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Commercial Energy Use: A Disaggregation by Fuel, Building Type, and End Use

Jerry R. Jackson
William S. Johnson

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CONTENTS

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ABSTRACT

This report describes the development of detailed estimates of energy use in the commercial sector. The level of detail includes five end uses, four fuel types, and ten commercial subsectors. Energy use estimates for each of the 200 components are developed for the years 1965 to 1975. Trends in commercial energy use by fuel type and end use are presented in a summary section; energy use estimates disaggregated by building type, fuel, and end use are presented in Appendices for 1970 and 1975.

The three distinct tasks required to develop these estimates are presented in detail. The first task includes reviewing, analyzing, and interpreting data on commercial energy use to reflect consistent commercial sector coverage. Floor space stock estimates are developed in the second task. In the third step, information on relative energy use by building type is synthesized from studies of individual buildings and is used, along with aggregate fuel and floor space estimates, to calculate detailed energy use by subsector and year. Energy use is presented both in terms of energy use indexes (Btu/ft^2) and energy consumed (Btu). The energy use estimates resulting from the reconciliation of fuel use, floor space, and engineering studies can be considered average figures for each subsector building type.

Future efforts to improve our estimation of disaggregated energy use are summarized in the final section.

1. INTRODUCTION

This report describes the development of detailed estimates of energy use in the commercial sector. As indicated in Table 1, the level of detail includes five end uses, four fuel types, and ten commercial subsectors. Energy use estimates for each of the 200 components are developed for the years 1965 to 1975. This study was initiated to develop input data for an engineering-economic model of commercial energy use. The surprising paucity of detailed information on commercial energy use prompted us to document our estimates and methodology in the hope that these data will prove useful to others concerned with energy consumption in the commercial sector.*

Two kinds of energy use data exist for the commercial sector. Detailed energy use information can be obtained from the results of metering existing buildings, from computer simulation studies, and from other sources such as trade associations. These data are typically quite accurate for the buildings covered in the studies. Their usefulness is limited, however, because of uncertainty about the representative

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*When we began our study, information on commercial energy use disaggregated by fuel, end use and, building type was virtually nonexistent. A recent report, undertaken by Jack Faucett Associates for the Consumption Studies Division of FEA, provides estimates of commercial subsector energy use that are similar to those developed in this report. The focus of our modeling work required a methodology that differs substantially from the Faucett approach; we can, however, incorporate information from the Faucett study in our estimation program in cases where the Faucett estimates are more accurate than our own. A comparison of both approaches and our future use of the Faucett work is examined in the fifth section of this report. General Electric's Center for Energy Systems recently embarked on a project to develop detailed energy use estimates for DOE. Results of this study are expected in the Fall of 1977.

Table 1. End use, fuel type, and subsector detail provided in ORNL commercial energy use estimates

End use	Commercial subsector
Space heating	Finance and other office-related activities
Cooling	Retail-wholesale
Water heating	Auto repair and garage
Lighting	Warehouse activities
Other	Educational services
	Public administration
Fuel type	Health care services
	Religious services
Electricity	Hotel-motel services
Natural gas	Miscellaneous commercial activities
Oil	
Other	

nature of such data with respect to the national buildings stock. Data on aggregate energy use are also available from utility associations (American Gas Association and Edison Electric Institute) and the Bureau of Mines. Because the definitions of terms vary among these groups, consistency adjustments to these data are necessary to relate the individual fuel use totals to a single commercial sector definition.

Detailed data sources can be related to aggregate energy use by means of capital stock estimates. For example, the fuel end use energy consumption characteristics derived from an office buildings study can be related to the total stock of office buildings to develop estimates of energy use by fuel and by end use for the national stock of office buildings. Because of the likelihood of using nonrepresentative values from a limited sample of office buildings, however, such an aggregation method is likely to provide aggregate fuel estimates that are at odds with existing estimates of aggregate fuel use. The biased nature of energy use data from individual buildings studies is caused primarily by the nonrepresentative climatic and structural characteristics of the building study area. Since this bias is likely to be of similar magnitude for all building types in the study area, information on relative values of energy use among building types can be used to more accurately reflect detailed energy use.*

Our methodology is illustrated in Fig. 1. Relative energy use information is used, along with an estimate of the stock of energy-using capital, to disaggregate total fuel consumption estimates. As indicated in Fig. 1, floor space is used in this study as a measure of the energy-using capital stock in commercial buildings.† Some additional information on fuel consumption is also required to complete the disaggregation process.

Figure 1 suggests the three distinct tasks involved in deriving detailed commercial energy use estimates. The first task includes reviewing, analyzing, and interpreting aggregate data on commercial energy use to reflect consistent coverage. Historical stocks of floor

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*Relative energy use information was developed from a detailed study conducted by Hittman Associates (ref. 37). Comparable data do not exist for other locations, so it is not possible to formally substantiate our claim that use of relatives rids the data of locational bias.

†Building designers typically "size" heating and cooling systems by determining the area served by these systems. Lighting requirements are also determined on the basis of illumination levels per square foot. Since most commercial energy is used to provide space heating, cooling, and lighting services (87% in 1975, see Sect. 2) and very little energy is used for processing, floor space represents an excellent proxy for the stock of energy-using capital.

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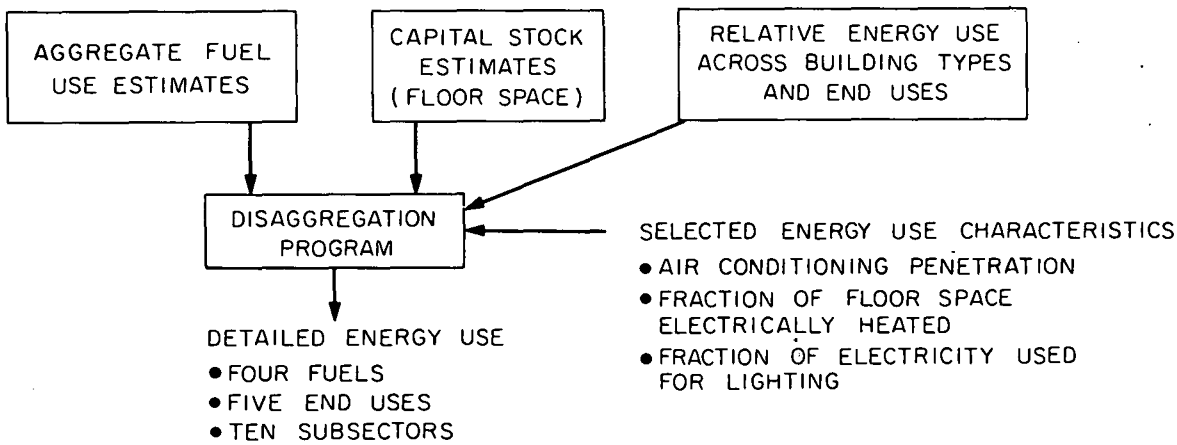

Fig. 1. Estimation of detailed commercial energy use.

space series are developed for commercial subsector building types in the second task. In the third task, information on relative energy use by building type is taken from individual buildings studies and is used, along with aggregate fuel and floor space estimates, to calculate detailed energy use by subsector and year.

Energy use estimates are provided in two forms. Our commercial sector engineering-economic energy use model requires information in terms of energy use per square foot of floor space (Btu/ft^2). These energy use indexes (EUI) are provided for each fuel end use combination for all ten subsectors. Information on energy consumption by each fuel end use combination is also provided for each subsector. A complete set of these data for 1970 and 1975 are presented in the Appendices.

The results of this analysis deserve attention for several reasons. Each fuel use estimate is adjusted to be consistent with our definition of the commercial sector. Considerable effort was also expended to improve on published estimates of commercial floor space by subsector. The most important feature of this analysis, however, is the reconciliation of data from energy use studies of individual buildings with estimates of the national stock of floor space and national energy use in the commercial sector. The energy use indexes which result from this reconciliation can be considered average figures for each subsector building type.

The remainder of this report is organized as follows. A summary of results is presented in Sect. 2. Section 3 outlines the development of our commercial fuel use estimates. In Sect. 4 we develop estimates of the stock of commercial floor space. Energy use indexes are developed by subsector and fuel type for each end use in Sect. 5. Section 5 also presents the process by which total energy use, floor space, and energy use figures from published studies are reconciled. A description of future efforts to improve our estimation of disaggregated energy use is summarized in Sect. 6.

2. COMMERCIAL SECTOR ENERGY USE: AN OVERVIEW

The major findings of our analysis of commercial energy use are presented in this section. The methodology used to develop these estimates is explained in detail in following sections.

Our definition of the commercial sector includes wholesale and retail trade; finance, insurance, and real estate; services; public administration; and buildings energy use in transportation, communication, electricity, gas, and sanitary services. We exclude from our analysis the consumption of energy for feedstock purposes, transportation services, and power generation services connected with the above activities.

Our estimates of aggregate commercial energy use are presented in Table 2 for selected years from 1950 through 1975. For comparative purposes, total energy use is also presented. As indicated in Table 2, energy use in the commercial sector grew at a faster rate than energy use for the nation. Commercial energy consumption represented 9.9% of the total energy use in 1950; with the exception of 1973 and 1974, the share of total energy consumed in the commercial sector steadily increased. In 1975 the commercial sector consumed 13.3% of total U.S. energy use.

The increasing importance of commercial energy use arises because the demand for services is increasing at a faster rate than total output of the economy. A number of changing societal factors contributed to this growth. The increase of secondary workers in the labor force created an increase in demand for services formerly provided in the home.

Table 2. Commercial and total energy use: 1950 through 1975 (10^{15} Btu)

Year	Total energy	Commercial energy	Commercial energy as percent of total
1950	33.99	3.37	9.9
1955	39.70	3.86	9.7
1960	44.57	4.53	10.2
1965	53.34	6.04	11.3
1970	67.44	8.28	12.3
1971	68.73	8.64	12.6
1972	72.11	9.28	12.9
1973	74.74	9.45	12.6
1974	72.88	9.19	12.6
1975	70.58	9.38	13.3

The recent growth of fast-food establishments is probably the most outstanding example of this phenomenon. Increasing real family incomes also contributed to the increasing economic importance of the commercial sector. Many of the services of commercial establishments can be classified as luxuries; as incomes increase many commercial sector services are purchased with increasing frequency (e.g., medical, recreational, and lodging services). While many of these causal influences are expected to diminish in the future (e.g., there is obviously an upper limit of 1.0 for female labor force participation rate), the increasing importance of commercial sector energy use appears likely to continue.

A disaggregation of total commercial energy use by fuel type reveals several interesting trends (Table 3). "Other" (coal and liquid natural gases) is the only fuel category that shows a continuous downward trend during the 25 years shown in Table 3. Gas and oil use increased through 1972; oil use then declined in 1973, 1974, and 1975; gas use also declined

Table 3. Commercial energy use by fuel type, 1950 through 1975

(10^{15} Btu)

Year	Electricity[a]	Gas	Oil	Other[b]	Total
1950	0.90	0.40	0.93	1.14	3.37
1955	1.32	0.61	1.22	0.71	3.86
1960	1.43	0.99	1.64	0.47	4.53
1965	2.43	1.22	1.96	0.43	6.04
1970	3.83	1.77	2.25	0.43	8.28
1971	4.11	1.98	2.12	0.43	8.64
1972	4.46	2.05	2.32	0.45	9.28
1973	4.71	2.03	2.30	0.41	9.45
1974	4.73	2.01	2.06	0.39	9.19
1975	5.04	2.05	1.92	0.37	9.38

[a]Electricity is reported in terms of primary energy; that is, losses in generation, transmission and distribution are included. The conversion factor varies for the years presented in the table from 11,300 to 16,450 Btu/kWhr. For conversion to SI units, 1 Btu = 1055 joules.

[b]Includes coal and liquid natural gases.

in 1973 and 1974 but increased again in 1975. The electricity series shows a continuous increase over the 25-year period.

Figure 2 presents fuel use in relative terms. Electricity's share of the energy market has doubled from 27% in 1950 to 54% in 1975. The coal and liquid natural gases ("other") market-share dropped precipitously from 34% in 1950 to 4% in 1975. Gas' share of the market increased from 12% in 1950 to 22% in 1960 and has held relatively constant since then. Oil captured an increasing portion of the commercial energy market from 1950 to 1960; however, oil's market-share has slowly declined from 36% in 1960 to 21% in 1975.

The aggregate data presented in Table 3 and Fig. 2 represent the only historical data series on commercial energy use that can be readily

Table 4. Commercial energy use by building type, 1975

Building type	Energy use[a] (10^{15} Btu)	Percentage of total energy use
Retail-wholesale	2.20	23.9
Educational	1.77	19.3
Finance and other office	1.44	15.7
Health	1.08	11.7
Hotel-motel	0.56	6.1
Public administration	0.40	4.3
Warehouses	0.32	3.5
Religious	0.26	2.8
Garages and service stations	0.09	1.0
Other	1.08	11.7
Total	9.20	100.0

[a]Energy use figures do not correspond exactly to totals given in Table 3 because of the slightly different estimates of "other" fuel use utilized in our estimation program. Electricity, gas, and oil totals are consistent with fuel use estimates in Table 3. See Sect. 5 for a more detailed discussion of these energy use estimates.

Table 5. Commercial energy use by fuel and end use, 1975 (10^{15} Btu)

	Space heating	Cooling	Water heating	Lighting	Other[a]	Totals
Electricity	0.33	1.83	0.04	2.09	0.76	5.05
Gas	1.66	0.14	0.08		0.17	2.05
Oil	1.88		0.10			1.98
Other[b]	0.12					0.12
Total	3.99	1.97	0.22	2.09	0.93	9.20

[a]Other end uses include cooking and electromechanical uses.

[b]Other fuels include coal and liquid natural gases.

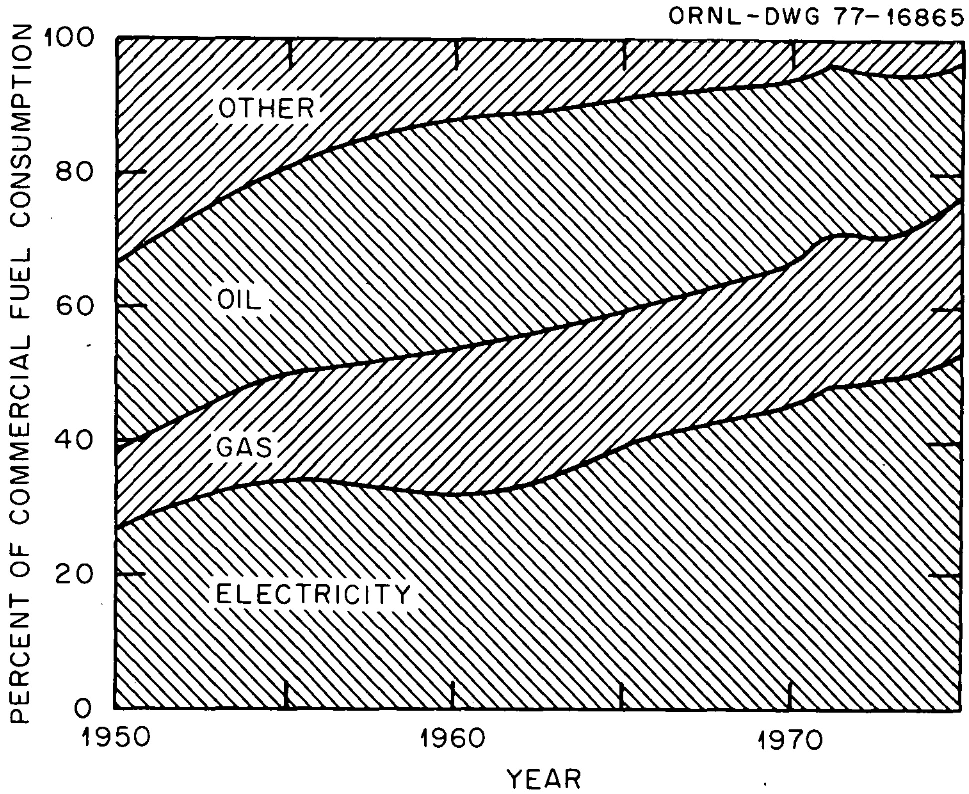

Fig. 2. Commercial energy use by fuel.

derived from public sources. Our modeling methodology necessitated the development of energy use estimates detailed by ten commercial subsector building types, four fuels, and five end uses.* Table 4 presents commercial energy use disaggregated by building type and Table 5 by each

*Our commercial subsector definitions relate specifically to building types. Some subsectors, such as educational services, represent both traditional subsector definitions (i.e. based on SIC codes) and specific building types. Other subsectors cut across SIC categories. For example, several SIC defined services (e.g., legal services) and the SIC category finance, insurance and real estate are assumed to correspond to our office-related subsector. The correspondence between building types and subsectors allows us to use these terms interchangeably.

fuel and end use combination for 1975. As indicated in Table 4, the major portion (71%) of commercial energy is consumed in four building types: retail-wholesale, office, health care, and education. No other building type (excluding miscellaneous) accounts for more than 7% of total energy use. The fuel end use disaggregation (Table 5) shows that the largest end use is space heating, which accounted for 42% of total commercial energy use in 1975. Lighting (23%) and cooling (21%) account for nearly identical shares. These two end uses are fueled almost entirely by electricity and they contrast with the space-heating end use where electricity represents only 8% of total space-heating energy use. The "other" end use, which represents largely electromechanical uses, is fueled primarily by electricity (natural gas in the "other" end use represents cooking). Ten percent of total commercial energy use is consumed by this "other" end use. In contrast to residential end-use patterns (where water heating consumes 14% of total energy use), commercial water heating represents an almost insignificant fraction (2%) of total energy use in the sector.

A historical perspective on the importance of different end uses is presented in Table 6 and Fig. 3. In terms of relative importance, end use characteristics of commercial energy have changed slowly over the last ten years. Electromechanical, cooling, and lighting energy use gained increasing shares of total energy consumption, while space heating and water heating shares declined. The effect of the oil embargo and the ensuing price increases is evident in Table 6. The large decline in space heating energy use in the 1973–1975 period reflects the fact that oil is used almost entirely for space heating (the price of commercial oil increased by 150% from 1972 to 1974) and the fact that there

Table 6. Commercial energy use by end use
(10^{15} Btu)

Year	Space heating	Cooling	Water heating	Lighting	Other[a]	Total
1965	3.124	1.037	0.1797	1.019	0.358	5.718
1966	3.296	1.145	0.1895	1.151	0.426	6.208
1967	3.519	1.261	0.2024	1.234	0.416	6.633
1968	3.650	1.365	0.2097	1.358	0.481	7.064
1969	3.760	1.466	0.2160	1.481	0.543	7.466
1970	3.979	1.605	0.2284	1.608	0.574	7.995
1971	4.149	1.735	0.2376	1.728	0.615	8.465
1972	4.333	1.876	0.2485	1.875	0.660	8.993
1973	4.319	1.945	0.2480	1.979	0.720	9.210
1974	4.050	1.899	0.2321	1.963	0.808	8.952
1975	3.995	1.962	0.2287	2.093	0.927	9.205

[a]Other end uses include cooking and electromechanical uses.

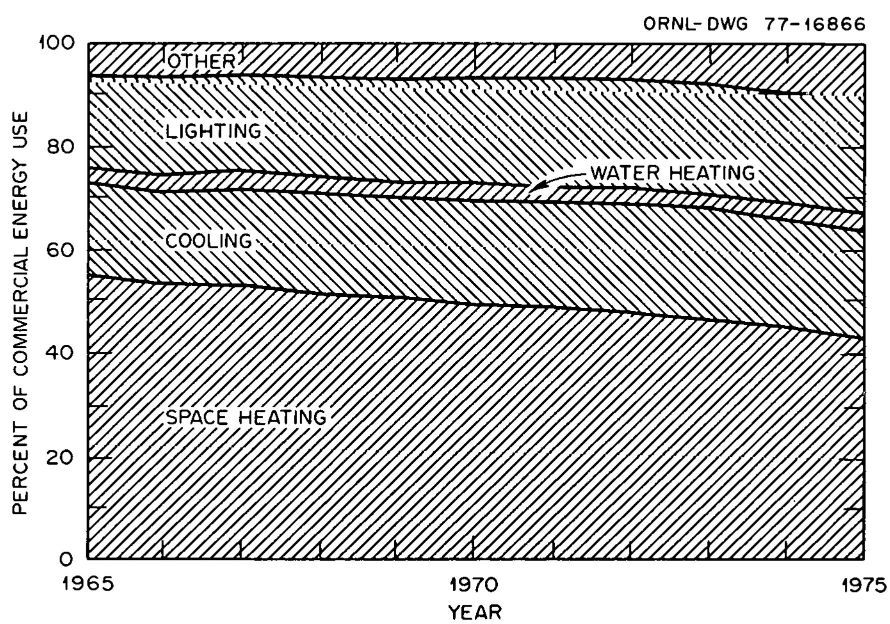

Fig. 3. Commercial energy use by end use shares.

is a relatively large conservation potential in space heating (the primary end use for oil). The effects of changing fuel prices are evident on the other end uses also, although not as dramatically. Since the stock of energy-using capital was relatively fixed in the 1973-1975 period, these changes represent almost entirely changes in energy use arising from behavioral changes such as thermostat set-back, delamping, etc.

An interesting characteristic of commercial energy uses is the diversity in energy use characteristics among building types. This variation is illustrated in Fig. 4 for the four most important building types. Energy use is presented as an energy use index (EUI) which is

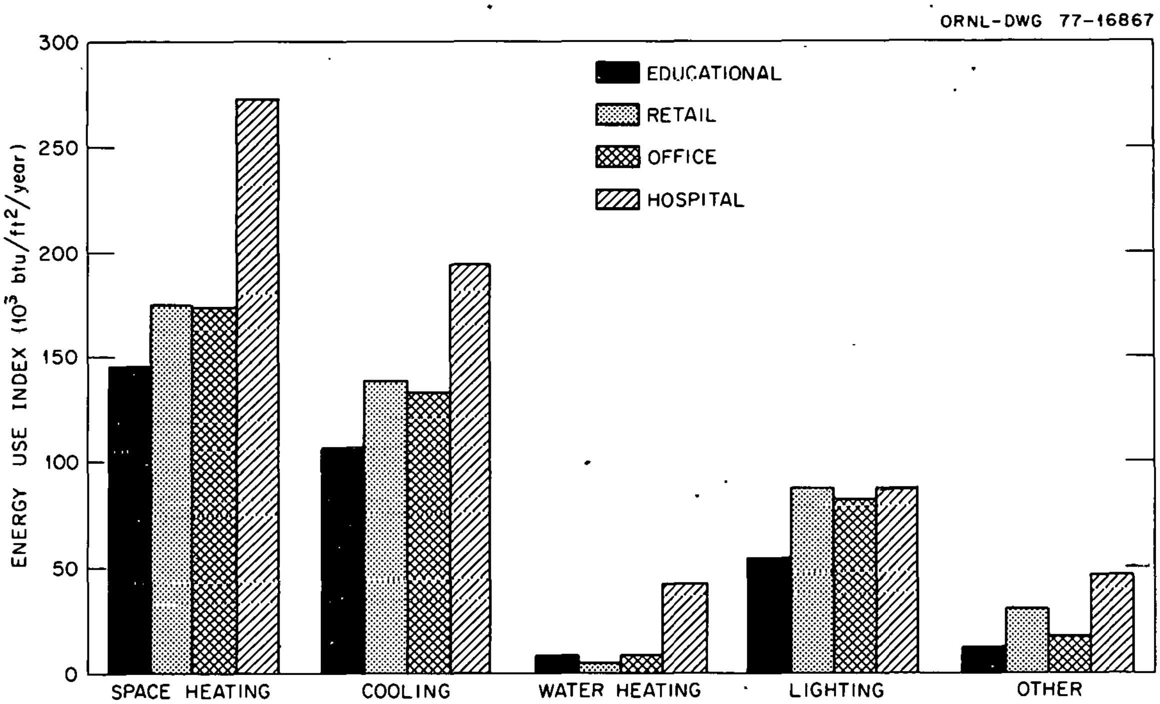

Fig. 4. Energy use indices for educational, retail, office, and hospital buildings, 1970.

a measure of energy used per square foot (Btu/ft^2) of floor space. As indicated in Fig. 4, a change in the building-type composition of the stock of buildings can be expected to have a substantial effect on aggregate energy use.

The energy use estimates presented above represent a considerable improvement in our knowledge of commercial energy use, especially historical trends by end use and building type. An equally important contribution of this study, however, rests in the development of a computerized algorithm that can be used to extend our estimates to other years and to quickly refine our estimates in light of new information.

The ensuing sections describe in detail both this methodology and the supporting data development.

3. COMMERCIAL FUEL USE

No commonly accepted definition of the commercial sector exists.[1] The definition used here includes activities in the following Standard Industrial Classification (SIC)[2] divisions:

SIC Division	Description
F	Wholesale trade
G	Retail trade
H	Finance, insurance, and real estate
I	Services
J	Public administration
part of E	Transportation, communication, electricity, gas and sanitary services

Only nontransportation and nongeneration activities occuring in post offices, transportation terminals, and communications and utilities buildings are of interest in division E. Since the focus in this study is on energy use in commercial buildings, we exclude asphalt and road oil consumption in the commercial sector and exclude transportation energy use related to the commercial sector.

Our objective in this section is to develop estimates of energy use by fuel type in commercial buildings. Our primary data sources are the Edison Electric Institute,[3] the American Gas Association,[4] and the Bureau of Mines.[5,6] The major problem in developing commercial energy use estimates by fuel concerns discrepancies between our definition of the commercial sector and the definitions used by the associations, the

Bureau of Mines, and the individual utilities. Consistency adjustments for each of the sources are detailed below by fuel type.

Natural gas. The American Gas Association (AGA) defines commercial gas customers to include: "service to customers primarily engaged in wholesale or retail trade, agriculture, forestry, fisheries, transportation, communication, sanitary services, finance, insurance, real estate, personal service (clubs, hotels, rooming houses, five or more households served as a single customer, auto repair, etc.) government, and to service that does not directly come in one of the other classification services."[7] Utilities reporting to the AGA are instructed to refer to the *Standard Industrial Classification Manual* to distinguish between industrial and commercial establishments.

The first adjustment to the AGA commercial gas use figures, as reported in *Gas Facts*, is to subtract gas sales to Agriculture, Forestry, and Fisheries (AFF), as estimated from the reported large volume gas sales.[8] This adjustment represents about 2% of our final estimated commercial gas use. Commercial gas use is also decreased by 22.2% to account for inclusion of gang-metered apartments in the AGA commercial definition. This figure was quoted by personnel at the AGA from an internal memorandum relating to 1970 gas use.[9]

Some gas used in public administration and reported by the AGA in an "other" category must be included in our estimate of commercial gas use. The AGA defines "other" customers as "service to municipalities or divisions (agencies) of state or federal governments under special contracts or agreements or service classifications which are applicable only to public authorities using gas for general or institutional purposes."[10] The "other" category includes some gas sales to municipalities for electric generation; this quantity is reported in a separate table and must be subtracted from other sales to derive the quantity of natural gas used for government institutional purposes.

Electricity. Commercial electricity use is derived from Edison Electric Institute's (EEI) statistical yearbook series.[3] Data on electricity use is submitted to EEI by individual electricity utilities. The EEI definitions are less precise than those used by the AGA. The *Glossary of Electric Utility Terms* reports that most companies classify customers as commercial or industrial using the Standard Industrial Classification or predominant kWhr use as yardsticks; others still classify as industrial all customers whose demands or annual use exceeds some specified limits — generally based on rate schedules.[11] The EEI commercial category ("small light and power") undoubtedly captures the bulk of electric energy used in the commercial sector. However it is difficult to know how closely this coverage corresponds to our commercial definition.

The inclusion of gang-metered apartments in the "small light and power" category also requires some adjustment. Jack Faucett Associates estimates electric use in gang-metered apartments as 4% of EEI's residential electric use total.[12] We subtract this figure from the "small light and power" total to factor out the electricity used by gang-metered apartments. The EEI "other public authorities" category includes "electric energy supplied to municipalities or divisions of agencies of federal or state governments (as ultimte customers) under special contracts or agreements or service classification applicable only to public authorities, except such items as are includable" in the other EEI classifications (sales for resale, street and highway lighting, etc.).[13] These other electric sales are included in our commercial electric use.

Petroleum. Commercial petroleum use is assumed to consist of all residual fuel oil used for space heating and a fraction of distillate oil used for space heating, as reported by the Bureau of Mines.[6] There is little disagreement that residual fuel oils used for space heating are properly assigned to the commercial sector. It is difficult, however, to determine how much of the distillate fuel oil is used for heating in the commercial sector. One approach to estimating the fraction of distillate oil that belongs under commercial petroleum use is to use data from the Census of Housing to determine the number of oil-burning space heating units in the residential sector and then to apply some average energy use estimates (by geographic area) to separate the residential use of distillate oil. This approach was followed; we assumed that 35% of distillate fuel oil reported as used for space heating is actually used in commercial establishments. This fraction was obtained from estimates derived for the AGA's TERA model as reported in the 1976 *National Energy Outlook*.[14]

Other fuels. Other fuels consists of coal and liquid gases. We could find no convincing information with which to disaggregate the Bureau of Mines residential/commercial use of these fuels[5] into their subsectoral components. We arbitrarily computed commercial use by multiplying total "other fuel" use by a fraction that represents commercial energy use divided by total residential/commercial energy use. This fraction is 0.38 for 1970; that is, 38% of coal and liquid gases are assumed to be consumed in the commercial sector. This admittedly crude procedure is partially justified because of the diminishing importance of these fuels (4% of total commercial energy use in 1975).

Table 7 summarizes our adjustments to AGA, EEI and Bureau of Mines data to derive energy use in commercial buildings. These adjustment procedures were used to derive the commercial energy use estimates by fuel type as shown in Table 3.

Table 7. Commercial energy use consistency adjustments to primary data sources

Fuel	Data source[a]	Add	Subtract
Electricity	Edison Electric Institute, *Statistical Yearbook*	• Small light and power sales, • Other public sales	• 4% of residential sales
Natural gas	American Gas Association, *Gas Facts*	• Commercial sales, • Other sales	• 22.2% of commercial sales, • Agriculture, Forestry and Fisheries gas sales, and • Gas sold to utilities included in other sales
Oil	Bureau of Mines, *Sales of Fuel Oil and Kerosene*	• Residual fuel oils used for space heating and • 35% of distillate oils used for space heating	
Other[b]	Bureau of Mines, annual news releases	• Residential/commercial use of coal and liquid gases	• Portion ascribed to residential sector. Residential fraction equals ratio of residential gas, electricity, and oil use to residential/commercial gas, electricity, and oil use

[a]Full references to these sources are given in refs. 3, 4, 5, and 6.

[b]Includes coal and liquid natural gases.

4. COMMERCIAL FLOOR SPACE

The second step in the development of a detailed picture of commercial energy use involves estimation of the stock of floor space by building types. Stock estimates are derived for ten building types for the years 1925 to 1975. Because the commercial model is calibrated for 1970, evaluation of our floor space estimates focuses on the year 1970.

The methodology used in this study to develop floor space estimates is often referred to as the additions approach.[15] This methodology consists of the following steps:

1. estimation of the stock of floor space in 1924;
2. summation of annual data on floor space additions (available in published sources for years following 1925);
3. subtraction of a fraction of floor space to account for building removals.

Many difficulties are encountered with this approach. Aside from the obvious problems in steps 1 and 3 above, the primary floor space additions data represent incomplete geographical coverage until 1970.

The only alternative to this approach is to use the results of cross-section studies to relate floor space to some index of activity and to use that factor to estimate floor space in years where the value of the activity index is known. While this approach might yield useful results for some building types (e.g., hospitals, where industry floor space "rules of thumb" can be used with an annually published inventory, such as number of hospital beds), most sectors are not characterized by such convenient activity indexes. The ratios relating floor space to an activity index also can be expected to vary over time so that the accuracy of any resulting historical series is questionable.

The information in these cross-section studies is useful however. For some building types, such as office buildings and schools, we use a single point-in-time floor space estimate, along with the floor space additions data, to derive an implied initial (1924) stock of floor space. For other building types, including public buildings and hospitals, the alternative estimates provide a cross-check for our additions-derived stock figures. For the hotel-motel building series, we use the cross-section approach exclusively to develop a limited stock series. The rapid removal of hotel buildings apparent in the data provided by the American Hotel and Motel Association suggests that the decay function used to estimate building removal rates for other commercial buildings is not appropriate in the hotel-motel sector. This problem is examined in more detail later in this section.

The remainder of this section is organized as follows. First, the primary data source on floor space additions is described. Next we discuss and offer our resolution to a number of problems encountered in applying the additions approach. Estimated stock series are then developed for each of our ten building types. Finally, historical trends apparent in these series are briefly examined.

Floor space additions data. The F. W. Dodge Division of McGraw-Hill Information Systems Company allows publication of a portion of its proprietary data on the value and floor space of buildings added in an annual series extending back to 1925. Data are disaggregated by seven commercial building types. The *Historical Statistics of the United States, Colonial Times to 1970*[16] provides a convenient source of additions data for the first 46 years of the series; more recent additions data are available in the *Statistical Abstract of the United States*[17] series. According to the series definition in the *Historical Statistics,* these additions data "are based upon daily reports by the F. W. Dodge field staff. This field staff contacts owners, architects, engineers, contractors, financial institutions, real estate brokers, and others able to supply reliable information on construction projects. The series include new construction, additions, and major alterations within 60 days of work start."[18]

The seven Dodge building categories are:

Commercial — Stores and other mercantile buildings (shopping centers and restaurants), office and bank buildings, commercial garages, and service stations.

Educational — Public and private school buildings (elementary, secondary, higher education, and related buildings).

Hospital and institutional — Public and private hospitals, other health treatment buildings, and related buildings.

Public — Federal, state and local public administration buildings, penal and correctional buildings, post office buildings, and police and fire stations.

Religious — Houses of worship and religious training buildings.

Social — Bowling alleys, theaters, and auditoriums.

Miscellaneous — Passenger terminals, freight terminal buildings, hangers, and other miscellaneous nonresidential and nonindustrial buildings.

Further disaggregation by building types [to 72 commercial building types and geographical area (to county level)] is available. Unfortunately the cost of such disaggregation is beyond most research budgets.

It is difficult to evaluate the quality of these data. Little public information is available to determine the accuracy of the Dodge data; the proprietory nature of the data series makes any large scale assessment extremely expensive. Our comparison, later in this section, of cross-section stock estimates and estimates from additions data suggests that the Dodge data are probably correct to within 10 to 15% of actual additions.

Difficulties in implementing additions methodology. Three major difficulties are posed by the additions approach. Since floor space additions are available only from 1925, the 1924 stock must be estimated. In addition, a simple summing of additions by year ignores the removal of commercial building from the stock. A decay rate must be applied to additions to take account of this removal. Finally, Dodge floor space additions data do not include construction in 11 western states until 1956. Although Alaska and Hawaii are ignored until 1970, this omission is not important because construction activity in these two states represents no more than 1% of commercial building construction activity in the pre-1970 period.[19] The analysis developed later in this section suggests that in the 1950s these unreported areas accounted for about 20% of the total national additions. Our resolution of these problems is discussed below.

1. <u>1924 stock estimates</u>

The importance of the initial stock estimate varies by building type depending on the historical growth of the commercial subsector. For example, information on the age distribution of retail buildings and office buildings standing in 1969 shows actual floor space before 1925 to be 13% of the rapidly growing retail subsector and 26% of the more slowly increasing stock of office buildings.[20]

Two methods are employed to estimate the 1924 stock of floor space. When cross-section estimates of the stock are available and considered to be fairly accurate, we use this point-in-time estimate, floor space additions, and a decay rate to work "backwards" to establish an initial stock. When little confidence is placed in the cross-section estimates, the 1924 stock is estimated independently of the additions data. The approaches used to derive these independent estimates are described later in our discussions of the individual building type series.

2. <u>Removal rate</u>

Determining the stock of floor space by the additions method requires the assumption of a removal, or decay, rate for commercial buildings. Actual removal rates depend upon a number of factors including deterioration of buildings over time, population shifts, and perceived changes in consumer tastes relative to marketing practices. Unfortunately, little information exists on the removal of structural capital in the commercial sector. We, as others before us, bow to the 45-year estimate attributed by A. D. Little to the National Bureau of Standards (NBS) as average commercial building lifetimes.[21] Because of the rapid increase in the number of commercial buildings within the last two decades, the uncertainty over a decay rate is not as serious as it at first appears. For example, a study published by the Treasury Department indicates that 50.5% of all office buildings standing in 1969 were built in the preceeding twenty years; an even greater percentage of the 1969 retail and wholesale floor space stock (71.3%) was added in the 1950-1969 interval.[20] Therefore the estimated stock for recent years is relatively insensitive to average building lifetimes differing by five or ten years from our estimated 45 years.

We chose the following function to estimate the fraction of floor space remaining t years after construction.

$$f(t) = 1 - \frac{1}{1 + \exp\,(6.91 - 0.1536\ t)}$$

Figure 5 illustrates the assumed decay function as well as the more commonly used exponential decay function. Our assumed decay function shows a very low removal rate for the first 20 years; only 2% of the original stock is removed. In the following ten years an additional 7% is removed. From thirty to forty years, however, the removal rate increases and an additional 23% of the original stock is demolished. The exponential decay rate represents a much different removal picture, as is evident in Fig. 5. After ten years, the exponential function predicts a removal of 16% of the original additions. There exist no data to empirically confirm or refute our assumed (or any other) decay function. The close correspondence noted later in the section between

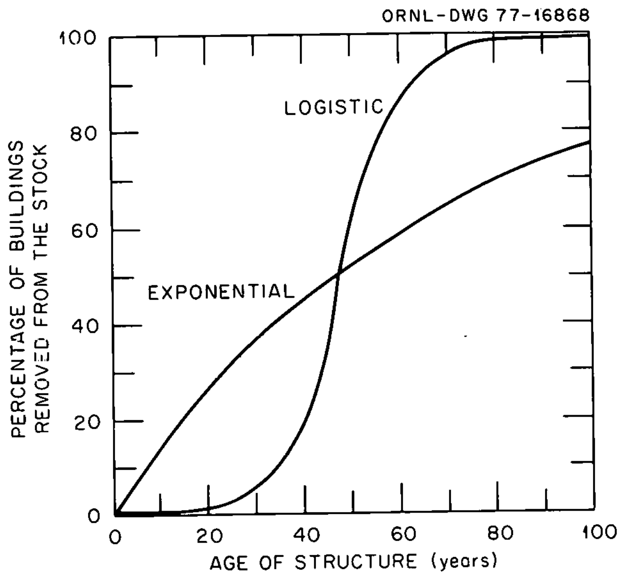

Fig. 5. Comparison of logistic and exponential decay functions.

some of our additions stock estimates and the cross-section stock estimates can be cited, however, as some indication that the lower removal rate in the early lifetime of a building is a more realistic assumption.

3. Incomplete geographical coverage

Dodge data on floor space additions do not include construction in 11 western states (Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, and California) until 1956. This omission is significant, especially in the later years. A rough idea of the coverage problem can be derived by calculating the fraction of the total U.S. population living in these 11 western states. This fraction is presented for selected years in Table 8. Simply inflating the additions data by this fraction is not appropriate, however, since one would expect more new construction in the West because of the more rapid

Table 8. Inflation of F. W. Dodge additions data

Year	West population / U.S. population	Simple population inflation factor	Population and growth inflation factor
1925	0.09	1.104	1.127
1930	0.10	1.111	1.144
1935	0.10	1.112	1.120
1940	0.11	1.122	1.182
1945	0.13	1.144	1.393
1950	0.13	1.153	1.216
1951	0.14	1.157	1.237
1952	0.14	1.163	1.324
1953	0.14	1.166	1.209
1954	0.14	1.167	1.213
1955	0.15	1.171	1.229

growth of the western region. This relationship is more clearly illustrated in the following derivation of an appropriate inflation factor.

Over time we expect the stock of commercial floor space to depend on several factors including income, population, construction costs, age distribution of population, and life style. At any point, however, we can expect to observe regional variation in the stock of commercial floor space primarily because of regional variation in population. That is, the variation of most of the other factors mentioned above occurs primarily over time and to a much smaller extent across regions. This situation allows us to relate the stock of commercial buildings in the West to the stock of buildings in the nonwest region on the basis of population; that is,

$$S_w = P_w \cdot S_{nw}/P_{nw} , \qquad (1)$$

where S_w is the stock of commercial buildings in the West, S_{nw} is the nonwest stock, and P_w and P_{nw} represent West and nonwest populations.*

We can derive an expression relating additions in the West to the western figures as follows:

$$A_w^t = S_w^t - S_w^{t-1} + \delta S_w^{t-1} = S_w^t - (1 - \delta)S_w^{t-1} , \qquad (2)$$

where t is time and δ is the depreciation rate of the existing stock. Using Eq. (1) and the nonwest version of Eq. (2) to rewrite Eq. (2) in terms of observable nonwest values of additions and stocks we get

$$A_w^t = P_{nw}\ A_{nw}^t + (1 - \delta)S_{nw}^{t-1}\left[\left(P_w^t/P_{nw}^t\right) - \left(P_w^{t-1}/P_{nw}^{t-1}\right)\right] . \qquad (3)$$

Equation (3) shows that both the size of the western population (relative to the nonwest population) and the growth of the western population (relative to the growth of the nonwest population) should be considered when inflating the observed nonwestern floor space additions data. The importance of considering growth is illustrated by comparing inflation factors based solely on population as given in column 3 of Table 8, and the more appropriate inflation factor in column 4. The difference between the two factors represents both the error that would occur in the national additions estimates using only population to inflate, and the portion of the inflation factor attributable to the growth of the West.

*A more satisfactory specification of Eq. (1) is $S_w = \alpha_i\ (P_w \cdot S_{nw}/P_{nw})$ where α_i reflects, for each building type i, interregional variation in income, population distribution by age, and variation resulting from different stages of economic development. Data constraints prohibited our consideration of these interregional variations.

Floor space stock estimates

The development of the stock series is detailed below for each of our ten commercial subsector building types.

1. Retail-wholesale (stores and other mercantile), office (office and bank buildings), garage (garages, service stations, and parking garages), and warehouse buildings

Floor space additions for the above building types are given in combined form under the Dodge Commercial (DC) category. We decided to subdivide the DC additions into several building types to more accurately reflect interbuilding variations in energy use. The development of a 1970 stock estimate and a stock series requires the following steps:

a. Estimate the 1924 stock using information from *Business Building Statistics*[20] and from 1950 - 1969 DC additions.

b. Disaggregate the 1969 DC stock by the four building types using information from *Business Building Statistics*.

c. Use Dodge estimates of the relative construction cost/ft^2, Department of Commerce estimates of value-put-in-place, and net DC additions to extend the four disaggregated stock series back to 1965 and forward to 1975.*

The 1924 DC stock is estimated with the help of information on the age structure of the stock standing in 1969, and the DC floor space additions for 1950 through 1969. The age distribution data are taken from *Business Building Statistics (BBS)*. In an effort to evaluate depreciation

*Cost/ft^2 is calculated from Dodge data; value-put-in-place estimates are taken from ref. 19.

practices of owners of structural capital, the Office of Industrial Economics at the Treasury Department conducted, in 1972 and 1973, a survey of 7032 buildings. The sample consisted of a randomly selected number of businesses taken from the Internal Revenue Service Business Master File (BMF), which contains information on all businesses that filed taxes in the previous three years. This information was supplemented with a field survey of selected areas. Supplemental information includes data on multi-establishment businesses (one entry in the BMF) and nonfiling businesses. This survey reports floor space for 16 commercial building types (6333 observations) in relative terms. For example, *BBS* reports that 5.65% of floor space in the sample is represented by bank buildings. In addition to the floor space and age distribution data, information on structure characteristics, value, and tax depreciation practices are also reported. In the calculations that follow, we assume that garages and warehouses have the same age distribution as retail buildings. *Business Building Statistics* reports that 50.55% of all office buildings and 71.35% of retail, garage, and warehouse floor space standing in 1969 were added to the stock in the previous twenty years. The *BBS* study also reports that 26.4% of the 1969 stock of office buildings and 13.4% of retail buildings were added before 1925. We assume here that the initial stock decay can be represented by the exponential decay rate corresponding to a building half-life of 45 years (1.53%). Since nearly all buildings built in the period 1950 to 1969 were still in the stock in 1969, the sum of 1950 to 1969 DC additions ($5{,}903 \times 10^6$ ft^2) should represent 50.55% of all office buildings and 71.35% of retail, garage, and warehouse buildings standing in 1969. *Business Building Statistics* information on retail, garage, and warehouse floor space (R) relative to office floor space (F) in 1969 (R = 1.838 F) allows us to solve the following equations to estimate the 1924 DC stock (DCS_{24}).

$$0.7135R + 0.5055\ F = 5903.3 \times 10^6\ ft^2 \quad (4)$$

$$R = 1.838\ F \quad (5)$$

$$DCS_{24} = (0.264\ F + 0.134\ R) \exp\ [(1.53)(1969-1924)] \quad (6)$$

Solving these three equations for DCS_{24} gives

$$DCS_{24} = 3{,}314 \times 10^6\ ft^2\ .$$

This initial stock estimate seems reasonable. Employment in retail and wholesale trades grew at an annual rate of 3.1% from 1909 to 1929.[22] Assuming a constant capital labor ratio implies net floor space additions that represent 3.1% of the stock. If we assume that 1.53% of the standing stock decays each year (i.e., one-half of any year's additions remains after 45 years), then gross additions can be expected to equal about 4.6% of the preceeding year's stock. The average DC addition of 158 × 10^6 ft^2 for 1925-1929 represents 4.8% of the estimated 1924 stock.

The estimated initial stock is used to derive a series of stock estimates for the DC category as shown in the first column of Table 9. The *BBS* data indicate that offices, retail, warehouses, and garages represent 35.2, 41.4, 18.1 and 5.3%, respectively, of the 1969 stock. The four building types (second through fifth columns) are derived for 1969 by applying these fractions to the estimated 1969 stock in column one. To extend these floor space estimates to cover the 1965-75 decade, we estimate the fraction of net additions assignable to each building

Table 9. Dodge "commercial" floor space total and disaggregation (10^6 ft^2)

Year	Commercial, total	Office	Retail-wholesale	Garage	Warehouse
1925	3,444				
1930	4,013				
1935	3,966				
1940	4,101				
1945	4,287				
1950	4,731				
1955	5,275				
1960	6,328	*a*	*a*	*a*	*a*
1965	7,767	2,851	3,163	375	1,381
1966	8,139	2,957	3,328	404	1,953
1967	8,489	3,037	3,496	433	1,526
1968	8,910	3,164	3,676	466	1,605
1969	9,404	3,313	3,891	501	1,700
1970	9,849	3,452	4,084	531	1,784
1971	10,316	3,614	4,278	554	1,869
1972	10,868	3,769	4,535	583	1,982
1973	11,491	3,940	4,837	601	2,114
1974	12,009	4,088	5,088	609	2,224
1975	12,327	4,180	5,241	618	2,291

[a]The procedure used in the text can be used to estimate components of the Dodge "commercial" floor space category back to 1955. Unfortunately, value-put-in-place figures for office buildings, retail, and wholesale garages are not available prior to 1955.

type on the bases of Commerce Department value-put-in-place statistics and estimates of relative cost/ft^2 for each building type. For example, the DC series yields a net (of replacement) additions estimate of 445.6×10^6 ft^2 for 1970. Data published by Dodge on value of construction and square feet of additions allows us to estimate ft^2/\$ for retail and warehouse together of 2.11 times the office building figure. The comparable estimate for garages is 2.78. Value-put-in-place statistics from the Commerce Department are 2806, 251, and 2601 million dollars for 1970. Using relative ft^2/\$ estimates and value-put-in-place figures allows us to assign 138.0, 26.9 and 278.8 to other, garages and retail-warehouses. The *BBS* estimate of relative floor space for the separate retail and wholesale building types (30.4% of the combined is warehouses) is used to disaggregate the retail-warehouse category. The same procedure is followed for each year reported in Table 9. Note that relative value-put-in-place figures are used so that the under-reporting inherent in building permits data is not a problem here.

In the process of deriving a 1924 DC stock, we could have calculated the 1969 DC stock (F + R). The resulting estimate is based on the *BBS* age structure estimates and the 1950-1969 DC additions. Although this estimate uses a large subset of the data employed to compute the DC series in Table 9, the additions from 1925-1959 and the 1924 stock, which together account for 36% of the 1969 stock, are not considered. Solving these equations for F and R gives a 1969 DC estimate of 9221×10^6 ft^2. Even considering the interdependence of the two 1969 stock estimates, a difference of only 2% is surprising. This unexpectedly close agreement increases our confidence in the additions approach.

2. Schools

Survey information from a random sample of 498 school districts is used to derive an estimate of the 1924 stock of floor space. These data were collected as part of a Federal Energy Administration study of national energy use in elementary and secondary school districts.[23] The FEA study reports energy use per square foot and energy use per pupil; dividing one ratio by another yields an estimate of 100.8 ft^2 per pupil.

Public and private school enrollments in kindergarden through grade 12[24] and the Department of Health, Education, and Welfare (HEW) estimates of floor space of college and universities[25] yield an estimate of 1970 school buildings' floor space of 5985×10^6 ft^2.

The 1970 stock estimate, the decay rate, and the Dodge educational additions series implies a 1924 stock estimate of 2150×10^6 ft^2. This floor space yields an estimated area per pupil (estimated enrollment of 26,829)[26] of about 80 ft^2 per pupil in 1924. Considering the fact that over 60% of all schools were one-teacher schools in 1924[27] (compared to 1.6% in 1970) and that small schools are not likely to have libraries, laboratories, or lunchrooms, the smaller figure appears reasonable. The resulting educational floor space series is presented in the sixth column of Table 10.

3. Public buildings

The stock of public buildings is determined from Dodge public administration additions series and an independently estimated 1924 stock of public buildings floor space. The 1924 stock estimate was derived by measuring growth in the public employment sector over the 1910 to 1930 period (2.21% annually).[28] If we assume that labor and structural capital are combined in approximately constant proportions over this time period, then we can expect the stock of floor space to grow on average at 2.21% per year to complement increased public employment. Using a stock decay rate of 1.53% per year, the average 1925-1929 public administration additions of 10×10^6 ft^2 implies an initial stock

Table 10. Additional commercial stock series
($10^6 \cdot ft^2$)

Year	Commercial	Office	Retail-wholesale	Garage	Warehouse	Educational	Public	Hospital	Religious	Hotel-motel	Misc.	Total commercial
1925	3,444					2,136	273	531	450		782	7,640
1930	4,013					2,312	321	599	501		883	8,678
1935	3,966					2,282	384	608	494		889	8,662
1940	4,101					2,387	447	652	502		1,071	9,114
1945	4,287					2,406	488	732	506		1,498	9,957
1950	4,731					2,683	512	888	594		1,681	11,123
1955	5,275					3,359	585	1,028	795		2,049	13,071
1960	6,328					4,203	720	1,175	972		2,368	15,801[a]
1965	7,767	2,851	3,163	375	1,381	5,049	870	1,413	1,185	1,273	2,650	20,269
1966	8,139	2,957	3,328	404	1,953	5,258	899	1,462	1,221	1,293	2,718	21,023
1967	8,489	3,037	3,496	433	1,526	5,961	928	1,516	1,254	1,313	2,782	21,777
1968	8,910	3,164	3,676	466	1,605	5,659	959	1,574	1,204	1,337	2,853	22,602
1969	9,404	3,313	3,891	501	1,700	5,833	985	1,648	1,306	1,360	2,936	23,506
1970	9,849	3,452	4,084	531	1,784	5,985	1,002	1,705	1,324	1,369	3,000	24,252
1971	10,316	3,614	4,278	554	1,869	6,126	1,034	1,771	1,339	1,378	3,071	25,061
1972	10,868	3,769	4,535	583	1,982	6,239	1,062	1,840	1,356	1,407	3,136	25,934
1973	11,491	3,940	4,837	601	2,114	6,339	1,100	1,900	1,372	1,425	3,225	26,883
1974	12,009	4,088	5,088	609	2,224	6,766	1,134	1,962	1,388	1,445	3,311	27,745
1975	12,327	4,180	5,241	618	2,291	6,564	1,168	2,010	1,405		3,383	28,328

[a] Total floor space figures prior to 1960 do not include Hotel-motel floor space.

of 268×10^6 ft^2. The resulting 1970 stock is 1002×10^6 ft^2. The historical series is given in Table 10.

It is possible to cross-check this estimate by using results of a study undertaken by Ide Associates, Inc.[29] The two-volume report provides estimates of floor space per employee by four-digit SIC categories. The data used in these calculations were gathered from planning commissions around the country by means of a mail survey. The mean floor space per employee figures are presented with a standard deviation statistic that indicates the variance of the individually obtained floor space per employee statistics. These data relate to the early and middle 1960s and consequently are becoming less useful. This source represents a very comprehensive reference for developing cross-sectional estimates of the stock of floor space. Unfortunately, the quality of the estimates varies widely across SIC categories, as suggested by variation in the standard deviations. Except for post offices, the floor space per employee statistics are relatively accurate for the public sector; thus we can use these estimates as an alternative method to derive federal, state and local floor space figures.

Post office estimates of total floor space are reported in *Energy Consumption in Commercial Industries By Census Division — 1974*.[30] Adding these figures to the Ide estimates should yield floor space estimates that are equivalent in coverage to the Dodge public administration stock estimates. The floor space per employee figures, standard deviations of the estimates, employment, and the post office data are given in Table 11. Employment data were taken from the 1970 census.[31] Industry classifications in the census are based on the SIC codes, thus coverage

Table 11. Ide-estimated public administration floor space

	Square feet per employee	Standard deviation	Employment	Estimated floor space (10^6 ft^2)
Federal government	194	4.3	1,622,043	314.7
State government	183	24.8	552,008	101.0
Local government	393	19.9	1,290,943	507.3
Post office				138.5
Total				1061.5

should be identical to the Ide categories. The Ide-estimated floor space is about 6% greater than the additions-estimated stock.

4. Hospitals

Hospital buildings consist of public and private hospitals, nursing homes, and other health treatment buildings. Since we were not able to locate reliable cross section information on this sector to facilitate estimation of the 1924 stock, we used an American Medical Association (AMA) series on number of hospital beds to estimate the initial stock.[32] According to the AMA, the number of hospital beds increased by 2.19% annually from 1924 to 1929. A replacement rate of 1.53% implies an additions rate of 3.72%. Applying this rate to average additions from 1925 to 1929, (19.8×10^6 ft^2) yields an initial stock estimate of 531×10^6 ft^2. Since nursing homes and other health care institutions were essentially nonexistent in 1924, the initial hospital stock is all that is required for this sector. The resulting series (Table 10, column 9) yields a 1970 stock estimate of 1705×10^6 ft^2.

In searching for sources of cross section estimates, personnel at the American Hospital Association suggested a rule-of-thumb floor space figure of 725 ft^2 per bed. This figure represents a "best guess" of floor space requirements in existing hospital buildings. In addition, 600 ft^2 per bed was quoted as the lowest feasible area per bed ratio for any single hospital. The 1924 stock estimate implies a ratio of 654 ft^2 per bed. The 1924 stock appears to represent an average building type that lies not quite midway between the minimum feasible area and the average area of the present day stock. We can also estimate 1970 stock using the area per bed ratio for hospitals of 725 ft^2 per bed and an estimate of 263 ft^2 per bed for nursing homes. The nursing home figure was derived by assuming that an average nursing home consists of two beds per room and that each room has space requirements similar to the hotel-motel sector (see following discussion). The resulting floor space estimate of 1662×10^6 ft^2 for 1970 is only about 3% less than the additions stock estimate. This close agreement with the rule-of-thumb estimates does not, of course, mean that our estimates are only 3% away from the true floor space. We present this comparison simply to indicate a general agreement with health industry estimates.

5. <u>Religious buildings</u>

The stock series of religious buildings was estimated in a similar manner to public buildings. The growth of church membership was 2.15%

in the 1910 to 1930 period.[33] Assuming an annual replacement rate of 1.53%, the average yearly additions figure of 16×10^6 ft^2 for the 1925-1929 time span yields an estimated stock of 435×10^6 ft^2. The resulting 1970 stock of religious floor space is 1324×10^6 ft^2. The historical series for religious floor space is given in column 10 of Table 10.

6. Hotel-motels

This sector represents the only building category for which Dodge additions were not used, at least in part, to develop a 1970 stock estimate. As indicated in Table 12 the total number of hotel rooms has declined over time reflecting in part the diminishing importance of center cities. Utilizing an estimate based on additions would require a significantly different decay rate than the 45 year half-life used for other buildings. We decided instead to relate number of rooms in existence to an average area per room to derive an estimate of the stock. Our search of the literature revealed a commonly quoted average room size of 350 ft^2.[34] This literature also indicated that about 40% of the room size should be added to account for corridors, lobbies, and other nonroom space. Consequently we used an estimate of 525 ft^2 per room to derive the stock of hotel and motel floor space. The resulting series in column 11 of Table 10 shows a 1970 stock estimate of 1369×10^6 ft^2.

Table 12. Hotel-motel rooms available per day (10^6)

	1948	1958	1963	1967	1969	1971	1972	1973	1974
Hotels	1.55	1.52	1.28	1.27	1.27	1.26	1.27	1.27	1.27
Motels	0.30	0.60	1.11	1.23	1.32	1.37	1.42	1.44	1.48
Total	1.85	2.12	2.39	2.50	2.59	2.68	2.69	2.72	2.75

Source: Provided by the American Hotel and Motel Association; data taken from "Trends in the Hotel-Motel Business," annual reports, published by Harris, Kerr, Foster & Company, New York.

7. Social and miscellaneous

The social and miscellaneous categories are combined because of the difficulty in establishing a representative building type for either category. These categories include sports coliseums, bowling alleys, YMCAs, passenger terminals, and hangers. To develop a 1924 stock estimate we assume that floor space in these buildings was growing at the same rate as the floor space in commercial buildings. Using the average 1925-1929 additions and the 4.67% rate of additions for commercial buildings yields a 1970 stock estimate of 3000×10^6 ft^2. It is difficult to evaluate this estimate since such a large number of building types are included. We intend to disaggregate this sector in the future.

Table 10 presents all stock estimates for selected years. The largest single building type is schools, which represents about 25% of all commercial floor space in 1970. Retail and wholesale (17%) and office buildings (14%) are next in floor space. Hospitals and warehouses utilize approximately the same floor space (7%). Hotels and motels represent 6% of commercial floor space. Public buildings (4%), religious buildings (5%), and garages (2%) are next. Finally miscellaneous building types account for the remaining 12% of floor space. From 1955 to 1970, offices, retail and wholesale, garage, warehouses, and educational buildings all grew at a faster rate than the total commercial building stock. Similar trends continue for all but educational through 1975, although at a somewhat smaller rate due to the economic recession occuring in this period. Educational buildings grew at an annual rate of 3.93% from 1950 to 1970 and 1.87% in the most recent five years. This trend undoubtedly reflects the decline in number of school-age children from the peak year of 1970. The Bureau of the Census estimates indicates that this trend is likely to continue.[35]

5. ENERGY USE INDEX DEVELOPMENT

The purpose of this section is to utilize data from individual buildings studies to develop energy use indexes (EUI) (i.e., energy use in Btu per square foot of floor space) for each of our five end uses, four fuel types, and ten building categories. Relative values of EUI among building types and fuels are developed with the aid of three primary references: reports by A. D. Little,[36] Hittman Associates,[37] and Westinghouse.[38]

The detailed methodology used to reconcile these individual energy use data with the total 1970 energy use and floor space estimates is presented in the first part of this section. The resulting baseline estimates of EUI are then examined. This section concludes with an analysis of trends in energy use from 1965 to 1975.

Space and water heating

The relative EUI values for space heating fuels are obtained from Westinghouse[38] and are assumed the same for all building types. The EUI for space heating with gas is 67% of that for electric resistance heat, and for oil heating it is 74% of the electric EUI. These values are based on the following efficiencies: electric — 30% (based on primary energy; includes generation and transmission losses); gas — 55%, and oil — 50%. In addition, it is assumed that the heat loss from electrically heated buildings is 80% of that from fossil-fuel-heated buildings because of better thermal characteristics and general location in warmer climates.

In order to obtain estimates of total gas and oil use for space heating, it is assumed that 15% of natural gas is used for cooking and space cooling;[39] the remaining natural gas and all oil are allocated to water and space heating. Preliminary calculations based on the Westinghouse study and a report by Hittman Associates[37] indicate that 4% of both gas and oil totals is used for water heating. According to A. D. Little, 5% of all commercial floor space was heated electrically in 1970 and 3% was heated by coal and liquid natural gas.

The following two equations can be solved for the fraction of commercial floor space heated by gas (F_G) and oil (F_O). It is assumed that these fractions are the same for all building types.

$$0.67\ F_G/0.74\ F_O = [(0.81)(1.77 \times 10^{15})]/[(0.96)(2.25 \times 10^{15})] \quad (8)$$

$$F_O + F_G = 0.92 \quad (9)$$

The solution of these equations gives $F_G = 0.39$ and $F_O = 0.53$.

Space heating information is obtained from the Hittman study, which lists measured EUI values based on more than 350 commercial buildings in the Baltimore area. The second column in Table 13 shows the Hittman EUI values relative to retail stores. Garages and public administration buildings are not included in the study and have been assumed equivalent to warehouses and office buildings respectively in terms of EUI. For convenience, we have added public administration floor space to office building floor space to derive a combined office-public administration building type. Likewise, medical buildings are assumed equivalent to

Table 13. Relative values of energy use index

Building type	Space heating[1]	Water heating[2]	Lighting: Illumination[3] level (ft candles)	Lighting: Hours of operation	Lighting: Relative product	Other[2]
Office-public administration	0.98	2.02	100	3500	0.92	0.40
Retail-wholesale	1.0	1.0	95	4000	1.0	1.0
Garage	0.44	0.16	35	4000	0.37	0.15
Warehouse	0.44	0.16	30	4000	0.32	0.15
Educational	0.83	2.02	95	2500	0.63	0.30
Hospital	1.54	9.68	67	5700	1.00	1.20
Religious	0.65	0.32	90	1500	0.36	0.10
Hotel-motel	1.54	3.39	40	3500	0.37	0.20
Other	0.86	1.66	65	3500	0.60	0.30

Sources: [1]Source — Ref. 33

[2]Source — Ref. 14 (A. D. Little)

[3]Source — Ref. 39

75% hotel space and 25% offices and treatment rooms; religious buildings and schools are assumed to fall between warehouses and offices. The "other" category is taken as the approximate average of all the building types.

Calculation of specific fuel end use EUI is illustrated for natural gas space heating in retail buildings. Gas consumption per square foot of floor space can be determined by solving the following equation:

$$EUI = \frac{\text{Total gas used for space heating}}{\sum_{I=1}^{9} [F_G \times S(I) \times EUIR(I)]} \quad (10)$$

where gas for space heating is 81% of the total gas use in 1970, S(I) is the floor space of building type I, and EUIR(I) is the relative energy use index for building type I. This calculation results in a value of 163×10^3 Btu/ft^2. For other building types, this value is multiplied by the appropriate values from Table 13 and for other fuel types it is multiplied by the ratio of efficiency of gas usage to the efficiency of usage of the other fuel. Estimates of space heating EUI for other fuels and building types are given for 1970 in Appendix A.

Fuels in the "other" category are coal (37%) and liquid gases (63%). Their primary use is in space heating; the energy use index was assumed to be the same as for fuel oil. The combination of these EUI values with the floor space figures produces a total use of "other" fuels well below that given in Table 3. The EUI values are not increased, however, because of the large uncertainties in the predicted "other" fuel total and because "other" fuels are expected to have only a minor impact on future energy consumption.

We assume that buildings heated by electricity, gas, and oil use the same fuel for water heating. That is, electrically heated commercial buildings are assumed to have electric water heating systems. We assume that buildings heated with coal and liquid natural gas utilize electric water heating systems. Relative EUI for the various building types as listed in Table 13 are determined from the Hittman study and the study by A. D. Little.[40] Relative values for different fuels are based on the following water heater efficiency estimates: electric 27%, gas 64%, and oil 50%. The calculation of water heating EUI fuel and building type is accomplished in the same manner as described above for space heating.

Lighting

The Rand Corporation[41] estimated that in 1972 42% of all electricity used in the commercial sector was for lighting. It is assumed that this percentage is the same for 1970; thus the total electricity used for lighting in 1970 is 1.61×10^{15} Btu. Using the Rand assumption that floor space is utilized an average of 3100 hours per year, the average 1970 lighting density is 2.0 watt/ft^2; this figure is the same as the Rand estimate for 1972.

To obtain EUI values for different building types, recommended average illumination levels are obtained from the *IES Handbook*[42] as shown in the fourth column of Table 13. Then annual operating hours for each building are estimated, as shown in the fifth column.

The product of these two numbers indicates the relative energy use for lighting among the various building types. Column 6 shows these values relative to retail stores. Using total lighting energy use and relative use for each building type, the EUI for lighting is determined for individual building types.

Space cooling

It is assumed that in 1970, 54% of commercial buildings were air conditioned either by electric or gas absorption systems.[38] It is also assumed that the coefficient of performance (COP) for cooling is 2.5 with electricity and 0.75 with gas. These assumptions simplify calculations by giving the same EUI value for both electricity and gas.

Total space cooling energy use is estimated using engineering process model results for a number of prototype buildings. We estimate a national average space cooling EUI that equals 43% of the sum of heating, lighting, and "other" EUI. Multiplying air conditioned floor space by the space cooling EUI provides an estimate of energy used for cooling in the commercial sector. It is interesting to note that our space cooling EUI is nearly identical to that developed in the Stanford Research Institute Study.[39]

The space cooling EUI values for individual building types are derived (in relative terms) by summing relative EUI values for space heating, lighting, and "other" uses and dividing by the sum of these values for retail buildings, which is the reference. Absolute estimates of building-specific space cooling EUI are estimated by reconciling the relative EUI values, estimates of total space cooling energy use, and air conditioned floor space.

Extrapolation based on SRI figures yields an estimated 0.13 x 10^{15} Btu of natural gas used for cooking with the remaining 0.14 x 10^{15} Btu assigned to space cooling. Since the EUI for gas and electric cooling is considered the same, floor space allocated to gas is directly proportional to the ratio of gas to electricity that is used for cooling.

Total electricity use (3.83 x 10^{15} Btu) minus electricity used for space heating (2.73 x 10^{14} Btu), water heating (3.01 x 10^{14} Btu), lighting (1.61 x 10^{15} Btu), and space cooling (1.47 x 10^{15} Btu) leaves 0.44 x 10^{15} Btu, which is assigned to the "other" category.

Auxiliary equipment and appliances

Relative values of electromechanical energy use indexes for various building types are obtained primarily from the A. D. Little report and are given in Table 13. High values for medical buildings are due to the special equipment; retail buildings also have a high value to reflect refrigeration equipment; office values are high because of computers and other office machines, etc. Total energy use and relative values for each building type yield detailed EUI values in the same way as the space heating example.

Twenty EUI estimates corresponding to the four fuels and five end uses discussed above (eight of these EUI components have zero entries) are derived for each building type and are presented in Appendix A for 1970. Nine building types are included; it is assumed that public administration buildings can be represented, on the average, by the office building category. Therefore, total floor space reported in the office building-public administration table represents the sum of both building types. Appendix B presents the same data for the most recent year in our data base, 1975. Our extension to this more recent year is discussed in the next section.

Analysis of disaggregated energy use estimates

The average values of the EUI developed in this study cannot be related directly to detailed commercial building specifications. The values can, however, be considered to represent "average" buildings that reflect the distribution of climate, structural characteristics, etc. of all buildings in the national stock. Since these distributions are accounted for implicitly in the analysis, we have little basis for assessing the accuracy of our estimates. Our confidence in these estimates diminishes with the level of disaggregation and, to a lesser extent, with the length of time from our 1970 base period. Since we are reasonably confident of the total energy use and commercial floor space estimates, we feel that the overall energy use index for all commercial buildings is close to the 329,600 Btu/ft^2/year (218,300 Btu/ft^2/year in terms of point-of-use) estimated for 1970. Many of our assumptions in the preceeding section are, of course, subject to error and will be revised in the future in light of additional information. While recognizing our own uncertainty over many of the EUI estimates, we feel that these estimates can serve as useful guideposts to other researchers and policy makers involved in analyzing energy use in the commercial sector.

Estimated energy use by end use and fuel type is presented in Table 14. In 1970 space heating was clearly the largest end use, representing about 49% of all commercial energy use. Cooling and lighting are next in importance and are characterized by an almost total dependence on electricity. "Other" end uses account for 7% of the total; these uses include electromechanical end uses and gas used in cooking. The least important end use is water heating, which accounts for only about 3% of commercial fuel use. The minimal use of electric space heating is indicated by the small fraction of total electricity consumed in this end use. The small fraction of gas used in cooling represents the relatively small penetration of gas absorption cooling equipment in the commercial air conditioning market.

Table 14. Fuel and end use disaggregation of commercial energy use (10^{15} Btu)

	Space heating	Cooling	Water heating	Lighting	Other[a]
1970					
Electricity	0.27	1.47	0.03	1.61	0.44
Gas	1.44	0.13	0.07		0.13
Oil	2.15		0.12		
Other[b]	0.12				
Total	3.98	1.60	0.22	1.61	0.57
1975					
Electricity	0.33	1.83	0.04	2.09	0.76
Gas	1.66	0.14	0.08		0.17
Oil	1.88		0.10		
Other[b]	0.12				
Total	3.99	1.97	0.22	2.09	0.93

[a]Other end uses include cooking and electromechanical uses.

[b]Other fuels include coal and liquid natural gases.

Energy use in 1975 is also shown in Table 11. Our extension of the estimation to other years is discussed later in this section. Fuel shares by end use are about the same as in 1970. Heating energy use drops (to 43%) relative to total energy use largely because of conservation efforts and because the space heating end use represents a large conservation potential. Air conditioning energy use increases slightly to reflect increasing penetration of commercially air conditioned establishments. The end use "other" increases slightly to reflect continued growth of electromechanical equipment in the commercial sector.

Information in Table 14 is presented in Appendices A and B for each building type. As indicated in Sect. 2 (Fig. 4), considerable variation in EUI exists across building types.

A recently completed study by Jack Faucett Associates uses another methodology to estimate energy use in commercial buildings. The Faucett approach relates energy use to an index of activity in each commercial subsector. These indexes are derived from trade association information, government reports, and other sources. This work represents a very detailed and careful research effort.

Our approach to estimating disaggregated energy use was guided in large part by the ultimate use of our estimates: the EUI are being used in our engineering-economic model of commercial energy use to forecast future commercial energy use and to evaluate alternative conservation policies. The disaggregation approach offers several advantages over the aggregation method with respect to our modeling effort. First, disaggregation accounts for all energy use in the commercial sector and relates this energy use to the amount of commercial floor space, which can be predicted without undue difficulty. Secondly, our approach lends itself to continual modification in light of new evidence from building studies. The final advantage in our application is the ability to estimate energy use across all subsectors without having to rely on a number of estimates derived from limited samples of energy use data.

The "bottom-up" approach utilized in the Faucett study can be used to refine EUI in a number of subsectors. A significant portion of our effort in the next year will be devoted to utilizing information from the Faucett study. For several subsectors, the buildings definitions are similar enough to allow a comparison of some of the Faucett and ORNL energy use estimates, which are presented in Table 15. The Faucett estimates are utilized with our floor space estimates to convert consumption figures to our EUI format. Our estimates are presented for the year 1974 to be consistent with the Faucett reference year. For offices, hospitals, educational buildings, and hotel-motels, the differences are relatively small in percentage terms. Considering the difference in methodologies and data sources, the estimates are very close. A reevaluation of the Faucett and ORNL EUI estimates is expected to reduce the discrepancy between the two independent estimates.

One advantage of our methodology is the ability to examine energy use trends over time. Our discussion earlier in this section indicated a number of assumptions concerning air conditioning penetration, electric space heating penetration, etc., necessary to disaggregate total commercial energy use. To trace energy use over time it is necessary to derive similar estimates as inputs to the disaggregation program for

Table 15. Comparison of Faucett and ORNL EUI for 1974 (Btu/ft^2/yr)[a]

	Building type			
	Office	Hospitals	Educational	Hotel-motel
Faucett	306,000	302,000	130,000	225,000
ORNL	274,000	347,000	167,000	291,000
Difference, %	12	13	22	23

[a]ORNL EUI are converted from primary energy to point-of-use to be consistent with Faucett estimates.

Source: Ref. 30 and estimates from this study.

each year in the time interval. Assumptions on these inputs are summarized in Table 16. Many of these assumptions are based on judgement because no empirical evidence is available. Temporal variations of the EUI and the detailed energy consumption estimates depend to varying degrees on these judgemental estimates. We believe that our assumptions are reasonable; we intend, however, to revise these inputs in light of new information as it becomes available.

The most accurate trends can be derived for space heating. Since gas, oil, and other fuels are used almost exclusively for space heating, and since little electricity is used in space heating, the EUI are determined primarily by floor space and fossil fuel use estimates. Trends in oil space heating EUI are given in Fig. 6 for office buildings. The upward trend in space heating energy intensiveness results primarily from the addition of new, less energy-efficient buildings to the stock. The sharp drop in energy intensiveness from 1973 to 1975 resulted, of course, from the large increase in fuel prices. Since this decrease was caused mostly by behavior-induced changes in the utilization of equipment,

Table 16. Assumptions for disaggregation program, 1965-1975

1. Floor space heated electrically is assumed to be 4% in 1965 and to increase linearly at the rate of 1% every 5 years.

2. Gas used for cooking is assumed to be proportional to retail floor space at the same (proportional) value used in 1970.

3. Electricity used for lighting is assumed to be 42% of total electricity use from 1965-1973. For 1974 and 1975 it is reduced to 41.5% to account for conservation.

4. Air conditioned floor space is assumed to be 46.5% in 1965 and increase at a uniform rate of 1.5% per year.

5. Gas and oil used for other than space heating were assumed constant at 19% and 4% respectively.

we can calculate percentage changes in use and relate these estimates to percentage change in prices to derive an estimate of the conventional short-run elasticities. The calculated price elasticity of demand for oil over the 1972 to 1974 period is -0.20. This estimate compares favorably to econometrically estimated elasticities, which are usually reported in the range of -0.1 to -0.6 for oil use.[43]

The effects of climate on national aggregate energy use appear to be less than one might suspect. National heating degree days are estimated by deriving the weighted sum of state heating degree days reported by the National Climatic Center.[44] The state weights are state population divided by national population. These data are presented along with oil space heating EUI for office buildings in Fig. 7. We also examined the temporal variation in an aggregate space heating EUI for all buildings; the trend is nearly identical to the office building oil EUI. We present data from 1965 to 1972 because we cannot separate the

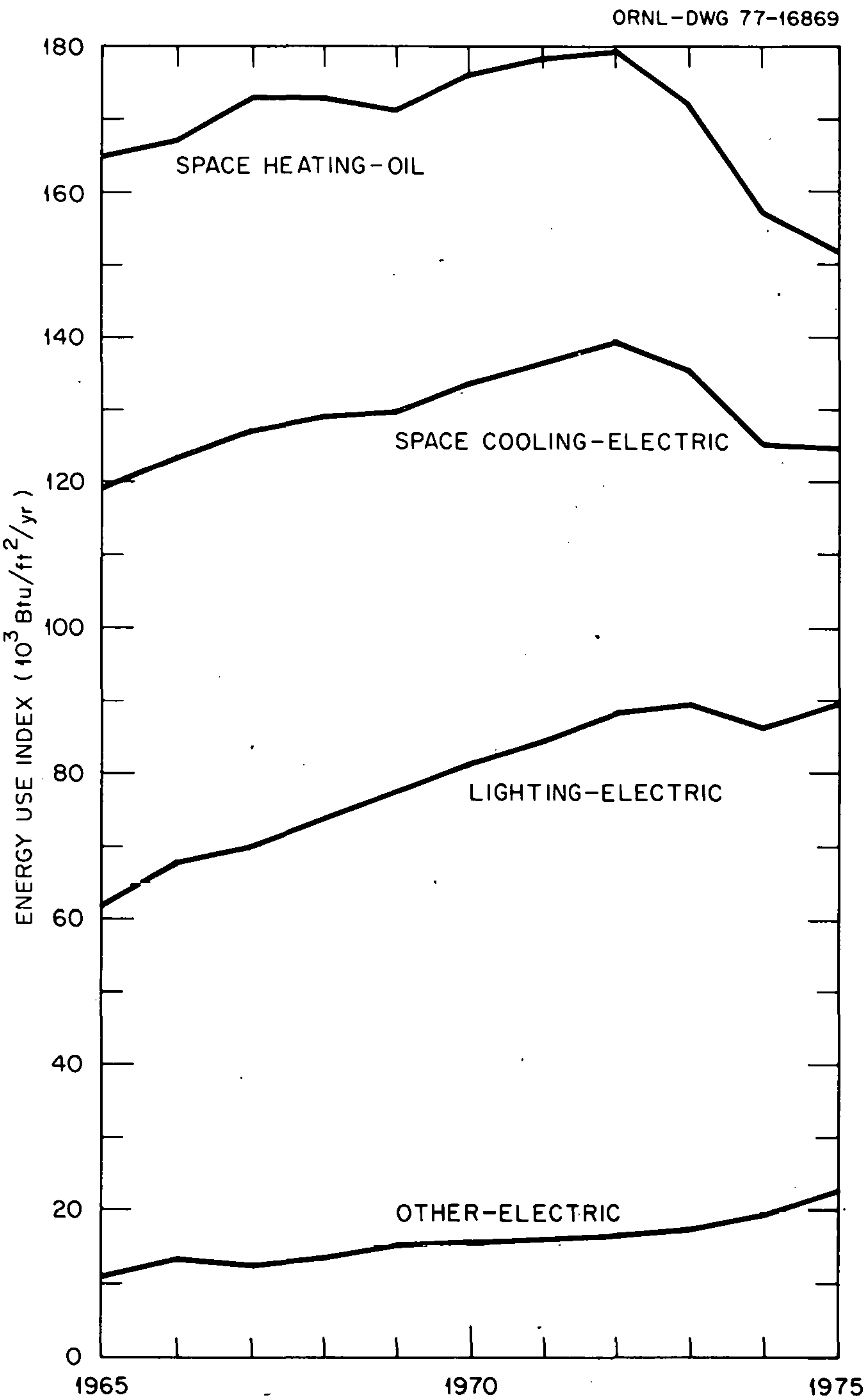

Fig. 6. Office building EUI trends, 1965-1975.

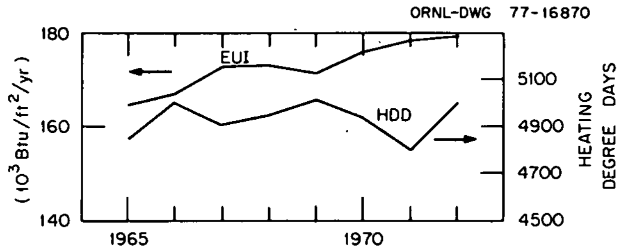

Fig. 7. Oil space heating EUI and national heating degree-days, 1965-1975.

effects of climate from the price effects which occured in the most recent three years in our sample. Several conclusions can be drawn from Fig. 7. First, national heating degree days do not display much temporal variation. The coldest year represents only 8% more heating degree days than the warmest year in our seven-year sample. (From 1955 until 1975 this figure is slightly higher, 11%.) This variation is almost insignificant when compared to interstate variation in heating degree days.[45] In fact, the simple correlation coefficient between national heating degree days and oil space heating EUI suggests no significant relationship between the two variables. These observations suggest that intertemporal variations in climate are not important (except possibly for extreme years) in explaning national commercial fuel use or trends in our calculated EUI.

Trends in the remaining end uses are not as reliable as those for space heating. Given estimates of air conditioning and electric space heating penetration and the fraction of electricity used for lighting, it is possible to estimate changes in energy intensity of the "other" end use, cooling, and lighting. While resulting estimates depend on judgemental considerations more than space heating, the results are, we believe, indicative of trends in these three end uses. Historical trends of the EUI for "other", cooling, and lighting are given in Fig. 6.

Space cooling EUI estimates exhibit the same trend as space heating; however, the downward trend in later years is not as pronounced because of the smaller increase in the cost of electricity. The "other" end use exhibits a significant (in percentage terms) increase over the ten-year period to reflect increased use of electromechanical equipment including computers, copying machines, and other business machines. Lighting EUI estimates increase by almost 50% over the 1965 to 1975 period. This upward trend was reversed in 1974 but increases again in 1975. The 1975 increase is anomalous. We believe that the smooth upward trend in the "other" end use is reasonable; conversations with personnel at the Commerce Department[46] suggest that no unforseen switch to electric space heating occurred from 1974 to 1975. Barring an unlikely one-year surge in air conditioning penetration, the increase in estimated lighting EUI from 1974 to 1975 is difficult to explain other than by interpreting the data to say that lighting conservation efforts were practiced in 1974 and were relaxed somewhat in 1975.

The trends in Fig. 6 highlight an important precaution that should be observed when using EUI in calculations of subsector energy use. The EUI vary considerably over the ten-year period studied in this report. For instance, the oil space heating EUI in Fig. 4 increased by 9% from 1965 to 1972 and then decreased from that peak by 15% over the next three years. Using outdated EUI estimates could result in substantial errors of estimation.

As noted above, detailed EUI are provided in the Appendices for all five end uses, four fuel types, and nine building types for 1970 and 1975. Estimated EUI for intervening and earlier years are available from the authors on request. The computer program used to disaggregate total commercial energy use is also available.

6. FUTURE RESEARCH EFFORT

This research effort suffers from budgetary and time constraints because it represents a small part of a larger research project (the development of an engineering-economic model of commercial energy use). We are convinced that more refined and accurate historical data can be developed using the disaggregation approach outlined in this report, and we intend to pursue these improvements in the future. Our efforts will focus on:

1. Utilization of new, additional information on characteristics of energy use. The recently published work by Faucett Associates represents a rich source of information that will be used to considerably refine our estimates.

2. Development of better estimates of aggregate commercial fuel consumption. Additional effort is required to improve estimates of commercial gas and distillate oil consumption.

3. Disaggregation of building types. We intend to approximately double the number of building types to more accurately account for interbuilding variations in energy use.

4. Improvement of estimates of inputs to the disaggregation program such as air conditioning and electric space heating penetration.

Increased attention recently directed to the commercial sector indicates that these improved historical series and current EUI estimates will allow more accurate and sophisticated analyses of energy policies concerning commercial establishments.

Appendix A

ENERGY USE ESTIMATES FOR NINE BUILDING TYPES, FOUR FUELS, AND FIVE END USES: 1970

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Subsector Office-public Year 1970

Aggregate Energy Use 1562.0 10^{12} Btu Total Floor Space 4455 10^6 ft^2

Aggregate EUI 350.6 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	222.7	2206	356.4	4455	4455
EUI[b]	237.2	133.8	16.6	81.3	15.6
Gas					
Floor space[a]	1737.0	199.4	1737.0		
EUI[b]	159.7	133.8	7.1		
Oil					
Floor space[a]	2362.0		2362.0		
EUI[b]	175.7		9.1		
Other[c]					
Floor space[a]	133.6				
EUI[b]	175.7				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	52.8	295.1	5.9	362.2	69.4	785.4
Gas	277.4	26.7	12.3			316.4
Oil	415.0		21.4			436.4
Other[c]	23.5					23.5
Total	768.7	321.8	39.6	362.2	69.4	1562.0

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Retail-wholesale Year 1970

Aggregate Energy Use 1692 10^{12} Btu Total Floor Space 4082 10^{6} ft^2

Aggregate EUI 414.5 10^{3} Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	204	2022	327	4082	4082
EUI[b]	242.1	138.5	8.2	87.8	38.9
Gas					
Floor space[a]	1592	182	1592		4082
EUI[b]	163.0	138.5	3.5		32.5
Oil					
Floor space[a]	2164		2164		
EUI[b]	179.3		4.5		
Other[c]					
Floor space[a]	122				
EUI[b]	179.3				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	49.4	280.1	2.7	358.3	159.0	849.4
Gas	259.4	25.3	5.6		132.9	423.2
Oil	388.1		9.7			397.8
Other[c]	22.0					22.0
Total	718.9	305.4	18.0	358.3	291.8	1692.0

[a]Floor space, 10^{6} ft^2.

[b]EUI, 10^{3} Btu/ft^2.

[c]Includes coal and LNG.

Subsector Garage and service stations Year 1970

Aggregate Energy Use 78.9 10^{12} Btu Total Floor Space 530.5 10^{6} ft^2

Aggregate EUI 148.8 10^{3} Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	26.5	262.7	42.4	530.5	530.5
EUI[b]	107.0	58.7	1.3	32.7	5.8
Gas					
Floor space[a]	206.8	23.7	206.8		
EUI[b]	72.0	58.7	0.6		
Oil					
Floor space[a]	281.2		281.2		
EUI[b]	79.3		0.7		
Other[c]					
Floor space[a]	15.9				
EUI[b]	79.3				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	2.8	15.4	0.05	17.3	3.1	38.8
Cas	14.9	1.4	0.1			16.4
Oil	22.3		0.2			22.5
Other[c]	1.3					1.3
Total	41.3	16.8	0.4	17.3	3.1	78.9

[a]Floor space, 10^{6} ft^2.
[b]EUI, 10^{3} Btu/ft^2.
[c]Includes coal and LNG.

Subsector Warehouse Year 1970

Aggregate Energy Use 254.9 10^{12} Btu Total Floor Space 1783 10^6 ft^2

Aggregate EUI 142.9 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	89.2	883.0	142.6	1783.0	1783.0
EUI[b]	107.0	566.8	1.3	28.0	5.8
Gas					
Floor space[a]	659.1	79.8	695.1		
EUI[b]	72.1	56.7	0.6		
Oil					
Floor space[a]	945.2		945.2		
EUI[b]	79.3		0.7		
Other[c]					
Floor space[a]	53.5				
EUI[b]	79.3				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	9.5	50.1	0.2	49.9	10.4	120.0
Gas	50.1	4.5	0.4			55.0
Oil	74.9		0.7			75.6
Other[c]	4.2					4.2
Total	138.8	54.6	1.3	49.9	10.4	254.9

[a] Floor space, 10^6 ft^2.

[b] EUI, 10^3 Btu/ft^2.

[c] Includes coal and LNG.

Subsector Education Year 1970

Aggregate Energy Use 1666 10^{12} Btu Total Floor Space 5980 10^6 ft^2

Aggregate EUI 278.7 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	299.0	2962.0	478.4	5980.0	5980.0
EUI[b]	199.9	107.0	16.6	54.9	11.7
Gas					
Floor space[a]	2332.0	267.7	2332.0		
EUI[b]	134.6	107.0	7.1		
Oil					
Floor space[a]	3170.0		3170.0		
EUI[b]	148.1		9.1		
Other[c]					
Floor space[a]	179.4				
EUI[b]	148.1				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	59.8	316.9	7.9	328.0	69.9	782.5
Gas	313.9	28.6	16.5			359.1
Oil	469.6		28.7			498.3
Other[c]	26.6					26.6
Total	869.9	345.6	53.1	328.0	69.9	1666.0

[a] Floor space, 10^6 ft^2.

[b] EUI, 10^3 Btu/ft^2.

[c] Includes coal and LNG.

Subsector Hospital Year 1970

Aggregate Energy Use 937.3 10^{12} Btu Total Floor Space 1690 10^{6} ft^2

Aggregate EUI 554.5 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	84.5	837.2	135.2	1690.0	1690.0
EUI[b]	374.0	194.2	79.5	88.3	46.7
Gas					
Floor space[a]	659.0	75.7	659.0		
EUI[b]	25.2	194.2	33.9		
Oil					
Floor space[a]	896.1		896.1		
EUI[b]	277.0		43.4		
Other[c]					
Floor space[a]	50.7				
EUI[b]	277.0				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	31.6	162.5	10.7	149.2	79.0	433.1
Gas	166.0	14.7	22.3			203.0
Oil	248.3		38.9			287.1
Other[c]	14.1					14.1
Total	459.9	177.2	72.0	149.2	79.0	937.3

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Religious Year 1970

Aggregate Energy Use 257.5 10^{12} Btu Total Floor Space 1323 10^6 ft^2

Aggregate EUI 194.5 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	66.2	655.4	105.9	1323.0	1323.0
EUI[b]	158.1	79.5	2.7	31.3	3.9
Gas					
Floor space[a]	516.0	59.2	516.0		
EUI[b]	106.4	79.5	1.1		
Oil					
Floor space[a]	701.6		701.6		
EUI[b]	117.1		1.5		
Other[c]					
Floor space[a]	39.7				
EUI[b]	117.1				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	10.5	52.1	0.3	41.4	5.2	109.4
Gas	54.9	4.7	0.6			60.2
Oil	82.2		1.0			83.2
Other[c]	4.6					4.6
Total	152.2	56.8	1.9	41.4	5.2	257.5

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Hotel Year 1970

Aggregate Energy Use 573.9 10^{12} Btu Total Floor Space 1369.0 10^6 ft^2

Aggregate EUI 419.3 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	68.4	677.8	109.5	1369.0	1369.0
EUI[b]	374.0	170.7	27.8	32.4	7.8
Gas					
Floor space[a]	533.6	61.3	533.6		
EUI[b]	251.8	170.7	11.9		
Oil					
Floor space[a]	725.6		725.6		
EUI[b]	277.0		15.2		
Other[c]					
Floor space[a]	41.1				
EUI[b]	277.0				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	25.6	115.7	3.0	44.3	10.7	199.3
Gas	134.4	10.5	6.3			151.2
Oil	201.0		11.0			212.0
Other[c]	11.4					11.4
Total	372.4	126.1	20.4	44.3	10.7	573.9

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Miscellaneous Year 1970

Aggregate Energy Use 972.3 10^{12} Btu Total Floor Space 2998 10^6 ft^2

Aggregate EUI 324.3 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	149.9	1485.0	239.8	2998.0	2998.0
EUI[b]	209.4	124.1	13.6	86.0	11.7
Gas					
Floor space[a]	1169.0	134.2	1169.0		
EUI[b]	141.0	124.1	5.8		
Oil					
Floor space[a]	1589.0		1589.0		
EUI[b]	155.1		7.4		
Other[c]					
Floor space[a]	89.9				
EUI[b]	155.1				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	31.4	184.2	3.3	257.9	35.0	511.8
Gas	164.8	16.7	6.8			188.2
Oil	246.5		11.8			258.3
Other[c]	14.0					14.0
Total	456.6	200.9	21.9	257.9	35.0	972.3

[a] Floor space, 10^6 ft^2.

[b] EUI, 10^3 Btu/ft^2.

[c] Includes coal and LNG.

Total Commercial — All Building Types — Year 1970

Aggregate Energy Use 7995 10^{12} Btu — Total Floor Space 24252 10^6 ft^2

Aggregate EUI 329.6 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND FUEL ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	1213.0	12004.0	1940.0	24252.0	24252.0
EUI[b]	225.5	122.6	17.6	66.3	18.2
Gas					
Floor space[a]	9438.0	1091.0	9438.0		4082.0
EUI[b]	152.2	122.6	7.5		32.5
Oil					
Floor space[a]	12854.0		12854.0		
EUI[b]	167.1		9.6		
Other[c]					
Floor space[a]	728.0				
EUI[b]	167.1				

FUEL USE BY END USE (10^{15} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	0.27	1.47	0.03	1.61	0.44	3.83
Gas	1.44	0.13	0.07		0.13	1.77
Oil	2.15		0.12			2.27
Other[c]	0.12					0.12
Total	3.98	1.61	0.22	1.61	0.57	8.00

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Appendix B

ENERGY USE ESTIMATES FOR NINE BUILDING TYPES, FOUR FUELS, AND FIVE END USES: 1975

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Subsector Office-public   Year 1975

Aggregate Energy Use 1841.0 10^{12} Btu   Total Floor Space 5346.0 10^6 ft^2

Aggregate EUI 344.4 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	320.7	3059.0	481.1	5346.0	5346.0
EUI[b]	204.7	123.7	14.4	89.8	22.2
Gas					
Floor space[a]	2393.0	229.0	2393.0		
EUI[b]	137.9	123.7	6.2		
Oil					
Floor space[a]	2471.0		2471.0		
EUI[b]	151.6		7.9		
Other[c]					
Floor space[a]	160.4				
EUI[b]	151.6				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	65.7	378.3	6.9	479.7	118.8	1049.0
Gas	329.9	28.3	14.7			373.0
Oil	374.7		19.5			394.2
Other[c]	24.3					24.3
Total	794.6	406.6	41.2	479.7	118.8	1841.0

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Retail-wholesale Year 1975

Aggregate Energy Use 2198.0 10^{12} Btu Total Floor Space 5239.0 10^6 ft^2

Aggregate EUI 419.5 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	314.3	2998.0	471.5	5239.0	5239.0
EUI[b]	208.9	128.4	7.1	96.9	55.6
Gas					
Floor space[a]	2346.0	224.4	2346.0		5239.0
EUI[b]	140.7	128.4	3.0		32.5
Oil					
Floor space[a]	2422.0		2422.0		
EUI[b]	154.7		3.9		
Other[c]					
Floor space[a]	157.2				
EUI[b]	154.7				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	65.7	384.9	3.4	507.5	291.1	1253.0
Gas	330.0	28.8	7.2		170.5	536.4
Oil	374.8		9.5			384.2
Other[c]	24.3					24.3
Total	794.7	413.8	20.0	507.5	461.6	2198.0

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Garages and service stations Year 1975

Aggregate Energy Use 89.7 10^{12} Btu Total Floor Space 617.6 10^6 ft^2

Aggregate EUI 145.3 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	37.1	353.4	55.6	617.6	617.6
EUI[b]	92.3	53.9	1.1	36.1	8.3
Gas					
Floor space[a]	276.5	26.5	276.5		
EUI[b]	62.2	53.9	48.8		
Oil					
Floor space[a]	285.5		285.5		
EUI[b]	68.4		0.6		
Other[c]					
Floor space[a]	18.5				
EUI[b]	68.4				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	3.4	19.1	0.06	22.3	5.1	50.0
Gas	17.2	1.4	0.1			18.8
Oil	19.5		0.2			19.7
Other[c]	1.3					1.3
Total	41.4	20.5	0.4	22.3	5.1	89.7

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Warehouse Year 1975

Aggregate Energy Use 317.5 10^{12} Btu Total Floor Space 2290.0 10^6 ft^2

Aggregate EUI 138.7 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	137.4	1310.	206.1	2290.	2290.
EUI[b]	92.3	51.7	1.1	30.9	8.3
Gas					
Floor space[a]	1025.	98.1	1025.		
EUI[b]	62.2	51.7	0.5		
Oil					
Floor space[a]	1059.		1059.		
EUI[b]	68.4		0.6		
Other[c]					
Floor space[a]	68.7				
EUI[b]	68.4				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	12.7	67.8	0.2	70.7	19.1	170.5
Gas	63.7	5.1	0.5			69.3
Oil	72.4		0.7			73.1
Other[c]	4.7					4.7
Total	153.5	72.9	1.4	70.7	19.1	317.5

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Education Year 1975

Aggregate Energy Use 1774.0 10^{12} Btu Total Floor Space 6561.0 10^{6} ft^2

Aggregate EUI 270.4 10^{3} Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	393.7	3754	590.5	6561.	6561
EUI[b]	172.5	97.9	14.4	60.5	16.7
Gas					
Floor space[a]	2938.	281.1	2938.		
EUI[b]	116.2	97.9	6.2		
Oil					
Floor space[a]	3033.		3033.		
EUI[b]	127.8		7.9		
Other[c]					
Floor space[a]	196.8				
EUI[b]	127.8				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	67.9	367.5	8.5	397.2	109.4	950.6
Gas	341.3	27.5	18.1			386.9
Oil	387.7		23.9			411.6
Other[c]	25.2					25.2
Total	822.1	395.0	50.5	397.2	109.4	1774.

[a]Floor space, 10^{6} ft^2.

[b]EUI, 10^{3} Btu/ft^2.

[c]Includes coal and LNG.

Subsector Hospital Year 1975

Aggregate Energy Use 1084 10^{12} Btu Total Floor Space 1993. 10^6 ft^2

Aggregate EUI 543.9 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	119.6	1140.	179.3	1993.	1993.
EUI[b]	322.7	176.5	69.2	97.4	66.7
Gas					
Floor space[a]	892.2	85.4	892.2		
EUI[b]	217.3	176.5	29.5		
Oil					
Floor space[a]	921.2		921.2		
EUI[b]	239.1		37.8		
Other[c]					
Floor space[a]	59.8				
EUI[b]	239.1				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	38.6	201.2	12.4	194.2	132.9	579.3
Gas	193.9	15.1	26.3			235.3
Oil	220.2		34.8			255.0
Other[c]	14.3					14.3
Total	467.0	216.3	73.5	194.2	132.9	1084.

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Religious Year 1975

Aggregate Energy Use 259.1 10^{12} Btu Total Floor Space 1404 10^6 ft^2

Aggregate EUI 184.5 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	84.3	803.4	126.4	1404.	1404.
EUI[b]	136.4	71.8	2.3	34.5	5.6
Gas					
Floor space[a]	628.7	60.2	628.7		
EUI[b]	91.9	71.8	1.0		
Oil					
Floor space[a]	649.1		649.1		
EUI[b]	101.0		1.3		
Other[c]					
Floor space[a]	42.1				
EUI[b]	101.0				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	11.5	57.7	0.3	48.5	7.8	125.8
Gas	57.8	4.3	0.6			62.7
Oil	65.6		0.8			66.4
Other[c]	4.3					4.3
Total	139.1	62.0	1.7	48.5	7.8	259.1

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Subsector Hotel Year 1975

Aggregate Energy Use 558.4 10^{12} Btu Total Floor Space 1444. 10^6 ft^2

Aggregate EUI 386.7 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	86.6	826.2	130.	1444.	1444.
EUI[b]	322.7	150.6	24.2	35.7	11.1
Gas					
Floor space[a]	646.5	61.9	646.5		
EUI[b]	217.3	150.6	10.3		
Oil					
Floor space[a]	667.5		667.5		
EUI[b]	239.1		13.2		
Other[c]					
Floor space[a]	43.3				
EUI[b]	239.1				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	28.0	124.4	3.1	51.6	16.1	223.1
Gas	140.5	9.3	6.7			156.5
Oil	159.6		8.8			168.4
Other[c]	10.4					10.4
Total	338.4	133.7	18.7	51.6	16.1	558.4

[a] Floor space, 10^6 ft^2.

[b] EUI, 10^3 Btu/ft^2.

[c] Includes coal and LNG.

Subsector Miscellaneous Year 1975

Aggregate Energy Use 1083. 10^{12} Btu Total Floor Space 3382. 10^6 ft^2

Aggregate EUI 320.4 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	202.9	1935.	304.4	3382.0	3382.0
EUI[b]	180.7	115.8	11.9	95.0	16.7
Gas					
Floor space[a]	1514.	144.9	1514.		
EUI[b]	121.7	115.8	5.1		
Oil					
Floor space[a]	1563.		1563.		
EUI[b]	133.8		6.5		
Other[c]					
Floor space[a]	101.5				
EUI[b]	133.8				

FUEL USE BY END USE (10^{12} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	36.7	224.0	3.6	321.2	56.4	641.9
Gas	184.2	16.8	7.7			208.7
Oil	209.3		10.1			219.4
Other[c]	13.6					13.6
Total	443.7	240.8	21.4	321.2	56.4	1083.0

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

Total Commercial - All Building Types Year 1975

Aggregate Energy Use 9200 10^{12} Btu Total Floor Space 28328 10^6 ft^2

Aggregate EUI 324.8 10^3 Btu/ft^2

DETAILED FLOOR SPACE AND EUI ESTIMATES BY END USE

Fuel type	Space heating	Cooling	Water heating	Lighting	Other
Electricity					
Floor space[a]	1700.0	16208.0	2553.0	28328.0	28328.0
EUI[b]	194.1	112.6	15.1	73.9	26.7
Gas					
Floor space[a]	12682.0	1213.0	12682.0		5239.0
EUI[b]	130.8	112.6	6.5		32.5
Oil					
Floor space[a]	13096.0		13096.0		
EUI[b]	143.9		8.3		
Other[c]					
Floor space[a]	85.3				
EUI[b]	143.9				

FUEL USE BY END USE (10^{15} Btu)

Fuel type	Space heating	Cooling	Water heating	Lighting	Other	Total
Electricity	0.33	1.83	0.04	2.09	0.76	5.05
Gas	1.66	0.14	0.08		0.17	2.05
Oil	1.88		0.10			1.98
Other[c]	0.12					0.12
Total	3.99	1.97	0.22	2.09	0.93	9.20

[a]Floor space, 10^6 ft^2.

[b]EUI, 10^3 Btu/ft^2.

[c]Includes coal and LNG.

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