AN OVERVIEW OF THE U.S. BUILDING STOCK[1]

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Introduction to the U.S. Building Stock

From the skyscrapers of Manhattan to the Victorian houses of San Francisco and the shopping malls of Anytown, USA, buildings in the U.S. are remarkable for their variety. Variety in the type of building (commercial warehouse, manufacturing facility, institutional and office buildings, apartment buildings, condos, single-family dwellings, mobile homes and the like) translates to variety in occupancy and use, which in turn, means differences in energy requirements and indoor air quality concerns.

For the past 40 years, energy prices in the U.S. were so low that there was little concern for energy-efficient design. With the oil shocks of the 70s, an increased awareness of energy and the environment led to greater interest and research in the use of energy and its environmental consequences. For the past 25 years, increasing attention has been given to the indoor environment—and with good reason: Americans reportedly spend up to 90% of their time in homes, shopping malls, and workplaces and have come to expect that temperatures, humidities and lighting conditions will be appropriate to their needs and desires for comfort, safety, ease of use, and health. Indeed, technological advances in air conditioning and lighting, in particular, have enabled us to create uniform indoor environmental conditions wherever we are—whether in cold northern cities, hot humid regions of the south, or the hot arid conditions of the southwest.

This re-creation of acceptable indoor climates that surmount external conditions comes at a price, however. In 1996, for example, over 34 quadrillion British thermal units of energy, at a cost of $232 billion, was expended on the energy resources associated with the heating, cooling, lighting and equipment in buildings. Buildings account for 37% of the total primary energy use in the U.S., compared to 37% for industry and 26% for transportation (Figure 1).

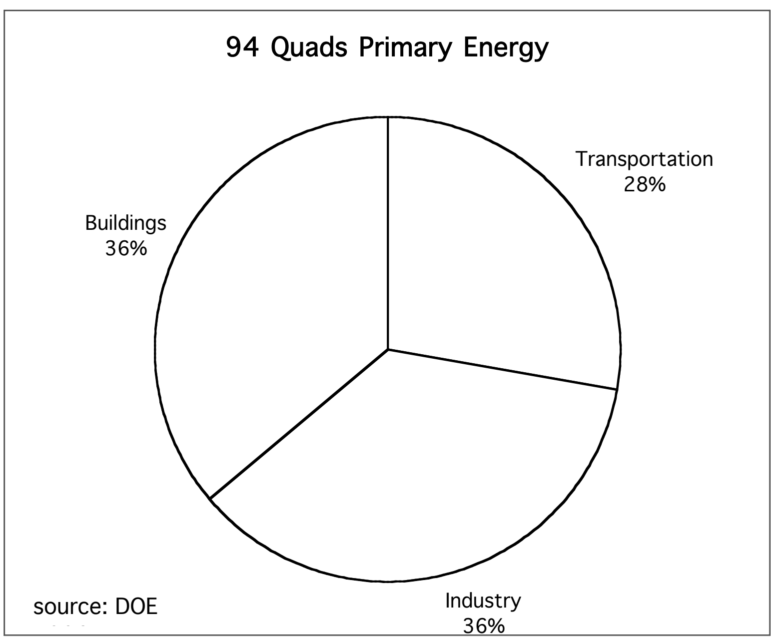

Figure 1. 1996 US Primary energy use by sector.

It is no surprise, then that the building construction industry accounts for 7% of the U.S. Gross Domestic Product—nearly $564 billion in 1996. Over one-third (38%) of the building construction activity is in remodeling and renovation (USDOE 1998a). Over 130,000 builders employ more than 163,000 architects and nearly 4 million construction workers, a significant fraction of the workforce. For these reasons the construction industry serves as an indicator of economic activity, and the number of new housing starts is used as an index of the nation's overall economic health.

Despite the key role that the construction industry plays in our economy and the advances it has made in materials and methods of building, the construction process, in many respects, has remained largely unchanged for the last century. The large number of players and specialized trades means that very little coordination occurs between the design, construction, and operation of buildings. The outcome is that buildings do not always perform according to design intent, and optimal indoor environmental conditions are not always achieved, including indoor air quality.

Commercial buildings, for example, are typically built under a "design/bid/build" approach in which the owner retains an architect to lead the project through the design stage. Following the design phase, the project is let out for bid by general contractors. After award of the project, the general contractor usually subcontracts most or all of the work to subcontractors. A drawback of this system is that, in a competitive environment, projects are awarded on the basis of the lowest bid, and contractors must then find ways to cut costs during construction, often at the expense of HVAC systems and controls.

In the case of commercial buildings, there is an alternative: the "design/build" approach, where the designer works for the contractor. A design/build contractor usually has in-house staff handle the architecture and engineering as well as other sub-specialties.

Unlike commercial buildings, residential housing is typically "designed" once and built several times, in different locations and with slight modifications. These new houses are built on site using a variety of specialized trades and craftsmen, but increasing, more factory-assembled components are being used to lower on-site construction costs. Only a few percent of the housing stock are custom designed by architects for specific clients.

One of the major differences between housing construction in the U.S. and that of other industrialized nations is the de-centralized nature of our building industry. Compared to Sweden where the large majority of new housing is built by a few large builders, the five largest residential home builders in the U.S. (Pulte, Centex, Ryland, JPI and Kaufman & Broad) built only 50,000 new homes in 1995, less than 4% of the total new houses. For that year, the top 100 builders built 16% of all new homes. Habitat for Humanity, a nonprofit builder serving low-income households, built 3,280 homes in 1995--less than 1% of the new housing construction (DOE 1998a).

Characteristics of the Existing U.S. Housing Stock[2]

This section first describes the number, location, type, ownership, age, size and household characteristics of the residential sector. The remainder of the section reviews the energy use characteristics, looking at both overall household consumption and individual components.

Number and location of U.S. households

In 1997 there were 101 million households in the United States, of which 19% were located in the Northeast, 24% in the Midwest, 35% in the South and 21% in the West. Over three-quarters of the households (77%) are in urban areas, with 36% in the central city and 41% in suburbia. The remaining households (22%) are in rural areas.

Type and Ownership of U.S. Households

The three basic categories of housing type are 1) single-family units (both as detached units and in row houses), 2) multifamily (both low-rise and high-rise apartments) and 3) mobile homes. In 1997 the stock was predominantly single-family units (73%), with apartments accounting for 21% of the total households and 6% for mobile homes (Figure 2). The U.S. is a nation of homeowners, with 67% of the households owner-occupied and the remaining 33% rented.

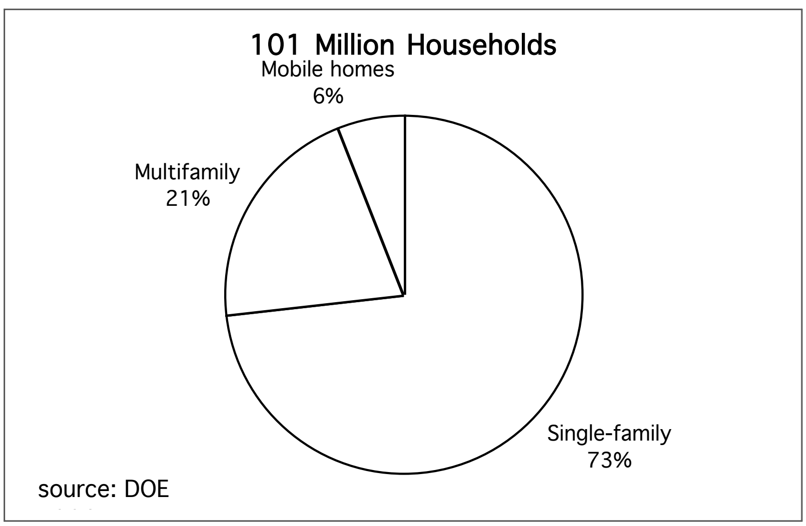

Figure 2. 1997 Distribution of US Households by housing type.

Age, Size and Equipment Characteristics of U.S. Households

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[2] Unless otherwise noted, the information on the residential sector comes from a single reference, the 1997 Residential Energy Consumption Survey, a representative sample of all U.S. households (US DOE 1997). For readers interested in perusing the data in more detail, the information can be found on the following web site: http://www.eia.doe.gov/emeu/recs/contents.html

Over 90% of the current U.S. housing stock was built before 1990; only 18% was built before 1940. The 1970s were the decade with the largest amount of housing built, with 19% of the current stock built during that period. The oldest housing stock is in the Northeast and Midwest and the newest is in the South.

The average existing single-family home has 3.0 bedrooms and 1.5 full bathrooms, for a total of 2,280 square feet of floor space, of which 1,950 square feet was heated space, the rest being unheated garage and basement areas. Air conditioning is installed in 70% of single-family households, with 47% having central units and 25% having wall or window units. Clothes washers are present in 93% of the units and 88% have clothes dryers.

The average existing multifamily dwelling has 1.6 bedrooms and 1.1 full bathrooms, for a total of 970 square feet, of which 920 square feet was fully conditioned space. Air conditioning is installed in 65% of apartment households, with 36% having central units and 30% having wall or window units. Clothes washers are less common than in single-family households, and are found in 31% of the units and 25% use clothes dryers.

Over 11 million apartment households—nearly half the sector (48%)—were eligible for Weatherization or for the Low-Income Home Energy Assistance Program, a federal subsidy for utility payments of low-income households. The average annual income of Federally eligible households in 1994 was $11,245. Over 3 million rental units, nearly 10% of the rental stock (both single- and multifamily) are defined as "inadequate" which refers to the absence of heating and plumbing equipment as well as information on upkeep and maintenance (Harvard, 1997).

The average existing mobile home has 1.6 bedrooms and 1.1 full bathrooms, for a total of 980 square feet, of which 940 square feet was conditioned space. Air conditioning is installed in 70% of mobile homes; 43% have central units and 29% have wall or window units. Clothes washers are found in 84% of the units and 75% have clothes dryers. Forty percent of the households in mobile homes were eligible for the Low-Income Home Energy Assistance Program.

Basement and foundation type are important in studying migration of moisture, radon and soil gas into housing. In 1995 nearly half (45%) of all single-family housing had a full or partial basement. About one-quarter (26%) of the single-family houses were built over crawlspaces and 27% were built on concrete slabs (US DOC 1997a).

Energy Use Characteristics

In 1997, over half of all households (52%) used natural gas as their primary fuel for space heating, 30% used electricity, 9% used fuel oil, 4% used LPG, 2% used wood; and 2% used some other fuel (Figure 3). Of the 52 million households using natural gas for space heating, 71% had a central, warm-air furnace, 13% had a steam or hot-water system, and 8% had a wall or floor furnace. Of the 30 million households using electricity for space heating, 37% had a central, warm-air furnace, 32% had heat pumps, and 25% had built-in resistance units. Portable space heaters are used in 12% of all households, the majority (88%) of which are electric. The remainder of the portable heaters are kerosene or fuel oil—a potential source of indoor air pollution.

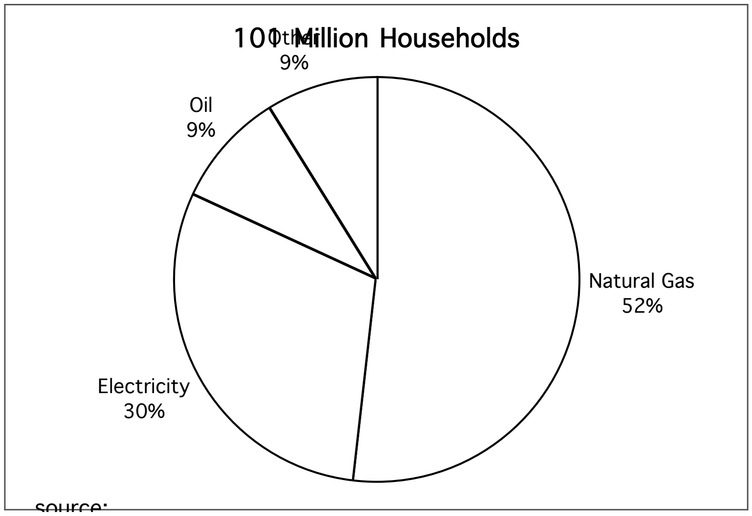

Figure 3. 1997 US residential heating fuel by source.

In 1997, air conditioning was present in 74% of U.S. households. Central air conditioning systems were installed in 48% of the households and 27% had window units. Of the households with central a/c that were surveyed by RECS, 33% said they used the system “all summer,” 14% said they used it “quite a bit” and 17% said they used it “only a few times.” In contrast, of the households with window a/c units, only 8% said they used the unit “all summer,” 9% said they used it “quite a bit” and 18% said they used it “only a few times.” More than half the U.S. households use some type of portable fan for cooling.

Humidifiers are used to increase the relative humidity in 14% of all households, with the highest use (26%) being in the Midwest. Dehumidifiers are used in 9% of all households. Again, the highest percentage is in the Midwest, where 22% of the households use these devices routinely. Six percent of U.S. households reported using some type of air cleaning device in 1993.

ASHRAE Standard 62-1989 sets minimum ventilation rates for providing acceptable air quality in buildings (ASHRAE 1989). For residential buildings the standard specifies 0.35 air changes per hour (ACH). This standard is a general guideline and does not anticipate health risk from acute and chronic exposure to a variety of sources or materials found in homes. Also, since most houses rely on infiltration to provide adequate ventilation, the ACH will vary by geographic location, orientation of the home, surrounding structures, vegetation, and of course, the season and weather conditions. The behavior of occupants, design of heating system, use of fans, etc., play an important role leading to variation in ACH, both between homes and within homes.

Information on the actual air exchange rates of the residential housing stock is sketchy at best, but estimates of air leakage based on blower-door measurements suggest that the existing single-family housing stock has, on average, 1.0 air changes per hour (Sherman 1996). Because of code changes and other mandates for more energy-efficient construction, new housing is considerably tighter than existing residences, with air exchange rates reported to be averaging 0.5 ACH for new construction.

While most single-family housing meets the ASHRAE standard of 0.35 ACH through infiltration and natural ventilation, new, tighter housing may require mechanical ventilation. Multifamily housing can have much lower infiltration rates, and mechanical ventilation is frequently required to provide acceptable ventilation. Unfortunately, the mechanical ventilation systems in apartment buildings often fail to perform, due to poor design, construction, operation and maintenance (DeCicco 1996).

Following the energy shocks of the 1970s there was increased awareness of the importance of improving the energy efficiency of new housing. Over the past 20 years, homeowners have improved the thermal integrity of their homes. Eighty-one percent of single-family houses have insulation in the roof or ceiling and 70% have insulation in the walls. Double or triple-pane windows are found in 36% of all households and 61% of replacement windows are double or triple-pane glass.

<u>Energy use consumption</u>

The average U.S. household consumed 136 million British thermal units (MBtu) of primary energy in 1996. Energy consumption varies regionally and by housing type. For the average single-family household, 39% of the energy use is attributable to space heating, 14% to water heating; 9% to refrigeration; 8% to cooling, 6% to lighting; 3% to cooking; 3% to clothes drying, and the rest (20%), to other uses (see Figure 4). In 1996 the average US household spent $1,355 for their residential energy needs (DOE 1998a).

While public interest in renewable energy sources, such as energy from sun and wind, is increasing, only 1% of U.S. households use solar energy directly for space or water heating.

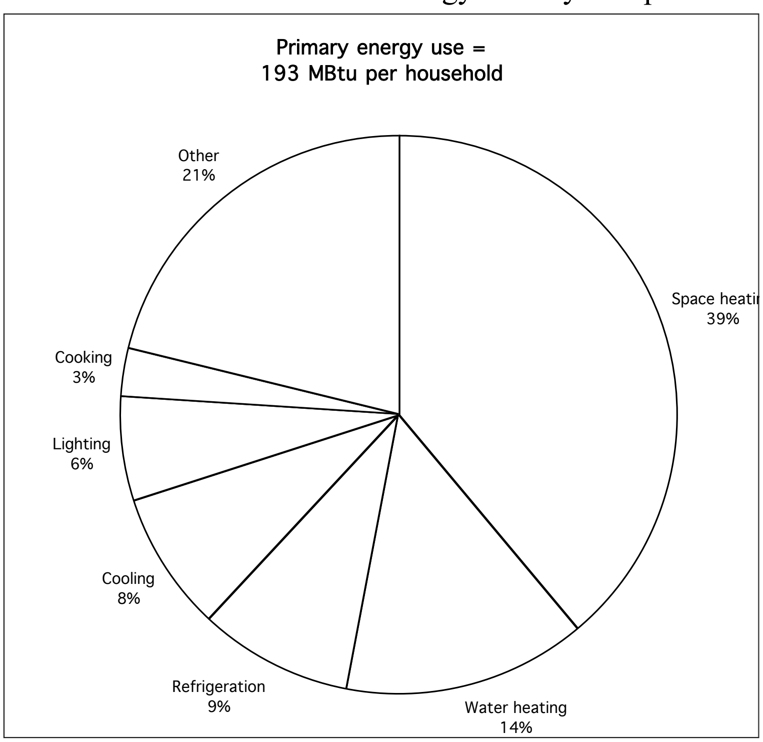

Figure 4. 1996 US Residential energy end use.

Characteristics of the New U.S. Housing Stock

Newer homes share many of the characteristics of the existing housing stock. The latest Residential Energy Conservation Survey (RECS) conducted in 1993 included a series of questions about single-family homes built between 1988 and 1993 (US DOE 1995) to look at changes in the newest additions to the housing stock.

Over one million new single-family housing units were completed in 1995, with an average floor area of 2,095 square feet, 17% larger than a new house in 1980. In 1995, 247,000 new multifamily housing units were also completed. The average floor area of these units was 1080 square feet, 9% larger than a new apartment unit in 1980. As for new mobile homes, 311,000 were placed in 1995 (US DOE 1998).

Between 1978 and 1993, the number of homes with central air-conditioning rose from 18 million homes to 42 million homes. The use of air-conditioning varied among the four census regions. In the South, where a/c needs are the greatest, 89% of all households had some type of air-conditioning in 1993, double the number from 1978.

The 1993 data also showed an increase in the number of households using window or ceiling fans, personal computers, color televisions, microwave ovens and electric clothes dryers. The appliances that decreased in use include black and white televisions, portable kerosene heaters and well-water pumps.

Trends in New Housing Construction

Several factors drive changes in new housing construction. First of all, the changing demographics of the U.S. population is bound to affect the size and location of new housing. Beyond that, the increased costs of disposing of construction wastes in urban landfills will lead to efforts to minimize construction waste and new materials and construction techniques will be introduced to improve the efficiency of housing production. Finally, the industry itself is changing: through mergers and acquisitions many large housing companies are absorbing smaller, more innovative firms. The implications of this transformation may be that changes could occur more quickly across the new housing stock.

Changing Demographics

Even as households continue to decrease in size, from an average household size of 2.7 people per household in 1995 to a projected 2.5 in 2015, the trend in new houses is towards more not less floor area. This trend signals an increase not only in floor area per capita, but in energy consumption per capita as well.

As the population ages, it is reflected in changes in energy use. The elderly, for example, often prefer higher indoor temperatures during the heating season than their younger counterparts. The next 10 to 20 years will also see the first generation of elderly growing old in suburbia and thus increasingly dependent on the automobile for access to health care and other services.

Minimizing construction wastes

Despite the strong environmental concerns of an increasingly vocal public, it is more likely to be economic factors that motivate builders to curb construction waste. Rising landfill costs have already persuaded builders to reduce the waste stream associated with residential construction. Construction of a typical 2,000 square foot, new, single-family, detached house creates an average of 4 tons of construction waste, generally consisting of wood/paper (45%), drywall (25%), masonry (13%), and miscellaneous other (17%). Annual construction and demolition waste accounts for roughly 24% of the municipal solid waste stream. As much as 95% of building-related construction waste is recyclable and most construction materials are clean and unmixed (US DOE 1998a).

Even though less than 1% of residential construction waste is classified as hazardous material (NAHB 1996), 15 to 70 pounds of hazardous waste are generated during the construction of a single-family house. Hazardous wastes include paint, caulk, roofing cement, aerosols, solvents, adhesives, oils and greases.

New Materials and Construction Techniques

The trend toward increased use of factory-built and assembled components will likely continue, both as an efficiency measure and as a way to satisfy individual requirements of prospective home buyers. On-site construction will consist primarily of assembling these components and modules rather than fabricating them from raw materials. Data from 1991 indicate that manufactured housing now accounts for 30-40% of new housing in parts of the West and South (Harvard, 1997).

Already, new materials and construction techniques such as are involved in steel framing, modular wall panels, advanced windows and integrated wiring and electronics are becoming widespread across the U.S. Advanced materials such as building-integrated photovoltaic roof tiles may become common as their price decreases. These tiles convert sunlight to electricity, that can be battery-stored or fed back to the utility grid when the electricity is not needed. Improved windows designed for solar control, and advanced lighting systems and controls will also see increased use in routine building. In addition, building materials will need to meet higher standards for reduced emissions and for recycling and reuse.

Consumers will increasingly demand houses that are comfortable and healthy, and mechanical ventilation systems will be increasingly common to ensure adequate ventilation. Smart controls and sensors designed to respond to either occupancy or carbon dioxide levels will operate the ventilation systems. Ventilation air will also be filtered to remove infectious agents and allergens.

Characteristics of Existing U.S. Commercial Buildings[3]

In 1995, there were 4,580,000 commercial buildings in the United States representing 60 billion square feet of floor space. The total number of commercial buildings in 1995 was only 6 percent of the total number of residential buildings in 1993, but commercial floor space was equivalent to 32 percent of total residential floor space.

Primary Activities in Commercial Buildings

The commercial buildings sector is dominated by four types of activity: retail and service, office, warehouse and storage, and education (Figure 5). Together they comprised 67 percent of commercial floor space and constituted 63 percent of all commercial buildings in 1995. Retail and service buildings were by far the most numerous type (more than 28 percent), but they account for less in floor space (22 percent) compared to other activity types.

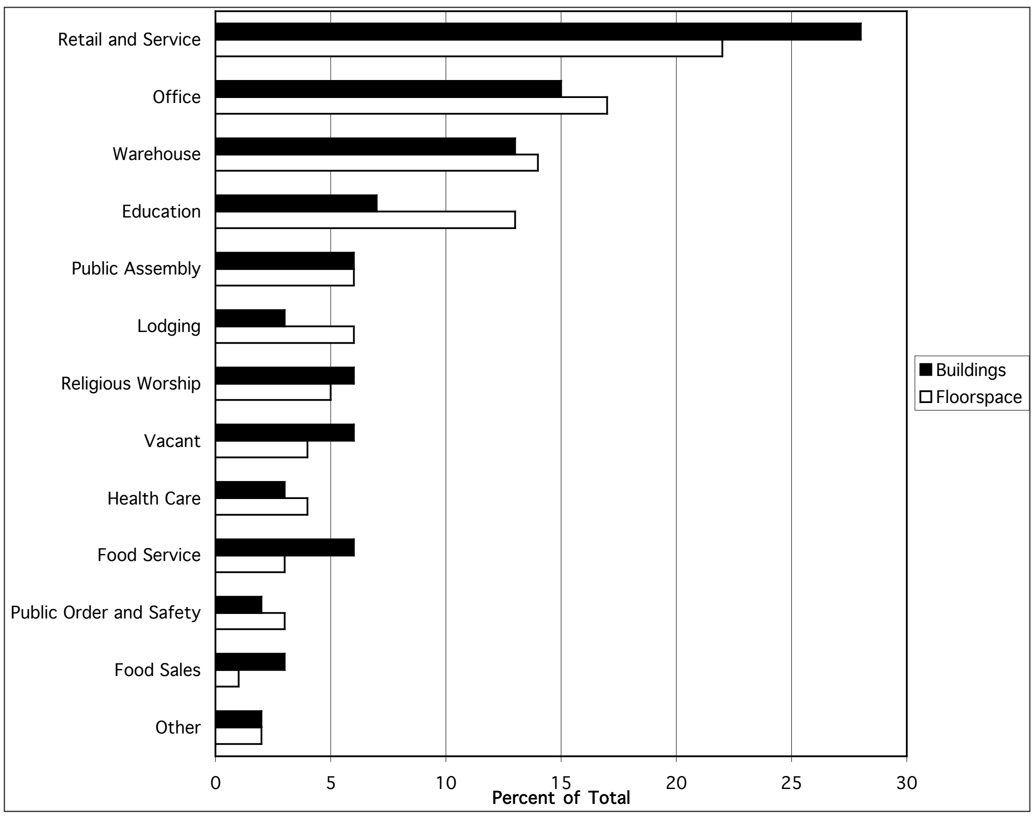

Figure 5. 1995 US Commercial sector by principal activity.

[3] The U.S. Department of Energy's *Commercial Buildings Energy Consumption Survey* (CBECS) collects information on physical characteristics of commercial buildings, building use and occupancy patterns, equipment use, energy-conservation features and practices, and types and uses of energy in buildings (US DOE 1998b). For additional information see their web site at: http://www.eia.doe.gov/emeu/cbecs/char95/profile.html

Comparison of the percentage of floor space and buildings for a given activity category gives an indication of the mean, or average, size of buildings in the category. For example, knowing that education buildings accounted for 13 percent of total floor space and 7 percent of total buildings, tells us that those buildings were larger in average size. At 25,100 square feet per building, education buildings were, in fact, the largest type, much larger than that of all other commercial buildings (12,840 square feet per building). Two other building activities, lodging and health care (22,900 and 22,200 square feet per building, respectively), were significantly larger than the average size of all buildings.

Both food sales and food service buildings, which include convenience stores, retail bakeries, fast food restaurants, and bars, were significantly smaller in average size (fewer than 5,000 square feet per building).

Office buildings, which included some of the very largest commercial buildings in the United States, had an average size (14,900 square feet). A common image of an office building is the multistory building that dominates the skyline of major urban cities. Actually, this category is dominated by smaller buildings, such as banks, real estate offices, and insurance offices. Collectively, they bring the overall office building average close to the mean of the total commercial population of buildings.

<u>Geographical Location of Commercial Buildings</u>

The U.S. Census Bureau divides the United States into four census regions, each having 9 to 16 states. For 1995, commercial buildings, floor space, and population were distributed in a similar pattern for the four regions (Figure 6). The high correlation of buildings and floor space with population was not surprising since commercial activity is mostly the provision of services to people.

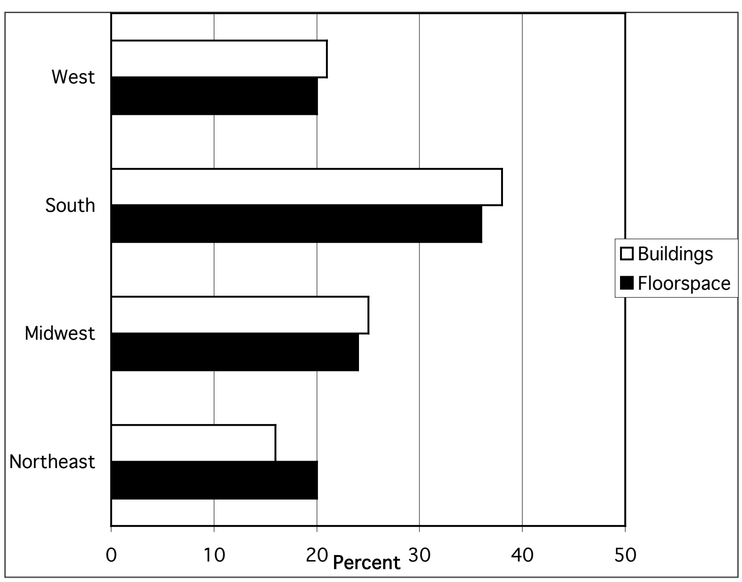

Figure 6. 1995 US Commercial floor space by region.

There were slight regional differences in the average floor space of commercial buildings. Those in the Northeast were larger on average (16,400 square feet per building) than those in the other three regions (11,900 to 12,600 square feet per building).

Size of Buildings

As evident in Figure 7, the vast majority of commercial buildings nationwide are in the smallest size categories. More than half (52 percent) are in the smallest category and three quarters are in the two smallest categories.

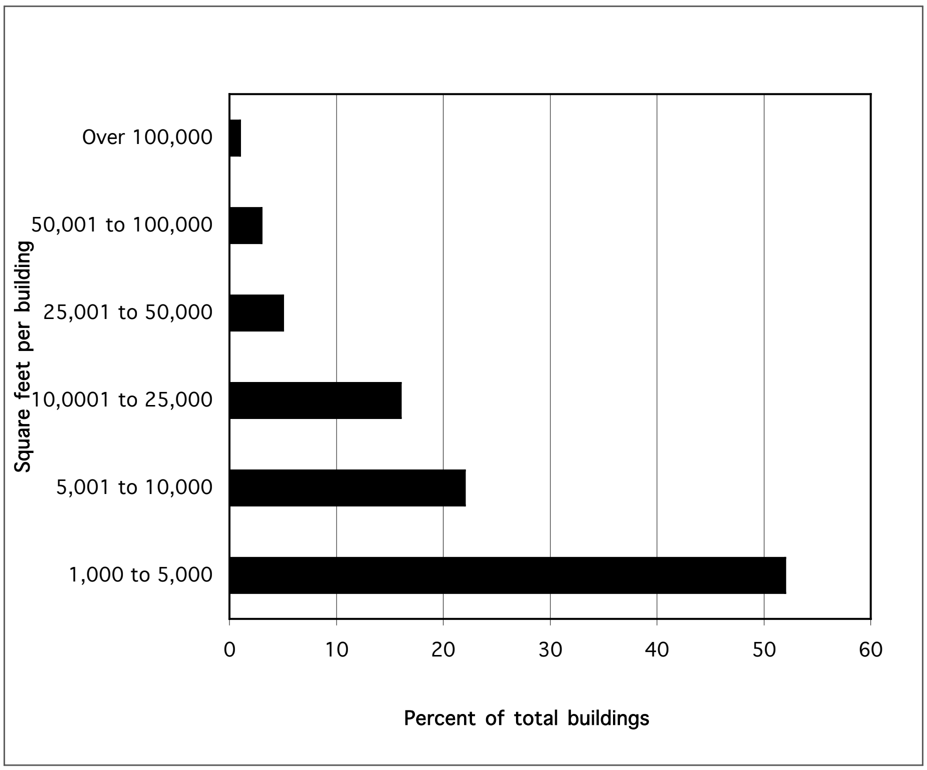

Figure 7. 1995 US Commercial buildings by size.

Less than 5 percent of the nation's commercial buildings (188,000 buildings) were larger than 50,000 square feet and less than 2 percent (73,000 buildings) were larger than 100,000 square feet. However, large buildings comprised a significant percentage of total floor space (44 percent for buildings larger than 50,000 square feet; 30 percent for buildings larger than 100,000 square feet).

The energy use characteristics of small and large commercial buildings are quite different, as might be expected. In smaller buildings, heating and cooling systems are employed primarily to moderate outside air temperatures (as they are in residential buildings). In larger commercial buildings, outside air conditions have less impact on heating and cooling systems than do activities within the buildings—equipment used, lighting levels, number of people, and hours of operation. For example, one part of a building might need to be heated and ventilated to provide comfortable conditions for employees, whereas a computer room might need to be cooled because of excess heat given off by the computer equipment.

Age of Commercial Building Stock

Most commercial buildings, once constructed, are expected to last for decades or longer. New buildings are constructed each year and older buildings are demolished, but the commercial building stock at any point in time remains dominated by older buildings. More than 70 percent of buildings and total floor space in 1995 were constructed prior to 1980, and more than 50% of buildings and floor space prior to 1970 (Figure 8).

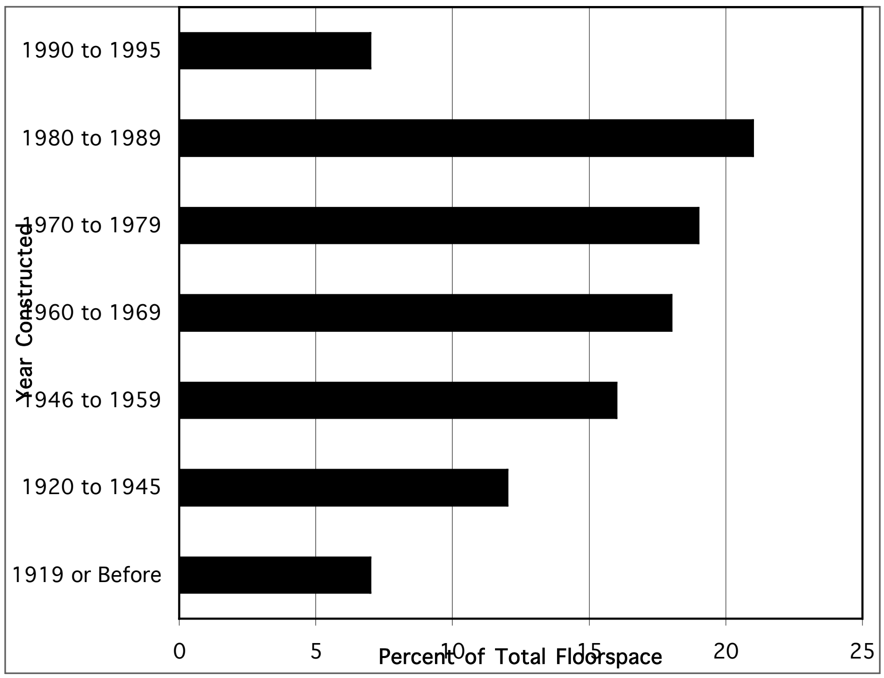

Figure 8. US Commercial building stock by age.

The 420,000 buildings and their more than 4.6 billion square feet of floor space added to the commercial buildings sector in the 1990s represented less than 10 percent of both buildings and floor space in the 1995 buildings stock.

Major Energy Sources Used in Commercial Buildings

Electricity and natural gas are used widely in commercial buildings. Electricity use is nearly universal (97 percent of floor space and 95 percent of buildings). Natural gas is used for 66 percent of floor space and 55 percent of buildings.

Of the other major energy sources, only fuel oil is used for as much as a quarter of total floor space (but in less than 14 percent of buildings). The other energy sources (district heat, chilled water, propane) are used for no more than 11 percent of floor space (or in 13 percent of buildings).

Major End Uses of Energy in Commercial Buildings

The types of activities within commercial buildings determine what specific energy-consuming services will be needed. The vast majority of commercial buildings used energy for lighting, space heating, water heating, and cooling (each of these end uses exceeded 73 percent of buildings and 60 percent of floor space).

Electricity is the most flexible energy source in commercial buildings, as well as the sole source for ventilation equipment, office equipment, and all other electrical equipment used in commercial buildings. Electricity was by far the dominant energy source for cooling (97.4 percent of cooled buildings and 95.0 percent of cooled floor space).

In 1995, the average commercial building in the U.S. consumed 203 thousand British thermal units (kBtu) of primary energy per square foot (see Figure 9). Although energy consumption varies regionally and by commercial building type, on average, 27% of primary energy use goes for lighting, 15% for space heating, 13% for cooling, 6% for office equipment, 4% for ventilation and the rest (35%) for refrigeration, water heating and miscellaneous other uses. The average amount spent on energy costs associated with the buildings operation was $1.33 per square foot of floor space (US DOE 1998a)

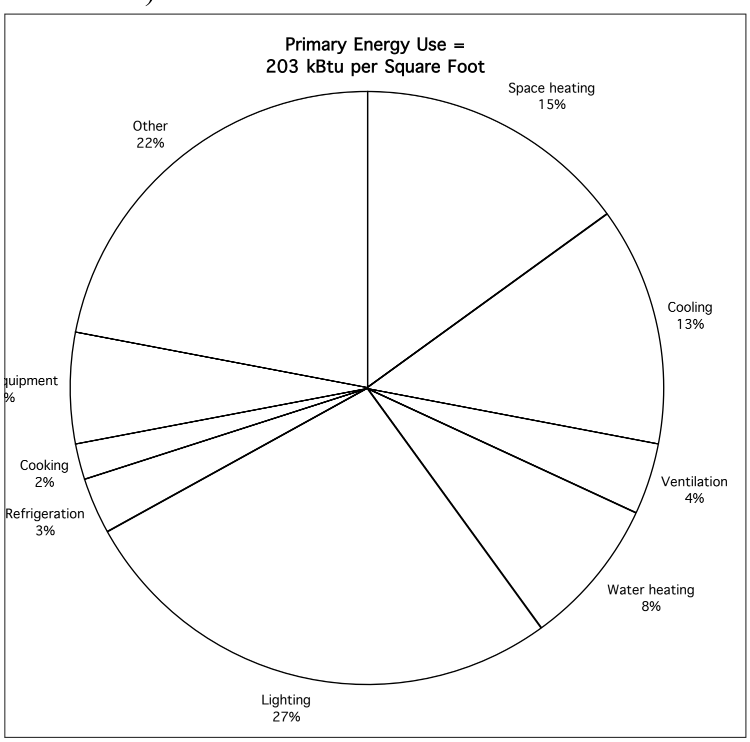

Figure 9. 1995 US Commercial building energy end use.

Energy Conservation Features and Practices

Energy conservation was widely practiced in commercial buildings. In an overwhelming majority of buildings (89 percent) some type of conservation feature had been installed or energy-efficient practice implemented.

Most commercial buildings report some type of building shell conservation feature (85 percent of buildings, 91 percent of floor space). The type most often found was roof or ceiling insulation (74 percent of buildings, 79 percent of floor space). HVAC conservation features were, in general, less common than building shell features. HVAC maintenance, the most widely practiced of the HVAC categories, was performed in about half of buildings and three-fourths of floor space.

Some type of lighting conservation feature is found in 46 percent of buildings and 66 percent of floor space. The most widely used lighting system conservation feature was the energy-efficient ballast, used in 30 percent of buildings and 48 percent of floor space.

Characteristics of New U.S. Commercial Buildings

The profiles of new commercial buildings showed no statistically significant changes in the major characteristics from 1989 to 1992 to 1995, the three years in which the last CBECS were conducted. Changes in the absolute numbers of buildings and floor space were noted within categories, but when each category was expressed as a percentage of the total, no significant differences were found from one to another.

Trends in new commercial construction

Most of the changes in commercial buildings over the next 10 to 20 years will be incremental in nature—increasingly improved environmental controls, more efficient equipment and systems, in lighting, for example, and advanced construction methods. One policy trend will be the "certification" or labeling of buildings that meet environmental or "green" criteria. We can also expect the widespread adoption of telecommunication technologies and other "information" technologies. Another trend is the increasing importance of "commissioning" the building to ensure that the systems operate as intended.

Advanced Construction Methods and Materials

The increased use of computer-aided design and computer-aided manufacturing (CAD/CAM) will result in the more efficient use of time and materials in the design and construction of buildings. Automated systems will lead to the more efficient use of materials. Modular components and systems that can be assembled on site will be increasingly available.

Engineered materials, such as wood composites, stressed-skin panels, and light-weight steel components, together with adhesive assembly techniques will be increasingly more common in building construction. Concerns for indoor air quality may drive the increased use of lowemission materials and environmental and economic concerns are likely to increase the use of recycled and re-used components.

Improved Building Envelopes

Recent improvements in window technology, which use selective glazings and gas fills, will develop into fully integrated building envelopes that take advantage of natural daylight and provide optimal solar control. Photo-sensors and other daylight controls to reduce electric lighting are becoming increasingly common and will continue to be used in a wide range of commercial buildings. Dynamic control of solar and thermal loads by "smart" materials and systems will play an increasingly more important role in building operation.

Integrated Building Controls

The trend toward increased automation and control of a building's mechanical and electrical systems will develop into fully integrated systems that rely on information technologies for their operation. Sensors that respond to occupants' programmed preferences for temperature, lighting, and ventilation will relay information to appropriate systems. Sophisticated design tools are now available to optimize the sizing of these systems and provide feedback mechanisms to building operators.

Labeling and Rating Schemes

One way to advance the development of energy-efficient and environmentally responsible buildings is to acknowledge their performance with a label or rating system. Several such schemes, e.g., LEED, BREEAM, Energy Star, have been developed in the U.S., Canada, and Europe, that certify the presence of sustainable design, materials and systems. These rating schemes have been developed for both new and existing commercial buildings.

High-Performance Buildings

It is possible that all phases of the design, construction and operation of commercial buildings will, ultimately, be linked electronically to ensure high levels of performance. No longer will design intent be lost in the construction phase. Electronic documentation of design intent and building construction will allow building owners and operators to optimize the performance of their buildings. A driving force for these changes is the continued expectation by the owners and occupants of buildings for comfortable, safe, and healthy indoor environments.

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