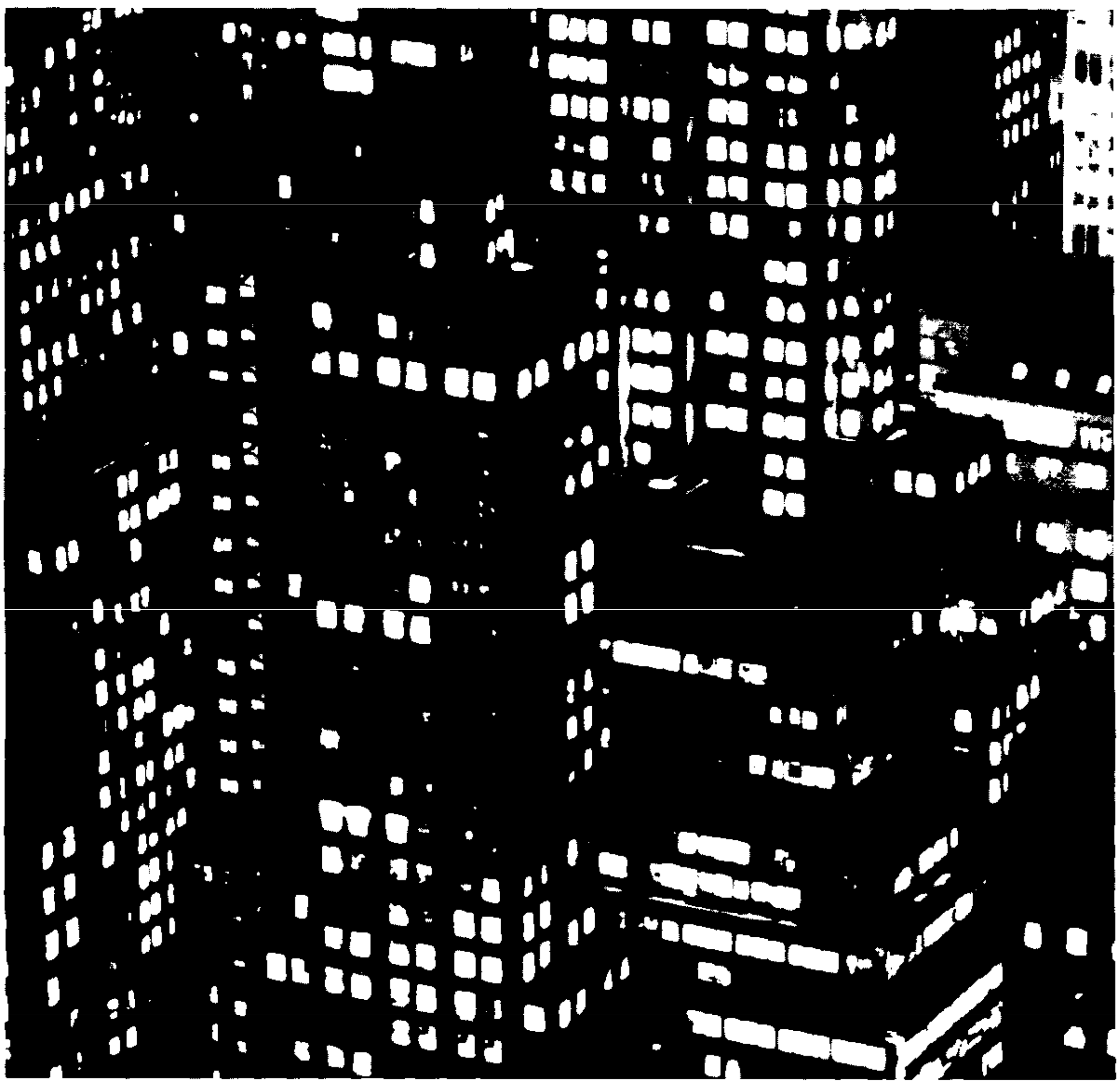
Chapter 4

The Buildings Sector



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The Buildings Sector

OVERVIEW

The buildings sector includes all activities related to residential and commercial buildings.[1] Two greenhouse gases are of primary importance in this sector-carbon dioxide (CO_2) and chlorofluorocarbons (CFCs). CO_2 is emitted when fossil fuels and biomass are burned (either directly onsite, or at electric powerplants) to provide services such as space conditioning, water heating, lighting, cooking, refrigeration, and entertainment. CFCs are emitted from foam insulation, air conditioners, and refrigerators.

Worldwide, the buildings sector accounts for about 30 percent of CO_2 emissions (108):

- direct, onsite burning of fossil fuels (coal, oil, gas) accounted for an estimated 14 percent of global $C0_2$ emissions in 1985 (108);
- electricity use in buildings accounted for 13 percent (i.e., over one-half of all CO_2 emissions from electricity generation) (108); and
- burning fuelwood for domestic heating and cooking accounted for an additional few percent.

In the United States, the buildings sector accounts for an estimated 36 percent of CO_2 emissions (see figure 4-1) and roughly 20 percent of CFC emissions (35).

Activities in the buildings sector are directly linked to other environmental and social concerns as well. Burning fuelwood and coal, for example, results in emissions of air pollutants such as particulate matter and acid gases. Building new residential and commercial developments can involve clearing forests and paving agricultural land. The spatial pattern of such developments greatly affects subsequent transportation requirements (see ch. 5). Construction materials are supplied through activities such as timber harvesting and processing, and sand and gravel dredging which can also have environmental impacts.

There is no single formula for reducing emissions in the buildings sector. To do so, many technical options will have to be implemented for both residential and commercial buildings. Otherwise, the effect of emission reductions in one area could easily be negated by growth in another.

OTA modeled potential CO_2 emissions in the U.S. buildings sector for three scenarios (Base case, Moderate, Tough). In the Moderate scenario, currently available technologies that pay for themselves over the life of the equipment are adopted; these include high-efficiency appliances and equipment, increased insulation, and more efficient lighting devices and designs. In this case, OTA estimates that U.S. CO_2 emissions in 2015 from buildings can be reduced by about 5 percent relative to 1987 levels (see figure 4-2). In the Tough scenario, technologies that are expected to be commercially available in the next decade could reduce U.S. building sector emissions in 2015 by about one-third relative to 1987 levels (see figure 4-2). These projected reductions are achievable without major changes in the mix of fossil fuels used for generating electricity for buildings. Because a large portion of the energy used in buildings is supplied by electricity which is produced primarily by coal, the most CO_2-intensive of the fuels, further reductions could be achieved by changing how electricity is generated (see ch. 3).

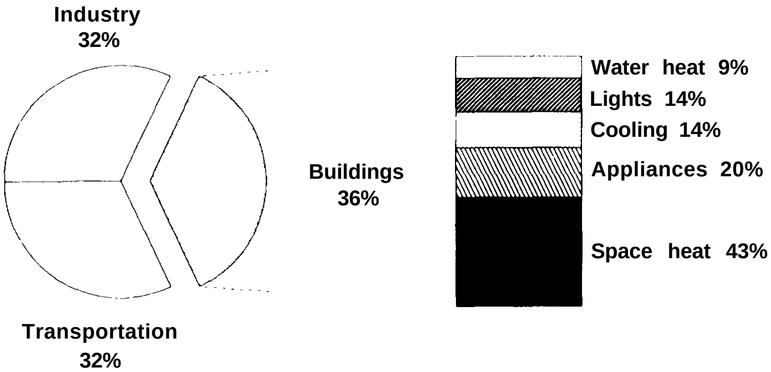
In the United States, available policy levers to implement these technical options include: energy-use taxes, initial purchase taxes, electric utility ‘ ‘Demand-Side Management, ’ appliance standards, building codes, consumer information and marketing, and research and development. These options can act synergistically to influence decisions regarding the design and operation of buildings and building services.

In developing countries, the demand for energy services in buildings will grow rapidly during the next 25 years: per-capita growth in energy consumption in this sector is about 10 times that of counties in the Organization for Economic Cooperation and Development (OECD)[2] (72). While developing coun-

[1] The commercial sector encompasses many enterprises, including offices, warehouses, schools, health care, food sales and services, and lodging.

[2] The 24-member OECD includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, h-eland, Italy, Japan, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, U. K., and U.S.

Figure 4-l–-Contribution of the U.S. Buildings Sector to U.S. CO_2 Emissions From Fossil Fuels



Percent of total by sector (1.3 billion metric tons/year)

Percent of emissions from buildings (0.47 billion metric tons/year)

SOURCE: Office of Technology Assessment, 1991.

tries currently meet a large share of their energy needs in buildings by using biomass, much of their growth in energy demand (and hence greenhouse gas emissions) in the buildings sector is associated with the spread of electrical services throughout their economies, The use of energy-efficient technologies and practices can slow the rate of increase of CO_2 emissions without compromising economic development. However, net reductions below current levels are unlikely.

BUILDINGS IN OECD COUNTRIES

Trends in Energy Use

In OECD countries, the buildings sector accounted for 38 percent of primary energy use in 1985[3]—23 percent in the residential portion and 15 percent in the commercial portion (67). Space conditioning (heating or cooling) dominates energy use, accounting for 60 to 80 percent of final energy demand in residential buildings and 60 to 65 percent in commercial buildings (30, 67).[4] Most of this is for heating; air-conditioning, for example, accounted for only 3 percent, on average, of residential energy use in 1980 throughout the OECD. Water heating and lighting generally are the other major uses in commercial buildings; water heating, electric appliances, and cooking are the other major uses in residential buildings.[5]

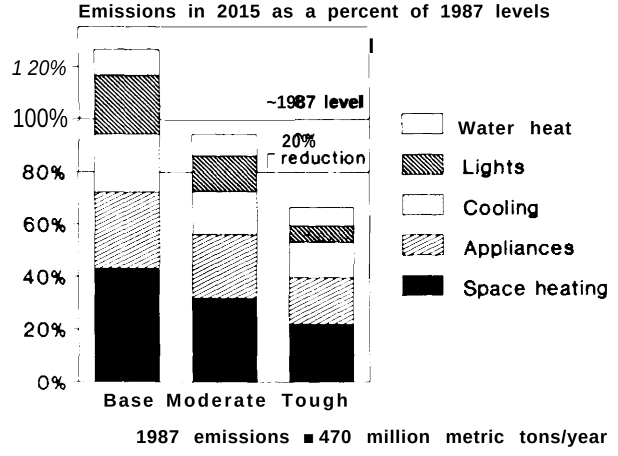
In the United States, space heating is the dominant energy user in buildings, accounting for 43 percent of CO_2 emissions from the entire sector (figure 4-l). In the residential portion, space heating accounted for **30** percent of the annual energy expenditures in average U.S. households in 1987 (see figure 4-3). Other important end uses in both types of buildings are lighting, water heating, and air-conditioning, along with refrigeration and cooking in residences and ventilation in commercial buildings (10, 75, 76). More than 20 percent of all electricity generated in the United States is used for lighting, primarily in buildings (other uses include, for example, street lighting) (97). In contrast with the OECD as a whole, air-conditioning is a significant end-use in the United States (78), accounting for 22 percent of the CO_2 emissions in the commercial sector, for example.

[3]Primary energy sources include nonrenewable fossil fuels (coat, petroleum, natural gas), potentially renewable biomass, and renewable such as solar, geothermal, and hydroelectric power. Electricity is a secondary energy source produced from primary energy sources.

[4]Space conditioning refers to ' 'active '' methods of cooling or heating, i.e., requiring inputs of fuel and usually some kind of mechanical deviee that must be deliberately activated or deactivated according to needs. Passive methods operate with relatively little deliberate intervention depend on natural flows of energy (e.g., solar energy), and are mediated by building design.

[5]Energy use during construction is not covered here; studies in the 1970s indicated that it is a relatively small portion Of total energy USe in the buildings sector, equal to about 5 yearn of operational energy use (36, 84).

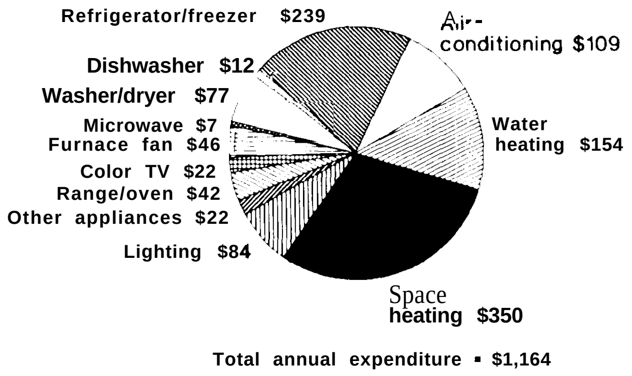
Figure 4-2—CO_2 Emissions From the U.S. Buildings Sector in 2015, Under the Base Case, Moderate, and Tough Scenarios



For comparison, lines representing the 1987 baseline and 20 percent below that level are indicated. Emissions from biomass fuels are not included here.

SOURCE: Off Ice of Technology Assessment, 1991,

Figure 4-3--Annual Expenditures for Energy in Average U.S. Households, 1987



Five major end-uses---space heating, refrigerating, water heating, air-conditioning, and lighting—account for 80 percent of average household expenditures. (This chart shows electric appliances only and assumes average cost of 7 cents per kWh.)

SOURCE: Office of Technology Assessment, 1991, adapted from U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption andExpenditure* (Washington, DC: 1989), figure 9 and table 3. Lighting data provided by A. Meier, Lawrence Berkeley Laboratory.

Energy use in U.S. residences, on a per-square-foot basis, is higher than in Japan, Italy, and Sweden, but lower than in France, the United Kingdom, and West Germany (77, 105). Energy use for heating and electricity in commercial buildings in Canada and the United States, after accounting for differences in climate, is 20 to 30 percent higher per unit area than in Europe (78).

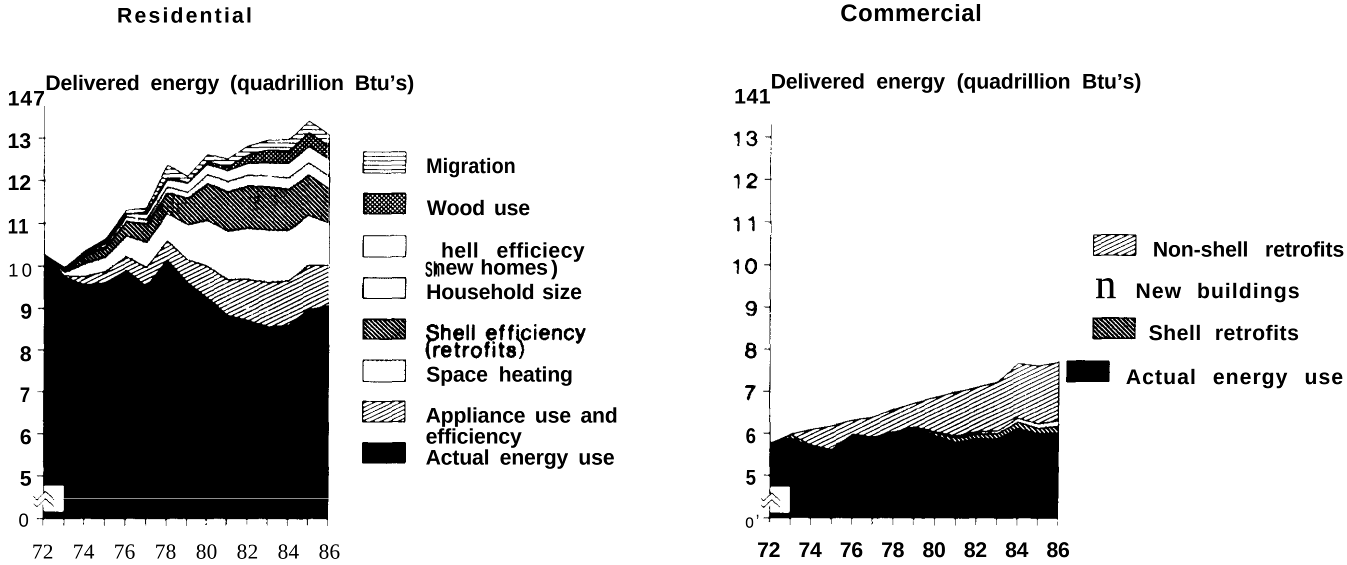
Most OECD countries have undertaken considerable efforts since 1973 to conserve energy (see ch. 9). These efforts have significantly slowed the growth in energy demand in residential and commercial buildings. Figure 4-4 shows how U.S. residential energy use dropped due to a combination of technical efficiency improvements, conservation (using less), and demographic changes (decreasing household size and migrating to warmer climates).

A countervailing trend, though, has been an increase in electrification, due to increases in the use of electricity for space and water heating and for electric appliances, and, in the United States, for air-conditioning. Of new U.S. homes built in 1986, 44 percent were electrically heated, compared to only 15 percent in 1983; 70 percent were built with central air-conditioning in 1986, compared with 34 percent in 1970. As a result, primary energy use in the United States between 1979 and 1985 increased by 9.1 percent in the commercial sector and 0.7 percent in the residential sector (62).

The net effect of electrification on CO_2 emissions depends partly on the mix of fuels used to generate electricity. If electricity is generated from nuclear power or renewable sources (i.e., solar, wind, geothermal, nuclear, biomass), more electrification will not increase CO_2 emissions, all other things being equal. The net effect also depends on the relative efficiencies of fuel- and electric-driven equipment. For example, electric resistance heat (e.g., electric baseboard radiators, or portable or wall-mounted coil heaters) uses about three times as much primary energy per delivered unit of final energy (the average efficiency of a U.S. powerplant) as the most efficient gas or oil furnaces and the most efficient electric heat pumps. When gas heat pumps reach the market, they will use even less primary energy per unit of delivered energy than today's electric heat pumps (see table 4-l).

Over the next **25 years,** slow growth in the demand for energy services is expected in the residential sector of OECD countries. This is because population and household growth are expected to be low, and because there is a saturation of major appliances in these countries. Most homes in OECD countries already have hot water, refrigera-

Figure 4-4-Components of Change in Fossil Fuel Energy Use in Residential and Commercial Buildings



A number of factors contributed to the 4 quads of delivered energy savings in the residential sector in 1986":

- **Appliance Use and Efficiency:** 1.0 quad. This reflects both the increase in more efficient household appliances and wiser use of appliances in general.
- **Space Heating Behavior:** 1.0 quad. This includes short-term reversible actions, such as adjustments to thermostat settings and closing off unused living areas. These savings are less than in 1982, suggesting a return of thermostat settings to higher levels.
- **Shell Retrofits:** 0.8 quad due to weatherstripping, insulation, and caulking. This component has decreased in recent years partly due to lower fuel prices and the end of energy-conservation tax credits.
- **New Home Shell Efficiency:** 0.4 quad. New homes and the equipment in them are more energy efficient.
- **Wood Use:** 0.3 quad, reflecting consumer use of wood in place of conventional heating fuel.
- **Household Size:** 0.3 quad. The number of persons per household has decreased steadily from 1972 to 1986, resulting in less energy use per household.
- **Migration:** 0.3 quad. This includes the population shift to the South and West regions of the United States, where households use less energy for heating but more for cooling.

Three major factors contributed to the 1.7 quads of delivered energy savings realized by the commercial sector in 1986:

- **Non-Shell Retrofits:** about 1.4 quads. These include more energy-efficient maintenance procedures, use of computerized energy-management systems, replacement of heating and cooling equipment, and more energy-efficient lighting.
- **New Buildings:** about 0.1 quad. The savings are attributable to the addition of new, more energy-efficient building designs with energy efficient equipment.
- **Shell Retrofits:** about 0.2 quads. These include increased insulation, weatherstripping, and installation of special windows.

SOURCE: U.S. Department of Energy, Office of Policy, Planning and Analysis, *Energy Conservation Trends: Understanding the Factors That Affect Conservation Gains in the U.S. Economy,* DOE/PE-0092 (Washington, DC: September 1989).

tors, electric lights, and central heating (which are kept at comfortable temperatures) (57, 32). On the other hand, increased domestic use of air-conditioning could occur.

However, energy demand in commercial buildings could grow rapidly if OECD economies continue to expand. Use of computers and other electronic equipment in offices, for example, is projected to increase. In the United States, the demographic shift to the South and West also will enhance the trend toward electrification—buildings in these regions are likely to be electrically heated, while buildings in the Northeast are generally heated by oil or gas (78).

Techniques To Reduce Energy Use and CO_2 Emissions

Energy use will vary with the type of building, In commercial buildings, for example, key determinants include the mix of activities (e.g., manufacturing v. office space v. living area), amount of floor space, thermal characteristics of the building, and types of fuel used. These factors in turn are influenced by the density, design, and distribution of surrounding buildings-e. g., demographic characteristics; climate; availability of land, materials, capital, and labor; energy costs; cultural and individual preferences; and the capabilities of the architects.[6]

Cost-effective reductions in energy use (and associated CO_2 emissions) can be achieved through greater use of energy-efficient equipment (lights, heaters, air conditioners), insulation, and improved windows; fuel switching; better operation and maintenance (O&M) practices; and changes in how families and businesses occupy buildings and use energy within them (30, 43, 50, 60). Reductions in CFC emissions also are possible (see below),

Because the average lifetime is about 100 years for a home and 50 years for a commercial building in the United States, initial reductions in greenhouse gas emissions will come primarily from retrofitting existing buildings with energy-efficient equipment and better insulation, windows, and other energy-conserving structural features (27, 28, 39). Existing commercial buildings, for example, can be retrofitted with lighting, insulation, and windows that use 20 to 25 percent less energy, with typical payback periods of 2 to 3 years (50). Since appliances and other equipment wear out significantly faster than buildings (lifetimes of about 10 to 25 years), replacement with more efficient equipment can bring about reductions in CO_2 and CFC emissions relatively quickly.

By 2010, however, about one-third of residences and over one-half of commercial buildings in the United States will have been built after 1990, so changes in building codes for new construction could also have an important effect over the next 25 years. Installing better insulation and efficient equipment during construction of new buildings is less expensive and more effective than retrofitting them later. New commercial buildings designed to be energy efficient use about one-half the energy on average of existing buildings (54).

In all buildings, more efficient operation and proper maintenance can significantly reduce energy use, generally at a relatively small cost compared to the cost of providing additional *energy.* A wide, available array of electronic systems, for example, can be installed to automatically control heating, lights, air conditioners, and other energy-using devices (for example, see box 4-D below).

Because the structure of energy use in the buildings sector is comparable throughout the OECD (67), these technical options should generally be applicable in most other OECD nations, despite variations in energy prices and weather conditions.[7] Even in countries like Sweden that have long promoted energy efficiency in buildings, reductions in CO_2 emissions still are possible (see box 4-A). The potential for improved energy efficiency and reduced CO_2 emissions is even greater in Eastern Europe and the U.S.S.R. (see box 4-B).

Lighting

The amount of energy used for lighting can be reduced by using more efficient bulbs, automatic lighting controls (such as occupancy sensors and individual controls), and design improvements such as task lighting. Lighting accounts for over 25 percent of CO_2 emissions in the commercial sector; it offers perhaps the single largest, and certainly the most cost-effective, method for reducing fossil fuel use in the commercial sector. Many of the options for reducing energy use in lighting offer paybacks in less than 2 years, depending on how intensively they are pursued.

The common incandescent bulb uses electricity to heat a filament until it glows, but approximately 90 percent of the electricity is converted to heat, not light. Replacing incandescent with fluorescent bulbs can reduce energy use by up to 75 percent (figure 4-5). Further gains of up to 50 percent are possible with the use of high-efficiency lamps and ballasts.[8] In addition to reducing the electricity needed for lighting, more efficient lighting gives off less heat to

[6] For discussions of the historical role of climate in determining the quality and location of buildings, s& refs. 19, 20.

[7] However, policies to implement these measures are not necessarily the same throughout the OECD (see ch. 9).

[8] A ballast is a device that Provides a voltage high enough to ionize vapor in the tube and then limits the current for stable operation.

Box 4-A—Sweden: Surprising Room for Improvement

Sweden is often viewed as a model energy-conserving society. For example, it is noted for having the most demanding construction standards in the world for new buildiings and, hence, the world's most energy-efficient buildings. Approximately 40 percent of buildings in Sweden are heated with district heat. Further, much of the heat comes from variety of unconventional sources including urban 'waste-to-energy' plants, large (up to 20 MW) heat pumps using sewage water as a heat source, wood waste, industrial waste heat, agricultural waste, and even solar energy (supplying housing developments at a scale of up to about 300 to 400 units per system). Despite this, there may still be room for improvement.

Building Standards and Policies

As early as 1975, thermal requirements for windows were set at levels that could only be satisfied by triple glazing, a practice not common in new homes at the time. The 1976 standards also required heat recovery systems for commercial and large apartment buildings, and insulation of heat distribution pipes. Sweden has tightened its standards several times since then (77, 112). To help meet these standards, Sweden also provided various incentives (1 12). For example, grants to promote energy conservation in existing buildings, available since 1984, have been given if adequate energy conservation measures are included in retrofit projects. "Soft loans" have been available for improvements in residential buildings more than 30 years old, and subsidies that cover about 50 percent of interest costs have been offered for multifamily houses. Some of these mechanisms, however, were suspended between 1987 and 1989 (100).

Other policies contributed to construction innovations. In the 1970s, for example, by promising to cancel loan payments for projects that did not produce expected energy savings, the government eliminated economic risks involved in testing experimental designs and technologies. National R&D funds for technology development helped bring new products, such as residential heat pumps, onto the market. These programs were implemented during a period of rising oil prices and low electricity prices (1 12).

A Scenario **for Future Improvements**

Potential for reducing energy use in buildings still may exist. One study estimated future energy use in Sweden based on implementing the best currently available technologies and advanced technologies expected to be commercialized between now and the year 2020 (31, 32). It projected dramatic reductions in CO_2 emissions, ranging from 78 to 90 percent, primarily as a result of: 1) major efficiency improvements; and 2) a shift away from direct use of fossil fuels toward electrification based on nonfossil fuel generating capacity. As a result, the building sector's share of total energy use was projected to drop from 35 to 20 percent.

This scenario also demonstrates how reducing demand can create more flexibility on the supply side. As demand is reduced, the most costly supply technologies, from an environmental and national security standpoint, do not have to be pursued, or at least their use can be minimized. For example, Sweden's program to reduce energy use in buildings is part of its strategy for eliminating nuclear power and reducing dependence on foreign oil over the next few decades.

the room, thus reducing air-conditioning requirements.

Excess use of light can be avoided by: placing light switches in convenient locations; installing individual switches for each light; and using automatic controls to turn lights off or to adjust their intensity. This can be done with simple timers, or sensors that measure light levels or detect whether or not an area is occupied. Excess energy use also occurs when individual lights generate more light than is needed. This can be avoided by using lower-wattage bulbs, task lighting, and using controls that permit light levels to be dimmed when less light is required.

Space Conditioning

The amount of energy used for heating and cooling can be decreased through improved thermal integrity, improved equipment energy efficiency, and siting and landscaping decisions.

Thermal integrity can be improved by insulating buildings to reduce infiltration of outside air. To retrofit buildings[9]—with typical savings of 20 to 25 percent and paybacks in 2 to 9 years (50), the most

[9] Building retrofits are modifications t. existing equipment or the building shell to reduce energy use (e.g., adding insulation, upgrading ventilation equipment in commercial buildings, adding storm windows, etc).

Box 4-B—Energy Use in Soviet and Eastern European Buildings

U.S.S.R.

The Soviet building sector accounts for approximately 20 percent of final energy use, including 49 percent of all heat and 14 percent of all electricity (71). Within the sector, energy is used predominantly for heat (77 percent), followed by electricity (17 percent) and direct fuel use (6 percent).[1] As of 1985, per-capita energy consumption in Soviet buildings was less than one-half that in the United States (7), at least partly because of smaller per-capita living area and less use of appliances (74).

Several opportunities exist for conserving energy in buildings. First, the thermal integrity of buildings could be greatly improved, as over one-third of all energy used in buildings is wasted (71). Housing shortages and lack of capital allocated to the sector have resulted in hastily erected apartment buildings with poor therma1 integrity. Building energy efficiency codes are very low; for example, recommended wall insulation for Moscow is the same as in California, which has a much warmer climate (74).

Second, heat losses from district heating distribution systems (due to poor insulation of pipelines, long distances between sources of heat and end use, lack of antirust materials, and frequent power outages) could be reduced (71). A large portion of urban Soviet buildings are heated by district heating, up to half of which may be cogenerated.

Third, the energy efficiency of appliances could be irnproved this is particularly important in light of expected growth in appliance use. Current Soviet appliances are less efficient than western ones; for example, Soviet refrigerators use an estimated 30 to 40 percent more electricity than larger sized models in western countries (71).

Fourth, natural gas, which the U.S.S.R. has in abundance, could be used in place of, for example, coal.[2] The building sector is the only branch of the Soviet economy where coal is the most prevalent fuel; in 1980, coal supplied over *40* percent of all heat for housing and municipal buildings. This accounted for one-third of total fuel use. Electricity is projected to supply only 13 percent of the sector's energy needs by 2000 (7).

One major obstacle to achieving these opportunities is government subsidization of energy costs to consumers-for example, occupants in Soviet buildings pay a fixed fee for heating based on the square footage of their apartments, regardless of how much energy they use (also see ch. 9). Metering systems are almost nonexistent. And, gains made in improved thermal integrity of buildings and in production of more efficient appliances could be more than offset by per-capita increases in living area and use of appliances, depending on the overall rate of economic growth.

Eastern Europe

Buildings accounted for *28* percent of primary energy demand in Eastern Europe in 1985 (46). As incomes grow, so will other attributes such as air-conditioning, living area per capita, and, consequently, overall energy demand. One study projected that without major policy changes encouraging energy efficiency, total energy consumption in the buildings sectors would double between 1985 and *2025;* even with the implementation of energy-efficiency policy measures, energy consumption was still projected to increase by nearly 50 percent.

Not surprisingly, potential changes vary considerably among countries. In the residential sector, for example, no decline in energy use per square foot should be expected in Romania, because energy consumption in Romanian residences already is very low. In contrast, improvements could occur in Poland, because high-quality coal or natural gas could replace low-quality coal, which currently provides the vast majority of heat in residences.

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[1] Direct fuel usc includes fuels not used to produce thermal power for space heating. However, many dual-purpose stoves used for cooking and heating, and fueled mostty by coat and wood, are considered indirect fuel consumers. Here, direct fuel use includes only natural gas, liquefied petroleum gas, and kerosene used for stoves, small boilers, hot water in laundries and bathrooms, etc. (71).

[2] Whether this would reduce greenhouse gas emissions depends partly on whether the U.S.S.R. can reduce its rate of methane leakage from natural gas production and distribution.

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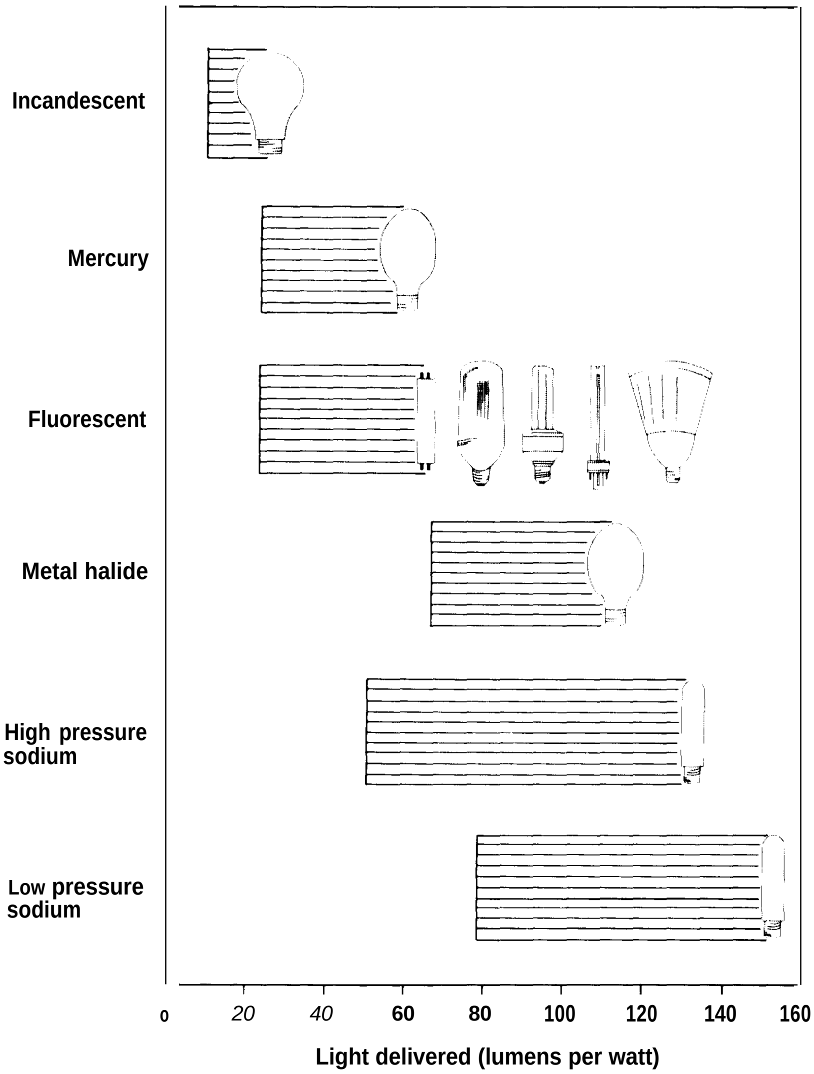
feasible options generally are to: 1) caulk and weatherstrip cracks around doors and windows; 2) add more insulation in roofs and walls; 3) install draperies and/or shades; and 4) improve windows, e.g., through installing double- and triple-paned windows with higher insulating values (see box 4-C). Just adding attic insulation alone in homes with little or none can reduce space heating require-

Figure 4-5-Energy Efficiency of Various Light Sources



fluorescent includes ballast losses.
SOURCE: U.S. Department of Energy, *Energy Efficient Lighting*, DOE/CE-0162 (Washington, DC: 1986).

ments by 15 to 33 percent with simple paybacks in 2 to 6 years (33).[10]

New buildings can be constructed with more compact forms, oriented to take advantage of sunlight, and designed with less and/or different glazing. ''Passive' solar-heating systems can be used to exploit the Sun's energy during cold periods. The most energy-efficient new houses use one-third to one-half of the energy required by the average new house (see figure 4-6).

Improved equipment for heating, ventilating, and air-conditioning (HVAC) will be important to decrease energy use in commercial buildings (39). The best new HVAC equipment uses 30 to 90 percent less energy than existing stock (39). Automatic controls play an increasingly important role; these

[10]Earth-sheltered homes, which use the surrounding earth itself as insulation and for protection from winds, can be cost-effective in colder climates with low humidities and proper soil and siting conditions (37, 48).

Box 4-C--Insulation and R-Values

Keeping buildings warm in winter and cool in summer requires a considerable amount of energy. This energy use can be cut by reducing the amount of heat (or ‘coolness”) lost through the ceiling, walls, and floor of a building.

All materials conduct heat to some extent, but some conduct more than others. A material’s resistance to heat flow is measured in units called “R”. A ceiling with an R-value of 20, for example, will lose only half as much heat as a ceiling with an R-value of 10. Some typical R-values for ceilings, walls, and floors in several locations in the United States are shown below. In general, homes in colder climates have higher R-values. Uninsulated homes have very low R-values.

Representative R-values

	Ceilings	walls	Floors
Uninsulated home	1-3	2-5	1-5
New homes:			
Louisiana	19-22	11-12	0
Washington, DC	30	12-17	11-19
Maine	38	17	19

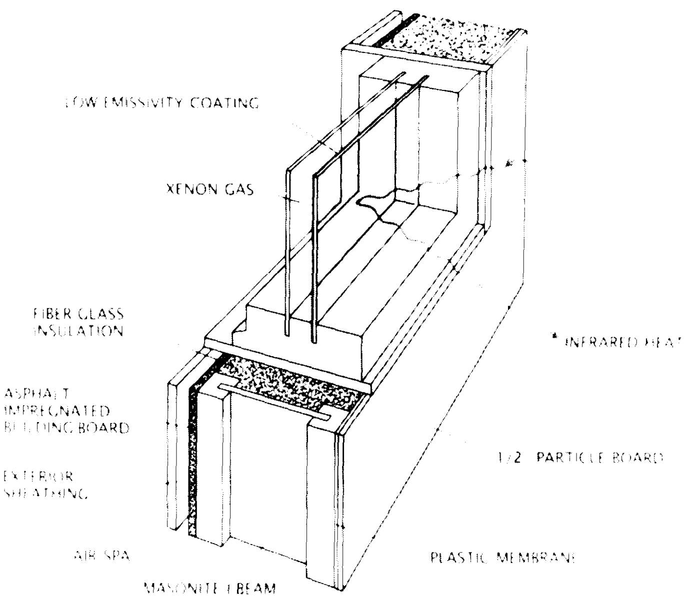
Almost half the heat in an uninsulated building is lost through the ceiling, about one-fourth through windows and air flow, 20 percent through the floor, and 12 percent through the walls. Increasing R-values can reduce these losses. Adding about 3.5 inches of wall insulation, for example, will increase wall R-value by about R-12. Achieving R-38 requires 9 to 18 inches of insulation. Increasing ceiling insulation in Washington, DC, from none to R-19 can reduce heating bills by about 40 percent and cooling bills by about 20 percent.

A normal single-glazed window is rated at about R-1, whereas a standard insulated wall is rated at R-n or better. Heat lost through windows can be cut in half by adding a second pane of glass (largely due to the insulating space between the two panes); such storm windows are rated R-2. Coating one of the inner surfaces with a thin film of a transparent low-emissivity material (such as tin oxide) reflects infrared heat back into the house-this will raise the rating to R-3. Replacing the air between the two panes of glass with better insulators (such as xenon or argon) will yield a R-4.5 to R-6 window.

Figure 4C-1 below depicts some of the newest insulation technologies for homes and windows. Superinsulated walls and windows can reduce home heating needs by more than 75 percent compared with homes built before 1973. This wall (built in Sweden) prevents heat seepage by using I-beam studs of masonite held between two pine flanges. The heavily insulated walls are sealed on the inside with a plastic membrane to prevent indoor moisture from condensing on the cold insulation in the wall. Heat loss through windows is cut by coating one of the double-glazed windows with tin oxide and filling the air space with argon or xenon gas.

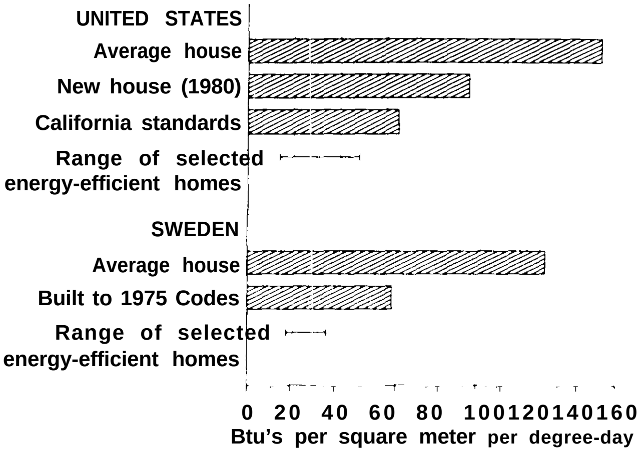
SOURCES: Refs. 17,70,80,86.

Figure 4C-1-Superinsulated Wall and Window



SOURCE: A.H. Rosenfeld and D. Hafemeister, "Energy-Efficient Building," *Scientific American* 258(4):78-85, April 1988.

Figure 4-6-Space Heat Requirements in Single-Family Dwellings in the United States and Sweden



The most energy-efficient new homes in Sweden and the United States use one-third the energy of the average new home and even less than the average home in general (including older homes).

SOURCES: Office of Technology Assessment, 1991, adapted from Goldemberg et al., 1988.

range from common household programmable thermostats to electronic devices that are capable of responding to ambient conditions (e.g., outside and inside temperature and humidity, as well as information from local utilities). Some designers and builders have attempted to develop ''smart' homes, in which energy management is electronically integrated with other household services (see box 4-D).

The efficiency of HVAC systems also can be improved through proper maintenance. Air conditioners, for example, contain heat exchangers that absorb heat from the building's air and discharge heat outside the building. The efficiency of these heat exchangers is compromised if dirt, dust, and debris reduce the flow of air over the exchangers and the rate of heat flow from the exchanger.

Building designs can be improved to make more use of natural ventilation and rely less on fans or air-conditioning. Planting trees and shrubs near buildings can reduce the use of energy through direct shading effects in the summer and wind protection in the winter (1; also see ch. 7). Large numbers of trees and light building surfaces may lessen the "heat island' effect associated with large cities and thereby reduce energy use (1, 42).

Changes in how buildings and energy are used by occupants also can contribute to energy savings. One option is to heat and cool only some rooms of a home and to conserve hot water. Another possibility is to minimize the conditioned space used per person, for example by purchasing smaller housing or by having more occupants in existing housing (e.g., children living at home for longer periods, renting rooms to borders). Multifamily dwellings share outside walls, thereby reducing wall area exposed to the elements and reducing space conditioning requirements.

Water Heating, Appliances, Cooking

The efficiency of other major end-uses also can be improved (28). The best 1988-model refrigerators, freezers, gas space heaters, air conditioners, electric water heaters, and lights are all at least 30 percent more efficient than typical models in use today (see figure 4-7). Several studies indicate potential life-cycle savings for a range of efficiency improvements in refrigerators, freezers, and water heaters (53, 101). Equipment expected to become available in the 1990s shows additional promise for efficiency gains.

The National Appliance Energy Conservation Act of 1987 (NAECA, Public Law 100-12), which set minimum-efficiency standards for many appliances,[11] will result in the least efficient appliances being taken off the market. One study estimated that this will lower residential energy use by about 0.9 quads (about 5 to 10 percent of current residential energy use) by the year 2000 (28). The American Council for an Energy-Efficient Economy estimated that appliances sold through the year 2000 in the United States could be operated at peak periods with 25 fewer large powerplants than would have been required had efficiency improvements not been made (2). However, NAECA does not set standards as high as can be achieved by the best currently available models,[12] nor is it specifically technology-forcing (28). The Act does require that standards be

11 Thirteen Product types are included: 1) refrigerators, refrigerator-freezers and freezers; 2) room air conditioners; 3) central air conditioners and central air-conditioning heat pumps; 4) water heaters; 5) furnaces; 6) dishwashers; 7) clothes washers; 8) clothes dryers; 9) direct heating equipment; 10) kitchen ranges and ovens; 11) pool heaters; 12) television sets; and 13) fluorescent lamp ballasts.

12 From a cost-effectiveness perspective, this may be reasonable for heating and cooling equipment--e. g., a high-efficiency furnace may be a reasonable investment in Maine, but it would not save enough energy to recover first costs in Florida.

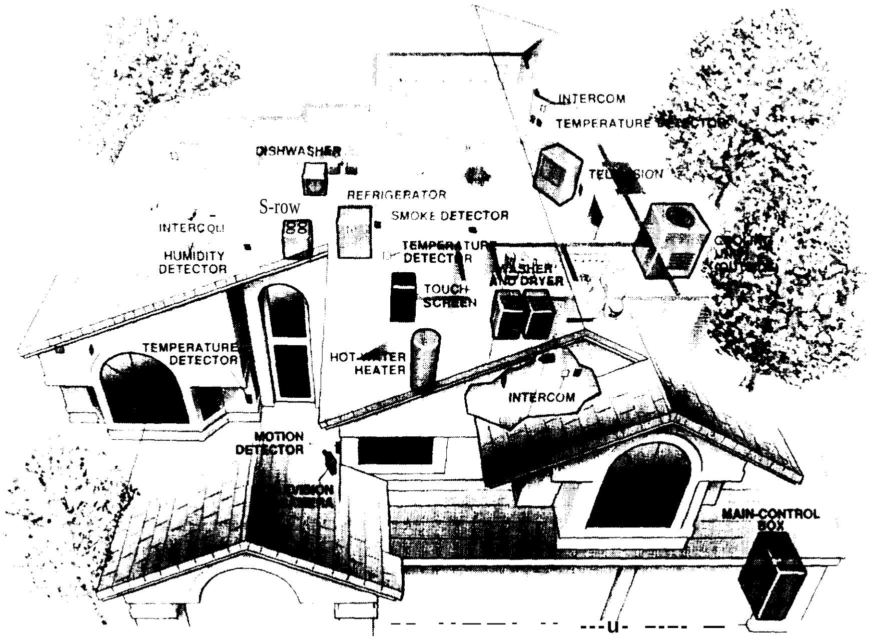
Box 4-D—Energy Management Systems and "Smart" Homes

Large reductions in energy use (and hence emissions) are possible with energy management systems. These systems basically allow energy demand in a building to be managed to meet a variety of objectives, including greater convenience, improved security, lower operating costs, and energy conservation. They range from relatively simple programmable thermostats for homes to expensive, sophisticated microprocessor systems for large commercial buildings.

One ambitious project in the United States involves designing, building, and operating a home that integrates energy management and other household functions in an electronic system that is linked to outside information sources. This "Smart House Project" is a cooperative effort headed by the Research Foundation of the National Association of Home Builders. As typically conceived, a house might use as many as 150 microcontrollers, all capable of being individually controlled and monitored but all integrated into a single system that permits control of any individual component from many locations within the building. Occupants could program the operation of appliances in advance. Appliance energy use and performance could be monitored, providing information that could be used to cut energy use and maintenance costs. The linkage with outside entities could allow inputs such as price-signals from the local utility or remote commands from absent occupants. This type of approach to automation is seen by some ***as*** being potentially revolutionary (9, 29, 47). Figure 4D-1 below is a diagram of a Smart House.

The Smart House Project is one of many whole-house automation efforts, including programs in Europe and Japan. These projects represent one area of a broader movement to increase the automation of buildings for a variety of reasons, ranging from load management (91) to improved building security. A small but rapidly expanding number of commercial buildings presently are automated with energy management systems (27, 59). Barriers to further penetration include a lack of familiarity with such systems, high costs, and lack of standardization.

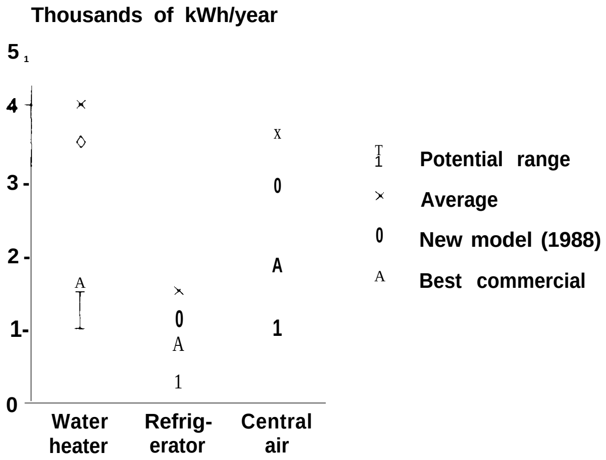
Figure 4D-1—A "Smart House"



"Smart Houses" offer increased comfort at a reasonable price and are far more energy-efficient than the average home. At the hear of each house is an automated-control box that monitors heating, air-conditioning, lighting, and security systems. In more advanced homes, the owner can adjust the temperature and humidity and turn appliances on and off by touching a wail-mounted screen. Passive measures, including well insulated walls, roofs that reflect solar radiation, and shade trees (particularly on the south and west sides of the building to mitigate the Sun's heat), can also save energy.

SOURCE: R. Bevington and A.H. Rosenfeld, "Energy for Buildings and Homes," *Scientific American* 263(3):76-86, September 1990.

Figure 4-7—Energy Efficiency Potential of U.S. Residential Appliances



SOURCE: H.S. Geller, "Residential Equipment Efficiency: A State-of-the-Art Review," contract prepared for the U.S. Congress, Office of Technology Assessment (Washington, DC: American Council for an Energy-Efficient Economy, 1988).

reviewed twice in the 1990s and allows for raising them. To date, 1993 standards for refrigerators, freezers, and small gas furnaces have been promulgated;[13] standards are currently being developed for dishwashers, clothes washers, and dryers (87).

Direct Energy Use in Buildings

In addition to changing how buildings use energy, as described in the preceding sections, energy savings also are possible by changing how buildings get energy. This can involve, for example, renewable fuels, cogeneration, and district heating.

Renewable energy sources such as wind, biomass, and solar power can be used directly at building sites. In 1981, the Solar Energy Research Institute estimated that renewable energy sources applied directly at buildings might replace 4 to 5 quads of energy by the year 2000(81), equivalent to about 15 to 20 percent of energy consumption in U.S. buildings in 1985. Nearly a decade has passed without major progress toward this goal, however.

Cogeneration is the production of electricity and useful heat at the same time, which improves the overall efficiency of fuel use.[14] Energy savings then can be achieved in buildings by using cogenerated heat to heat space and water, and to drive cooling devices. One obstacle to cogeneration is that buildings often are distant from their source of heat. This can be overcome by situating cogeneration facilities near or inside buildings. "District' heating systems, which supply heat (commonly in the form of steam) to a network of buildings, also can be developed.[15] Cogeneration thus is particularly appropriate in medium- and large-sized commercial buildings (including shopping centers; see ref. 85), multifamily buildings, and densely settled residential communities.

To date, however, cogeneration has barely penetrated the buildings sector in the United States—only about 50 megawatts of cogenerating capacity were installed as of 1987 (5).[16] While heat can be used in many ways in industrial settings, its primary use in commercial buildings is for space heating, which is only needed during part of the year. In some buildings where heat build-up from people and office equipment is a problem, additional heat often is not needed. One possibility is to use cooling systems run with heat (i.e., "thermally activated refrigeration' '); some air conditioners that use waste heat are available on the market (4, 11, 22, 56). Additional R&D is needed on computer monitoring and control technologies for integrating cogeneration into utility grids and reducing maintenance costs. Also needed are institutional arrangements to manage interconnected cogeneration facilities.

CFC and Halon Use

Chlorofluorocarbons (CFCs) and halons are major agents of the destruction of stratospheric ozone and also are important greenhouse gases (see ch. 2). CFCs are used in large quantities in buildings, principally in insulation and air-conditioning; they also are used in refrigeration (see ch. 8). Halons are used in fire extinguishers because they possess

[13] Of all classes of refrigerators, refrigerator-freezers, and freezers, only 7 models out of 2,114 listed in the directory Published by the Association of Home Appliance Manufacturers (6) meet the 1993 standards. Most models must therefore be improved or redesigned over the next 3 years (87).

[14] While a typical fossil fuel powerplant achieves fuel use efficiency of around 30 to 35 percent, by capturing waste heat cogeneration facilities can achieve efficiencies of 45 to 80 percent or more (see ch. 3).

[15] District heating already is used extensively in many European countries. It is relatively rare in the United States, although it is used in portions Of some major cities (e.g., New York and St. Paul) and in several entire small towns in the Midwest.

[16] Estimates of the technical potential for cogeneration in commercial buildings range between 3 and 40 gigawatts (i.e., several hundred times what is currently installed) (5, 62).

Box 4-E--CFCs and Halons in Buildings

In the buildings sector, the main sources of CFCs are in insulation and air-conditioning; halons are a principal component of fire extinguishers. Because the United States and other signatories to the Montreal Protocol (see ch. 2) have agreed to rapidly reduce and eliminate production of CFCs, intensive efforts are being made to limit emissions from current sources and to deploy alternatives. Additional information on alternatives discussed in this box can be found in refs. 88, 106, and 107.

Insulation-some CFCs used in insulating foams are released during the manufacturing process, but most remain in the foam and slowly leak out over time. A large reservoir of CFCs therefore exists within existing buildings. Opportunities to change this situation are limited. For new buildings, though, some emissions can be reduced during foam manufacturing and, more significantly, alternatives to CFC-based insulation exist and others are being developed. In addition, building designs and construction techniques can reduce the need for supplemental insulation.

Air-conditioning--CFCs are released during the manufacturing, servicing, and disposal of air-conditioning units. Some emissions can be reduced at each one of these steps, for example, through recycling. Over the long term, the use of CFCs can be reduced by exploiting alternative ways to maintain comfortable temperatures in buildings. These range from using other refrigerants (such as HCFC-123 or -134a), using air-conditioning technologies based on waste heat or solar energy, and designing and constructing buildings in ways which reduce the need for air-conditioning in the first place.

Fire-extinguishers— Halons can be released from fire extinguishers as a result of leaks, testing, or actual use to suppress fires. For existing equipment, halon emissions can be reduced by using effective leak detection technologies and methods for testing fire-extinguishing systems without releasing the halon components. Use of existing halon-based extinguishers also can be limited to applications where their advantages are most critical-for example, fires in sensitive electronic equipment or aircraft. In the longer term, alternative fire extinguishing substances can be developed and deployed.

excellent flame-extinguishing properties and are nontoxic to humans.

CFCs are used to produce rigid foams, which are used primarily for insulation in buildings. In 1985, roughly one-third of CFC-11 production in the United States was for this purpose (83). Globally, approximately 39 percent of CFC-11 and 12 percent of CFC-12 consumption in 1985 were for rigid foams (35).[17] CFC-11 and CFC-12 also are used in large, high-volume air conditioners, although most air conditioners use CFC-22, which is somewhat less damaging to stratospheric ozone (see ch. 2). Methods for reducing the use of CFCs and halons in buildings are described in box 4-E.

BUILDINGS IN DEVELOPING COUNTRIES

Trends in Energy Use

About 40 percent of total energy use in developing countries currently is derived from noncommercial sources (e.g., firewood, crop residues, charcoal) .18 This percentage varies widely from country to country (e.g., from nearly 100 percent in Nepal, to less than 10 percent in Libya) (72). Much of this noncommercial energy use occurs in the buildings sector, particularly in rural areas and residences. One study, for example, estimated that households accounted for 35 to 60 percent of total energy use in four low-income countries and 15 to 35 percent of total energy use in four transitional developing countries (52). Lower income households tend to use noncommercial fuels mainly for cooking; thus cooking is the largest end-use of household energy in developing countries.

The use of commercial fuels (i.e., coal, oil, gas, and electricity) is growing, however. Between 1978 and 1984, for example, growth in per-capita commercial energy use was about 18 percent in Asia, 21 percent in Latin America, and 36 percent in West Africa (72). In comparison, OECD growth rates for this period were 2 to 3 percent. Although developed countries are currently responsible for the largest share of CO_2 emissions in the buildings sector, the

[17] I.e., in countries reporting their production to the Chemical Manufacturers Association; countries with centrally planned economies are not included.

[18] The distinction between commercial and noncommercial fuels, though, is blurry (see ch. 9 and ref. 94).

developing countries' share of energy use and associated CO_2 emissions in the sector should increase over the next 25 years.

There are many reasons why energy use will increase in these countries, including their continuing urbanization and adoption of modern cooking technologies[19] and appliances. Greater urbanization and wealth tend to lead to the construction of western-style buildings, both residential and commercial, which generally require commercial energy sources for space conditioning. The number of commercial buildings will continue to grow. Ownership of electric appliance s--+. g., refrigerators, televisions, washing machines-is also growing rapidly in some countries (72, 94). These factors and population growth are causing electricity demand to climb sharply, yet current electric power generating infrastructures often are already short of capacity (89).[20]

Lighting currently accounts for only a small fraction of total energy use in developing countries (94). In rural areas, people often are limited to light from wood fires or perhaps kerosene wick lamps—the primary sources of light for more than 2 billion people. As rural incomes increase, or as people move to urban areas, though, lighting services (e.g., butane or pressurized kerosene mantle lamps, electric lighting) and the energy used to provide them increase dramatically.

Using energy to heat buildings is not an important end-use in the majority of developing countries, since most have tropical climates, although it is important in mountainous, and mid- and high-latitude areas (e.g., northern China) (94). Similarly, little energy currently is used for space cooling, despite typically hot climates. Traditional building designs (e.g., natural ventilation and other techniques that do not require additional energy inputs) and careful siting have long been used to moderate temperatures and keep indoor environments as comfortable as possible (18, 20, 21, 114). However, urbanization and increasing use of commercial building materials, mechanical ventilation, electric fans, and air-conditioning are making traditional designs less common and increasing energy requirements.[21]

Opportunities To Reduce Energy Use

As the economies of developing countries grow, demands for energy will continue to increase. As this happens, developing countries will have many opportunities to employ technologies and practices that allow for the most efficient generation and use of this energy. Given the critical needs for economic development in many countries, this will not reduce energy demand below current levels, but it can allow overall energy use (and associated CO_2 emissions) to grow more slowly without hindering overall economic development.

In the residential sector, more efficient cooking practices are the most pressing need. This can be accomplished by switching to modern fuels such as natural gas, liquefied petroleum gas, kerosene, or electricity, or using more efficient wood stoves (see ch. 7). Significant opportunities also exist for using electricity more efficiently; the technologies for reducing appliance and lighting energy use are basically the same as those discussed above for the OECD countries.

Commercial buildings now being built in developing countries will last well into the next century. Opportunities for more efficient energy use in commercial buildings are similar to those available in industrialized nations, with similar levels of potential savings (12, 23, 24, 32). Nonetheless, because of the anticipated growth of demand for energy services in the buildings sector over the next 25 years, there is likely to be an aggregate growth in energy consumption, despite increased efficiency. Energy conservation can slow this growth and also reduce foreign debt accumulation by minimizing the importation of fossil fuels and equipment for building electricity-generating installations.

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[19] The use of modern cooking fuels (i.e., natural gas, propane, fuel oil, kerosene, biogas) and cooking technologies makes a substantial difference in energy efficiency. The average consumption level for cooking with biomass is 9.5 to 14 million Btu's per year compared to 1,9 to 2.8 million Btu's per year for fossil fuels. Thus, a switch to more modem fuels, per se, is not necessarily associated with an increase in total residential energy use, but it is associated with the increase in ancillary energy uses that goes along with higher income levels.

[20] The exact effect on CO_2 emissions will depend on the mix of fuels (including electricity); the relative efficiencies of commercial versus noncommercial fuels; and whether the use of noncommercial fuels was causing deforestation or forest degradation (see ch. 7).

[21] Air-conditioning currently is rare in residential buildings in developing countries, but it is used in many commercial buildings (73).

OTA EMISSION REDUCTION SCENARIOS

Tables 4-1 and 4-2 show the assumptions that we used to model potential CO_2 reductions in U.S. residential and commercial buildings, respectively, for three scenarios—business as usual (Base case), and after the adoption of Moderate and Tough controls (app. A describes the model in detail). There are three major strategies for controlling emissions (see table row headings). The Operation & Maintenance/Existing Stock category involves measures that are possible with existing stock; these can be implemented quickly and require no new investment. New Investment incentives would encourage a consumer to buy, for example, a more efficient heater when the existing one needs to be replaced. In the Accelerated Turnover and New Technology category, retirement of old equipment and use of new technologies would occur 5 years sooner than now anticipated.

The model's projections of CO_2 emissions in the year 2015 for the three scenarios are given as a percentage *of* 1987 emissions, with a breakdown by end-use (see figure 4-2). The model's overall results from 1987 to 2015 are shown in figure 4-8 as a percentage change *from* 1987 emissions.[22] Under the Base case, we estimate that U.S. CO_2 emissions in 2015 from the buildings sector will be almost 30 percent higher than emissions in 1987. In the Moderate case, if technologies that are currently available and that pay for themselves over the life of the equipment are adopted, CO_2 emissions in 2015 from the U.S. buildings sector can be reduced by about 5 percent relative to 1987 levels. In the Tough case, technologies that are expected to be commercially available in the next decade could reduce buildings sector emissions by about one-third relative to 1987 levels by 2015,

Other analyses of future energy use in the U.S. buildings sector yield results ranging from an increase of 11 percent by 2010 (27, 28) to a net reduction of 41 percent (based on total penetration of cost-effective, energy-saving technologies) by 2020, relative to 1985 emissions (3 1). Our scenarios generally fall within the midrange of these estimates.

These projected reductions do not assume major changes in the fuel mix used to produce energy for buildings (figure 4-9 shows this mix for each scenario). Note that a large portion of the energy used in buildings is electricity. Since electricity in the United States is produced primarily from coal, which is the most CO_2-intensive fuel, additional emissions reductions could be achieved by changing how electricity is generated. Dramatic changes in the fuel mix used by utilities (see ch. 3) to generate electricity would affect potential CO_2 reductions in the buildings sector.[23] A major shift to nonfossil fuels might even change the attractiveness of some technical options; for example, cogeneration could become less attractive.[24]

How the use of wood would change in response to shifts in demand for other energy sources is not modeled. Most residences burning wood also have a second fuel source. As energy prices for these secondary sources increase, wood will be used more. Conversely, as oil and gas energy bills drop as a result of falling prices or conservation investments, wood may be partially replaced with these purchased fuels. The effect of different levels of wood use on CO_2 emissions depends on how quickly wood is being grown. If wood is grown at least as fast as it is burnt, then wood use effectively has zero CO_2 emissions. However, since wood is often burned inefficiently, the emissions from wood burning (especially when deforestation is factored in) may exceed even coal emissions (per unit of useful energy).

Base Case

For residential buildings, the base case shows a 6 percent increase in CO_2 emissions by 2015, relative to 1987 levels. This projected increase is lower than other studies (16, 105) and even GRI's base case (41) because we include the effects of the new NAECA standards. We assume slower growth

[22] Note that the results presented in this figure show emissions as a percentage change from **1987** levels; this should not be confused with the format presented in figures 4-2, 4-10, and 4-11, which present results as a percentage of 1987 emissions.

[23] In the United States, the average emission factor per quadrillion Btu's of delivered electricity currently is 57 million metric tons of carbon, based on a fuel mix of 55 percent coal, 11 percent gas, 5 percent oil, and 30 percent nonfossil sources (including hydroelectric power, nuclear, and renewables) (44).

[24] Changes in the level of demand for electricit, also might affect supply choices by utilities (e.g., very low demand would retie it mom. difficult for utilities to justify investments in new, less carbon-intensive generating technologies).

Table 4-l—Residential Buildings: Measures in the OTA Model

	Base case	Moderate controls	Tough controls
Operation and maintenance/ existing stock:			
Housing shell retrofits	10% savings by 2015	20% savings by 2015	Northern homes 30°/0 savings by 2000. Southern homes same as Moderate.
Compact fluorescent	None	Replace heavily used bulbs, net 35°/0 savings	Replace more bulbs, net 50°/0 savings (technical maximum about 650A)
New *Investments:*			
Shell efficiency of new homes	New homes 15°A more efficient than existing average	New homes space heat 50°A more efficient than existing average, AC 25% more efficient	Northern new homes space heat 8570 more efficient than existing average, AC 45°/0 more efficient. Southern new homes same as Moderate.
HVAC equipment			
Gas space heat	82% efficient by 2005	Mix of 84% and 92°/0 (pulse combustion)	All gas pulse combustion
	Gas heat pump introduced in 1995, 10% new share by 2015	Same as Base case	Move market share of gas heat pump forward by 5-10 years and reduce other gas heat
Oil space heat	81% efficient by 2005	Same as Base case	Same as Base case
Electric space heat	Heat pump COP of 2.5 by 2015	Replace 20$40 of new electric resistance space heat with heat pump	Replace 5070 of new electric resistance space heat with heat pump
Wood space heat	None	None	Improved efficiency of wood use
Appliances	National appliance standards	Most efficient on market today	Most efficient on market today
Water heaters			
Gas water heaters	National appliance standards	Same as Base case	Same as Base case
Heat pump water heaters	None	Replace 80% of new electric water heaters with heat pump water heater	Replace 100% of new electric and oil water heaters with heat pump water heater
Accelerated *turnover* **and** *new technology:*			Existing equipment lifetimes 5 years shorter
HVAC equipment	Not applicable	Not applicable	Gas heat pump heating COP of 1.7 by 201 5; electric heat pump heating COP of 2.8 by 201 5; improved AC efficiency
Appliances	Not applicable	Not applicable	New prototype appliances (for example, heat pump dryer)
Water heaters	Not applicable	Not applicable	Replace gas water heat with 80% efficient prototype

Abbreviations: AC=air-conditioning; COP=coefficient of performance; HVAC=Heating, ventilating, and air-conditioning equipment.

SOURCE: Office of Technology Assessment, 1991.

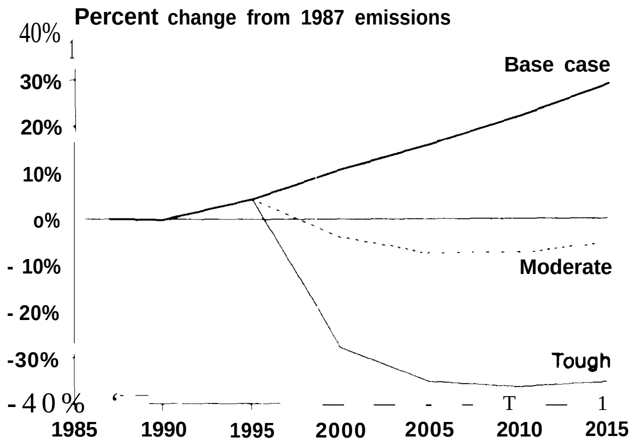
Table 4-2—Commercial Buildings: Measures in the OTA Model

	Base case	Moderate controls	Tough controls
Operation and maintenance/ existing stock:			
Building retrofits	60% savings by 2015	150/0 savings by 2005, 25% by 2015	40% savings by 2000
Lighting	None	High efficiency bulbs, net 120/. savings (80°/0 of 15%--assume 20% market already)	High efficiency bulbs, net 120/. savings (80°/0 of 150/assume 200/' market already)
New investments:			
Shell efficiency of new buildings	New buildings 150/. to 22%0 more efficient than existing 1987 average	New buildings 500/. more efficient than average (42% above new Base case buildings)	New buildings 75°/0 more efficient than average (71 °/o above new Base case buildings)
HVAC equipment			
Gas space heat	84% efficiency by 2010 Gas heat pump introduced in 1995, 2% new share by 2015	Mix of 640/. and 920/. efficient Same as Base case	All 92% efficient Move market share of gas heat pump forward by 5-10 years and reduce other gas heat
Electric space heat	Heat pump COP of 1.95 by 2015	Replace 20°/0 of new electric resistance space heat with heat pump	Replace 50% of new electric resistance space heat with heat pump
Air-conditioning	None	Adjust variable speed drives and economics, net 200/0 savings	Same as Moderate case
Cogeneration	0.13 quad by 2005, 0.20 quad by 2015	0.18 quad by 2005, 0.26 quad by 2015	0.64 quad by 2015
Water heaters	None	Replace 80°/0 of new electric water heaters with heat pump water heater	Replace 100% of new electric water heaters with heat pump water heater
Lighting	None	Combination of high efficiency bulbs, ballasts, reflectors, and daylight; net 50°/0 savings in new, 40% in replacements	Combination of high efficiency bulbs, ballasts, reflect, and daylight; net 60% savings in new, 50% in replacements
Electronic office equipment	Increased usage	50% savings from improved technology and 20°/0 in reduced idle time: total 600/0 savings by 2015	65% savings from improved technology and 40°/0 in reduced idle time: total 80% savings by 2015
Accelerated turnover and new technology:			Existing equipment lifetimes 5 years shorter
HVAC equipment	Not applicable	Not applicable	Gas heat pump COP of 1.4 by 2015, electric heat pump COP of 2.4 by 2015. Heat exchangers yielding 28% AC savings
Cogeneration	Not applicable	Not applicable	0.96 quad by 2015 including fuel cells and improved chillers
Water heaters	Not applicable	Not applicable	Replace gas water heater with 80% efficient prototype

Abbreviations: AC=air-conditioning; COP-coefficient of performance; HVAC=Heating, ventilating, and air-conditioning equipment.

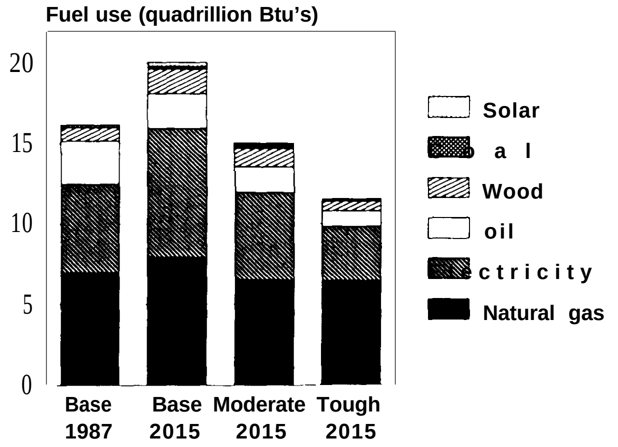
SOURCE: Office of Technology Assessment, 1991.

Figure 4-8-Summary of CO_2 Emissions From the U.S. Buildings Sector by Year, Under the Base Case, Moderate, and Tough Scenarios



SOURCE: Office of Technology Assessment, 1991.

Figure 4-9--Fuel Use Under the Base Case, Moderate, and Tough Scenarios, by Fuel Type



SOURCE: Office of Technology Assessment, 1991.

in electricity use than do other models; of the major commercial energy sources electricity is still the fastest growing energy source in the sector. However, in OTA's base case, residential electricity use increases by 0.5 percent per year, whereas other models assume it increases by 2 to 2.5 percent per year, at least until the year 2000.

For commercial buildings, CO_2 emissions in the base case grow about 50 percent between 1987 and 2015. While total delivered energy use in commercial buildings increases by about 40 percent between 1987 and 2015, the increase in CO_2 emissions is greater because we assume that electricity use grows by about 68 percent, primarily because of growing demand by commercial users for air-conditioning and office equipment. This corresponds to an electricity growth rate of 1.9 percent per year. Since electricity generated by U.S. utilities currently exhibits relatively high CO_2 emissions per unit of delivered energy, increasing electricity consumption increases CO_2 emissions disproportionally faster than does increasing use of other energy sources in this sector.

Moderate Scenario

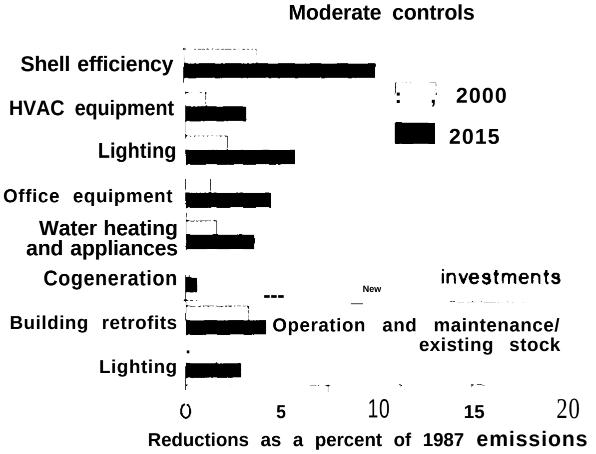
In the Moderate scenario, improving the shell efficiency (or thermal integrity) of new (residential and commercial) buildings can reduce emissions by about 10 percent of 1987 levels by 2015; similar improvements in existing buildings can achieve a 4 percent reduction by 2015 (see figure 4-10). installing new, more efficient lights and electronic office equipment will reduce emissions in 2015 by about 6 and 5 percent of 1987 levels, respectively; these two options, along with cogeneration, were applied only to commercial buildings in the model. Installing more efficient water heaters and appliances will reduce emissions in 2015 by about 4 percent, primarily in residential buildings.

After accounting for growth in energy use between now and 2015, together these Moderate residential and commercial options can reduce CO_2 emissions by about 5 percent in 2000 and 2015, compared to 1987 levels (see figures 4-2 and 4-8). Controls in the commercial sector account for over two-thirds of the reductions. In 2000, New Investment options for both residential and commercial buildings contribute over 70 percent of the total reductions, but by 2015, when a greater proportion of old buildings has been replaced, this percentage increases to over 80 percent. In both residential and commercial buildings, improvements in building shells yield the highest reductions of any individual option.

Tough Scenanio

In the Tough scenario, more ambitious investment in increasing the shell efficiency of new residential and commercial building can reduce emissions by about 18 percent relative to 1987 levels by 2015, while similar improvements in existing buildings (i.e., ''building retrofits") can reduce emissions by 4 percent (see figure 4-1 1). Retrofits provide the

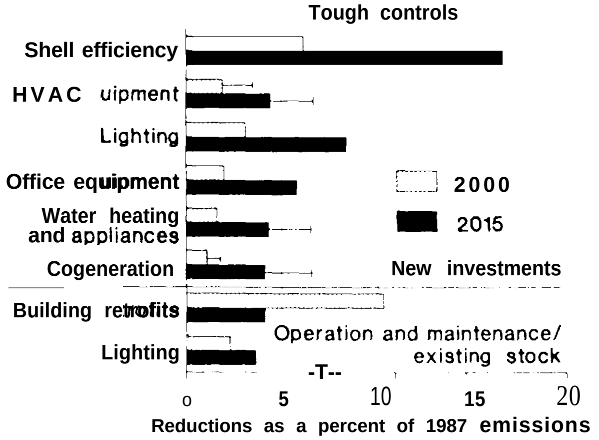
Figure 4-10--CO_2 Emissions Reductions in 2000 and 2015 Expressed as a Percentage of 1987 Building Sector Emissions, by Control Method, Under the Moderate Scenario



Note that emissions reductions are expressed as a percentage of 1987 emissions. This format should not be confused with the format in figure 4-8, which presents emissions, by year, as a percentage change *from* 1987 emissions.

SOURCE: Off Ice of Technology Assessment, 1991.

Figure 4-1 1-CO_2 Emissions Reductions in 2000 and 2015 Expressed as a Percentage of 1987 Building Sector Emissions, by Control Method, Under the Tough Scenario



Note that emissions reductions are expressed as a percentage of 1987 emissions. This format should not be confused with the format in figure 4-8, which presents emissions, by year, as a percentage change *from* 1987 emissions.

SOURCE: Office of Technology Assessment, 1991.

largest reductions of any individual option in the short term (i.e., around 10 years), but this option becomes less effective over time since fewer older buildings remain in which to install retrofit technologies. Installing new, more efficient lights and electronic office equipment will reduce emissions in 2015 by about 8 and 6 percent of 1987 levels, respectively. As in the Moderate scenario, these last two options, along with cogeneration, were applied only to commercial buildings.

More reductions could be achieved if existing equipment is replaced 5 years sooner than normal with new technologies that could become available within the next 20 years (see thin bars in figure 4-1 1). This accelerated schedule can augment total emissions reductions from each of the above three options by another 2 percent in 2015 compared to 1987 levels. About half of these additional reductions come from increasing the rate of turnover and half come from the new technologies themselves.[25]

Together, these Tough options can reduce CO_2 emissions in 2000 by about 28 percent below 1987 levels and about one-third below 1987 levels by 2015 (see figure 4-8). Controls in the commercial sector alone account for about 60 percent of these reductions. In 2000, New Investment options for both residential and commercial buildings contribute about 55 percent of the total reductions from the buildings sector, but by 2015, when a greater proportion of old stock has been replaced, this percentage increases to about 70 percent.

Costs of the Tough Scenario

Costs for all Tough measures that are applicable to buildings in both the residential and commercial sectors fall in a range between net *savings* (i.e., equipment costs minus fuel savings) of $53 billion per year to net *costs* of $7 billion per year (1987 dollars). The costs of the individual measures are summarized below and presented in greater detail in appendix A.

Costs for the residential sector are best estimated by household. By 2015, there will be about 115 million households, 35 million built after 1995 and 80 million built before. We estimate that shell improvements to pre-1995 houses under our Tough

[25]The effect of increasing the turnover rate is greatest in space heating, where furnaces have a long lifetime, and in appliances, where the difference between new and average efficiencies is large; increased R&D has the biggest impact on appliances because numerous promising developments exist in this area (25, 27).

scenario will cost about $2,300 per single family house in northern climates and $1,000 per single family houses in southern ones.[26] The cost of shell improvements in post- 1995 houses under our Tough scenario are somewhat higher. In northern climates, costs might be in the range of $6,000 to $8,000 per house and about $2,500 per house in the South. For the 25 percent of households that live in multi-family dwellings, shell improvements will cost about half of the single-family home estimates given above. More efficient furnaces, air conditioners, water heaters, and appliances might total about $1,000 to $1,500 per household.

Assuming the shell improvements have a 30-year life and the more efficient appliances average a 15-year life, total costs for the residential sector will be in the range of $30 to $40 billion per year. However, fuel savings from these appliances are about $55 billion per year assuming 2015 fuel prices. Thus, the net costs for the residential sector fall in the range of *savings* of $15 to $25 billion per year. The cost effectiveness of these reductions is in the range of -$175 to -$300 per ton of carbon (i.e., savings of $175 to $300 per ton of carbon avoided).

By 2015, we anticipate about 72 billion square feet of commercial building space (up from about 45 billion today). Though costs of energy efficiency improvements vary by budding type, they appear to cluster in the range of $5 to$11 per square foot (65a) for a package of measures similar to our Tough lighting, shell, and heating and cooling equipment efficiencies. Costs for these improvements are in the range of $30 to $65 billion per year but fuel savings are approximately $55 billion per year at 2015 fuel prices. Thus net costs for these measures fall between savings of $25 billion per year and costs of $10 billion per year. The cost effectiveness of these reductions ranges between --$190 per ton and $75 per ton of carbon avoided.

The remaining reductions from installing cogeneration equipment and more efficient office equipment might yield net costs in the range of savings of $3 billion per year to costs of $12 billion per year, Thus total costs for the commercial measures fall between savings of $28 billion to costs of $22 billion per year.

POLICY OPTIONS

Reducing CO_2 emissions from the buildings sector will require implementing numerous technical options, as well as individual behavioral changes, and removing a variety of barriers to investment in energy conservation. For example, translating our ‘‘Moderate’ residential emission reductions into practice means that all existing homes are retrofitted to achieve an average shell improvement of 20 percent; new home shells must be, on average, 50 percent more energy efficient than today’s homes. In our ‘Tough’ scenario, existing homes are improved by 30 percent in northern (cold) parts of the country[27] and 20 percent elsewhere; new home shells are 85 percent more efficient than the existing average in the same five areas of the country.[28] To accomplish such changes on a broad scale will require a combination of policies and consistent fiscal and regulatory signals.

This section discusses a wide range of ways to implement the various tactics available to control greenhouse gas emissions from buildings. In many cases, there is not a clear distinction between policy instruments that change, say, maintenance and those that accelerate actual turnover of equipment. Congress could combine several options to achieve modest or aggressive reductions from this sector depending on its goals.

Overview: Barriers and Policy Instruments

In both residential and commercial construction, minimization of upfront costs often takes precedence over total life-cycle costs because of the overriding concerns about cash flow and the cost of capital at the time of purchase. This creates a barrier to greater investment in energy conservation. In addition, most consumers lack expertise in evaluating energy information and prefer products similar to those they are replacing. An additional barrier is that those who make purchase decisions (e.g., builders) are often not those who pay utility bills. Policies for reducing emissions must address these obstacles.

[26] See ref. 65a for the primary data source from which the costs of our Tough scenario are estimated.

[27] Using the Census regions, this includes West and East North Central, New England, Mid-Atlantic, and Mountain region # 2.

[28] This efficiency level is between that of the Minnesota Energy Efficient Housing Demonstration Project Home (a well-insulated home; see ref. 32) and the Northern Energy Home (a superinsulated home with triple-glazed windows and night shutters; see ref. 61).

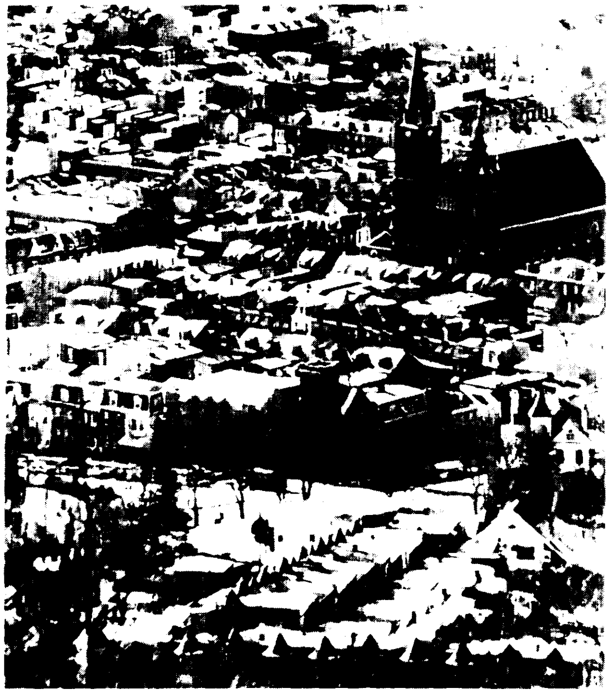


Photo credit: M. Procter

Rowhouses, churches, warehouses, and factories densely packed in Reading, Pennsylvania.

Policies for reducing CO_2 emissions in the building sector include: end-use taxes, initial purchase taxes, utility least-cost planning, appliance standards, building codes, consumer information and marketing, zoning ordinances, and research and development. The synergisms possible among these policies are vital to reducing emissions. Taxation sends the price signals to reduce energy consumption. Regulation (codes and standards) can be used to remove the least efficient equipment, appliances, and buildings from the market. Incentive and information programs can be used to create a market for exceeding the standards, as well as to provide consumers with the information needed to make energy-conserving choices in response to price signals from taxation. There is also a role for government-sponsored R&D in the construction industry, the fragmented nature of which discourages the private sector from making capital-intensive and risky investments.

Congress could also mandate increased energy conservation in government procurement and in buildings the Federal Government owns or operates.[29] Such steps would reduce perceptions of risk and provide an example for the rest of the country (98). Also, demonstration projects can provide data to improve our ability to predict savings from conservation measures. The Federal Government is the single largest consumer of energy in the Nation; Federal buildings consume 2 percent of the energy used in this sector—about 2 quads at a cost of $8.7 billion (105a). Congress has directed Federal agencies to reduce their energy use by 10 percent (per square foot of floor space) from 1985 to 1995 (Public Law 1,00-615). The DOE Federal Energy Management Program (FEMP) is responsible for reporting to Congress on the progress toward this goal.[30] Legislation in 1986 authorized[31]-and legislation in 1988 required[32]—Federal agencies to establish a program of 'Shared Energy Savings' (SES). Agencies were to contract with private energy-service companies (for up to 25 years) who would supply the capital for improvements to Federal facilities in exchange for a portion of cost savings. By the end of 1990 only four contracts were in place. Congress could try to streamline the contract process or provide further incentives for compliance.[33]

End-Use Taxes

Energy end-use taxes would increase the price of energy, thereby encouraging lower energy consumption. Thus, they affect all levels of our model: O&M, new investment decisions, the rate of turnover, and the intensity of private sector R&D. End-use taxes can stimulate conservation in both new and existing buildings, and can send signals regarding energy use and purchases. However, end-use taxes can often be less effective in influencing consumer purchase decisions than other policy measures such as appliance standards, building codes, and initial purchase taxes or rebates set at similar levels of stringency. Taxes do not address issues such as the lack of

[29]OTA is completing a study in this area ''Energy Use in The Federal Government' which will be released in summer 1991.

[30]Executive Order 12003, issued in 1977, mandated a 20 percent reduction in Federal energy use below 1975 levels by 1985. When the order expired in 1985, the executive agencies had not reached the goal, During the following 3 years, energy use rose 6 percent (98a).

[31]Consolidated Omnibus Budget Reconciliation Act (COBRA) Public Law 99-272.

[32]The Federal Energy Management Improvement Act (FEMIA) Public Law 100-615.

[33]Ref. 108a discusses several impediments that exist under the current SES structure.

information about life-cycle costs, uncertainty, and divergent incentives between purchaser and user. The large number of highly cost-effective energy-efficient investments currently not chosen by consumers indicates that price alone does not stimulate optimal investment decisions (61).

If fuel taxes reflected ' 'externalities" (or non-monetary costs of a good or service) fuel choice could be influenced. We did not model taxes, but other organizations have. Their results are not necessarily consistent with one another (45, 55, 63, 90). From these studies, price and income elasticities[34] appear to be such that a high tax rate would be needed to achieve substantial reductions in energy consumption over the 25-year timeframe of this study.

High end-use taxes based on CO_2 emissions would generate a larger amount of government revenue. For economic (and political) reasons it may be necessary to reduce other taxes. Assuming that the cuts are applied to expenditure taxes and that the net impact is revenue neutral (i.e., as much is given out as is taken in), end-use taxes raise equity issues and might impose hardships on lower income households.

Initial Purchase Taxes

An initial purchase tax would place a lump-sum tax on energy inefficient appliances and equipment (and possibly buildings and homes) at the time of purchase.[35] It could be applied to all equipment and appliances, to only the most polluting, or on a revenue neutral basis (i.e., fees on the most polluting items, and rebates for the least polluting that are equal in sum to the amount collected for the most polluting). The major advantage of an initial purchase tax is that it will send the appropriate signals regarding consumer purchasing decisions, which are often based largely on first cost. This type of tax would not affect usage decisions.

Tax Credits and Incentives

The combination of financial incentives to pursue efficiency coupled with disincentives for high energy use--the ''carrot and stick' approach-can be particularly effective. For example, investment tax credits can be aimed at changing both the level of investment as well as investment targets (e.g., commercialization of high-efficiency heat pumps, installation of energy-efficient equipment). Generally speaking, however, this country has not experimented extensively with financial carrots expressly to induce conservation, although it has experimented with regulatory/statutory energy-related carrots such as tax credits for powerplant investment and the Price-Anderson oil depletion allowances. One problem with the experience to date is that there has been little effort made to evaluate the strengths and weaknesses of different approaches.

The Federal Government passed legislation that provided solar and conservation tax credits for the years 1978 through 1984. The 1986 tax reform act allowed the energy conservation tax credits for residential use to expire but extended residential solar tax credits and some commercial energy conservation credits. The Omnibus Budget Reconciliation Act of 1990 extended the 10-percent business energy tax credit for solar and geothermal property through December 31, 1991. Studies on the impact of these credits are inconclusive. Some say they were too low to affect homeowners' behavior. However, one study indicates that the level of the tax credit may not be as important as its presence (39).

The Federal Government also funds several subsidy programs. Four State and local assistance Programs (SLAP), administered by DOE provide States with Federal technical assistance as well as money for specific energy conservation programs, including low-income home weatherization, matching grants to schools and hospitals for energy conservation projects, energy education, and various other State and local conservation programs. The SLAP programs are funded through both direct congressional appropriations and the States' use of Petroleum Overcharge Funds.[36] Congress has maintained funding for these programs throughout the 1980s despite administration recommendations that these programs be terminated. The Institutional Conservation Program (ICP) pays for audits and half of any conservation investments in schools and hospitals. State and Federal officials rate this program successful, with over 32,000 buildings participating since 1977 and a cumulative energy bill

[34] A price elasticity measures the change in energy demand in response to a change in price of energy.

[35] Congress has implemented this idea with the ''Gas Guzzler Tax'' on inefficient cars (see ch. 5).

[36] Funds delegated to the States as a result of pricing violations by oil companies.

savings of $1.9 billion .37 The Weatherization Assistance Program funds States to retrofit low-income housing with insulation to conserve energy .38 The State Energy Conservation Program (SECP) provides financial assistance to the State Energy offices to promote energy efficiency and conservation in the commercial and residential sectors. The Energy Extension Service (EES) is a Federal/State effort to provide small scale energy users with individually tailored technical assistance for energy conservation and increased use of renewable. The SECP and the EES have been consolidated under the State Energy Conservation Programs Improvement Act (Public Law 101-440), signed into law October 18, 1990.

Other federally funded programs include the Low Income Home Energy Assistance Program (LIHEAP), the Residential Conservation Service (RCS), and the Solar Energy and Energy Conservation Bank (SEECB); the RCS and SEECB have recently expired. RCS is discussed under ''Home Energy Audits" below. SEECB helped finance energy conservation and solar measures in low- and moderate-income housing and in commercial buildings owned by nonprofit organizations. LIHEAP (a Department of Health and Human Services program) gives grants to States to subsidize energy bills in low-income housing; 15 percent of the funding can be used for retrofits. The 1990 amendments to the Housing and Community Development Act of 1974 also included low-income housing conservation and efficiency grants to be administered by the Department of Housing and Urban Development.

Demand-Side Management (DSM)

DSM refers to utility programs designed to encourage customers to modify their pattern of electricity usage (17a). Particularly promising—from a global warming perspective-are those situations where utilities allow energy conservation to compete with traditional supply technologies (e.g., powerplants) to balance energy supply and demand .39 Because demand-side investments can be less expensive than new supply, and because utilities traditionally have longer time horizons than consumers, DSM can result in greater investments in energy efficiency than would be made by consumers alone. Utility programs can capture the potential in both the new and retrofit markets, for both equipment efficiency and building shell improvements. The ability to reach retrofit markets is particularly attractive because they are difficult to reach through building codes. Another attractive feature of DSM is that there is already considerable support for it by many State energy offices, State legislatures, and public utility commissions (34) (also see app. B, and box 3-C in ch. 3). Recalling figures 4-10 and 4-11, the biggest CO_2 savings from the buildings sector as a whole came from increased thermal integrity of building shells and from raising the efficiency of space conditioning equipment. Therefore, DSM could play an important role in reducing greenhouse gas emissions from the buildings sector.

For DSM to stimulate significant investment in conservation, incentive structures must be changed so that utilities are equally willing to make supply- and demand-side investments. Currently, there can be a disincentive for investment in conservation, because utility revenues and profits depend on the amount of electricity sold. Methods used by some States to address this problem include:

1. a volume-of-sales adjustment that adjusts retail prices when the level of forecasted sales differs from actual sales; thus, sales drop due to conservation efforts, but a utility's return on investment will not drop;
2. a higher rate of return on conservation investments;
3. shared savings between customers and shareholders;
4. a contract bonus based on energy conservation performance in the form of increased rate of return, or an expanded concept of the rate base (i.e., adding conservation investments to the rate base); and
5. comparative bill earnings in which the performance of a utility is compared to that of other utilities in the region, with a higher rate of return available to utilities that achieve above average energy savings.[40]

37 DOE testimony of May 2, 1989, as reported in ref. 102a.

38 Recently Public Law 101-440 expanded the original focus of this program to include cooling efficiency modifications in an effort to emphasize *annual* energy efficiency.

39 OTA references to DSM in this chapter include measures improving efficiency as well as innovative programs to reduce total demand.

40 For a discussion of the comparative bill earnings scheme, see ref. 58. For discussion of all of these options, see ref. 13.

Federal and State governments share the regulation of electric utilities. The Federal Energy Regulatory Commission (FERC) has jurisdiction over wholesale transactions, both inter- and intra-state. This gives FERC jurisdiction over inter-utility sales for interstate holding companies and power pools and over many transactions within a State.[41] Congress can play a leadership role in directing utility planning through the legislation that guides FERC. This ability is most apparent in the Public Utility Regulatory Policies Act of 1978 (PURPA), which required utilities to purchase electricity from qualifying facilities at avoided cost. Qualifying facilities include cogeneration and those using renewable energy sources. Recently Congress amended PURPA (Public Law 101-508) to eliminate the 80-megawatt capacity limitation for qualifying facilities fueled by wind, geothermal, solar, or waste energy.

The Federal Government also maintains a Least Cost Utility Planning Program at DOE; appropriations for 1991 were increased from $1 to $3 million. Its limited budget had allowed it to play only a catalytic role, working closely with the national laboratories and industry research institutes to provide utilities with data and analysis on a variety of DSM issues.[42]

There has been considerable activity in demand-side planning by State commissions, trade associations, and utilities themselves. Different approaches may be most appropriate to different utilities, States, or regions. As DSM implementation is still nascent, it may be useful to let diversity flourish. Thus, any Federal legislation would ideally be general enough to allow States flexibility in implementation and specific enough to have a truly positive impact on conservation.

To promote demand-side planning, Congress could:

1. require Federal electric utilities (like the Tennessee Valley Authority) to expand DSM programs and set rates for their distributors based on achievement of DSM goals;
2. require States to formally consider demand-side resources in their planning;
3. require least-cost planning for utilities whose projects fall under the jurisdiction of Federal Energy Regulatory Commission; and
4. require all utilities to use least-cost planning.

Congress could also encourage public utility commissions to formally assess the various incentive rate schemes and determine if any were applicable to their utility. This step would be analogous to the one taken in 1978, when PURPA directed the States to review a wide range of strategies to promote pricing. To increase the possibility of useful findings from the process, funding could be included so that nonprofit groups could participate in these proceedings.

Congress has already mandated, in the 1980 Pacific Northwest Electric Power Planning and Conservation Act (Public Law 96-501), that the Northwest Power Planning Council adopt rate structures that give conservation measures a cost break over other, more traditional supply-side measures.

To move beyond the above measures, Congress could also direct the Federal Government to establish a cost for the environmental externalities of supply-side options. The New York Public Service Commission, for one, requires explicit consideration of environmental factors (with a weight that amounts to 15 percent of the total score or up to 1.4 cents per kWh for the most polluting sources; see app. B) in utility assessment of bids for supply and demand resources (82). Or, Congress could require all States to develop a method for making demand-side investments as attractive as supply-side investments.

Appliance Standards

Appliance standards overcome the problem of emphasis on first cost by fiat, by removing inefficient appliances from the market. Properly set, standards can also be ‘technology forcing. A DOE study comparing various policy alternatives concluded that standards result in more savings than other methods, including tax credits, rebates, and consumer education (101).

The National Appliance Energy Conservation Act (NAECA), approved by Congress in 1987, set minimum-efficiency standards for many appliances (see “Space Conditioning” above). The NAECA Amendments in 1988 extended the standard to some commercial building lighting ballasts. NAECA re-

[41] There is a history of tension over the sharing of jurisdiction for electricity planning (93a).

[42] Congress has considered expanding PURPA to include DSM as a new form Of qualifying facility.

quires that the standards be reviewed twice during the 1990s, which provides an opportunity to obtain additional energy reductions through new or more stringent standards. Congress could consider extending standards to other equipment such as commercial HVAC equipment, light bulbs, and building components such as windows.

When Congress set the current standards, a payback period of 3 years was termed ' 'economically justifiable. '[43] Alternatively, a longer payback or a lifecycle costing rule could be used to set the standard.[44] Because current economic analyses do not include the costs of environmental externalities, more stringent standards could be justified as a way of reflecting these environmental costs.

Congress could make standards even more effective by using them in conjunction with other incentives. For example, standards can be used to set a regulatory ''floor, ' removing the least efficient equipment and buildings from the market, while policies such as utility programs, appliance labeling, and tax schemes can provide incentives to exceed the standards.

One problem with standards is that they may drive up the purchase price so that a prohibitively large upfront payment is required. This problem could be remedied with loans, purchase credits, or some other form of initial purchase cost defrayment.

Building Energy Codes

Building energy codes serve a function analogous to that of appliance standards in that they keep the least efficient buildings from being constructed. Similarly, they can be used in conjunction with other policies such as utility programs, building rating systems, and tax schemes. Since most of the CO_2 savings in 2015 in the Moderate case come from improved space conditioning equipment and better thermal integrity, codes could play an important role in controlling CO_2 emissions.

Building codes have traditionally been under the jurisdiction of States and localities. Mandatory national building codes are finding little support from the States or the construction industry (61).

Photo credit: M. Jackson

The Manhattan skyline: Commercial buildings harbor tremendous potential for energy savings. Replacing the lights and the heating, ventilating and air-conditioning (HVAC) systems with new equipment can cut a building's energy costs by 30 percent.

During the 1970s, however, there was some interest in a national code as a response to the patchwork of codes passed at the State level.[45] In 1973, the National Council of States Building Codes Standards asked the National Bureau of Standards (now the National Institute for Science and Technology, or NIST) to provide the technical basis for a performance-type standard for energy conservation in buildings.[46] By the time of the oil embargo, the Bureau of Standards, in cooperation with consultants from design professions and industry, had prepared a document defining energy budgets based on the specific functional requirements of buildings

[43] Additionally, factors such as impact on consumers and impact on manufacturers can be used to determine what is economically justified.

44 Electric supply projects typically have paybacks of well over one decade.

[45] Some States, notably California, have instituted mandatory building standards for both residential and commercial buildings.

[46] This chronology supplied by ref. 113.

and providing energy- and cost-effective choices for components of energy systems in buildings. The document and the energy budgets were turned over to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) as bases for developing a national consensus standard. ASHRAE released standards in 1975 and updated them in 1980. According to an independent evaluation (53a), energy savings would range from 10 to 60 percent, compared to then-conventional practices, at reduced construction costs. Extra costs for higher performance envelopes were more than offset by savings in the space conditioning equipment required.

In addition to NIST, DOE also plays a role in developing building standards. In 1976, Congress enacted legislation that required the development of the Building Energy Performance Standards (BEPS), a national code based on performance standards. In 1981, prior to DOE releasing a final version of BEPS, the law was modified so that the standards were mandatory only for Federal buildings. (It is voluntary for non-Federal buildings, although DOE is mandated to encourage its adoption by States and localities.) DOE's proposed standards became effective 6 months after they were placed in the January 1989 *Federal Register* (102). Since then DOE has initiated demonstration grants.

DOE shares its role in building energy code development with the ASHRAE.[47] The proposed Federal building code is nearly identical to the recently released ASHRAE; standards (3). All 50 States have adopted all or a portion of the ASHRAE standards. The 1980 standard was estimated to result in reduced energy use in commercial buildings of 5 to 25 percent compared to buildings constructed in the late 1970s (15). The new standard is expected to provide 20 to 25 percent energy savings in commercial buildings over the existing code (27). However, the average energy efficiency of new homes in most States now exceeds the existing (i.e., 1980) ASHRAE standards (39).

Recently, the National Affordable Housing Act of 1990 (Public Law 101-922) required the Department of Housing and Urban Development (HUD) to develop energy-efficiency standards for new public housing, and housing subject to mortgages under the National Housing Act (i.e., mortgages that include a loan for financing energy-conserving improvements or adding solar energy systems).

Changes in Federal building code policy that could achieve greater energy savings by changing the investment decisions of builders and buyers include:

1. the establishment of a uniform code by either mandating compliance or creating incentives for States to adopt the national code;
2. the development of a more stringent national code;
3. the development of energy standards for all existing buildings, with compliance taking the form of a mandatory performance test upon sale (an option that could also quickly affect O&M practices detailed in our model); and
4. increased funding for implementation and enforcement.

Adequate enforcement is difficult, but necessary, for a building code to achieve significant savings.

Consumer Information and Marketing Programs

Lack of information is a key obstacle to greater investment in energy conservation. It adversely affects O&M practices, investment decisions, and incentives to develop new energy-efficient technologies. The Federal Government can play a role in overcoming this barrier by providing information about opportunities to increase energy efficiency. Information dissemination is a key element of several of the policy options discussed above, including appliance standards, building codes, and utility planning.

In the past, the Federal Government has played a role in several consumer information and marketing programs. These include:

Energy rating systems. Energy rating systems tell buyers how efficient their prospective home or office is. One national survey found energy savings from a home energy rating system (HERS) to be 15 to 50 percent (110, 111). (No study has been done on a newer rating program for the commercial sector.) The Federal Government has helped to legitimize the use of HERS through its involvement in the

[47] The Department of Housing and Urban Development (HUD) also plays a role in building codes through its regulation Of manufactured housing (mobile homes). For a discussion of regulation of manufactured housing, see ref. 92. HUD is currently contemplating significant changes to its codes.

Photo credit: Dr. J. Hill, U.S. Department of Commerce, National Institute of Standards and Technology, Building Environment Division

Caulking joints and increasing insulation can be relatively inexpensive ways to reduce energy use in old buildings.

mortgage market.[48] Currently many successful rating systems are funded through State offices and run via third-party, nonprofit organizations. The Federal Government could play a further role in expanding these partnerships by establishing a uniform energy rating system and a national housing databank for both residential and commercial buildings.[49] If ratings are not standardized, the added overhead expenses for lending agencies to include the energy costs in their evaluation of mortgages may be unacceptably high. A national databank of all rated homes would allow profiling of the energy efficiency of housing stock in any part of the country. More importantly, typical energy costs for different house types with different fuel mixes could be generated. This would allow lenders and buyers to better evaluate the savings of more efficient houses .50 As a first step in this direction, the National Affordable Housing Act of 1990 requires HUD to develop a plan to make housing more affordable through mortgage financing incentives for energy efficiency.

Home energy audits. The Federal Residential Conservation Service (RCS) was created in 1978 to provide consumers with information on energy conservation for their homes. It mandated that gas and electric utilities provide their customers with on-site energy audits. The program was implemented in 1981 and recently expired. There has been very little evaluation of the program, and little reliable information has been kept on its success in reducing energy consumption.[51]

Any future Federal initiatives in the utility sector to provide energy audits should require the audits to generate a uniform energy rating with regular reporting of all audited/rated houses. This would make the data collected from the utility-audited/ rated houses available for future analysis.

Appliance labels. Energy users often have very little knowledge about appliance energy use and energy costs (46a). Appliance labels to supply this information for selected appliances were required by the National Energy Policy and Conservation Act of 1975. These labels were required on refrigerator-freezers, freezers, room air conditioners, clothes washers, dishwashers, and electric and gas water heaters. These labels provide information on energy use and costs, and also indicate the highest and lower energy costs for models with similar features.

Evaluations of the effectiveness of these labels have been inconclusive. Some have argued that information, such as appliance labels, are necessary

[48]The Federal National Mortgage Association and the Federal Home Loan Mortgage Corp. have endorsed this concept and approve HERS for qualification in the secondary mortgage market. The Federal Housing Administration and the Veterans Administration have their own set of qualified HERS.

[49]For a discussion of the technical considerations in developing HERS, see ref. 69.

[50]For example, if an energy-efficient home is being purchased, mortgages could be approved for a higher percentage of a home buyer's income based on anticipated lower monthly energy expenses.

[51]One study (37) concluded that the programs' contribution t. national energy savings was small. However, some of the State programs worked well, suggesting that home energy audits could be a successful part of a home energy conservation policy.

but not sufficient for improving efficiency—that such information programs, when combined with financial incentives and other programs, will be most effective (1 la).

General information campaigns. As mentioned above, the Federal Government funds a State-implemented information service called the Energy Extension Service (EES). It serves as a local source of information on energy use and efficiency. Discussions with State Energy Officers indicate that generalized advertising was their least effective tool. They found onsite workshops, auditor training, and campaigns targeted to a specific group to be their most effective activities (39). The Federal Government has also supported consumer information and outreach activities by State energy offices (e.g., New York), trade associations, and national laboratories.

Research, Development, and Demonstration

There are major barriers to private investment in R&D in the building shell, prefabrication, construction, and design industries. These barriers include the fragmented industry structure and the short-term perspective of many of the decisionmakers. Thus, the Federal Government has a key role to play in funding R&D for this sector.

The U.S. Government currently spends a negligible amount on housing research. In contrast, Sweden, with a population of only 9 million, spends more on research for home construction than the United States (93). In countries such as Sweden and Japan, R&D spending has been part of the trend toward prefabricated housing, which has contributed to the energy efficiency of homes through standardization of energy saving features and quality control in the design and manufacture of building components.

Areas that could benefit from more governmental R&D efforts include:

Building shell systems. Items of potential energy-saving value include wall materials that are highly insulating and load-bearing, inovative window systems, and insulating foams that do not need CFCs.

Energy-efficient field practices, In order to fully realize the advantages of the new, standardized building components, it will be necessary to evaluate and improve current construction (on and offsite) techniques and technologies (e.g., joint sealants and structural support units).

Manufacturing and design tools. In order to maximize the energy savings possible with new techniques and technologies, designers need to have design tools that enable them to factor in energy efficiency. As was mentioned earlier, the lack of design tools is a significant barrier to the diffusion of energy-efficient technologies and techniques. Similarly, better manufacturing techniques are needed that will allow builders to cut the costs (and energy requirements) of producing new construction components.

Technology performance, Energy requirements can be minimized through better prediction of building performance (66). In many instances the estimates of how much energy will actually be saved by certain measures prove incorrect, yet little effort goes into studies of why this is so. For example, the Hood River Conservation Project achieved 40 percent of predicted savings (38). Evaluation programs should be aimed at boosting measured performance and developing more accurate estimates of savings. Equally important is evaluation aimed at anticipating future problems caused by energy efficiency measures. For example, as houses are tightened to decrease infiltration, moisture buildup and indoor air quality problems can ensue.

Demonstration. As a first step, Congress has required HUD, in the National Affordable Housing Act of 1990, to develop a plan to improve energy efficiency in newly constructed, rehabilitated, and existing housing; and demonstrate various methods of improving the energy efficiency of existing housing. Such projects should encourage the development of ‘‘energy-efficiency businesses’ that can bridge the gap between owners, builders, and occupants of buildings.

The Federal Energy Management Program (FEMP), administered by the Department of Energy, works with government agencies to implement cost-effective, energy-efficiency improvements. Congress could authorize FEMP to test and demonstrate performance, acceptance, and cost-effectiveness of new technologies in Federal buildings.

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