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Energy End-Use Intensities in Commercial Buildings

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Energy Information Administration
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Contacts

This publication was prepared under the general direction of W. Calvin Kilgore, Director of the Office of Energy Markets and End Use (202/586-1617), and Lynda T. Carlson, Director of the Energy End Use and Integrated Statistics Division (EEUISD) (202/586-1112). Specific information regarding the contents or preparation of this publication can be obtained from Dwight K. French, Chief of the Transportation and Industrial Branch (202/586-1126). Questions regarding the Commercial Buildings Energy Consumption Survey (CBECS) may be referred to Martha M. Johnson, Survey Manager (202/586-1135). The FAX number for all EEUISD personnel is 202/586-0018.

Detailed technical questions on the topics in this publication may be referred to the following members of EEUISD:

Eugene M. Burns	Principal Author, End-Use Estimates	(202) 586-1125
Jay K. Olsen	Data Imputation (other than end-uses)	(202) 586-1137

The following persons also made important contributions to this publication:

Vicki Moorhead	Table Preparation	(202) 586-1133
Hattie Ramseur	Report Production	(202) 586-1124

This report was undertaken in response to CBECS customer requests for more information on how energy is used in buildings, which was an overall theme of the 1992 User Needs Study. (See *User-Needs Study for the 1992 Commercial Buildings Energy Consumption Survey*, DOE/EIA-0555(92)/4 (Washington, DC, September 1992).) This is EIA's first report to present data on how much energy is used for heating, cooling, lighting, and other end uses in commercial buildings. We encourage comments from our readers. Feedback from the readers of this report will allow us to enhance our methodology and presentation as we undertake the end-use estimates based on the 1992 CBECS. Comments and suggestions regarding end-use estimates should be addressed to Eugene M. Burns by phone at (202) 586-1125, by FAX at (202) 586-0018, or by e-mail at eburns@eia.doe.gov. The mailing address is:

EI-632, Mail Stop 2G-090
1000 Independence Avenue, SW
Washington, DC 20585.

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Executive Summary

The demand for energy in U.S. stores, offices, schools, hospitals, and other commercial buildings has been increasing. This report examines energy intensities in commercial buildings for nine end uses: space heating, cooling, ventilation, lighting, water heating, cooking, refrigeration, office equipment, and "other." The objective of this analysis was to increase understanding of how energy is used in commercial buildings and to identify targets for greater energy efficiency which could moderate future growth in demand.

The source of data for the analysis is the 1989 Commercial Buildings Energy Consumption Survey (CBECS), which collected detailed data on energy-related characteristics and energy consumption for a nationally representative sample of approximately 6,000 commercial buildings. The analysis used 1989 CBECS data because the 1992 CBECS data were not yet available at the time the study was initiated. The CBECS data were fed into the Facility Energy Decision Screening (FEDS) system, a building energy simulation program developed by the U.S. Department of Energy's Pacific Northwest Laboratory, to derive engineering estimates of end-use consumption for each building in the sample. The FEDS estimates were then statistically adjusted to match the total energy consumption for each building.

This is the Energy Information Administration's (EIA) first report on energy end-use consumption in commercial buildings. This report is part of an effort to address customer requests for more information on how energy is used in buildings, which was an overall theme of the 1992 user needs study. (See *User-Needs Study for the 1992 Commercial Buildings Energy Consumption Survey*, DOE/EIA-0555(92)/4, Washington, DC, September 1992.) The end-use data presented in this report were not available for publication in *Commercial Buildings Energy Consumption and Expenditures 1989* (DOE/EIA-0318(89), Washington, DC, April 1992). However, subsequent reports on end-use energy consumption will be part of the Commercial Buildings Energy Consumption and Expenditures series, beginning with a 1992 data report to be published in early 1995.

Since EIA is publishing commercial energy end-use estimates for the first time, readers are urged to provide comments and suggestions for the improvement of 1992 and future end-use energy estimates.

Overview of Energy Consumption in Commercial Buildings

In spite of the gains in energy efficiency made since the 1970's, economic expansion and increases in energy-consuming services during the 1980's caused a net increase in energy consumption in the commercial sector. Energy demand in the commercial sector grew during the 1980's by 1.0 percent a year, second only to the transportation sector's rate of 1.4 percent a year. In contrast, energy demand in both the residential and industrial sectors declined during the 1980's. Commercial buildings in 1989 consumed almost 6 quadrillion Btu of energy for end uses and ran up an energy bill of over $70 billion.

By type of building, the three largest energy users were (a) office buildings (1.2 quadrillion Btu); (b) department stores, drugstores, gasoline stations, post offices, and other mercantile and service buildings (1.0 quadrillion Btu); and (c) education buildings (0.7 trillion Btu).

Of the various end uses, space heating accounted for the largest share of consumption (35 percent), followed by lighting (18 percent), water heating (9 percent), office equipment (7 percent), cooling (5 percent), ventilation (5 percent), cooking (5 percent), and refrigeration (3 percent).

Of the four major energy sources (electricity, natural gas, fuel oil, and district heat) consumed in commercial buildings in 1989, electricity accounted for almost 50 percent of all the energy delivered to commercial sites, while natural gas accounted for 36 percent of site consumption. Natural gas space heating and electric lighting were the

two largest consumers of site energy. However, the amount spent on electric lighting was more than double the amount spent on natural gas for all end uses, due to the higher price of electricity compared with the price of natural gas.

An "energy intensity" is the ratio of energy consumption to a measure of the demand for energy services. A common measure of energy intensity is the ratio of the amount of energy consumed for the building as a whole or for a particular end use to the square footage of a building's floorspace. More precise measures of energy intensity can account for such factors as building operating hours or weather conditions. Intensity ratios allow buildings to be compared in terms of energy consumption, even though they are of different sizes, are located in different climates, and have different operating hours.

Analysis of energy intensities for the buildings in the 1989 CBECS showed that:

- The highest energy intensities per square foot were found in buildings constructed in the 1960's, with buildings constructed in the 1980's continuing a trend towards lower intensities.

- Buildings in the coolest climates had the highest energy intensities per square foot because of their greater demand for space heating, despite their lower demand for cooling.

- Each type of commercial building had a different end-use intensity profile, with no two end-use profiles being alike. Some end uses, such as heating, cooling, ventilation, and lighting, were found, to some degree, in all types of buildings. However, other end uses reflected the special activities performed within particular types of buildings.

Space-Conditioning Intensities

Space conditioning--heating, cooling, and ventilation--accounted for 45 percent of all energy consumed in commercial buildings in 1989. Natural gas was the dominant energy source for space heating in commercial buildings in 1989, providing 63 percent of all the energy consumed for space heating.

- Whether electricity is measured by site energy (consumed by the end user) or by primary energy (consumed at the generating plant), natural gas provided a much higher percentage of the space heating energy consumed in buildings constructed during the 1980's than electricity did, even though the amount of floorspace heated by the two energy sources was roughly equal.

- Buildings constructed in the 1970's had the highest cooling intensities, defined as the ratio of energy used for cooling to the product of the cooled square footage, the annual building operating hours, and the average daily cooling degree-days (CDD's).

- Larger buildings had the highest ventilation intensities, defined as the ratio of energy used for ventilation to the product of the square footage and the annual building operating hours.

Intensities of Other End Uses

Other end uses--lighting, water heating, cooking, refrigeration, office equipment, and miscellaneous uses--accounted for 55 percent of all energy consumed in commercial buildings in 1989. Lighting intensities were defined as the ratio of energy used for lighting to the product of the lighted square footage and the annual building operating hours. Intensities for the remaining end uses were defined as the ratio between the energy used and the product of square footage and the annual operating hours.

- Office buildings had the highest intensities for lighting and for office equipment.

- Buildings constructed during the 1970's and 1980's had the highest lighting intensities, while the oldest buildings had the lowest lighting intensities.

- Food service and health care buildings had the highest water-heating intensities per square foot--more than five times the average for all buildings.

- Food sales and food service buildings had the highest energy intensities for cooking and refrigeration.

Targets for Reducing Energy Intensities

The method used to determine targets for reducing energy intensities was to extrapolate the energy consumption patterns of the 1980's buildings to the entire commercial building stock. Intensities were based upon the entire building stock, not just buildings using a particular fuel for a given end use. This method of extrapolation reflected both the level of penetration and the efficiencies of 1980's technologies in computing hypothetical consumption levels for the total building stock.

- If all commercial buildings used natural gas for heating with the same intensity as did buildings constructed in the 1980's, the total consumption of natural gas for space heating would fall 201 trillion Btu, or 17 percent.

- If all buildings used electricity for cooling with the same intensity as did buildings constructed in the 1980's, the total consumption of electricity for cooling would drop by 9 percent (23 trillion Btu). However, the consumption of electricity for ventilation would rise by 5 percent (14 trillion Btu), for a net reduction of 9 trillion Btu, or 2 percent.

The analysis showed that lighting and office equipment presented especially worthwhile opportunities for moderating future growth in energy demand by increasing energy efficiency. Although energy efficiencies may have improved during the 1980's, the demand for these two energy services, especially for office equipment, also increased dramatically.

- If all commercial buildings had the same lighting intensity as buildings constructed in the 1980's, consumption of electricity for lighting would increase 9 percent (94 trillion Btu).

- If all buildings used energy for office equipment with the same intensity as 1980's buildings, consumption of electricity for office equipment would increase by 26 percent (99 trillion Btu).

Section 1. Introduction

The demand for energy has been increasing in U.S. stores, offices, schools, hospitals, and other commercial buildings. To find out where the best opportunities lie for improving energy efficiency, this report looks at the intensities of energy use in commercial buildings in 1989, the latest year for which energy consumption figures for commercial buildings are available.

This report is the first published by the Energy Information Administration (EIA) on the topic of energy end-use consumption in commercial buildings. The study of end-use energy consumption is important for the understanding of how and why energy is used. Conceptually, the end-uses of energy provide an intermediate level of analysis, below the consuming unit (the commercial building) but above the actual equipment used to perform the end use.

This report is part of an effort to address requests from customers for more information on how energy is used in buildings--an overall theme of the 1992 user needs study. (See *User-Needs Study for the 1992 Commercial Buildings Energy Consumption Survey*, DOE/EIA-0555(92)/4, Washington, DC, September 1992.) Subsequent reports on end-use energy consumption will be part of the Commercial Buildings Energy Consumption and Expenditures series, beginning with a 1992 data report to be published in early 1995. It is hoped that each successive report will increase understanding of how energy is being used in commercial buildings and, consequently, of where the best opportunities for improving energy efficiency lie.

Report Outline

This report has five sections. Section 1 gives background information on energy consumption in commercial buildings and introduces energy end-use intensities. Section 2 presents an overview of energy consumption and energy intensities in commercial buildings. Section 3 is devoted to the largest end use: space conditioning--heating, cooling, and ventilation. Section 4 deals with all other end uses--lighting, water heating, cooking, refrigeration, and office equipment. The concluding section, Section 5, discusses potential targets for reducing end-use intensities in commercial buildings.

The main body of the report is followed by three appendices and a glossary. Appendix A discusses the methodology for developing the end-use intensity estimates. Appendix B consists of 13 tables presenting detailed energy end-use consumption data. Appendix C contains maps of U.S. climate zones and Census regions and divisions. The report concludes with a Glossary, which should be consulted for explanations of terms used in this report.

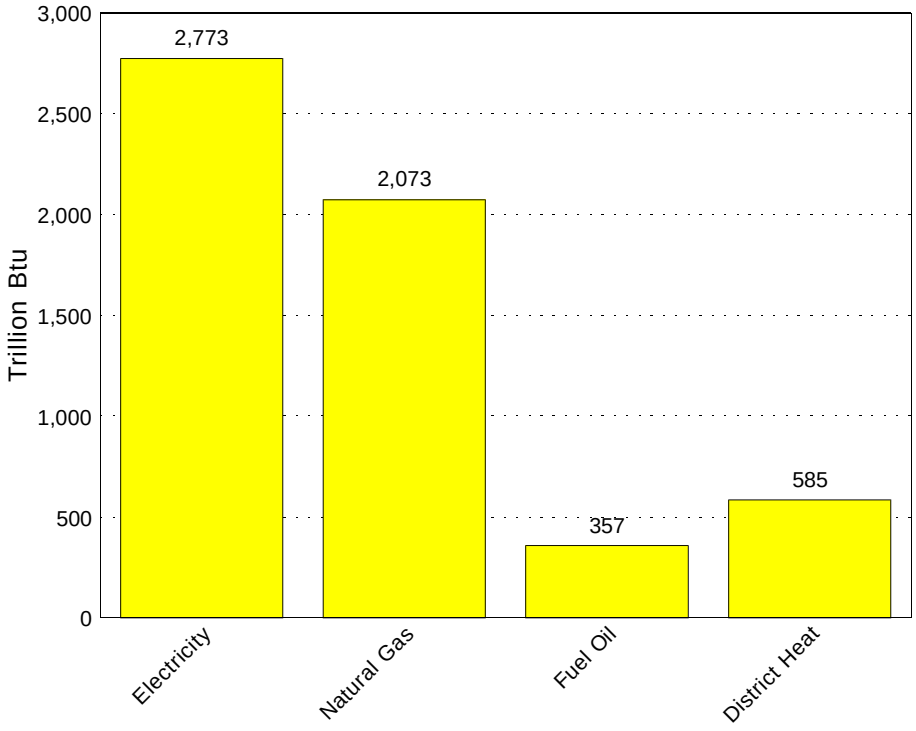
Trends in Energy Consumption in Commercial Buildings

In the 1960's, when energy was cheap and the earth's resources seemed inexhaustible, building designers seldom discussed the conservation of energy during the design process. They saw little reason for making a building in Maine look different from one in Florida, and they favored all-glass buildings in all regions. They considered the climate in which the building was located to be largely irrelevant.

Then came the oil supply disruptions of 1973 and 1979, which caused the price of oil to skyrocket and triggered fears about U.S. energy security. At the same time, reports on how fossil fuel emissions were damaging the air, water, plant life and wildlife made Americans aware of the need to protect the environment.

As a result, energy conservation became a major concern in the 1980's. New commercial buildings built in that decade were designed for their specific climates. They were well-insulated, with multipane and reflective windows, more efficient space conditioning equipment, and better lighting systems. Furthermore, many older buildings were retrofitted to improve their energy efficiency.

Figure 1. Energy Consumption in U.S. Commercial Buildings, by Energy Source, 1989



Source: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-871A through F of the 1989 Commercial Buildings Energy Consumption Survey.

In spite of the gains in energy efficiency made since the 1970's, an expanding economy and increases in energy-consuming services during the 1980's caused a net increase in energy consumption in the commercial sector. This demand was largely due to more computers and other office equipment, better lighting, and more comfortable heating, cooling, and ventilation. In the 1980's, energy demand in the commercial sector grew by 1.0 percent a year, second only to the transportation sector's rate of 1.4 percent a year. In contrast, energy demand in both the residential and industrial sectors declined during the 1980's.

In 1989, U.S. commercial buildings used 5.8 quadrillion Btu of energy, the equivalent to 260 million short tons of coal, 5.6 trillion cubic feet of dry natural gas, 1.0 billion barrels of crude oil, or 128 days of petroleum imports.

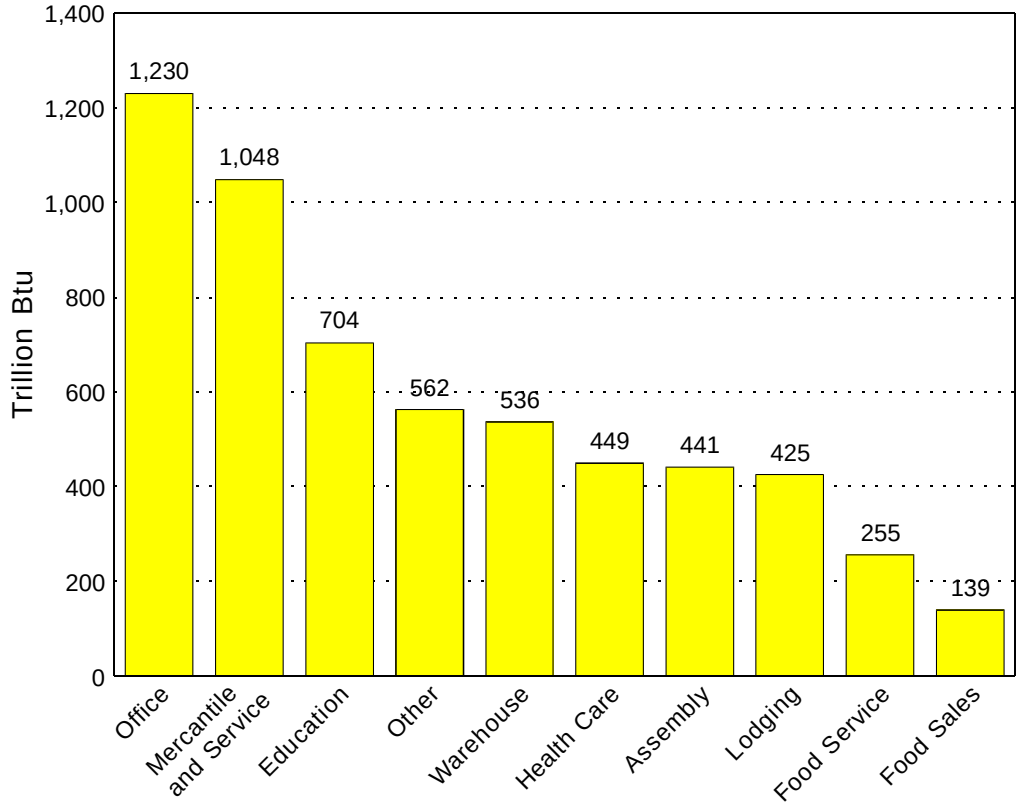
- Figure 1 shows that commercial buildings used 813 billion kilowatthours (2,773 trillion Btu) of electricity, equivalent to 478 million barrels of crude oil.

- Commercial buildings used 2.0 trillion cubic feet (2,073 trillion Btu) of natural gas, equivalent to 357 million barrels of crude oil.

- Commercial buildings used 2.55 billion gallons (357 trillion Btu) of fuel oil, equivalent to 61 million barrels of crude oil.

- Commercial buildings used 585 trillion Btu of district heat (steam and hot water delivered to a building from a central plant or utility), equivalent to 569 billion cubic feet of natural gas or 4.2 billion gallons of fuel oil.

Figure 2. Energy Consumption in U.S. Commercial Buildings, by Principal Building Activity, 1989



Source: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-871A through F of the 1989 Commercial Buildings Energy Consumption Survey.

- Figure 2 shows that the three largest energy users were: (a) **office** buildings (1,230 trillion Btu); (b) department stores, drugstores, automotive dealers, gasoline stations, laundries, post offices and other **mercantile and service** buildings (1,048 trillion Btu); and (c) **education** buildings (704 trillion Btu).

- The next largest energy users were: (a) **warehouses** (536 trillion Btu); (b) hospitals and other **health care** buildings (449 trillion Btu); (c) concert halls, night clubs, theaters, bowling alleys, indoor pools, skating rinks, auditoriums, convention halls, stadiums, and other buildings used for **assembly** (441 trillion Btu); and (d) hotels, motels, convents, dormitories, and other buildings used for **lodging** (425 trillion Btu).

- The smallest energy users were: (a) restaurants and other **food service** buildings (255 trillion Btu), and (b) supermarkets, grocery stories, bakeries, and other buildings used for **food sales** (139 trillion Btu).

- Laboratories, parking garages, public order and safety buildings, vacant buildings and all **other** commercial buildings not included in above categories used 562 trillion Btu.

Energy Intensities for Commercial End Uses

"Energy intensity" is the term used to express the ratio of energy consumption to a measure of the demand for energy services. A common measure of energy intensity is the ratio of the amount of energy consumed for the building as a whole or for a particular end use to the square footage of a building's floorspace. This is the measure used throughout Appendix B, "Detailed Tables." However, a more precise measure would consider the building's operating hours and climate. Taking these factors into account allows the energy intensities of buildings to be compared, even though the buildings are of different sizes, are located in different climates, and have different operating hours.

In this report, energy intensities are often measured by taking into account operating hours or climate. For example:

- Space-heating intensity is expressed as the ratio of the energy used for space heating to the product of (1) the number of square feet of heated floorspace in a building, (2) the building's annual operating hours, and (3) the average daily number of "heating degree-days" (HDD's). The HDD's for a single day are the difference between 65 degrees Fahrenheit and the average temperature if the average temperature is below 65 degrees Fahrenheit, and is zero otherwise. Obviously, the more HDD's a building experiences the higher will be its demand for space heating.

- Cooling intensity is expressed in the same way as space-heating intensity, except that "cooling degree-days" (CDD's) are used instead of HDD's. The CDD's for a single day are the difference between 65 degrees Fahrenheit and the average temperature if the average temperature is above 65 degrees Fahrenheit, and is zero otherwise. Again, the more CDD's a building experiences the higher will be its demand for cooling.

- Ventilation intensity is expressed as the ratio of the energy used for ventilation to the product of the square footage of the building and the annual building operating hours. Since ventilation is used for both heating and cooling, as well as for circulating air within a building, HDD's and CDD's are irrelevant.

- Lighting intensity is expressed as the ratio of the energy used for lighting to the product of the square footage of lighted floorspace and the annual building operating hours.

- All other intensities (water heating, cooking, refrigeration, office equipment, and "other") are expressed only as the ratio of the energy used for the particular end use to the square footage of building floorspace.

Data Sources and Methodology

The estimates of end-use energy intensities presented in this report were based on data from the 1989 Commercial Buildings Energy Consumption Survey (CBECS) in conjunction with end-use estimates modelled by the Facility Energy Decision Screening (FEDS) system.

The CBECS is a nationally representative probability sample of commercial buildings. For purposes of this survey, a commercial building is defined as one whose principal activity is not residential or industrial. The survey covers all commercial buildings over 1,000 square feet. For each of the roughly 6,000 buildings in the sample, the CBECS collects data on (1) energy-related characteristics of the building through personal interviews with the buildings' owners or managers and (2) total energy consumption for all end uses from billing data provided by the buildings' energy suppliers. The 1989 CBECS, which provides data for that calendar year, was used for the present analysis because this survey was the latest one available at the time the study was initiated. It is anticipated that the report containing estimates for 1992 will be published in early 1995.

The separate end-use consumption estimates were derived for each sampled building by using the FEDS system, a building energy simulation program developed at the Pacific Northwest Laboratory for the U.S. Department of Energy's Federal Energy Management Program and the U.S. Army Construction Engineering Research Laboratory. The FEDS engineering model was originally designed to assess the potential for energy retrofits at large federal installations. The FEDS was used to calculate the initial engineering end-use estimates for each building in the 1989 CBECS sample. These engineering estimates were then statistically adjusted to match the total energy consumption for each building.

The method for identifying targets for reducing energy intensities relied on the extrapolation of the energy consumption patterns of the 1980's buildings to the entire commercial building stock. This method highlights the ways in which new construction differs from the rest of the building stock. Thus, the end uses with significantly higher energy consumption would make the best targets for energy efficiency measures.

The method, performed for five major end uses (natural gas space heating and electric cooling, ventilation, lighting, and office equipment use), had two parts.

- First, the energy intensities of 1980's buildings were calculated by using the more precise measures of energy intensities. Energy intensities were calculated by principal building activity categories. For the five most numerous types of buildings in the CBECS sample (education, health care, mercantile, office, and warehouse), the buildings were divided into two groups: (1) small buildings, having 50,000 square feet of floorspace or less, and (2) large buildings, having over 50,000 square feet of floorspace.

- Second, estimates were made of the energy intensities and consumption for the five end uses, assuming that all buildings had the same end-use intensities as those of 1980's buildings.

The end uses that showed the greatest growth in consumption were identified as targets for energy efficiency measures.

For further information on sources and methodology, see Appendix A, "The Development of End-Use Intensity Estimates."