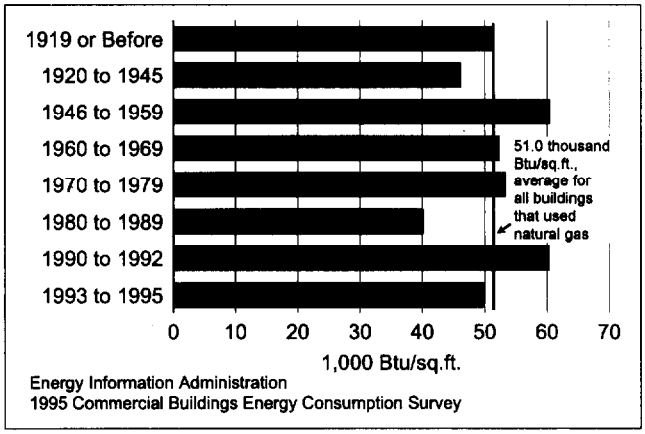

Figure 23. Natural Gas Intensity by Year Constructed, 1995.

Summary

When the Commercial Buildings Energy Consumption Survey was conducted in 1979 it was the first statistically representative, comprehensive national-level commercial *buildings* survey of any kind, and remains the only such national-level survey. The CBECS has tracked energy-related buildings characteristics and energy consumption in commercial buildings from 1979 to the most recent survey in 1995. Over the period, the number of buildings and total amount of floorspace increased, total consumption remained flat, and total energy intensity declined. By 1995, there were 4.6 million buildings that comprised 58.8 billion square feet of floorspace and consumed a total of 5.3 quadrillion Btu of energy. By 1995, electricity consumption was the single largest source of energy used in commercial buildings. Since 1979, total fuel oil consumption decreased and district heat consumption increased.

Over the period 1979 to 1995, natural gas far exceeded the other sources as the primary space heating source used (about 50 percent of total floorspace). Electricity became more widely used for space heating (either primary or secondary)—it increased from 25 to 38 percent of floorspace, while the use of fuel oil for space heating declined.

Several building shell and lighting conservation features showed significant increases in use. Two shell features—exterior or interior shading or awnings, and storm or multiple window glazing—increased in use from 1989 to 1995. Three lighting features had increased use from 1992 to 1995—specular reflectors, natural lighting, and occupancy sensors.

The three end uses that consumed the greatest amount of energy were space heating, lighting , and water heating; together they accounted for 70 percent of total consumption. Natural gas was the dominant source for both space heating and water heating (64 percent of total space heating consumption and 64 percent of total water heating consumption). The pattern of energy consumption in several of the categories of buildings characteristics are worth noting. Office buildings and mercantile and service buildings were the two buildings types that consumed the most amount of energy (37 percent of the total) in 1995. Total energy intensities were greatest for health care, food service and food sales buildings. Half of total energy was consumed in buildings constructed since 1970; however, electricity was used much more intensively in those buildings, consistent with the increased use of additional electricity end uses in newer buildings.

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