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Energy Consumption Series

Assessment of Energy Use in Multibuilding Facilities

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Contents

Tables

Figures

Executive Summary

The purpose of this report is to address a known problem in the Energy Information Administration's (EIA) data systems regarding energy consumption in buildings. The problem is in measuring the consumption of energy in a particular building that is located within a multibuilding facility that utilizes district heating and/or cooling. When such a building is surveyed by EIA, total energy use for that particular building is normally not measured and can only be estimated from related information that is provided for the multibuilding facility as a whole. Since a facility usually includes a wide variety of building types with differing heating and/or cooling requirements, the estimation procedures are subject to error. This then adversely affects the quality of the energy consumption estimates that are made for the surveyed building.

The 1989 Facility Survey, an adjunct to the 1989 Commercial Buildings Energy Consumption Survey (CBECS), was targeted at multibuilding facilities with central physical plants. The Facility Survey was intended to determine the best way to collect information on district heating and cooling for commercial buildings. The total energy delivered in the form of district heat to commercial buildings is of the same magnitude as the total energy delivered from fuel oil. Roughly three-quarters of the commercial floorspace with district heating or cooling receives that district heating or cooling, not from a utility, but from a central physical plant located on the same facility.

The two main objectives of the Facility Survey were:

- to improve CBECS estimates of district heat consumption for commercial buildings that lacked individual metering, and

- to estimate primary fuel consumption by central physical plants that provide energy to commercial buildings.

In terms of these main objectives, the 1989 Facility Survey was largely unsuccessful. Cases lacking building-level data tended also to lack facility-level output data. Accurate estimates of primary fuel consumption by central plants could not be produced due to the widespread inability of respondents to provide good data, the small sample size (361 eligible facilities, of which 124 did not respond), and the considerable amount of inherent variation of the population.

However, the Facility Survey was successful at discovering the characteristics of these multibuilding facilities.

Key Findings

- In 1989, one-third of all commercial buildings (1.5 million buildings) and 41 percent of all commercial floorspace (26 billion square feet) were located on multibuilding facilities (with or without central physical plants) (Table ES1).

- Although only 4 percent of all commercial buildings were located on multibuilding facilities with central physical plants, these buildings accounted for 13 percent of all commercial floorspace and 28 percent of all commercial buildings energy consumption in 1989.

These findings demonstrate the importance of multibuilding facilities for the analysis of energy consumption in commercial buildings. In particular, commercial buildings located on multibuilding facilities with central physical plants tend to be considerably larger than commercial buildings in general, and tend to be either engaged in energy-intensive activities such as health care, or associated with industrial activities. By CBECS definition, commercial buildings can have up to 49 percent of their floorspace devoted to noncommercial use, so that predominantly

commercial buildings on industrial facilities may include significant amounts of manufacturing energy use. District heat energy may also be overstated if consumption reported to CBECS includes energy transmission losses between the central physical plant and the sampled buildings.

Table ES1. Commercial Buildings on Multibuilding Facilities, 1989

Commercial Buildings	Number of Buildings (thousand)	Floorspace (million square feet)	Energy Consumption (trillion Btu)[a]
All Buildings	4,528	63,184	5,788
Buildings on Multibuilding Facilities	1,497	25,947	2,901
Buildings on Multibuilding Facilities with Central Physical Plants	203	8,346	1,593

[a]Electricity, Natural Gas, Fuel Oil, and District Heat (Steam and Hot Water).

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

Characteristics of Facilities

What are the multibuilding facilities?

- The types of multibuilding facilities with the most commercial floorspace were colleges, universities and other schools, office complexes, shopping centers and malls, hospitals, industrial facilities, and warehouses. Each of these types of facilities contained over 2 billion square feet of commercial floorspace in 1989.

- A total of 2.5 billion square feet of commercial floorspace, including 1.0 billion square feet of warehouses and 741 million square feet of offices, was located on industrial facilities.

- Government (local, State, and Federal) owned 35 percent of the floorspace on multibuilding facilities (9.0 billion square feet). Government buildings consisted primarily of colleges and universities (2.2 billion square feet), other schools (2.8 billion square feet), and offices (1.2 billion square feet).

What types of multibuilding facilities are more likely to have central physical plants?

- Eighty-three percent of the college and university floorspace was located on facilities with central plants. In contrast, only 21 percent of the "other schools" floorspace (mainly elementary and secondary schools) was located on such facilities.

- Among hospitals, 79 percent of the commercial floorspace was located on facilities with central plants.

- Slightly more than half (52 percent) of the commercial floorspace on industrial facilities was located on facilities with central plants.

- Warehouse facilities, shopping centers and malls, religious facilities, entertainment complexes, and hotels and motels were unlikely to have central physical plants.

What are the characteristics of multibuilding facilities with central physical plants?

- In 1989, there were about 30,000 multibuilding facilities with central physical plants and at least one commercial building. These facilities contained 12 billion square feet of floorspace.

- Overall, 61 percent of the floorspace on facilities consisted of commercial buildings. By sector, 92 percent of the floorspace on commercial facilities, and 21 percent of the floorspace on industrial facilities, was contained in commercial buildings.

- The mean floorspace per facility was 395,000 square feet. Among commercial facilities the largest were colleges and universities (1,393,000 square feet); the smallest were other schools (114,000 square feet). Industrial facilities averaged 298,000 square feet.

Energy Outputs and Inputs[1]

What are energy outputs produced by the central physical plants?

- Of the facilities with central plants, 75 percent produced steam, while 25 percent produced hot water, 18 percent produced chilled water, and 24 percent reported electricity generation. (However, the incidence of electricity generation was probably overstated.)

- Sixty-seven percent of the central plants on commercial facilities produced steam, 32 percent produced hot water, and 33 percent produced chilled water.

- The commercial sector accounted for 75 percent of all chilled water plants, but only 20 percent of all plants reporting electricity generation.

- Central physical plants produced 3.8 quadrillion Btu of output in 1989, which consisted primarily of steam (79 percent of the total).

- Although commercial sector central plants produced less than 20 percent of the overall total, they produced 68 percent of the hot water and 78 percent of the chilled water.

What types of energy are used as inputs by the central physical plants?

- Natural gas, used at 64 percent of the central plants, was the most common energy input. Fuel oil and electricity were each used at about half of the central plants

- Thirty-one percent of all facilities used both fuel oil and natural gas. This overlap in fuel use may reflect either separate equipment or equipment with dual fuel capability.

- Some regional differences were evident. Seventy percent of the commercial plants in the Northeast used fuel oil, while 99 percent of the plants in the Midwest used natural gas.

- Total inputs to central plants were estimated at 5.8 quadrillion Btu, 32 percent of which was natural gas. The commercial sector physical plants accounted for 1.2 quadrillion Btu, 50 percent in the form of natural gas.

- The overall ratio of energy output (3.8 quadrillion Btu) to energy input (5.8 quadrillion Btu) was 0.66.

- Based on 0.66 as the ratio of outputs to inputs, it can be estimated that 0.8 quadrillion Btu of primary energy would have been required to produce the 0.5 quadrillion Btu of district heat consumed by commercial buildings on multibuilding facilities in 1989.

[1]The estimates of central physical plant energy inputs and outputs are subject to a substantial amount of reporting error, particularly with regard to the quantities of energy involved. Despite their weakness, these estimates are being presented due to the lack of any comparable national data on this important aspect of commercial energy consumption.

Apart from particular findings, the 1989 Facility Survey also raised awareness of the importance of multibuilding facilities in general. To the extent that the facility, rather than the individual building, coincides with the economic decision-making unit, facilities represent a fruitful area for future work on conservation and energy management.

1. Introduction

This report presents findings from a methodological study to explore ways of improving energy data collection in the commercial energy sector, specifically relating to multibuilding facilities. Multibuilding facilities involve groups of buildings that are located at a single site, such as a college campus or a hospital complex. These facilities are owned and/or managed as a single unit, and frequently include a central physical plant which provides energy in the form of district heat to the individual buildings located on the facility. As such, they have presented significant data collection difficulties for the Commercial Buildings Energy Consumption Survey (CBECS), which is used by the Energy Information Administration (EIA) to collect energy consumption data from a sample of individual buildings in the commercial sector.

This study originally had two primary objectives: (1) to improve EIA's estimates of district heat consumption for commercial buildings in the CBECS sample that lacked individual metering and (2) to provide a basis for estimating primary fuel consumption by central plants serving commercial buildings. These objectives were later expanded to include additional questions relating to these central plants, including the extent to which they engage in cogeneration (which is more likely to be found at central plants than in ordinary commercial buildings), the amounts and forms of energy they consume (inputs), and the amount of energy they supply (outputs).

As an adjunct to the 1989 CBECS, EIA conducted a pilot Facility Survey using a sample selected from multibuilding facilities identified by CBECS respondents. The Facility Survey targeted district heating and cooling systems that presented the greatest problems for CBECS data collection--i.e., multibuilding facilities with central physical plants. The Facility Survey excluded multibuilding facilities with no central physical plant as well as facilities that did not include any buildings whose activities were primarily commercial in nature. Some industrial combined heat and power systems were included, but only in cases where the industrial site included at least one commercial building. The size of the multibuilding facilities ranges from large college campuses with central physical plants to small two-building systems in which an annex is heated with steam from a central plant located in the main building.

This chapter provides background information on the CBECS and on district heating and cooling, which is the most important type of energy-related service provided by multibuilding facilities with central physical plants. Chapters 2 and 3 present data results on multibuilding facilities from the 1989 CBECS and the pilot Facility Survey. Chapter 2 presents the characteristics of multibuilding facilities and the individual buildings located on these facilities. Chapter 3 provides estimates of energy inputs and outputs of multibuilding facilities with central physical plants. Chapter 4 assesses the quality of the pilot Facility Survey and includes recommendations for future work in this area. The appendices provide more detailed information on the Facility Survey itself, in particular the limitations on the use of these results.

Of particular importance is Appendix B, "Data Quality", which provides detailed information relating to the limitations of the data and the conclusions presented in this report. As a pilot study, the 1989 Facility Survey has some serious flaws and limitations which are recognized in this report. The methodology is nevertheless worth reviewing for its applicability to future work in this area. Given the absence of other comprehensive data, the survey results also provide useful insights (subject to appropriate caveats).

The Commercial Buildings Energy Consumption Survey

EIA is responsible for publishing national-level statistics on energy consumption by end users. Currently, the EIA publishes statistics for the residential, residential transportation (personal vehicles), commercial, and manufacturing sectors. For the commercial sector, consumption data are collected via a nationwide survey of commercial buildings, the CBECS.

The CBECS uses several different data collection strategies and instruments. The basic CBECS collects data only at the level of individual commercial buildings. In the Building Characteristics Survey, building characteristics, including physical and operating characteristics, are collected for each sampled building on the Building Questionnaire (Form EIA-871A). This form is administered by an in-person interview with a knowledgeable respondent.

The Building Questionnaire asks respondents to provide the names and addresses of the companies that supply energy to their buildings in the form of electricity, natural gas, fuel oil, or district heating and cooling and to sign a form authorizing EIA to collect billing information directly from these energy supply companies. A separate mail survey, the Energy Suppliers Survey, asks these energy suppliers to provide data on the amounts and costs of energy delivered to the building during the survey year. A specialized data collection form is used for each fuel type.

The survey design for the CBECS focuses on individual buildings in the sampling process, in the wording of the Building Questionnaire, and in the types of consumption data requested from energy suppliers. Ordinarily, this approach works well for surveys in the commercial sector, where energy consumption is largely building-related (i.e., energy is consumed to provide heating, cooling, lighting, and other services in the buildings where commercial activities take place).

The individual building approach does not work well, however, for buildings that are part of a multibuilding facility, as the relationships among all the buildings in such a facility make it difficult to collect data for individual buildings. In some cases, energy supplier data for individual buildings is nonexistent because energy sources are purchased for the group of buildings as a whole. A further complication arises at multibuilding facilities that include a central physical plant that transforms one source of energy into another form of energy. For example, natural gas may be transformed into steam or electricity that is supplied to the individual buildings.

CBECS data show that multibuilding facilities are a significant part of the commercial buildings sector, particularly with respect to district heating.

- In 1989, one-third of all commercial buildings (1.5 million) and 41 percent of all commercial floorspace (26 billion square feet) were located on a multibuilding facility.[1]

- Only 4 percent of all commercial buildings (203,000) were located on multibuilding facilities with central plants; however, these buildings accounted for 13 percent of all commercial floorspace and 28 percent of all commercial buildings energy consumption in 1989.

- District heating and cooling is found almost exclusively at multibuilding facilities. In 1989, commercial buildings located on multibuilding facilities accounted for 90 percent of all district steam or hot water consumed at commercial buildings (527 trillion Btu). Those located on multibuilding facilities with central physical plants accounted for 81 percent of all district steam or hot water consumed at commercial buildings (427 trillion Btu).

Data on district heating and cooling has been troublesome to track in the CBECS because respondents to the Energy Suppliers Survey typically cannot provide consumption data for individual buildings. The Facility Survey undertaken as an adjunct to the basic CBECS for 1989 was designed to learn more about energy use in multibuilding facilities, particularly with respect to district heating and cooling. The survey addresses both the consumption of district heating and cooling at individual buildings and the consumption of primary fuel at central physical plants.

[1]Energy Information Administration, Office of Energy Markets and End Use, *Commercial Buildings Characteristics 1989*, DOE/EIA-0246(89) (Washington, DC, June 1991), Table 52.

District Heating and Cooling in Commercial Buildings

District heating has been in use in the United States for over 100 years. There are three basic types of district heating systems in operation.

- **Systems associated with electric utility generating plants.** These systems, which circulate byproduct steam from electricity generation, were prevalent earlier in this century but lost ground to fuel oil and natural gas beginning in the 1930's and 1940's. As generating stations became larger, these systems were located further away from potential district heating customers, who took advantage of the increasing availability of alternative energy sources (fuel oil or natural gas) for their space-heating needs.

- **Systems operated by individual establishments, such as universities and hospitals.** This type of system, which may also provide chilled water for cooling, is the most common type today.

- **Systems operated by municipalities.** Currently the least common type of district heating, these systems are frequently part of urban redevelopment projects. In some cases, older district heating networks that were originally built and operated by utilities have been rehabilitated and are now operated by local authorities.

The lack of comprehensive and accurate national data makes it difficult to assess the extent of district heating and cooling.[2] The 1989 CBECS indicates that 13 percent of heated commercial floorspace was in buildings served by district steam or hot water, and 6 percent of air-conditioned commercial floorspace was cooled by district chilled water. Energy in the form of district heat accounted for 10 percent of the energy supplied to commercial buildings (585 trillion Btu) in 1989.[3]

The estimates for energy consumed as district heat have been increasing with each CBECS since 1979. Most of the increase, however, is recorded in older (pre-1980) buildings (Table 1) rather than in buildings constructed during the 1980's, and may reflect more accurate identification of district heating rather than actual increases in its use. The relative standard error associated with district heating estimates, however, is high. In the 1989 survey, for example, the relative standard error associated with the estimate for district heat consumption in buildings constructed between 1980 and 1989 exceeded 50 percent, rendering the estimate unpublishable.

CBECS surveys have evolved over the 1979-1989 period to reflect a growing understanding of the nature of district heating and cooling.

- Even though the 1979 and 1983 CBECS asked Building Characteristics Survey respondents whether purchased steam was brought into the sampled building, some respondents to the Energy Suppliers Survey portion of the survey provided no information on expenditures for "purchased" steam by these buildings. This disparity may relate to the unfamiliarity of CBECS respondents with financial details related to energy systems.

[2]International Energy Agency, *District Heating and Combined Heat and Power Systems: A Technology Review*, (Paris, Organization for Economic Co-Operation and Development, 1983), p. 258.

[3]Energy Information Administration, Office of Energy Markets and End Use, *Commercial Buildings Characteristics 1989*, DOE/EIA-0246(89) (Washington, DC, June 1991), Tables 79 and 80; Energy Information Administration, Office of Energy Markets and End Use, *Commercial Buildings Energy Consumption and Expenditures 1989*, DOE/EIA-0318(89) (Washington, DC, April 1992), Table 11.

Table 1. Estimates of District Heat Consumption by CBECS Survey Year, for Buildings Constructed Before 1980

CBECS Survey Year	Floorspace Served by District Heat (million square feet)	District Heat Consumption (trillion Btu)	Consumption (thousand Btu per square foot)
1979	3,593	192	53
1983	3,883	253	65
1986	4,367	390	89
1989	5,722	548	96

Notes: •The 1979 and 1983 CBECS asked for purchased steam; the 1986 CBECS asked for purchased and nonpurchased steam and hot water; the 1989 CBECS asked for district steam or district hot water piped into the building. •See the "Glossary" for definitions of terms used in this report. •Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Office of Energy Markets and End Use, 1979, 1983, 1986 and 1989 Commercial Buildings Energy Consumption Surveys.

- The 1983 CBECS included questions about the temperature and pressure of the delivered steam. Responses to these questions indicated that respondents were including both hot water and steam in their reported district "steam" consumption.

- The 1986 CBECS addressed the above sources of confusion by defining district heating and cooling and explicitly asking about both purchased and nonpurchased sources. The definition included district steam, district hot water, and district chilled water piped into a building from a central source that is located outside the building and serves more than one building.

- The procedures developed for the 1989 CBECS to identify district heating situations are now standard for CBECS. When estimates from the 1992 CBECS become available, the estimates are expected to remain in the range of the 1989 CBECS estimate.

The 1989 CBECS made a special, one-time effort to collect more accurate consumption data about district heating and cooling in commercial buildings by undertaking an adjunct survey of multibuilding facilities with central plants, the Facility Survey. The facility survey collected data, by mail, at the entire facility level, using the Facility Form EIA-871B (Appendix F), to supplement the usual CBECS building-level data. (See Appendix A, "The Facility Survey," for more information on how this survey was conducted.)

In designing the Facility Survey, it was necessary to establish clear, workable definitions of district heating and cooling. Some types of district heating and cooling were easy to identify (e.g., electric utilities that sell steam and municipal systems that resemble utilities). District heating or cooling purchased from a utility or similar vendor is usually metered and billed in much the same way as electricity or natural gas. Thus, consumption information is relatively easy to obtain for district heating and cooling purchased from utilities or municipal systems.

Roughly three-quarters of the commercial floorspace with district heating or cooling, however, is served by a central physical plant within the multibuilding facility itself.[4] Such systems typically do not meter steam, hot water, or chilled water use by individual buildings. Instead, they may maintain metering records for an entire district, for a system that serves several buildings, or for the total output of the central plant only. Some systems may not even maintain records of the overall output, in which case the only available data may be the total volume of fuel input to the facility.

[4]Energy Information Administration, Office of Energy Markets and End Use, *Commercial Buildings Characteristics 1989*, DOE/EIA-0246(89) (Washington, DC, June 1991), Tables 52 and 55.

Partly as a result of improved identification, the 1989 survey estimate for pre-1980 floorspace served by district heat was 31 percent higher than the 1986 CBECS estimate (Table 1). The improved identification of district heating also affects estimates of natural gas, fuel oil, and other fuels commonly used as central plant inputs. For example, estimates of commercial consumption of these fuels may be lower than they otherwise would be under procedures used in the earlier CBECS, since the 1989 CBECS more accurately identifies this consumption as inputs to central physical plant buildings rather than as consumption by individual commercial buildings.