

Jan F. Kreider “Introduction to the Buildings Sector”  
*Handbook of Heating, Ventilation, and Air Conditioning*  
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# 1

## Introduction to the Buildings Sector

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- 1.1 [Energy Use Patterns in Buildings in the U.S](#)  
Commercial Buildings • Industrial Processes  
and Buildings • Residential Buildings
- 1.2 [What Follows](#)

### Introduction

Buildings account for the largest sector of the U.S. economy. Construction, operation, and investment in buildings are industries to which every person is exposed daily. One of the major expenditures in the life cycle of a building is the operation of its space conditioning systems — heating, ventilation, and air conditioning (HVAC) — dwarfing the initial cost of these systems or of even the entire building itself. Therefore, it is important to use the best, most current knowledge from the design phase onward through the building life cycle to minimize cost while maintaining a productive and comfortable indoor environment.

HVAC systems are energy conversion systems — electricity is converted to cooling or natural gas is converted to heat. Because it is important to understand from the outset the nature of energy demands placed on HVAC systems, that subject is discussed immediately below. The chapter closes with a short outline of the rest of the book with its coverage of HVAC design, commissioning, operation, and problem diagnosis.

### 1.1 Energy Use Patterns in Buildings in the U.S.

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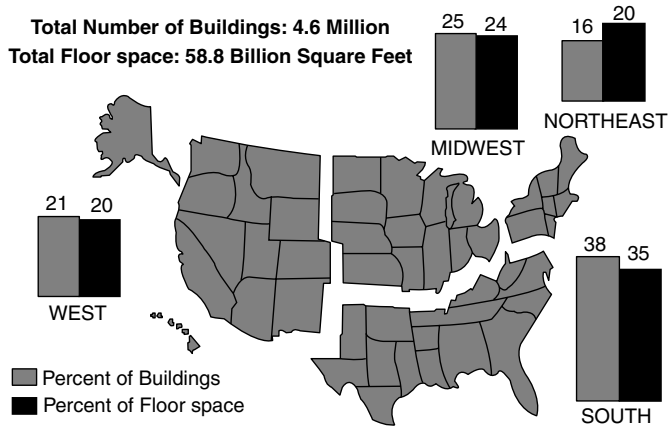
It is instructive to examine building energy use, sector by sector, to get an idea of the numbers and to clarify the differences between large and small buildings as well as between industrial and office buildings. The next several sections discuss each.

#### 1.1.1 Commercial Buildings

In 1997, there were 4.6 million commercial buildings, occupying 58.8 billion square feet of floor space (PNNL, 1997). These buildings consumed 126.5 thousand Btu of delivered energy use (or 252.4 thousand Btu of primary energy) per square foot of space. [Figure 1.1](#) shows that of the four main census regions, the South contains the highest percentage of commercial buildings, 38%, and the Northeast contains the least, 16%.

#### Commercial Buildings Disaggregated by Floor Space

Sixty percent of U.S. commercial buildings range between 5,000 and 100,000 square feet, 82% range between 1,000 and 200,000 square feet. The size class with the largest membership is the 10,000–25,000 square foot range. [Table 1.1](#) shows the size distribution in the U.S.



**FIGURE 1.1** Commercial building geographical distribution. (From the 1995 *Commercial Buildings Energy Consumption Survey*.)

**TABLE 1.1** Size Distribution of U.S. Commercial Building Space

Commercial Building Size as of 1995 (percent of total floor space)	
Square Foot Range	Percent
1,001 to 5,000	10.80%
5,001 to 10,000	12.80%
10,001 to 25,000	19.80%
25,001 to 50,000	13.10%
50,001 to 100,000	13.60%
100,001 to 200,000	11.50%
200,001 to 500,000	9.40%
Over 500,000	9.00%
	100%

### Commercial Energy Consumption and Intensity by Square Footage (1995)

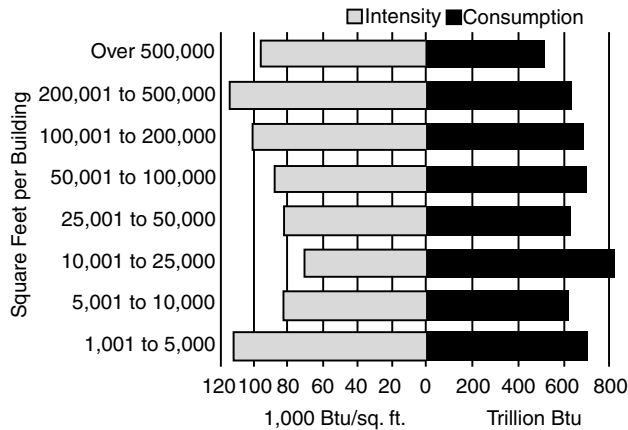
Total consumption is fairly evenly distributed across building size categories; only the largest size category (over 500,000 square feet per building) showed a significant difference from any of the other categories. Buildings in the 10,001–25,000 square feet per building category have the lowest energy intensity of all categories.

### Commercial Buildings Disaggregated by Building Type and Floor Space

The usage to which building space is put is a key influence on the type and amount of energy needed. Of the total square footage of commercial office space, 67% is used for mercantile and service, offices, warehouses and storage places, or educational facilities. The average square footage for all building types ranges between 1,001 and 25,000 square feet. The largest building types, between 20,000 and 25,000 square feet, are lodging and health care facilities. Medium sized building types, between 10,000 and 20,000 square feet, are public order and safety, offices, mercantile and service, and public assembly. Small building types, less than 10,000 square feet, include warehouse and storage facilities, education facilities, food service, and sales. [Table 1.2](#) summarizes sector sizes and typical floor sizes.

### Commercial End-Use Consumption

Mercantile and service, and office buildings consume almost 40% of total commercial energy, in terms of Btu per square foot. Education and health care facilities, lodging, and public assemblies also consume



**FIGURE 1.2** Energy consumption and usage intensity for eight commercial building size categories. (From the 1995 *Commercial Buildings Energy Consumption Survey*.)

**TABLE 1.2** Commercial Building Sector Size and Typical Floor Area

1995 Average and Percent of Commercial Building by Principal Building Type (1)

Building Type	Floor Space (%)	Average Floor Space/Building (SF)
Mercantile and Service	22%	11260
Office	18%	12870
Warehouse/Storage	14%	6670
Education	13%	1770
Public Assembly	7%	12110
Lodging	6%	22900
Health Care	4%	22220
Food Service	2%	4750
Food Sales	1%	4690
Public Order and Safety	2%	14610
Vacant (2)	9%	18480
Other	2%	—

a large amount of energy, making up another 40% of total commercial energy consumption. [Table 1.3](#) summarizes the energy use intensities for the 12 most important categories.

### End Use Consumption by Task

Finally, one must know the end use category — space heating, cooling, water heating, and lighting. Space heating and lighting are generally the largest energy loads in commercial office buildings. In 1995, energy consumed for lighting accounted for 31% of commercial energy loads. Space heating consumed 22%, and space cooling consumed 15% of commercial energy loads. On average, water heating is not high at 7%; actual load varies greatly according to building category. Health care facilities and lodging are unique in their high water heating loads; however, offices, mercantile and service facilities, and warehouses require minimal hot water. [Figure 1.3](#) shows the distribution of energy end use by sector for 1995. Another way of considering the data in [Figure 1.3](#) is to consider the end uses aggregated over all buildings but further disaggregated over the nine main end uses in commercial buildings. [Figure 1.4](#) shows the data in this way.

### Commercial Energy Consumption and Intensity by Principal Building Activity (1995)

Commercial buildings were distributed unevenly across the categories of most major building characteristics. For example, in 1995, 63.0 percent of all buildings and 67.1 percent of all floor space were in

**TABLE 1.3** End Use Consumption Intensity by Building Category

1995 Commercial Delivered End-Use Energy Consumption Intensities by Principal Building Type <sup>1</sup> (1000 Btu/SF)						
Building Type	Space Heating	Space Cooling	Water Heating	Lighting	Total <sup>2</sup>	Percent of Total Consumption
Office	24.3	9.1	8.7	28.1	97.2	19%
Mercantile and Service	30.6	5.8	5.1	23.4	76.4	18%
Education	32.8	4.8	17.4	15.8	79.3	12%
Health Care	55.2	9.9	63	39.3	240.4	11%
Lodging	22.7	8.1	51.4	23.2	127.3	9%
Public Assembly	53.6	6.3	17.5	21.9	113.7	8%
Food Service	30.9	19.5	27.5	37	245.5	6%
Warehouse and Storage	15.7	0.9	2	9.8	38.3	6%
Food Sales	27.5	13.4	9.1	33.9	213.5	3%
Vacant <sup>3</sup>	38	1.4	5.5	4.5	30.1	3%
Public Order and Safety	27.8	6.1	23.4	16.4	97.2	2%
Other <sup>4</sup>	59.6	9.3	15.3	26.7	172.2	3%
All Buildings	29	6	13.8	20.4	90.5	100%

Notes: <sup>1</sup> Parking garages and commercial buildings on multibuilding manufacturing facilities are excluded from CBECS 1995.

<sup>2</sup> Includes all end-uses.

<sup>3</sup> Includes vacant and religious worship.

<sup>4</sup> Includes mixed uses, hangars, crematoriums, laboratories, and other.

Source: EIA, Commercial Building Energy Consumption and Expenditures 1995, April 1998, Table EU-2, p. 311.

four building types: office, mercantile and service, education, and warehouse. Total energy consumption also varied by building type. Three of these — health care, food service, and food sales — had higher energy intensity than the average of 90.5 thousand Btu per square foot for all commercial buildings. [Figure 1.5](#) shows the 13 principal building types and their total consumption and intensity.

### Commercial Building Energy Consumption by Fuel Type

Five principal energy types are used in U.S. commercial buildings:

- Natural gas
- Fuel oil
- Liquefied petroleum gas (LPG)
- Other and renewables
- On-site electric

[Table 1.4](#) shows the relation between end use type in [Figure 1.5](#) and the corresponding energy sources. Space heating, lighting, and water heating are the three largest consumers of energy. Natural gas and electricity directly competed in three of the major end uses — space heating, water heating, and cooking. In each of these three, natural gas consumption greatly exceeded electricity consumption.

[Table 1.5](#) shows expected commercial sector energy use growth in the U.S.

## 1.1.2 Industrial Processes and Buildings

The industrial sector consists of more than three million establishments engaged in manufacturing, agriculture, forestry, fishing, construction, and mining. In 1997, these buildings occupied 15.5 billion square feet of floor space and 37% (34.8 quadrillion Btus) of total U.S. primary energy consumption.

After the transportation sector, the manufacturing sector consumes the most energy in the U.S. Of the 37% of primary energy consumption in the industrial sector in 1997, 33% was used for manufacturing purposes and 4% was used for nonmanufacturing purposes. Thus, manufacturing establishments consume the majority of the energy in the industrial sector even though they are far outnumbered by nonmanufacturing establishments. Because there is a lack of information regarding nonmanufacturing

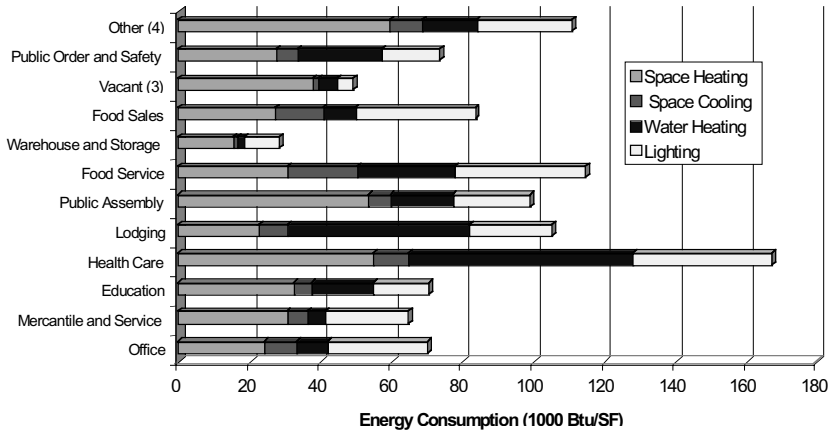


FIGURE 1.3 End use categories for commercial buildings.

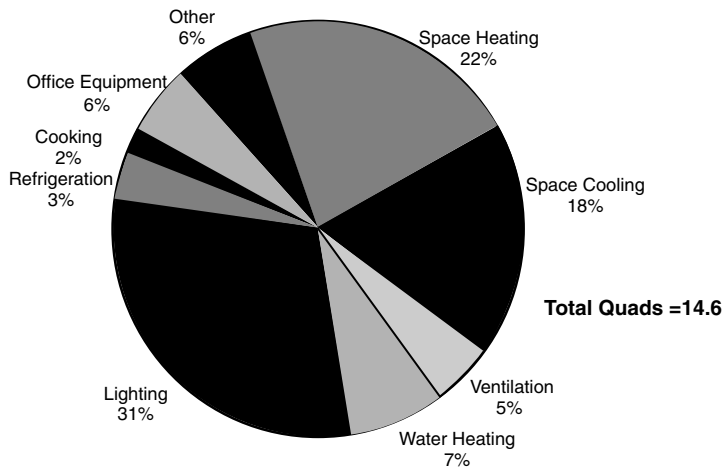


FIGURE 1.4 Commercial building energy end uses aggregated over all building types.

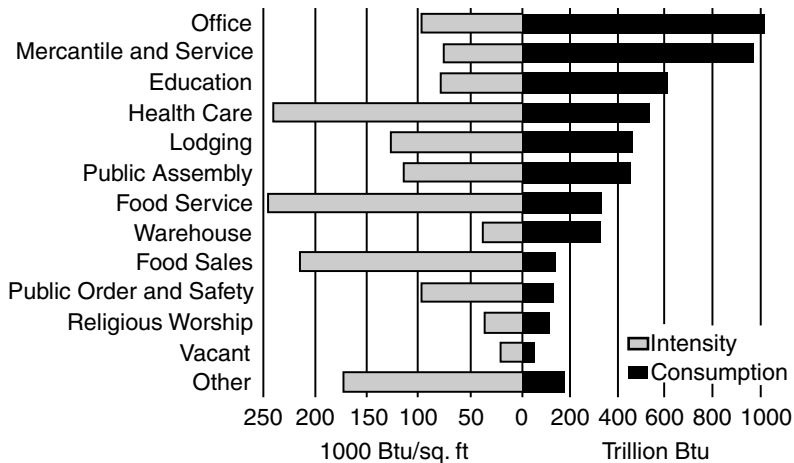
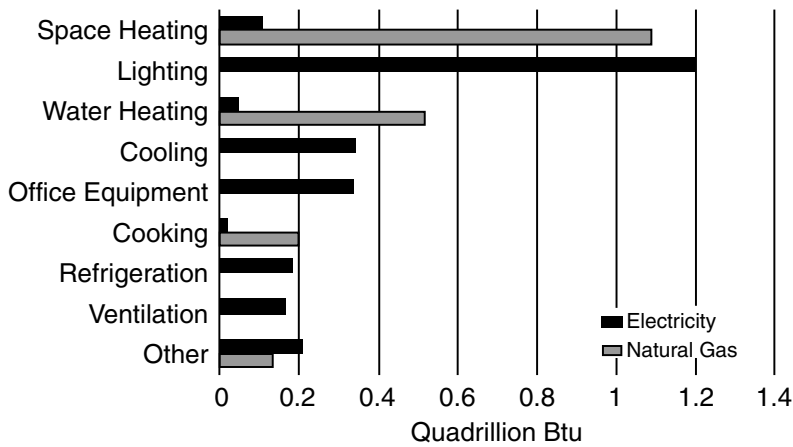


FIGURE 1.5 Energy usage and usage intensity by building type. (From the 1995 Commercial Buildings Energy Consumption Survey.)

**TABLE 1.4** Fuel Type Usage in Commercial Buildings

	Natural Gas	Fuel Oil (2)	LPG Fuel (3)	Other	Renw. En. (4)	Site Electric	Site		Primary Total
							Total	Percent	
Space Heating (8)	1.58	0.37		0.11		0.16	2.22	29.10%	0.53
Space Cooling (7)	0.02					0.34	0.35	4.60%	1.08
Ventilation						0.17	0.17	2.20%	0.53
Water Heating (8)	0.75	0.07			0.02	0.09	0.93	12.10%	0.29
Lighting						1.22	1.22	15.90%	3.9
Refrigeration						0.18	0.16	2.40%	0.59
Cooking	0.23					0.02	0.25	3.30%	0.07
Office Equipment						0.4	0.4	5.30%	1.3
Other (9)	0.21	0.04	0.08	0.03	0	0.25	0.61	8.00%	0.81
Miscellaneous (10)	0.59	0.12				0.61	1.32	17.20%	1.95
<b>Total</b>	<b>3.37</b>	<b>0.6</b>	<b>0.08</b>	<b>0.14</b>	<b>0.02</b>	<b>3.44</b>	<b>7.65</b>	<b>100%</b>	<b>11.03</b>



**FIGURE 1.6** Gas and electric consumption in commercial buildings by task. (From the *1995 Commercial Buildings Energy Consumption Survey*.)

sectors and the majority of energy is consumed in manufacturing, the manufacturing sector is the main focus in this section.

Standard industrial classification (SIC) groups are established according to their primary economic activity. Each major industrial group is assigned a two-digit SIC code. The SIC system divides manufacturing into 20 major industry groups and nonmanufacturing into 12 major industry groups. In 1991, six of the 20 major industry groups in the manufacturing sector accounted for 88% of energy consumption for all purposes and for 40% of the output value for manufacturing:

1. Food and kindred products
2. Paper and allied products
3. Chemical and allied products
4. Petroleum and coal products
5. Stone, clay, and glass products
6. Primary metals

Table 1.6 summarizes the key characteristics of the energy using SIC categories with an overview of each. Table 1.7 shows the floor space inventory by SIC.

**TABLE 1.5** Expected Future Consumption Trends for Commercial Buildings

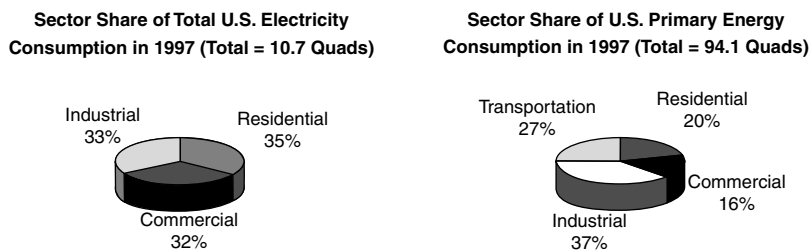
Commercial Primary Energy Consumption by Year and Fuel Type (quads and percents of total) <sup>3</sup>											Growth Rate, 1980-Year	
Year	Natural Gas		Petroleum <sup>1</sup>		Coal		Renewable <sup>2</sup>		Electricity			TOTAL
1980	267	25%	1.29	12%	0.09	1%	NA		6.55	62%	10.59	—
1990	27	21%	0.91	7%	0.09	1%	NA		9.12	71%	12.82	1.90%
1997	337	22%	0.73	5%	0.08	1%	0.02	0%	11.03	72%	15.24	2.20%
2000	355	22%	0.6	4%	0.09	1%	0.03	0%	11.76	73%	16.02	2.10%
2010	384	22%	0.57	3%	0.1	1%	0.03	0%	12.73	74%	17.27	1.60%
2020	4	22%	0.55	3%	0.1	1%	0.04	0%	13.4	74%	18.08	1.30%

Notes: <sup>1</sup> Petroleum induces distillate and residual fuels, liquid petroleum gas, kerosene, and motor gasoline.

<sup>2</sup> Includes site marketed and nonmarketed renewable energy.

<sup>3</sup> 1997 site-to-source electricity conversion = 321.

Sources: EIA, State Energy Data Report 1996, Feb. 1999, Table 13, p. 28 for 1980 and 1990; EIA, AEO 1999, Dec. 1998, Table A2, p. 113-115 for 1997-2020 and Table A18, p. 135 for nonmarketed renewable energy.



**FIGURE 1.7** Primary energy and electrical consumption in the U.S. (1997).

Of a total of 15.5 billion square feet of manufacturing space, 17% is used for office space, and 83% is used for nonoffice space. Six groups account for 50% of this space: industrial machinery, food, fabricated metals, primary metals, lumber, and transportation (PNNL, 1997).

Manufacturers use energy in two major ways:

- To produce heat and power and to generate electricity
- As raw material input to the manufacturing process or for some other purpose

Three general measures of energy consumption are used by the U.S. Energy Information Administration (EIA). According to its 1991 data, the amount of total site consumption of energy for all purposes was 20.3 quadrillion Btu. About two thirds (13.9 quadrillion Btu) of this was used to produce heat and power and to generate electricity, with about one third (6.4 quadrillion Btu) consumed as raw material and feedstocks. Figure 1.8 shows the relative energy use for the energy consuming SIC sectors.

### Energy Use by Standard Industrial Classification

Energy end uses for industry are similar to those for commercial buildings although the magnitudes are clearly different. Heating consumes 69% of delivered energy (45% of primary energy usage). Lighting is the second largest end use with 15% of delivered energy (27% of primary energy usage). Finally, ventilation and cooling account for 8% each.

### Industrial Consumption by Fuel Type

As with commercial buildings, a variety of fuels are used in industry. Petroleum and natural gas far exceed energy consumption by any other source in the manufacturing sectors. Figure 1.9 indicates the fuel mix characteristics.



**TABLE 1.6** General Characteristics of Industrial Energy Consumption SIC

Standard Industrial Code	Major Industry Group	Description
High-Energy Consumers		
20	Food and kindred products	This group converts raw materials into finished goods primarily by chemical (not physical) means. Heat is essential to their production, and steam provides much of the heat. Natural gas, byproduct and waste fuels are the largest sources of energy for this group. All, except food and kindred products, are the most energy-intensive industries.
26	Paper and allied products	
28	Chemicals and allied products	
29	Petroleum and coal products	
32	Stone, clay, and glass products	
33	Primary metal industries	
High Value-Added Consumers		
34	Fabricated metal products	This group produces high value-added transportation vehicles, industrial machinery, electrical equipment, instruments, and miscellaneous equipment. The primary end uses are motor-driven physical conversion of materials (cutting, forming, assembly) and heat treating, drying, and bonding. Natural gas is the principal energy source.
35	Industrial machinery and equipment	
36	Electronic and other electric equipment	
37	Transportation equipment	
38	Instruments and related products	
39	Miscellaneous manufacturing industries	
Low-Energy Consumers		
21	Tobacco manufactures	This group is the low energy-consuming sector and represents a combination of end-use requirements. Motor drive is one of the key end uses.
22	Textile mill products	
23	Apparel and other textile products	
24	Lumber and wood products	
25	Furniture and fixtures	
27	Printing and publishing	
30	Rubber and miscellaneous plastics	
31	Leather and leather products	

Source: Energy Information Administration, Office of Energy Markets and End Use, Manufacturing Consumption of Energy 1991, DOE/EIA-0512(91).

**TABLE 1.7** Industrial Building Floor Area Distribution

1991 Industrial Building Floor Space (10 <sup>6</sup> square feet)				
SIC	Manufacturing Industry	Office Floor Space	Nonoffice Floor Space	Total Floor Space
20	Food	203	1207	1410
21	Tobacco	6	51	56
22	Textiles	42	581	623
23	Apparel	73	451	523
24	Lumber	53	1135	1187
25	Furniture	49	521	569
26	Paper	72	827	899
27	Printing	351	477	827
28	Chemical	185	714	899
29	Refining	20	105	125
30	Rubber	97	768	865
31	Leather	9	44	53
32	Stone, Clay	57	808	864
33	Primary Metals	81	1121	1202
34	Fabricated Metals	182	1175	1357
35	Industrial Machinery	337	1149	1485
36	Electronic Equipment	266	629	894
37	Transportation	289	776	1065
38	Instruments	225	170	395
39	Misc. Manufacturing	52	190	242
Total		2,641	12,898	15,539

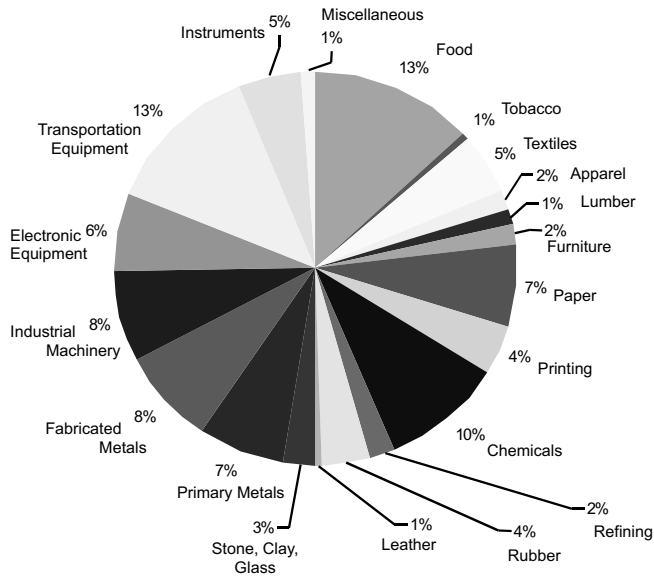


FIGURE 1.8 Energy use by SIC category.

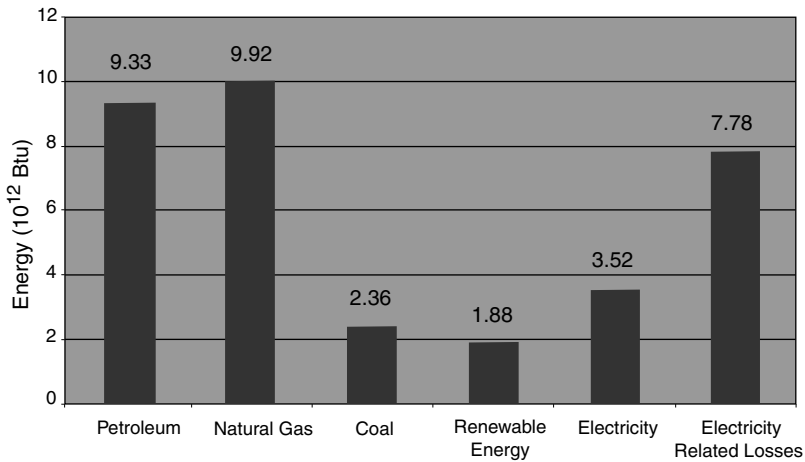


FIGURE 1.9 Industrial consumption by fuel type.

### 1.1.3 Residential Buildings

Although residential buildings are not often equipped with engineered HVAC systems, it is important to understand usage by this sector because it is large and many of the design and operation principles for large buildings also apply to small ones. The following data summarize residential energy use in the U.S. Figure 1.10 shows energy use by building type.

#### Residential Sector Overview

In 1993, there were 101.3 million households, or 76.5 million buildings with an average of 2.6 people per household. The households consisted of 69% single-family, 25% multi-family, and 6% mobile homes. These buildings consumed 107.8 million Btu of delivered energy (or 187.5 million Btu of primary energy) per household.

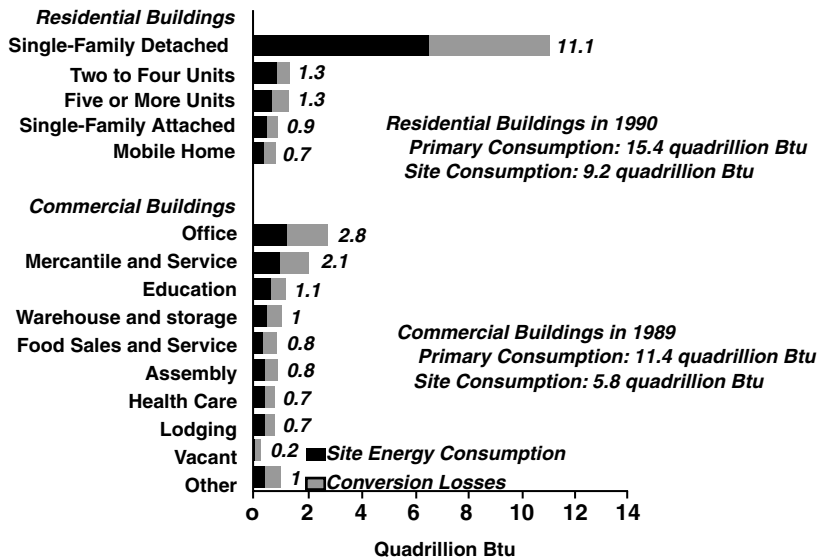


FIGURE 1.10 Comparison of commercial and residential sector energy use.

TABLE 1.8 U.S. Residential Buildings Disaggregated by Size

Household Size in Heated Floor Space as of 1995	
Square Foot Range	Percent
Fewer than 599	7.8%
600 to 999	22.6%
1,000 to 1,599	28.8%
1,600 to 1,999	12.8%
2,000 to 2,399	10.0%
2,400 to 2,999	8.5%
3,000 or more	9.6%
	100%

More than 50% of all residences range between 600 and 1,600 square feet; 23% are between 1,600 and 2,400 square feet, and 29% are in the 1,000 to 1,600 square feet range as shown in Table 1.8.

### Residential Energy Consumption Intensity

Table 1.9 and Table 1.10 summarize residential fuel utilization. Natural gas and electricity are the key residential energy sources. Table 1.11 shows expected growth through the year 2020.

## 1.2 What Follows

In order to cover all topics affecting the design and operation of HVAC systems in modern buildings, this book is divided into eight sections as follows:

1. Introduction to the Buildings Sector
2. Fundamentals
  - 2.1 Thermodynamics Heat Transfer and Fluid Mechanics Basics
  - 2.2 Psychrometrics and Comfort

**TABLE 1.9** Energy Consumption Intensities by Ownership of Unit

1993 Residential Delivered Energy Consumption Intensities by Ownership of Unit				
Ownership	Per Square Foot (10 <sup>3</sup> Btu)	Per Household (10 <sup>6</sup> Btu)	Per Household Members (10 <sup>6</sup> Btu)	Percent of Total Consumption
Owned	52.0	118.5	44.0	75%
Rented	67.0	75.2	31.0	25%
- Public Housing	69.0	58.2	27.0	2%
- Nonpublic Housing	67.0	77.2	31.0	23%

Source: EIA, Household Energy Consumption and Expenditures 1993, Oct. 1995, Table 5.1, p. 37-38.

**Table 1.10** Residential End-Use Consumption by Fuel Type and by End Use

1997 Residential Energy End-Use Splits by Fuel Type (quads)											
	Natural Gas	Fuel Oil	LPG Fuel	Other	Renw. En. (3)	Site			Primary		
						Electric	Total	Percent	Electric	Total	Percent
Space Heating	3.58	0.84	0.32	0.15	0.61	0.50	6.00	54.8%	1.61	7.10	37.3%
Space Cooling	0.00					0.54	0.54	4.9%	1.72	1.72	9.1%
Water Heating	1.27	0.10	0.07		0.01	0.39	1.83	16.8%	1.24	2.69	14.2%
Lighting						0.40	0.40	3.6%	1.27	1.27	6.7%
White Goods	0.05					0.78	0.82	7.5%	2.49	2.54	13.4%
Cooking	0.16		0.03			0.23	0.42	3.9%	0.74	0.93	4.9%
Electronics						0.27	0.27	2.5%	0.86	0.86	4.5%
Motors						0.05	0.05	0.5%	0.18	0.18	0.9%
Heating Appliances						0.10	0.10	0.9%	0.31	0.31	1.6%
Other	0.09	0.00	0.01				0.10	0.9%		0.10	0.5%
Miscellaneous						0.41	0.41	3.7%	1.30	1.30	6.9%
Total	5.15	0.94	0.43	0.15	0.62	3.66	10.94	100%	11.73	19.01	100%

3. Economic Aspects of Buildings
  - 3.1 Central and Distributed Utilities
  - 3.2 Economics and Costing of HVAC Systems
4. HVAC Equipment and Systems
  - 4.1 Heating Systems
  - 4.2 Air Conditioning Systems
  - 4.3 Ventilation and Air Handling Systems
  - 4.5 Electrical Systems
5. Controls
  - 5.1 Controls Fundamentals
  - 5.2 Intelligent Buildings
6. HVAC Design Calculations
  - 6.1 Energy Calculations — Building Loads
  - 6.2 Simulation and Modeling — Building Energy Consumption
  - 6.3 Energy Conservation in Buildings
  - 6.4 Solar Energy System Analysis and Design
7. Operation and Maintenance
  - 7.1 HVAC System Commissioning
  - 7.2 Building System Diagnostics and Predictive Maintenance
8. Appendices

**Table 1.11** Expected Growth in Residential Energy Use

Residential Primary Energy Consumption by Year and Fuel Type (quads and percents of total)													
Year	Natural Gas		Petroleum <sup>1</sup>		Coal		Renewable <sup>2</sup>		Electricity		TOTAL	Growth Rate, 1980-Year	
1980	4.86	32%	1.75	12%	0.06	0%	NA <sup>3</sup>		8.41	56%	15.069	100%	—
1990	4.52	27%	1.27	8%	0.06	0%	0.63	4%	10.05	61%	16.53	100%	0.9%
1997	5.15	27%	1.47	8%	0.06	0%	0.62	3%	11.73	62%	19.01	100%	1.4%
2000	5.21	26%	1.38	7%	0.06	0%	0.62	3%	12.79	64%	20.06	100%	1.4%
2010	5.52	26%	1.23	6%	0.05	0%	0.65	3%	13.68	65%	21.13	100%	1.1%
2020	5.94	26%	1.12	5%	0.05	0%	0.70	3%	15.09	66%	22.90	100%	1.1%

Notes: <sup>1</sup> Petroleum includes distillate and residual fuels, liquefied petroleum gas, kerosene, and motor gasoline.

<sup>2</sup> Includes site marketed and non-marketed renewable energy.

<sup>3</sup> 1980 Renewables are estimated at 1.00 quads.

Sources: EIA, State Energy Data Report 1996, Feb. 1999, Tables 12-15, p. 22-25 for 1980 and 1990; EIA, AEO 1999, Dec. 1998, Table A2, p. 113-115 for 1997-2020 consumption and Table A18, p. 135 for nonmarketed renewable energy.

The book is indexed for all detailed topics, and adequate cross-references among the chapters have been included. The appendices include the nomenclature and selected lookup tables.

## References

PNNL (1997). An Analysis of Buildings-Related Energy Use in Manufacturing, *PNNL-11499*, April.

Energy Information Administration (EIA, 1995). *1995 Commercial Buildings Energy Consumption Survey*.