Chapter 9. Buildings

Lead Author: James E. McMahon[1]

[1]Lawrence Berkeley National Laboratory

KEY FINDINGS

- The buildings sector of North America was responsible for the annual emission of 2,712 Mt CO_2 in 2003, which is 36% of total North American CO_2 emissions and 9% of global emissions. U.S. buildings alone are responsible for more CO_2 emissions than total CO_2 emissions of any country in the world, except China.
- Carbon dioxide missions from energy use in buildings in the United States and Canada has increased by 30% since 1990, an annual growth rate of 2.1% per year.
- Carbon dioxide emissions from buildings have grown with energy consumption, which in turn is increasing with population and income. Rising incomes have led to larger residential buildings, with the amount of living area per capita increasing in all three countries of North America.
- These trends are likely to continue in the future, with increased energy efficiency of building materials and equipment and slowing population growth, especially in Mexico, only partially offsetting the general growth in population and income.
- Options for reducing the CO_2 emissions of new and existing buildings include increasing the efficiency of equipment and implementing insulation and passive design measures to provide thermal comfort and lighting with reduced energy. Current best practices can reduce emissions from buildings by at least 60% for offices and 30% for homes. Technology options need to be supported by a portfolio of policy options that take advantage of synergies, avoid unduly burdening certain sectors and are cost effective.
- Because reducing CO_2 emissions from buildings is currently secondary to reducing building costs, continued improvement of energy efficiency in buildings and reduced CO_2 emissions from the building sector will require a better understanding of the total societal cost of CO_2 emissions as an externality of building costs, including the costs of mitigation compared to the costs of continued emissions.

Buildings are responsible for 36% of carbon emissions in North America (2712 Mt CO_2 in 2003) (Natural Resources Canada, 2005; SENER México, 2005; U.S. DOE-EIA, 2005a[1]) and 9% in the world (U.S. DOE-EERE, 2005[2]). U.S. buildings alone are responsible for more CO_2 emissions than total CO_2 emissions of any country in the world except China (Kinsey *et al.*, 2002). Significant carbon emissions are due to energy consumption during the operation of the buildings; other emissions, not well quantified, may occur from water use in and around the buildings and from land-use impacts related to buildings. Buildings are responsible for 72% of U.S. electricity consumption and 54% of natural gas consumption (U.S. DOE-EERE, 2005.[3]). The discussions in this chapter include an accounting of CO_2 emissions from electricity consumed in the buildings sector; however, this accounting represents a potential double-counting of the CO_2 emissions from fossil fuels that are used to generate that electricity (see Chapter 6). This chapter provides a description of how energy, including electrical energy, is used within the buildings sector. Following the discussion of such end uses of energy, this chapter then describes the opportunities and potential for reducing energy consumption within the sector.

Many options are available for reducing the carbon impacts of new and existing buildings, such as increasing equipment efficiency and implementing alternative design, construction, and operational measures to provide thermal comfort and lighting with reduced energy. Current best practices can reduce carbon emissions by at least 60% for offices[4] and 30% for homes.[5] Residential and commercial buildings in the United States and Canada contain 27 billion m^2 (2.7 million hectares) of floor space, providing a large area available for siting non-carbon-emitting on-site energy supplies (e.g., photovoltaic panels on roofs). With the most cutting-edge technology, at the least, emissions can be dramatically reduced, and, at best, buildings can produce electricity without carbon emissions by means of on-site renewable electricity generation.

Carbon Fluxes

Carbon fluxes from energy emissions in buildings are well understood. Primary energy inputs from the source of production are tracked, their emissions rates are known, and the total end user consumption data are gathered and reported by energy utilities, typically monthly. The quantity of energy consumed by each end use is slightly less well known because attribution requires detailed data on use patterns in a wide variety of contexts. The governments of North America have invested in detailed energy consumption surveys, which allow researchers to identify opportunities for reducing energy use.

[1]U.S. Sector Emissions from Table 18 in U.S. DOE-EIA (2005a).
[2] See Table 3.1.1 in U.S. DOE-EERE (2005).
[3] See Tables 1.1.6 and 1.1.7 in U.S. DOE-EERE (2005).
[4] Leadership in Energy and Environment Design (LEED) Gold Certification.
[5] U.S. DOE Building America Program.

Currently, the influence of secondary fluxes due to use of materials and consumption of water is more uncertain.

The largest contribution to carbon emissions from buildings is through the operation of energy-using equipment. The energy consumed in the average home accounts for 10.7 metric tons [6] of carbon dioxide per year in the United States, 6.5 metric tons [7] per year in Canada, and 5.0 metric tons [8] in Mexico (U.S. DOE-EIA, 2005a; Natural Resources Canada, 2005; SENER México, 2005). Energy consumption in a 500-m^2 commercial, government, or public-use building in the United States produces 7.1 metric tons of CO_2 (U.S. DOE-EIA, 2005a).[9] Energy consumption includes electricity as well as the direct combustion of fossil fuels (natural gas, bottled gas, and petroleum distillates) and the burning of wood. Because most electricity in North America is produced from fossil fuels, each kilowatt-hour consumed in a building contributed about 660 g of CO_2 to the atmosphere in 2003 (U.S. DOE-EIA, 2005a).[10] The equivalent amount of energy from natural gas or other fuels contributed about 190 g of CO_2 (U.S. DOE-EIA, 2005a).[11] Renewable energy accounted for 9% of electricity production in 2003, down from 12% in 1990. Renewable site energy use in buildings also decreased in that time, from 4% to 2%, mostly due to decreasing use of wood as a household fuel (U.S. DOE-EERE, 2005).[12]

Buildings sector carbon dioxide emissions and the relative contribution of each end use are shown in Fig. 9-1. In the United States, five end uses account for 87% of primary energy consumption in buildings: space conditioning (including space heating, cooling, and ventilation), 40.9%; lighting ,19.8%; water heating, 10.5%; refrigeration, 9%; and electronics (including televisions, computers, and office equipment), 7.7% (U.S. DOE-EERE, 2005).[13] Space heating and cooling are the largest single uses for residences, commercial, and public-sector buildings, accounting for 46% and 35% of primary energy, respectively, in the United States (U.S. DOE-EERE, 2005).[14] Water heating is the second-highest energy consumer in the United States and Canada, while lighting is the second-highest source of carbon dioxide emissions, due to the higher emissions per unit of electricity compared to natural gas.

Fig. 9-1. U.S. carbon emissions by sector and—for commercial and residential buildings—by end use.

[6] U.S. residential sector emissions of 1213 Mt CO_2 divided by 114 million households in 2004.
[7] Canada residential sector emissions of 45.2Mt CO_2 divided by 12.2 million households in 2003.
[8] Mexico residential sector emissions of 85.2 Mt CO_2 divided by 167 million households in 2004.
[9] U.S. commercial sector emissions per m^2 in 2003 times 500 m^2.
[10] U.S. emissions from electricity divided by delivered energy.
[11] U.S. emissions from electricity divided by delivered energy.
[12] See Table 1.5.4 and Summary Table 2 in U.S. DOE-EERE (2005).
[13] Does not include adjustment EIA uses to relieve differences between data sources.
[14] Table 1.2.3 and Table 1.3.3; available on-line at http://buildingsdatabook.eere.energy.gov (2003 data).

Heating and cooling loads are highly climate dependent; colder regions use heating during much of the year (primarily with natural gas), while warm regions seldom use heating. The majority of U.S. households own an air conditioner; and, although air-conditioner ownership has been historically low in Mexico, sales of this equipment are now growing significantly, 14% per year over the past 10 years.[15] Space-conditioning energy end use depends significantly on building construction (e.g., insulation, air infiltration) and operation (thermostat settings). Water heating is a major consumer of energy in the United States and Canada, where storage-tank systems are common.

Aside from heating and cooling, lighting, and water heating, energy is consumed by a variety of appliances, mostly electrical. Most homes in the United States and Canada own all of the major appliances, including refrigerators, freezers, clothes washers, clothes dryers, dishwashers, and at least one color television. The remainder of household energy consumption comes from small appliances (blenders and microwaves, for example) and, increasingly, from electronic devices such as entertainment equipment and personal computers. In Mexico, major appliances are common in middle- and upper-income households, and even the poorest electrified households own a television, a refrigerator, and small appliances.

Many end uses—such as water heating and heating, cooling, and ventilation—occur in most commercial sector buildings. Factors such as climate and building construction influence the carbon emissions from these buildings. In addition, commercial buildings contain specialized equipment, such as large-scale refrigeration units in supermarkets; cooking equipment in food preparation businesses; and computers, printers, and copiers in office buildings. Office equipment is the largest component of electricity use aside from cooling and lighting. Due to heat from internal loads, many commercial buildings use air-conditioning year round in most climates in North America.

Residential and commercial buildings in the United States are responsible for 38% of CO_2 emissions from energy nationally and 33% of emissions from energy in North America as a whole. Total emissions from buildings in the United States are ten times as high as in the other two countries combined, due to a large population compared to Canada, and high per capita consumption compared to Mexico. On a per capita basis, building energy consumption in the United States is comparable with that of Canada, about 40 GJ equivalent per person per year. This is about six times higher than in Mexico, where 7 GJ is consumed per person per year.

In general, contributions from the residential sector are roughly equal to that of the commercial sector, except in Mexico, where the commercial sector contributes less. Electricity contributes twice as many emissions as all other fuels combined in the United States and Mexico (2.2 and 2.1 times as much, respectively). In Canada, natural gas is on par with electricity (1.03 times as many emissions), due to high

[15] *Air conditioner sales 1995–2004 from* Asociacion Nacional de Fabricantes de Aparatos Domesticos (ANFAD).

heating loads resulting from the cold climate. Fuel oil represents most of Canada's "other fuels" for the commercial sector. Firewood (leña) remains an important fuel for many Mexican households for heating, water heating, and cooking. Table 9-1 summarizes CO_2 emissions by country, sector, and fuel.

Table 9-1. Carbon dioxide emissions from energy consumed in buildings.

The energy consumed during building operation is the most important input to the carbon cycle from buildings; but it is not the only one. The construction, renovation, and demolition of buildings also generate a significant flux of wood and other materials. Construction of a typical 204-ft^2 (2200-ft^2) house requires about 20 Mt of wood and creates 2 to 7 Mt of construction waste (U.S. DOE-EERE, 2005).[16] Building lifetimes are many decades and, especially for commercial buildings, may include several cycles of remodeling and renovation. Water consumption in buildings also impacts the carbon cycle because water supply, treatment, and waste disposal require energy. In California, for example, total water use accounts for 19% of statewide electricity (CEC, 2005). In the United States as a whole, water supplied to residential and commercial customers accounts for about 6% of total national freshwater consumption.

Trends and Drivers

Several factors influence trends in carbon emissions in the buildings sector. Some driver variables tend to increase emissions, while others decrease emissions. In general, the trend over the last decade has been toward emissions growth, with emissions from energy use in buildings in the United States and Canada increasing 30% since 1990 (U.S. DOE-EERE, 2005; Natural Resources Canada, 2005),[17] corresponding to an annual growth rate of 2.1%.

Carbon emissions from buildings have grown with energy consumption, which in turn is increasing with population and income. Demographic shifts therefore have a direct influence on residential energy consumption. Rising incomes have led to larger residential buildings—the amount of living area per capita is increasing in all three countries in North America. On one hand, total population growth is slowing, especially in Mexico, as families are having fewer children than in the past. Annual population growth during the 1990s was 1.1% in the United States, 1.0% in Canada, and 1.7% in Mexico. In the period from 1970 to 1990 it was 1.0%, 1.2%, and 2.5%, respectively.[18] On the other hand, a shift from large, extended-family households to nuclear-family and single-occupant households means an increase in

[16] Table 2.1.7. Wood content estimated from lumber content. Construction waste from Table 3.4.1.
[17] U.S.DOE-EERE, 2005 Table 3.1.1.
[18] *Source:* UN Department of Economic and Social Affairs.

the number of households per unit population—each with its own heating and cooling systems and appliances.

The consumption of energy on a per capita basis or per unit economic activity [gross domestic product (GDP)] is also not constant but depends on several underlying factors. Economic development is a primary driver of overall per capita energy consumption and influences the mix of fuels used.[19] Per capita energy consumption generally grows with economic development because wealthier people live in larger households and have more appliances. Recently, computers, printers, and other office equipment have become commonplace in nearly all businesses and in most homes. These end uses now constitute 7% of primary household energy consumption. As a result of these growing electricity uses, the fraction of electricity to total household primary energy has increased. This is significant because of the large emissions associated with the combustion of fossil fuels in power plants. Electricity can be generated from renewable sources, such as solar or wind, but their full potential has yet to be realized.

In the United Stages, the major drivers of energy consumption growth are growth in commercial floorspace and an increase in the size of the average home. The size of an average U.S. single-family home has grown from 160 m^2 for a house built in 1980 to 216 m^2 in 2003. In the same time, commercial floor space per capita has increased from 20 m^2 to 22.6 m^2 (U.S. DOE-EERE, 2005).[20] Certain end uses once considered luxuries have now become commonplace. Only 56% of U.S. homes in 1978 used mechanical space-cooling equipment (U.S. DOE-EIA, 2005b). By 2001, ownership grew to 83%, driven by near total saturation in warmer climates and a demographic shift in new construction to these regions. Table 9-2 shows emissions trends, as well as the underlying drivers.

Table 9-2. Principal drivers of buildings emissions trends

Although the general trend has been toward growth in per capita emissions, emissions per unit of GDP has decreased in past decades, due to improvements in efficiency. Efficiency performance of most types of equipment has generally increased, as has the thermal insulation of buildings, due to influences such as technology improvements and voluntary and mandatory efficiency standards and building codes. The energy crisis of the 1970s was followed with a sharp decline in economic energy intensity. Efficiency increases were driven both by market-related technology improvements and incentives and by the establishment of federal and state/provincial government policies designed to encourage or require energy efficiency.

[19] For example, whether biomass, natural gas or electricity is used for space heating and cooking.
[20] See Table 2.1.6 and 2.2.1 in U.S. DOE-EERE (2005). Residential data are from 1981.

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Options for Management

A variety of alternatives exist for reducing emissions from the buildings sector. Technology- and market-driven improvements in efficiency are expected to continue for most equipment but will probably not be sufficient to adequately curtail emissions growth without government intervention. The government has many different ways in which it can manage emissions that have been proven effective in influencing the flow of products from manufacturers to users (Interlaboratory Working Group, 2000). That flow may involve six steps: advancing technologies; product development and manufacturing; supply, distribution, and wholesale purchasing; retail purchasing; system design and installation; and operation and maintenance (S. Wiel and J. E. McMahon, 2005). Options for specific products or packages include government investment in research and development, information and education programs, energy pricing and metering, incentives and financing, establishment of voluntary guidelines, procurement programs, energy audits and retrofits, and mandatory regulation. The most effective approaches will likely include one or more of these options in a policy portfolio that takes advantage of synergies, avoids unduly burdening certain sectors, and is cost-effective. Major participants include federal agencies, state and local governments, energy and water utilities, private research and development firms, equipment manufacturers and importers, energy services companies (ESCOs), nonprofit organizations, building owners, and occupants.

- **Technology adoption supported by research and development:** Government has the opportunity to encourage development and adoption of energy-efficient technologies through investment in research and development, which can advance technologies and bring down prices, therefore enabling a larger market. Successful programs have contributed to the development of high-efficiency lighting, heating, cooling, and refrigeration. Research and development has also had an impact on the improvement of insulation, ducting, and windows. Finally, government support of research and development has been critical in the reduction of costs associated with development of renewable energy.
- **Voluntary Programs:** By now, there are a wide range of efficiency technologies and best practices available, and if the most cost-effective among them were widely utilized, carbon emissions would be reduced. Voluntary measures can be effective in overcoming some market barriers. Government has been active with programs to educate consumers with endorsement labels or ratings [such as the U.S. Environmental Protection Agency's (EPA's) Energy Star Appliances and Homes], public-private partnerships [such as the U.S. Department of Energy's (DOE's) Building America program]. Government is not the only player, however. Energy utilities can offer rebates for efficient appliances,

and ESCOs can facilitate best practices at the firm level. Finally, nongovernment organizations and professional societies (such as U.S. Green Building Council and the American Institute of Architects) can play a role in establishing benchmarks and ratings.

- **Regulations:** Governments can dramatically impact energy consumption through well-considered regulations that address market failures with cost-effective measures. Regulations facilitate best practices in two ways: they eliminate the lowest-performing equipment from the market, and they boost the market share of high-efficiency technologies. Widely used examples are mandatory energy efficiency standards for appliances, equipment, and lighting; mandatory labeling programs; and building codes. Most equipment standards are instituted at a national level, whereas most states have their own set of prescriptive building codes (and sometimes energy performance standards for equipment) to guarantee a minimum standard for energy-saving design in homes and businesses.

Although large strides in efficiency improvement have been made over the past three decades, significant improvements are still possible. They will involve continued improvement in equipment technology but will increasingly take a whole-building approach that integrates the design of the building and the energy consumption of the equipment inside it. The improvements may also involve alternative ways to provide energy services, such as cogeneration of heat and electricity and thermal energy storage units.

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Whole-building certification standards evaluate a package of efficiency and design options. An example is the Leadership in Energy and Environmental Design (LEED) certification system developed by the U.S. Green Building Council, a nongovernment, nonprofit organization. In existence for five years, the LEED program has certified 36 million m^2 of commercial and public-sector buildings and has recently implemented a certification system for homes. The LEED program includes a graduated rating system. Typical energy savings achieved by LEED Gold-rated buildings are 50–60% (U.S. GBC, 2005).

On the government side, the EPA’s Energy Star Homes program awards certification to new homes that are independently verified to be at least 30% more energy-efficient than homes built to the 1993 national Model Energy Code, or 15% more efficient than state energy code, whichever is more rigorous. Likewise, the DOE’s Building America program partners with home builders, providing research and development toward goals to decrease primary energy consumption by 30% for participating projects by 2007, and by 50% by 2015.

Research and Development Needs

Research, development, demonstration, and deployment of technologies and programs to improve energy efficiency in buildings and to produce energy with fewer carbon emissions have involved significant effort over the last 30 years. These efforts have contributed options toward carbon management. Technologies and markets continue to evolve, representing new crops of "low-hanging fruit" available for harvesting. However, in most buildings-related decisions in North America, reducing carbon emissions remains a secondary objective to other goals, such as reducing first costs. The questions for which answers could significantly change the discussion about options for carbon management include the following.

- What is the total societal cost of environmental externalities, including carbon emissions? Energy resources in North America have been abundant and affordable, but externality costs have not been completely accounted for. Most economic decisions are weighted toward the short term and do not consider the complete costs. Total societal costs of carbon emissions are unknown and, because it is a global issue, difficult to allocate. Practical difficulties notwithstanding, this is a key issue, answers to which could influence priorities for research and development as well as policies such as energy pricing, carbon taxes or credits.
- What cost-effective non-carbon-emitting equipment and building systems (including energy demand and supply) are available in the short, medium, and long term? Policymakers must have sufficient information to be confident that particular new technology types or programs will be effective and affordable. For consumers to seriously consider a set of options, the technologies must be manifested as products that are widely available and competitive in the marketplace. Therefore, economic and market analyses are necessary before attractive options for managing carbon can be proposed.
- How do the costs of mitigation compare to the costs of continued emissions? The answers to the previous two questions can be compared in order to develop a supply curve of conserved carbon comprising a series of least-cost options, whether changes to energy demand or to supply, for managing carbon emissions. The roadmap will need to be updated at regular intervals to account for changes in technologies, production practices, and market acceptance of competing solutions.

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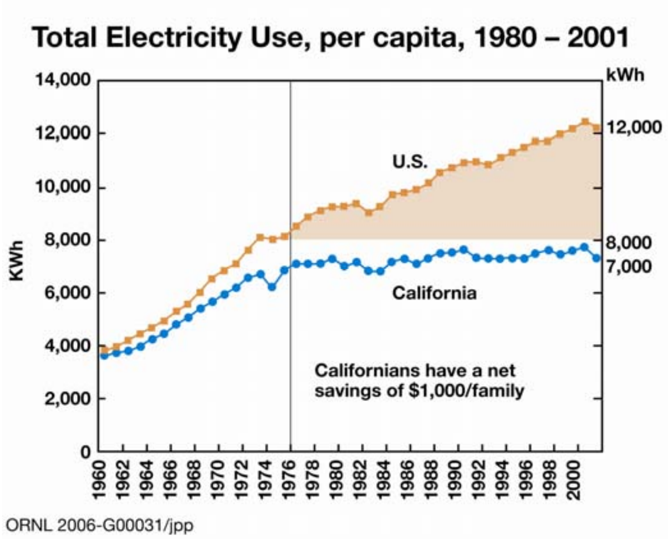
[BEGIN SIDEBAR 1]

Since the mid-1970s, the state of California has pursued an aggressive set of efficiency regulations. As a result, per capita electricity consumption has stabilized in that state even while it continues to grow in the United States as a whole.

Source: California Energy Commission— Available at http://www.energy.ca.gov/2005publications/CEC-999-2005-007/CEC-999-2005-007.PDF, Slide 5

Per capita electricity consumption in the U.S. and California



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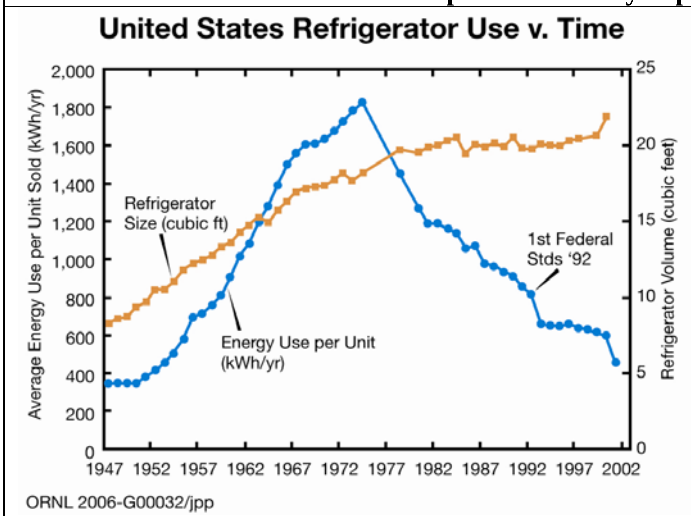
Between 1974 and 2001, the energy consumption of the average refrigerator sold in the United States dropped by 74%, a change driven by market forces and regulations. From 1987 to 2005, the U.S. Congress and DOE promulgated minimum efficiency standards for more than 30 residential and commercial product types. Canada and Mexico also have many product efficiency standards, and a program is under way to harmonize standards throughout North America in connection with North American Free Trade Agreement.

Source: California Energy Commission—Available at http://www.energy.ca.gov/2005publications/CEC-999-2005-007/CEC-999-2005-007.PDF, slide 7

Impact of efficiency improvements



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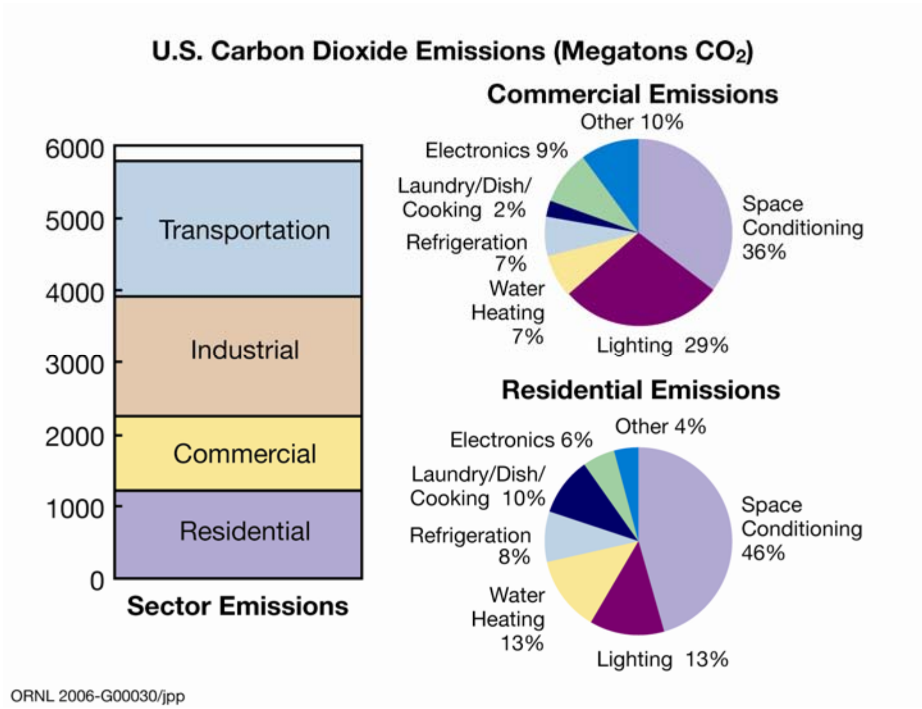

Fig. 9-1. U.S. carbon emissions by sector and—for commercial and residential buildings—by end use.

Table 9-1. Carbon dioxide emissions from energy consumed in buildings

	Greenhouse emission (megatons) CO_2				
	Electricity	Natural gas	Other fuels	Wood	Total
United States	**1609.1**	**434.6**	**166.3**	**0.0**	**2210.0**
Residential	823.7	265.9	105.1	0.0	1194.7
Commercial	785.4	168.7	61.2	0.0	1015.4
Canada	**61.6**	**58.5**	**22.0**	**1.9**	**143.9**
Residential	31.4	32.3	9.1	1.9	74.7
Commercial	30.2	26.2	12.9	0.0	69.3
Mexico	**52.7**	**1.7**	**16.2**	**2.1**	**72.7**
Residential	40.2	1.3	15.8	2.1	59.4
Commercial	12.5	0.4	0.4	0.0	13.3
Total	**1723.4**	**494.8**	**204.5**	**4.0**	**2426.6**

Table 9-2. Principal drivers of buildings emissions trends

Drivers	United States		Canada		Mexico	
	Total 2000	Growth rate 1990–2000	Total 2000	Growth rate 1990–2000	Total 2000	Growth rate 1990–2000
Population (millions)	288	1.1%	31.0	1.0%	100	1.7%
Household size (persons/HH)	2.5	–0.6%	2.6	–0.9%	5.3	–0.1%
GDP/Cap (thousand $U.S. 1995)	31.7	2.0%	23.0	1.8%	3.8	1.8%
Res. floorspace (billion m^2)	15.7	0.0%	1.5	2.4%	NA	NA
Comm. floorspace (million m^2)	6.4	0.6%	0.5	1.6%	NA	NA
Building energy emissions/GDP (g CO_2/$U.S.)	256	–0.5%	217	–0.9%	NA	NA