Chapter 2

Technologies for Improving Energy Efficiency in Buildings

Box 2-A--Chapter Summary

Recent advances in equipment design have yielded remarkable efficiency improvements, and there is considerable potential for further gains. For example, while the typical new gas furnace in the 1970s was only 63 percent efficient, new gas furnaces are now available with 97 percent efficiency. New windows are available with an insulating value of R-8—an eight-fold improvement over the old R-1 single-pane window-and window designs in the laboratory suggest R-10 to R-15 may soon be available. Computerized controls can cut commercial building energy use by 10 to 20 percent. Improved design can reduce both energy use and construction costs in large office buildings.

In many cases these improved technologies are commercially available yet are rarely used, even though they offer attractive paybacks (the amount of time needed for the initial investment to be recovered by the reduced energy costs). For. example, highly efficient electronic ballasts for fluorescent lights typically pay back in 3 to 4 years-yet accounted for less than 4 percent of U.S. balIast shipments in 1990.

- If these efficient technologies were used more widely, energy use in buildings would be reduced considerably.
- The large gap between what is already available on the market and what is actually used suggests that implementation, rather than just technical advancement, is key to increasing energy efficiency.

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Technologies for Improving Energy Efficiency in Buildings

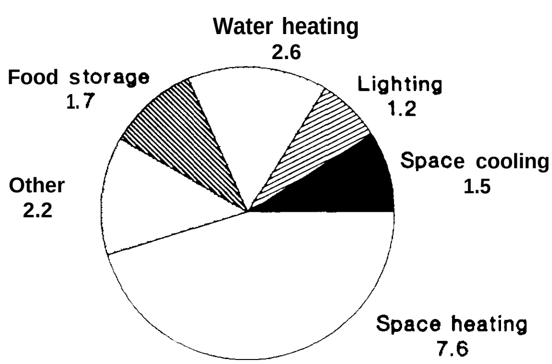
INTRODUCTION

Chapter 1 discussed how changes in technology influenced past energy use in buildings and argued that technology will continue to influence strongly future energy use. This chapter examines specific technologies used to convert energy into useful services (heating, cooling, lighting, etc.) in buildings. The discussion focuses *on three specific* questions:

- What technologies are currently used to provide energy services in buildings?
- Are there technologies available that can provide the desired services while using less energy?
- What are the costs and other attributes of these energy saving technologies?

The discussion is organized by end-use service, starting with space conditioning, followed by lighting, water heating, food refrigeration and freezing, and other energy services (figures 2-1 and 2-2).[1]

Figure 2-l—Residential Sector Energy Use by End-Use Service, 1989 (quads/year)



NOTE: Primary conversion used (see app. 2-C).

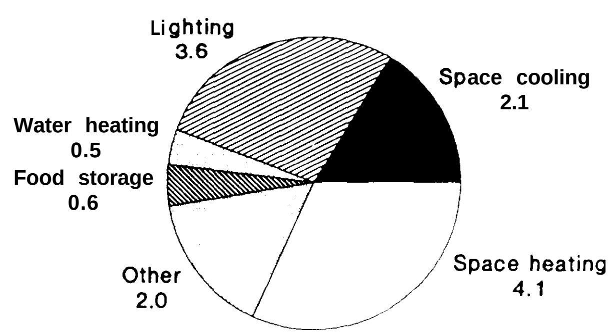
SOURCE: Office of Technology Assessment, 1992 (see app. 1 -B).

SPACE CONDITIONING

Space conditioning (heating, cooling, ventilation, and humidity control) requires more energy than any other service in both residential and commercial buildings, accounting for more than half of total residential/commercial energy use. In the residential sector space heating accounts for about 46 percent, and space cooling for about 9 percent, of energy use; while in commercial buildings space heating and cooling account for about 32 percent and 16 percent, respectively, of energy use.[2]

There have been impressive advances in the efficiency of space-conditioning equipment in recent years. New residential gas furnaces, for example, are now available that are 97 percent efficient, a vast improvement compared to the 63 percent efficient units commonly sold in the 1970s. New room air conditioners are now available that require only half the energy to provide the same amount of cooling as units sold in 1972. The efficiency of building shells has advanced as well: one can now purchase windows with an R-value of 8, an eight-

Figure 2-2—Commercial Sector Energy Use by End-Use Service, 1989 (quads/year)



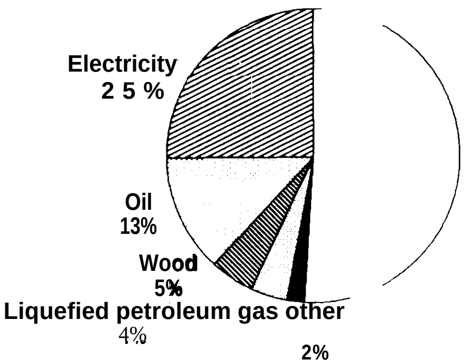
NOTE: Primary conversion used (see app. 2-C).

SOURCE: Office of Technology Assessment, 1992 (see app. 1-B).

[1] This chapter is intended to be comprehensive and broad rather than exhaustive and to provide a sense of the opportunities rather than a complete list of all technologies. This report focuses on efficiency improvements; a separate OTA report in preparation will address renewable energy technologies.

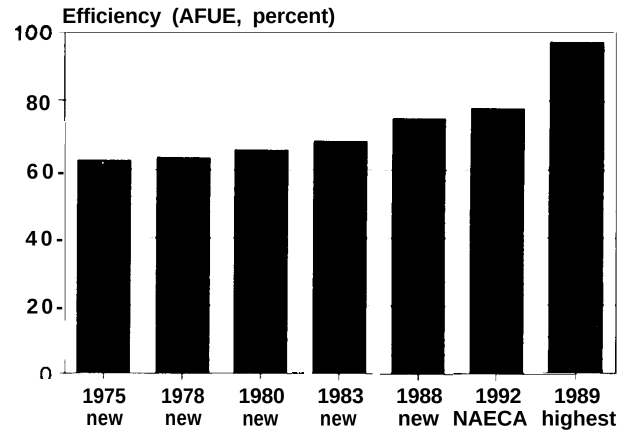
[2] For sources, see app. 1-B. Unless otherwise noted, energy consumption data in this report refer to primary energy-i. e., electricity 1S converted to energy units using a conversion factor that reflects the energy used to generate the electricity, as well as the energy equivalent of the electricity itself. See app. 2-C for a comparison and discussion of different methods of converting energy units.

Figure 2-3—Residential Space Heating Fuels (percent of households, 1989)



SOURCE: U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in 1989,* H150/89 (Washington, DC: U.S. Government Printing Office, July 1991), p. 42.

Figure 2-4-Trends in the Efficiency of Natural Gas Furnaces



NOTES: 'New' is shipment-weighted average of all units shipped in that year. 'NAECA' is the minimum allowable according to the national standard. 'Highest' is the most efficient commercially available. See app. 2-A for a definition of AFUE.

SOURCES: 1975 to 1983: SAIC, *Trends in the Energy Efficiency of Residential Electric Appliances,* EPRI EM-4539 (Palo Alto, CA: Electric Power Research Institute, April 1988), pp. 2-9. 1988 and 1989: American Council for an Energy-Efficient Economy, *The Most Energy Efficient NewAp@iances-1989-90 edition* (Washington, DC: 1989), pp. 21-22.1992 NAECA: Public Law 100-12.

fold improvement over the single-pane windows still found in many buildings.[3]

This section reviews space conditioning and shell technologies-those currently in use, those improved technologies commercially available, and those still under development. It is found that highly efficient, commercially available technologies are often not utilized, despite their technical and economic advantages over conventional technologies.

Space Conditioning in Residential Buildings

Both the efficiency of the space conditioning equipment and the design of the building itself influence the amount of energy needed to maintain comfort in a residential building. A very efficient furnace will still use a lot of energy to heat a poorly insulated, drafty building, while a well-insulated building in a moderate climate may need no additional energy for space conditioning. This section discusses equipment and shell technologies separately.

Residential Space Heating Equipment

A variety of fuels and technologies are used to heat U.S. residences (figure 2-3). More than half (51 percent) of U.S. households use natural gas for space heating; the remainder use electricity (25 percent), oil (13 percent), and other fuels.[4]

Natural gas fired warm-air furnaces, currently found in about41 percent of households,[5] have made impressive gains in energy efficiency in recent years (figure 2-4). The use of electronic ignition, vent dampers, and other design improvements contributed to an efficiency increase of 12 percent in new units between 1975 and 1988. Further improvement is mandated by the National Appliance Energy Conservation Act (NAECA, Public Law 100-12), which sets minimum efficiency standards for gas furnaces.[6]

There are many commercially available gas furnaces, however, that are far more efficient-in the range of 95 to 97 percent. These units use ' 'condensing' ' technology, in which the latent heat of the

[3] R-value is a measure of resistance to heat flow. The higher the R-value, the better the insulation value. These R-values are for center-of-glass.

[4] These other fuels include wood (5 percent), liquefied petroleum gas (LPG) (4 percent), and various other fuels. Data refer to percent of occupied households using that fuel as their main space heating fuel. U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in 1989,* H150/89 (Washington DC: U.S. Government Printing Office, July 1991), p. 42.

[5] U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987,* DOE/EIA-0314(87) (Washington, DC: May 1989), p. 33.

[6] As required by NAECA, units manufactured on or after January 1, 1992 must have a minimum efficiency of 78 percent. NAECA is discussed in more detail in ch. *4.*

combusted gas is recovered. At present, sales of condensing furnaces are low, due in part to their high price--typically about $1,500 to $2,000, or about $500 more than a noncondensing furnace.[7] These costs may drop, however, if production volumes increase. The cost-effectiveness of these furnaces depends on the climate; however, economic analyses of measured energy savings resulting from condensing furnace installations in colder climates found simple paybacks of 4 to 7 years.[8]

Electric resistance space heating units are relatively simple and inexpensive to install but are quite expensive to operate and therefore are more common in milder climates. Electricity costs about 2.3 cents per 1,000 Btus of delivered heat, while natural gas costs about 0.8 cents per 1,000 Btus; that is, heat from an electric resistance heater costs two to three times as much as heat from a natural gas furnace.[9] There are essentially no opportunities for technical improvement in the heating units themselves, as efficiencies are about as high as physically possible.

Electric heat pumps, however, hold considerable promise for future energy savings. A heat pump is essentially an air conditioner in reverse. Just as an air conditioner pumps heat from a relatively cool room into the warmer outside air, a heat pump moves heat from the cooler outside air into the warmer room.[10] The efficiency of a heat pump is typically about twice that of an electric resistance heater.[11] Most heat pumps installed in residential buildings can be run as air conditioners as well, meaning that one device provides both heating and cooling. Heat pumps are growing in popularity. Although they are found in only about 7 percent of U.S. households,[12] heat pumps were installed in 23 percent of all new single-family homes in 1990.[13] The typical heat pump sold today has a heating efficiency (HSPF) of about 6.9 Btus per watthour and a cooling efficiency (SEER) of about 9.1 Btus per watthour.[14] The best units currently on the market have efficiencies of about 9.2 and about 16.4, respectively (table 2-1).15 These best units cut heating and cooling costs by

Table 2-l—Electric Heat Pump Efficiencies and Annual Operating Costs

	Heating efficiency		Cooling efficiency	
	HSPF	cost/yr	SEER	cost/yr
Average for new units sold, 1988	6.9	$380	9.1	$170
Best commercially available, 1989	9.2	290	16.4	90
NAECA standard, effective 1992	6.8	390	10.0	150

NOTE: HSPF and SEER are defined in app. 2-A.

SOURCES: Average 1988: "Integrated Heat Pump System," *EPRI Journal*, vol. 15, No. 2, March 1990, p. 41. Best commercially available: American Council for an Energy-Efficient Economy, The *Most Energy Efficient New Appliances—1989-90* edition (Washington, DC: 1989), p. 18. NAECA standard: for split systems, from NAECA (Public Law 100-12), sec. 5. Operating costs are for energy only, and assume a heating load of 33.8 MBtus/yr and a cooling ioad of 19.6 MBtus/year (from J. Koomey, J. McMahon, and C. Wodley, *Improving the Thermal Integrity of New Single-Family Detached Residential Buildings*, LBL-29416 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1991), p. 32). Electricity price of 7.8 cents/kWh assumed.

[7] S. Cohen, C. Goldman, and J. Harris, *Measured Energy Savings and Economics of Refitting Existing Single-Family Homes: An Update of the BECA-B Database*, LBL-28147, vol. 1 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1991), p. 22.

[8] Simple payback is defined in app. 2-B. The 4-to 7-year payback discussed here is based on the additional first cost and savings of the condensing unit over a new, 75-percent efficient baseline unit. Ibid., p. 15.

[9] Assuming an electricity price of 7.8 cents/kWh, 100 percent of electricity consumed is converted to heat, a natural gas Price of $5.61/l@ Btu, and a 70-percent natural gas furnace conversion efficiency (AFUE, see app. 2-A for definition).

10 Heat Preps can extract heat from the ground or from outside water (typically from a well or pond), but usually use outside air as the heat source.

11 The 1992 NAECA requirement for heat pumps sets a minimum Heating Seasonal Performance Factor (HSPF) of 6.8 (there are several measures of heat pump efficiency currently in use, see app. 2-A). This corresponds to about 6,800 Btus of heat for each kWh consumed. An electric resistance heater will deliver at most 3,412 Btus for each kWh consumed.

12 U.S. Department of Commerce, Bureau of the Census, American *Housing Survey for the United States in 1989*, H150/89 (Washington, DC: U.S. Government Printing Office, July 1991), p. 40.

13 U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990*, C25-9013 (Washington DC: June 1991), p. 22.

14 HSPF and SEER are defined in app. 2-A.

15 An alternative heat pump design is the thermally activated heat pump, which uses a fuel such as natural gas rather than electricity. This design has the potential to offer even higher efficiencies, although costs and performance are uncertain. See Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Deference,* ' vol. 2, Part I of 3, End-Use Technology, ORNL-6541/V2/P1 (Springfield, VA: National Technical Information Service, December 1989), p. 33.

about $160 per year, relative to units meeting the 1992 NAECA standard, in a typical new house. With heat pumps, as with most other residential energy-using equipment, there is a large efficiency gap between units currently being installed and the most efficient units commercially available.

Oil-fired space heating **systems are** currently used in 13 percent of U.S. households but are being installed in only about 5 percent of new single-family homes and 1 percent of new multifamily units.[16] These new installations are found almost entirely in the Northeast, presumably in areas without natural gas service. The high perceived variability in oil prices has limited the demand for oil furnaces in new construction. The 1992 NAECA standard for oil furnaces is 78 percent (AFUE). Currently available units, however, perform far better. The best on the market achieve efficiencies over 90 percent.[17]

Distribution systems and controls are frequently overlooked opportunities for improving the efficiency of space heating and cooling systems. For example leaky air distribution ducts can result in significant energy losses, suggesting that greater attention to quality control in duct installation is warranted. Although much of the research to date has focused on space cooling, the findings apply in principle to space heating as well. For example, a study of air-conditioned homes in Florida found that air conditioner energy use was reduced 18 percent simply by repairing leaky ducts. The payback for this relatively easy fix was less than 2 years.[18] Similarly, measured data in a study of California households indicated that 20 to 40 percent of peak cooling day consumption was due to duct leakage.[19] Night setback, dual zone, and programmable thermostats can all reduce energy use through better system control. In multifamily buildings, the addition of reset and cutout controls can increase efficiency as well.[20]

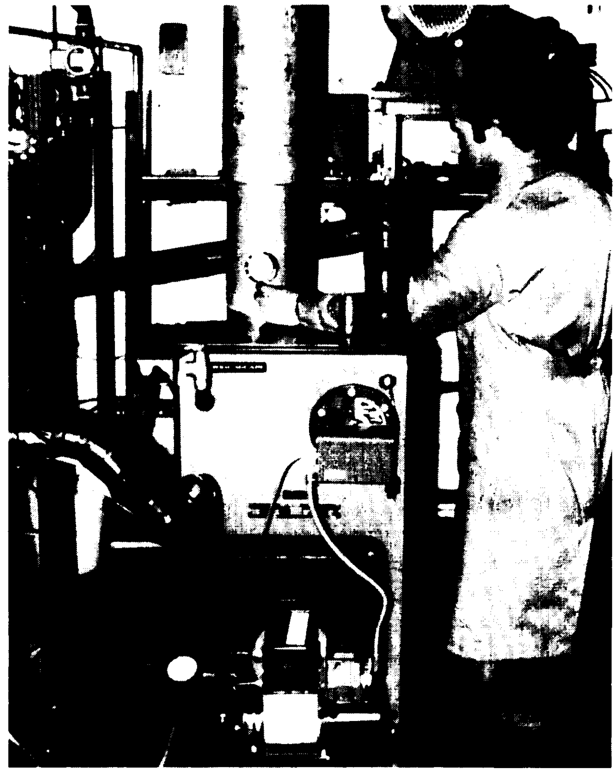


Photo credit: U.S. Department of Energy

Oil-fired space heating systems are used in 13 percent of U.S. households, mostly in the Northeast.

Retrofits to improve the efficiency of space heating systems already in place are usually limited to simple maintenance, such as replacing filters, oiling motors, and cleaning burners. Older oil-fired furnaces can benefit from the use of a flame-retention burner head, which better atomizes the fuel and thereby allows more complete burning; paybacks for this simple retrofit were 2 to 5 years in

16 U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990, C25-9013* (Washington, DC: June 1991), PP. 20, 39.

17 American Council for an Energy-Efficient Economy, *The Most Energy Efficient New Appliances—1989-90 edition* (Washington, DC: 1989), P. 23.

18 J. Cummings, J. Tooley Jr., N. Moyer, R. Dunsmore, ''Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Homes, ' *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1990), p. 9.65.

19 M. Modera, ''Residential Duct System Leakage: Magnitude, Impacts, and Potential for Reduction,'' *ASHRAE Transactions,* vol. 96, Part 2, 1989.

20A reset allows boiler hot water temperature t. change in response to outside temperature, and a cutout allows the boiler to shut off when outside temperature is such that no space heat is needed. See F. Jablonski, "Rethinking Multifamily Resets and Cutouts, " *Home Energy, vol. 8, No, 4,* July/August 1991, p. 40.

recent evaluations using measured consumption data.[21]

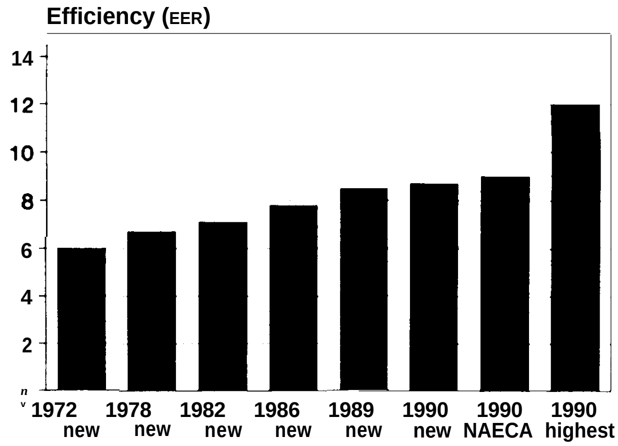
Residential Space Cooling Equipment

Over two-thirds (69 percent) of U.S. households have air conditioning-+0 percent with central systems and 29 percent with room units.[22] The trend in new construction has clearly been toward greater use of central air conditioning; about 76 percent of new single-family homes and 78 percent of new multifamily buildings have central air conditioning.[23]

Central air conditioning systems are integrated into the building ductwork and come in two basic designs: cooling-only systems and heat pumps (discussed above). Cooling-only systems typically have an outdoor unit housing the compressor, condenser coil, and fan; and an indoor unit built into the existing ductwork containing the evaporator coil. Central air conditioning systems show a trend of increased efficiency; the average unit sold in 1981 had a SEER of 7.8 Btus per watthour,[24] while the best units available in 1989 achieved SEERS of up to 16.9.[25] This impressive efficiency increase came from continual free-tuning and adjustment: larger condenser and evaporator coils, better motors, improved insulation, reduced airflow-path resistance, and better fan blade design.[26] NAECA sets a minimum SEER of 10 for split systems manufactured on or after January 1, 1992.

Room air conditioners, like refrigerators, are free-standing appliances that are generally selected and installed by consumers. The energy efficiency of room air conditioners has improved, due to higher efficiency compressors, improved fan designs, and larger heat exchangers.[27] The average new unit bought today needs about 30 percent less electricity

Figure 2-5—Trends in the Efficiency of Room Air Conditioners



NOTES: 'New' is shipment-weighted average of all units shipped in that year. 'NAECA' is the minimum allowable according to the national standard. 'Highest' is the most efficient commercially available. See app. 2-A for a definition of EER.

SOURCES: 1972 to 1989: Association of Home Appliance Manufacturers (AHAM), *Major Home Appliance Industry Fact Book 1990/91,* (Chicago, IL), p. 27.1990 new: R. Gants, Vice President, Association of Home Appliance Manufacturers, personal communication, Oct. 18, 1991.1990 highest: Association of Home Appliance Manufacturers (AHAM), "1 991 Directory of Certified Room Air Conditioners," Edition No. 1, October 1990, 1990) p. 10.1990 NAECA: Public Law 100-12, sec. 5; refers to a 8,000 to 13,999 Btu/hr unit without reverse cycle, with louvered sides.

to deliver the same cooling as the average unit bought in 1972; even more efficient units are commercially available in some size categories (figure 2-5). Note that the most efficient new units in 1990 consume only about half the electricity to deliver the same cooling as the average unit bought in 1972.

The incremental costs of high-efficiency air conditioners are unclear. Highly efficient models often come with additional features such as better

21 S. Cohen, C. Goldman, and J. Harris, *Measured Energy Savings and Economics of Retrofitting Existing Single-Family Homes: An Update of the BECA-B Database,* LBL-28147, vol. 1 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1991), p. 15.

22 U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United States in* 1$'&?, H150/89 (Washington, DC: U.S. Government Printing Office, July 1991, p. 40.

23 U.S. Department of Commerce, Bureau of the Census, *Characteristics of New Housing: 1990,* C25-9013 (Washington, DC: June 1991), pp. 4, 36.

24 SAIC, *Trends in the Energy Efficiency of Residential Electric Appliances,* EPRI EM-4539 (Palo Alto, CA: Electric power Research Institute, April 1986), p. 2-2. See app. 2-A for a definition of SEER.

25 American Council for an Energy-Efficient Economy, The *Most Energy Efficient New Appliances—1989-90 edition* (Washington, DC: 1989), pp. 16-17.

26 Battelle-Columbus Division and Enviro-Management and Research, Inc., *DSM Technology Alternatives,* EPRI EM-5457 (Palo Alto, CA: Electric Power Research Institute, October 1987), p. A-42.

27 SAIC, *Trends in the Energy Efficiency of Residential Electric Appliances,* EPRI EM-4539 (Palo Alto, CA: Electric Power Research Institute, April 1986), p. 2-5.

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Photo credit: Electric Power Research Institute

Wall insulation can significantly reduce energy use for space heating and cooling.

temperature control, more fan speeds, and improved air circulation, making it inappropriate to charge the additional cost of the efficient unit solely to the efficiency feature. Nevertheless if one considers only the energy savings benefit, the payback to the consumer of buying the most efficient unit, relative to a standard unit, is about 6.4 years.[28]

Residential Shell Technologies

The amount of energy needed to keep people comfortable is determined in part by the efficiency of the heating and cooling equipment, discussed above, but also by features of the building shell. A well-constructed building with plenty of insulation, tight-fitting doors and windows, well-designed windows, and other energy saving features can use significantly less energy than a poorly constructed building. For example superinsulated houses, which often have double the usual amounts of insulation, can use 80 to 90 percent less space-conditioning energy than conventional houses.[29]

Opportunities to enhance the energy efficiency of a building shell occur throughout a building's lifetime. Prior to construction, siting and orienting a building with careful attention to natural features—sunlight, wind, earth-sheltering-can reduce energy use. In the design of a building, specifying adequate insulation levels, designing overhangs to block out

Box 2-B—How a Building Gains and Loses Heat

Heat can be lost from a building several ways.[1] Much of the heat in a typical single-family residence is lost as conduction through the ceiling, walls, windows, and floor. Increasing the insulating value of all surfaces can reduce these conductive losses. Some heat is lost from air infiltration through gaps in windows, doors, and other areas. Reducing infiltration losses by reducing air flows throughout the building reduce heat losses as well. A building gains heat from its occupants, from the space heating equipment, from the Sun, and from other interior equipment (all the energy consumed by a refrigerator, for example, ends up as heat in the kitchen.)

The space conditioning requirements of a building are strongly influenced by the climate-and climatic conditions vary widely in the United States. Heating requirements are often measured by heating degree-days,[2] which vary from 100 in southern Florida to over 10,000 in mountainous areas. Cooling requirements, measured by cooling degree-days, also vary tremendously.

1 This discussion of heat loss applies to "cool" losses (more accurately heat gains) as well.

2 Degree-days are typically measured relative to a base temperature, usually 65 degrees F. If the daily average temperature one day is 60 degrees F, then that day has 5 (65 minus 60) heating degree-days. Degree-days are usually given on an annual basis, by adding up 1 year's worth of daily degree-days.

28 Based on retail prices quoted in Washington, DC in 1991; assuming Washington, DC climate and electricity price of 7.8 cents/kWh. Payback period will of course depend heavily on climate. Another perspective on the economic analysis is that of the electric utility. Since residential space-cooling often occurs at or near times of peak demand, the additional first cost of the most efficient unit can be compared to the cost of on-peak generation to meet the demand of the standard unit. For the two air conditioners considered here, the most efficient unit costs about $70 more but uses about 250 watts less of power, which works out to about $280/kW. For comparison a gas-turbine for electricity generation costs about $400/kW (Electric Power Research Institute, *TAG Technical Assessment Guide, Electricity Supply-1989,* EPRI P-6587-L (Palo Alto, CA: Electric Power Research Institute, September 1989), p. 7-56).

29 D. Hafemeister and L, Wall, "Energy Conservation in Buildings and Appliances," in R. Howes and A. Fainberg (eds.), *The Energy Sourcebook (New* York, NY: American Institute of Physics, 1991), p. *445.* The additional construction costs of superinsulation vary, but one estimate puts them at about $4,000 to $7,500 for a 1,500-square-foot house. 1991 *Residential Building Cost Guide,* Boeckh/American Appraisal Associates (Milwaukee, WI: *1991), p. R75.*

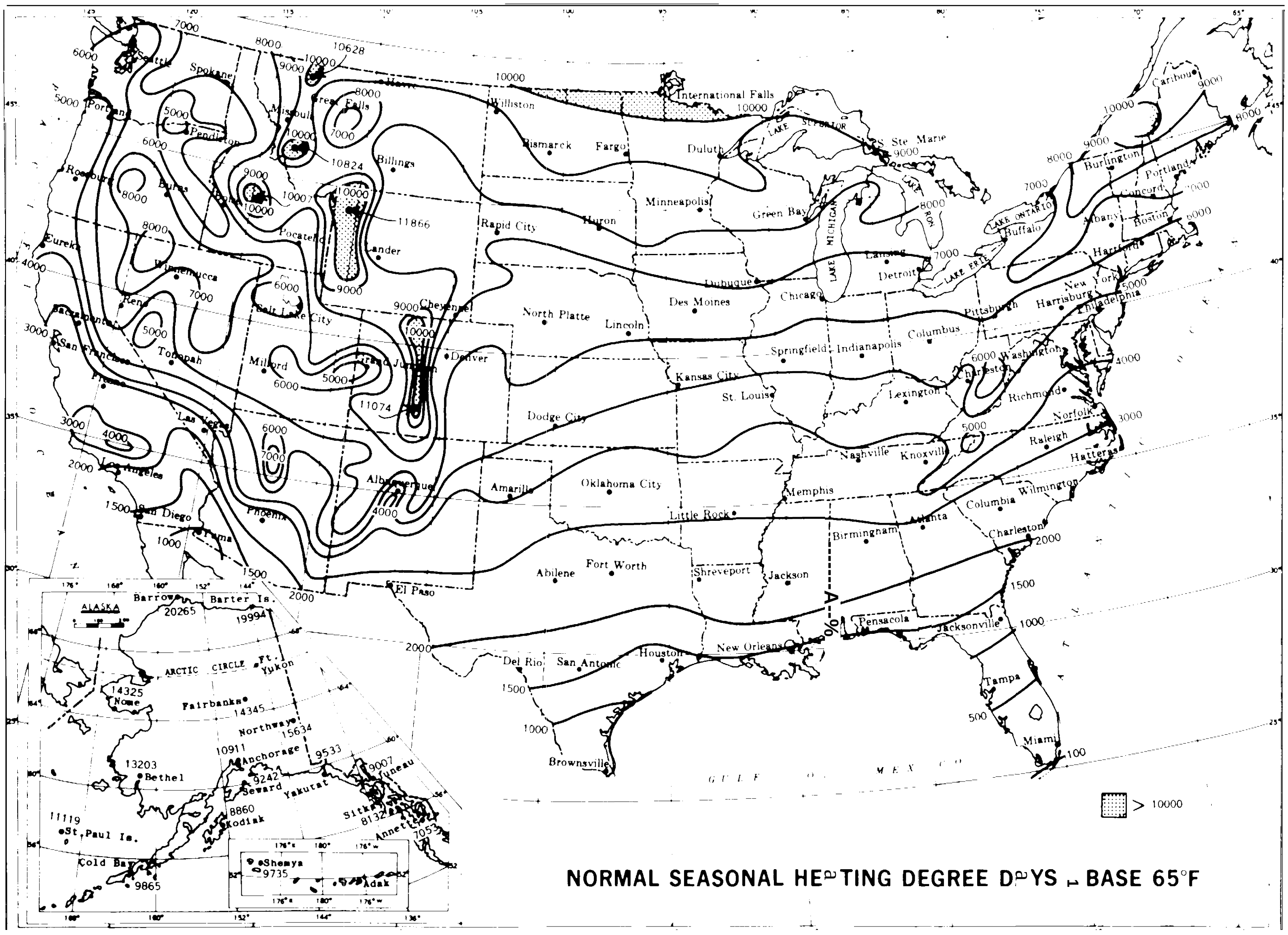


Photo credit: U.S. Department of Commerce

Space heating requirements in the United States, shown here in annual heating-degree-days, vary from less than 100 in southern Florida to over 20,000 in northern Alaska.

unwanted sunlight in summer, specifying high-quality windows, and installing whole-house fans where appropriate will reduce energy use. In construction, careful attention to sealing joints and corners, window and door fits, and ensuring adequate and well-distributed insulation is important. In operation, keeping doors and windows closed when appropriate, using blinds to block out unwanted sunlight in summer, and other occupant actions will affect energy use. And retrofit--one-time actions taken to improve the energy efficiency of an existing building, such as the addition of caulk and weather-stripping, insulation, and storm doors and windows—can help as well.

Technologies for improving building shell efficiencies are discussed in two earlier OTA reports.[30] The best ways to improve building shells—generous and careful installation of insulation, careful caulking and weatherstripping, taking natural features such as trees and terrain into account, using high-quality windows—have been recognized since at least the 1970s.[31] Recent research has essentially refined these ideas. For example, methods for sealing buildings to reduce infiltration have improved, and the use of greater insulation levels in walls and ceilings is becoming more common. The use of factory-assembled components and structures has increased, which has allowed for tighter tolerances and therefore reduced infiltration.[32]

Significant efficiency advances have occurred in window technologies. These improvements are important, as by one estimate 25 percent of the heating and cooling requirements in the United States are due to losses through windows.[33] A single pane of glass has an insulating value of about R-1, which is very low relative to the R-15 typical of a wall in a new house.[34] One way to increase the insulating value of a window is to add a second or even a third pane, increasing the R-value to about R-2 and R-3, respectively. However more panes add weight, limit

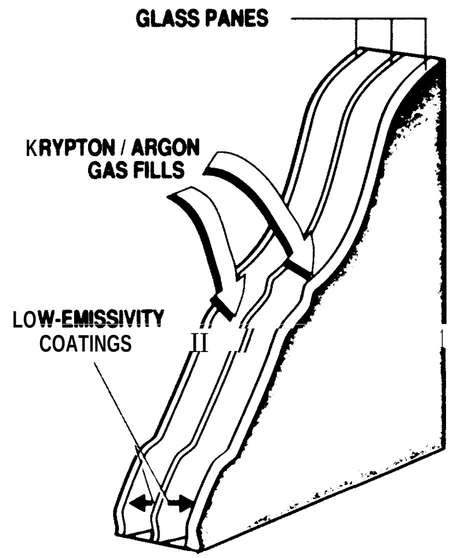


Photo credit: Lawrence Berkeley Laboratory

New window technologies offer up to eight times the insulating value of old single-pane windows.

natural light, and raise costs considerably. A recent innovation has been the addition of clear coatings to glass surfaces. These so called low-emissivity (or low-e) coatings allow the transmission of solar radiation into the interior, but reduce radiative heat losses back out again. The addition of a low-e coating can increase the insulating value of a double-pane window from R-2 to about R-2.5 to R-3.2. Low-e windows cost 10 to 20 percent more than regular windows but are quite popular. About half of all new double-pane windows incorporate the low-e coating.[35] Large window manufacturers now offer low-e glass in many of their products.[36] Window frames have improved as well, with greater use of thermal breaks to limit conduction losses through the frame.

30 U.S. Congress, Office of Technology Assessment, *Energy Efficiency of Buildings in Cities, OTA-E-168* (Washington, DC: U.S. Government Printing Office, March 1982); U.S. Congress, Office of Technology Assessment, *Residential Energy Conservation,* OTA-E-92 (Washington, DC: U.S. Government Printing Office, July 1979).

31 See, e.g., R. Socolow (cd.), *Saving Energy in the Home* (Cambridge, MA: Ballinger, 1978).

32 Issues of automation in the construction industry are discussed in U.S. Congress, Office of Technology Assessment, *Technology and the Future of the US. Construction Industry* (Washington, DC: AIA Press).

33 R. Bevington and A. Rosenfeld, "Energy for Buildings and Homes,' *Scientific American,* vol. 263, No. 3, September 1990, p. 80.

34 "R" is a measure of resistance t. heat flow, with units of hour-square feet-degree F per Btu. The higher the R-value, the better the insulating value.

35 Advanced Sciences, Inc., "Wtidow Innovations," CARIERS, Silver Spring, MD, February 1990.

36 "Wtidow Company Standardizes Low-E Glass,' *Home Energy,* vol. *7, No. 3, May/June* 1990, p. *6.*

Several additional window innovations are commercially available. Gas-filled windows, which substitute argon for air in the space between the panes, offer insulating values of about R-4. A window using gas-filled spaces and two suspended reflective films achieves R-8.[37] However these very advanced windows are expensive, which suggests they may be economically justified only in severe climates.[38]

Retrofits: Energy efficiency improvements can be applied to existing buildings as well. Many older residential buildings in the United States were built with little regard for energy efficiency. Retrofitting these buildings could save considerable energy; however, the cost-effectiveness of these retrofits depends on the specific design of a building, the climate, energy costs, and other factors. Estimating the cost-effectiveness of a shell retrofit with simple engineering calculations is not as straightforward as it may seem; buildings are surprisingly complex, and engineering estimates of energy savings are often inaccurate. Measuring actual savings-the difference in energy use before and after the retrofit--is preferable.[39] The most comprehensive effort to collect and analyze actual savings from building retrofits has been conducted by Lawrence Berkeley Laboratories (LBL), where information and data on building retrofits from across the United States are collected and analyzed. A summary of some typical results is shown in table 2-2. Results vary considerably, however it appears that additions to insulation offer typical paybacks of about 5 to 7 years (table 2-2).

Photo credit: U.S. Department of Energy

Caulking gaps around windows and doors can reduce infiltration, and thereby reduce energy use for space heating and cooling.

In addition, there are numerous case studies of building retrofits. Although the results of these case studies may not be applicable to all buildings, they do illustrate the potential and diversity of retrofit opportunities.

- In the Twin Rivers study performed at Princeton University in the 1970s, a cluster of typical

Table 2-2-Cost-Effectiveness of Residential Shell Retrofits

Action	Average cost (1989 dollars)	Average savings (percent of main space heat fuel)	Typical payback (years)
Ceiling insulation.	500 to 970	12 to 21	6.0
Wall insulation.	810 to 1,600	12 to 17	6.8
Foundation insulation.	1,020	NA	5.7

NOTE: Foundation insulation data are for interior of conditioned spaces.

SOURCE: S. Cohen, C. Goldman, and J. Harris, *Measured Energy Savings and Economics of Retrofitting Existing Sing/e-Family* Homes: An *Update of the BECA-B* Database, LBL-28147, vol. 1 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1991), p. 2. Paybacks are calculated at the midpoint of the costs and savings estimates, and assume the saved fuel is natural gas at a price of $5.61/106 Btu.

37 A. Wilson, ''An Improved Outlook' *Architecture,* August 1990, p. 95. All R-values given are center-of-%'indow values.

38 U.S. Congress Office of Technology Assessment, *Energy Technology Choices: Shaping Our Future,* OTA-E-493 (Washington, DC: U.S. Government Printing 'Office, July 1991), p. 33.

39 'fil$ method also has its problems. Weather fluctuations, changes in occupant behavior, and data requirements complicate savings estimates; however innovative evaluation tools, notably the PRISM (PRInceton Scorekeeping Model), have improved the accuracy of these estimates. See M. Fels, "PRISM: An Introduction, ' *Energy and Buildings, vol. 9, Nos. 1/2,* February/May 1986, pp. 5-18.

Photo credit: U.S. Department of Energy

Many houses in the United States still lack basic efficiency features such as storm windows.

townhomes were retrofitted with movable window insulation, careful sealing of joints and corners, and increased insulation throughout. The result was a two-thirds reduction in the energy needed for space heating, with no change in indoor temperature and no changes in the space heating furnace.[40]

- In a comprehensive research project in the Pacific Northwest in the mid-1980s (known as the Hood River Conservation Project), homes were retrofitted with increased insulation, improved windows and doors, and several other measures. The result was an average reduction in space heating electricity use of 36 percent.[41]

Given the diversity in the building stock, climate and energy price variability, and the dependence of costs on the building design, it is difficult to provide blanket recommendations on building retrofits. Adding insulation can offer reasonable paybacks (table 2-2), but final determinations must be site-specific. When replacing space conditioning equipment, highly efficient equipment should be considered, but again the optimal level of efficiency will depend on the building, climate, energy prices, occupant behavior, and other site-specific factors.

There is some evidence that many residences in the United States lack basic efficiency features. For example 39 percent of U.S. households lack storm doors, 22 percent lack wall insulation, and 12 percent lack ceiling insulation.[42] Although the economic justification for such features will depend on climate and other factors, these data suggest that there is considerable potential to improve the energy efficiency of the existing building stock, As further evidence of this potential, the Hood River Conservation Project (mentioned above) resulted in homes that use about one-fourth less energy for space heating than the average U.S. home.[43]

Space Conditioning in Commercial Buildings

Larger commercial buildings are quite different from residential buildings.[44] They have much larger and more complex heating and cooling systems, they usually have active ventilation systems (since natural airflow is insufficient to maintain air quality), and

40 R. Socolow (cd,), *Saving Energy in the Home* (Cambridge, MA: Ballinger, 1978), p. xx.

41 Space heating electricity consumption, pre- versus post-, all housing types. The economics of these retrofits are dependent on lifetime assumptions* discount rates, and other assumptions, but the cost of conserved energy (CCE, see app. 2-B for definitions) was about 7.1 to 7.9 cents/kWh. E. Hirst, *The Hood River Conservation Project,* DOE/BP-l 1287-18 (Washington, DC: U.S. Department of Energy, June 1987), pp. 34,41.

42 U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987,* DOE/EIA-0314(87) (Washington DC: May 1989), p. 109.

43 The Hood River Project achieved a post-retrofit intensity of 2.6 Btu per square foot-degree-day (S. Cohen, C. Goldman, and J. Harris, *Measured Energy Savings and Economics of Retrofitting Existing Single-Family Homes: An Update of the BECA-B Database,* LBL-28147, vol. 1 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1991), p. 74), while the average electrically heated single-family home required 3.4 Btu per square foot-degree-day (U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987--Part 1: National Data,* DOE/EIA-0321(87) (Washington DC: October 1989), p. 11).

44 ‘Larger” refers to commercial buildings with more than 10,000 square feet, representing about 79 percent of total commercial floor space. U.S. Department of Energy, Energy Information Administration *Commercial Building Characteristics 1989, DOE/EIA-0246(89)* (Washington DC: June 1991), p. 17.

Box 2-C—Indoor Air Quality

Homes obtain fresh air through natural infilltration—uncontrolled airflow through doors, windows, and leaks in the building shell. Recent efforts to reduce energy use by reducing infiltration, however, have raised concerns about indoor air quality. In some situations, concentrations of pollutants such as carbon monoxide, nitrogen oxides, radon, and various organic compounds can reach unhealthy and even dangerous levels-for example, when gas stoves or unvented kerosene heaters are used for space heating, or in very “tight” (low infiltration) houses.

Field research has shown that the strength of the pollutant source maybe more important than the tightness of the building, as tight buildings can have no indoor air problems while leaky buildings can have severe problems. There are several methods for responding to air quality concerns, but the best method is often to isolate and remove the source of the problem, rather than merely to increase the ventilation rate. In the case of radon, active ventilation systems may be necessary regardless of building tightness.

Determining minimum ventilation rates for residences is difficult; however, there is some agreement that a minimum of 0.3 air changes per hour is acceptable.[1] In very tight houses some advocate the use of active ventilation such as air-to-air heat exchangers to maintain minimum air exchange rates.

[1] See J, Nisson and G. Dutt, The *Superinsulated Home Book* (New York, NY: Wiley, 1985), ch. 4.

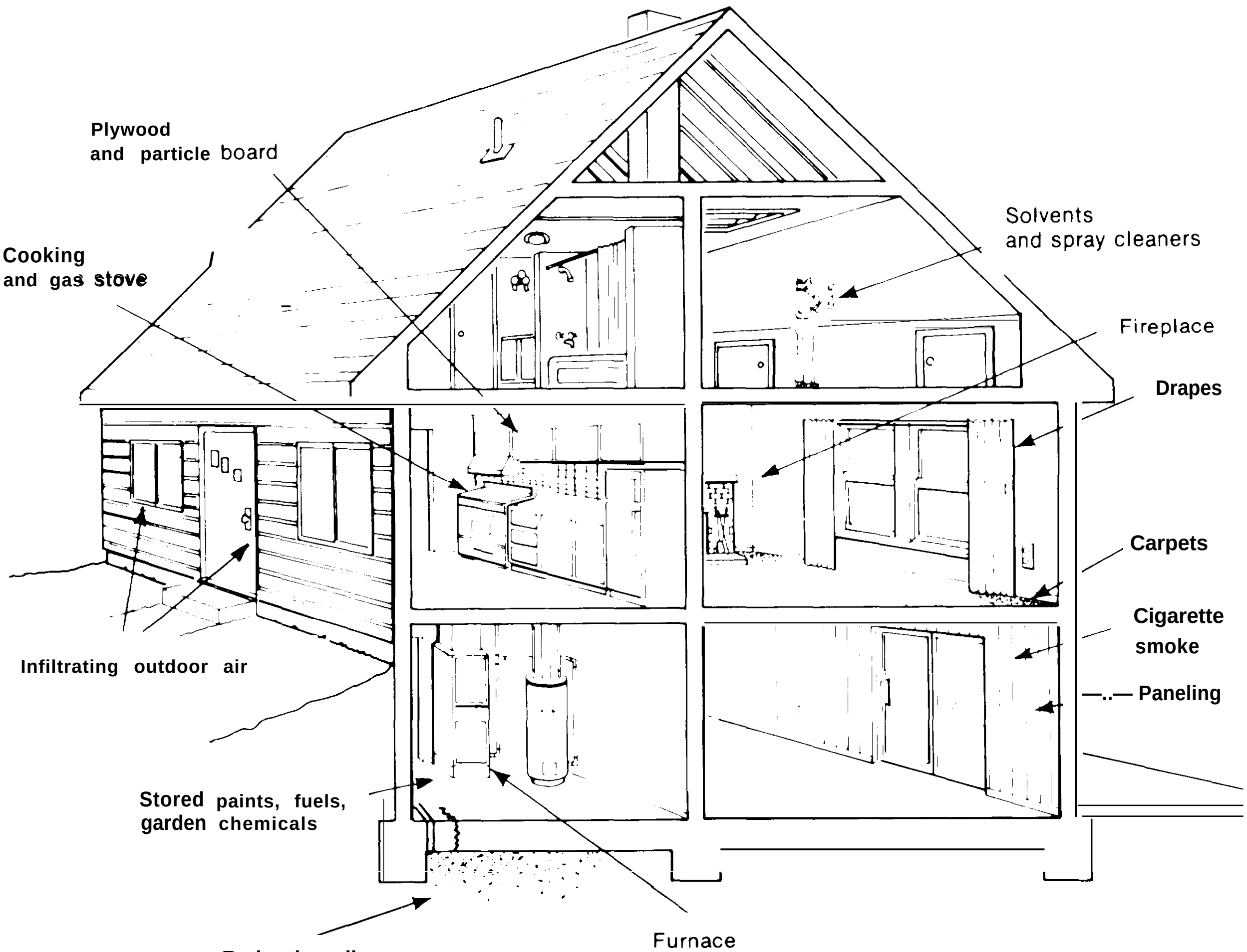


Photo credit: U.S. Department of Energy

Indoor air quality problems often are best dealt with by addressing the source of the problem.

Table 2-3—Space Heating Technologies in Commercial Buildings

Technology/type	Percent[a]
Gas furnace/boiler	48
Oil furnace/boiler	25
Electric boiler	22
Electric heat pump	2
Other	3

[a]The percent of all commercial square footage heated with the technology, in 1988.

SOURCE: Gas Research Institute, "Baseline Projection Data Book," 1991 ed., Washington, DC, p. 127.

Table 2-4—Selected Technologies for Improving Energy Efficiency in Commercial Space Conditioning

Space heating
- High efficiency furnaces and boilers
- Substitute heat pumps for electric resistance heat
- Heat exchangers to reclaim heat from vented air
- Packaged cogeneration systems

Space cooling
- High efficiency electric chillers
- Direct evaporative cooling
- Outside air economizers

Air handiing
- Variable air volume (VAV) systems
- Energy efficient motors
- Variable-speed drive motors
- Reduced outside air ventilation if excessive
- Improved duct layout
- Reduced duct leakage, reduced air flow if excessive

Overall system
- Dual fuel heat pump
- Ground source heat pump
- Energy efficient motors
- Variable-speed drive motors
- Improved system control/energy management system
- System shut-off/set-back during unoccupied hours
- Heat recovery systems

SOURCE: Office of Technology Assessment, 1992.

they are "load-dominated," meaning that much of the space conditioning needs arise from the activity within the building-people, lights, and energy-using equipment—rather than from the influence of the outside (ambient) conditions. In a large commercial building, the space conditioning (commonly called HVAC, for heating, ventilating, and air conditioning) system might simultaneously be heating an exterior office, cooling a computer room, and ventilating a kitchen. HVAC systems in commercial buildings can be extraordinarily complex, and the opportunities for efficiency improvements complex as well. In general, energy efficiency improvements can come from:

- improving the efficiency of the energy-using device (e.g., using a higher efficiency chiller);
- improving the design of the overall system (e.g., routing and designing ducts to minimize losses);
- switching to a different system (e.g., using a heat pump rather than electric resistance heating);
- improving the control of the system (e.g., by using outside air for cooling when appropriate);
- improving maintenance (e.g., by changing filters as needed); and
- reducing demand for the services provided by the system (e.g., installing more efficient lights to reduce the need for space cooling).

Space Heating in Commercial Buildings

A range of technologies is used to provide space heating in commercial buildings, including residential-style oil and natural gas furnaces in smaller buildings, oil and natural gas boilers, heat pumps, and electric boilers (table 2-3). Energy use for space heating in commercial buildings is almost double that of space cooling;[45] however, much Of the recent research on improving energy efficiency has focused on the latter. Despite the relative lack of research, opportunities for efficiency improvements in commercial building space heating do exist (table 2-4). Gas boilers and furnaces produce almost half of all commercial space heat (table 2-3), and high-efficiency units are available in the smaller sizes (less than about 150,000 Btu per hour). A typical commercial gas furnace has an efficiency of about 70 percent, while a high-efficiency unit can achieve over 90 percent efficiency.[46] The diversity of commercial buildings makes it difficult to generalize about the energy savings potential, however there is some evidence that this potential is large. For example, a computer simulation of a new office building in New England found that the addition of

45 In 1988, primary conversion used. For sources, see app. 1-B.

46 Decision Focus Inc., *TAG Technical Assessment Guide*, EPRI P-4463-SR, vol. 2, Part 2 (Palo Alto, CA: Electric Power Research Institute, October 1988), p. 5-60.

a heat recovery device reduced heating energy use by 44 percent. The estimated payback on the investment was about 8 years .47

Very large commercial buildings in warmer climates often require very little space heat during occupied periods. A large office building in Tennessee, for example, generates all its space heat from internal sources—lights, computers, and people.[48] The only energy needed for space heating is that required to move the heat from the warmer interior offices to the cooler exterior offices. Smaller buildings and those in colder climates, however, do require space heating.

District heating is an entirely different approach to space heating in commercial buildings and involves the production of heat (in the form of hot water or steam at a central plant), which is then distributed directly to buildings through underground pipes. Such systems currently heat 11 percent of commercial building floor space in the United States.[49] Many European countries apply these systems more widely—in Denmark, for example, almost half of all building space heating needs are met with district heating systems .50 Such systems are appropriate mainly in colder climates with large space heating needs. The efficiency of such a system depends on the method used to produce the heat. If a cogeneration system is used to produce both heat and electricity, for example, the overall system efficiency can be quite high,[51] but one must have a demand for hot water large enough to justify the system.

Space Cooling/Air Transport in Commercial Buildings

Space cooling technologies for commercial buildings have been the focus of considerable research and development, as a large portion of peak electricity demand is due to commercial building space cooling. Many commercially available technologies could provide space cooling with less energy; some of these technologies are listed in table 2-4. The applicability and energy savings potential of these technologies will vary from building to building. Case studies, however, have shown that better cooling system design and operation can save significant amounts of energy. The use of variable speed drive motors in the air distribution system of a large office building in New Jersey reduced fan energy consumption by 52 percent, with a payback of 5 years.[52] Improved valving and control of a large space cooling system in a hospital cost $32,000 and saved $45,000 in electricity costs, with a payback of less than 9 months.[53]

A number of technologies can improve the energy efficiency of both space heating and space cooling systems (table 2-4). Energy management systems provide computerized control of space conditioning equipment and can reduce energy use by 10 to 20 percent.[54] The use of an energy management system in a large office building in New Jersey reduced energy costs by about $57,000 per year, with a payback of less than 4 years.[55] Despite attractive paybacks, less than one-quarter of all commercial building floor space is controlled by energy management systems .56

47 Northeast Utilities, *Energy and Economics—Strategies for Office Building Design* (Hartford, CT), p. 45.

48 M. McCarley, ''Tune-up of a Modem Office Building, ' *Proceeding From the International Symposium Energy Options for the Year 2000,* Center for Energy and Urban Policy Research, University of Delaware, Newark, DE, 1988, p. 3-181.

49 U.S Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989*, DOE/EIA-0246(89) *(Washington* DC: June 1991), p. 128.

50 P. Kunjeer, ''District Heating and Cooling: Solution for the Year 2000, ' *Proceedings From the International Symposium Energy Options for the Year 2000,* Center for Energy and Urban Policy Research, University of Delaware, Newark, DE, 1988, p. 1-109.

51 Cogeneration is discussed in detail in U.S. Congress, Office of Technology Assessment, *Industrial and Commercial Cogeneration*, OTA-E-192 (Washington, DC: U.S. Government Printing Office, February 1983).

52 With static pressure reduction. S. Englander and L. Norford, "Fan Energy Savings: Analysis of a Variable Speed Drive Retrofit, " *Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1988), p. 3.51.

53 R.J. Parson, ' 'Simplified Retrofit of a Large chilled Water System, " in F. Payne (cd.), *Strategies for Energy Efficient Plants and Intelligent Buildings* (Lilburn, GA: Fairmont Press, 1987), p. 599.

54 Decision Focus Inc., *TAG* Technical *Assessment Guide*, EPRI P-4463-SR (Palo Alto, CA: Electric Power Research Institute, October 1988), vol. *2,* Part 2, p. **5-106.**

55 A Usibelli, S. Greenberg M. Meal, A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. A-9.

56 In 1989. U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989*, DOE/EIA-0246(89) (Washington, DC: June 1991), p. 211.

There are numerous examples of other innovative technologies to reduce space conditioning energy use. Energy efficient motors can reduce motor energy use by 3 to 8 percent at a cost of $100 to $300 per kW, by one estimate.[57] A combination of improved maintenance and improved scheduling of HVAC equipment reduced energy costs at the Houston airport by 20 percent, saving $400,000 per year with no capital investment.[58] Electronic controls for space conditioning systems (often called direct digital controls, or DDC) offer improved management of temperature and air flow; in one analysis, the paybacks for using electronic controls instead of pneumatic controls in new construction were 1 to 3 years.[59] Heat recovery technologies, which recover the waste heat from space cooling equipment and use it to supply hot water, space heating, or other needs, can offer considerable energy savings.

Commercial Shell Technologies

Opportunities for shell improvements in smaller commercial buildings are similar to those in residential buildings. Increased insulation to reduce heat transfer, tighter construction to reduce infiltration, and the use of high-R windows can all reduce energy requirements for space conditioning.

Larger commercial buildings often have somewhat different requirements; their space conditioning needs are typically influenced more by internal loads (lights, people, office equipment, etc.) than by external loads (sun, outdoor temperature), as shown in table 2-5. For a typical office building in San Francisco, for example, more cooling energy would be saved from a 25 percent reduction in lighting energy use than from completely eliminating all the windows (table 2-5). This is not to suggest that shell and window design are trivial components of energy efficient building design; only that as building size increases internal loads become increasingly important.

Table 2-5-Annual Cooling Loads for a Typical Large Office Building in San Francisco

bad Component	Percent of load
Internal loads	
Lights	*55*
People	*21*
Air handling system	*19*
Miscellaneous equipment. ... ,	*9*
External loads	
Windows	13
Roof	-1
Walls	- 0
floor.	-1
Outside air ventilation	-15
Total	100

SOURCE: A. Usibelli, S. Greenberg, M. Meal, A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-Sector Conservation Technologies*, LBL-1 8543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 19S5), p. 2-105. Office equip ment, notably computers, is becoming an important additional cooling load in offices. See "Other Energy Services" section of this chapter.

LIGHTING

Lighting is the single largest consumer of electricity in commercial buildings. About 41 percent of electricity, and 28 percent of total energy, consumed in the commercial sector is for lighting. In the residential sector, lighting energy use is small though not trivial, representing about 7 percent of residential energy use.[60] The opportunities for improved lighting efficiency-delivering the same or better quality of light with less energy—are considerable. Using technologies already on the market, electricity use for residential lighting could be cut by about one-third.[61] Similarly, electricity use for commercial lighting could be reduced considerably—with estimates of 39 to 83 percent—using commercially available technologies.[62]

These energy savings come largely from the use of new, efficient lighting technologies. Lamps, ballasts, reflectors, and lighting control technologies

57 A. Usibelli, S. Greenberg, M. Meal, A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-Sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 2-73.

58 R. Bevington and A. Rosenfeld, ''Energy for Buildings and Homes, ' *Scientific American,* vol. 263, No. 3, September 1990, p. 78.

59 C.E. Lundstrom, "Comparison of Cost and Performance of HVAC Controls, " in F. Payne (cd.), *Strategies for Energy Efficient Plants and Intelligent Buildings* (Lilburn, GA: Fairmont Press, 1987), p. 55.

60 See app. 1-B for data sources.

61 See calculations in this section.

62 ''Lighting the Commercial World,'' *EPRI Journal,* vol. 14, No. 8, December 1989, p. 6; estimates 39 to 55 percent savings. M.A. Piette, F. Krause, and R. Verderber, *Technology Assessment: Energy -Efficient Commercial Lighting,* LBL-27032 (Berkeley, CA: Lawrence Berkeley Laboratory, March 1989), p. 6-2; estimate 78 to 83 percent technical potential for savings.

Box 2-D—Smart Design Reduces First Cost by $500,000 and Cuts Operating Costs in Half

Anew office building in Pittsburgh cost $500,000 less to build, and about haIf as much to operate, due to the use of smart design and innovative energy-efficient technologies. The 10-story, 175,000 square foot (gross) Comstock building, completed in 1983, uses heat pumps to provide heating and cooling, innovative air-return windows, high-efficiency light fixtures, and an energy management system. High insulation levels and careful placement and design of windows allowed for the use of a smaller HVAC (heating, ventilating, and air conditioning) system than would otherwise be needed; and the heat pump system cost about half as much as a conventional system. Net savings, even after covering the additional costs of the windows, exceeded $500,000. Careful monitoring of building energy use has shown that consumption is well below the target, and operating costs are about one-half those of other large office buildings in the area.[1]

Similarly, a detailed computer simulation of a new 60,000-square-foot office building in the Northeast found that a well-designed building using commercially available equipment would cost the same to build as a standard new building, yet would cost 37 percent less to operate.[2]

Photo credit: *Burt Hill Kosar Rittelmann* Associates

Smart design allowed this building to be less expensive to both build and operate.

[1] P. Rittelmann and P. Scanlon, "HVAC Design Delivers Twin Benefits," *Building Design and Construction*, November 1984.

[2] Northeast Utilities, *Energy and Economics—Strategies for Office Building Design* (Hartford, CT,), pp. 96-97.

have all advanced considerably in recent years. This section reviews some of these recent technical advances and provides an indication of the costs and benefits of energy efficient lighting.

Lighting in Residential Buildings

Improved Incandescent Lamps

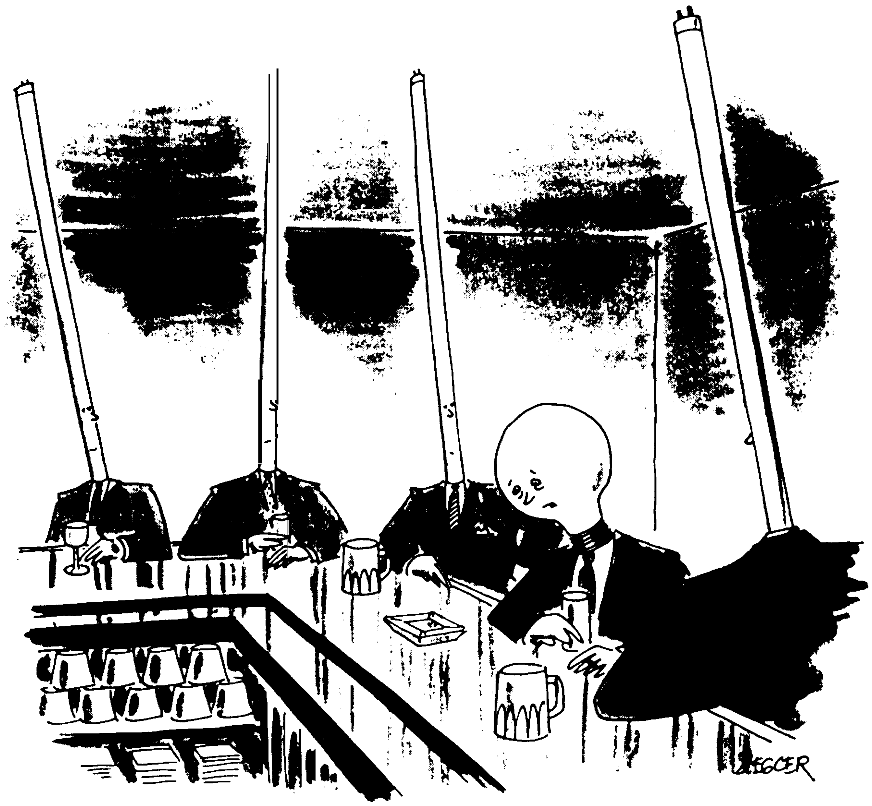
Incandescent lamps provide most lighting in the residential sector (box 2-E). There are several technologies available to improve incandescent lamp efficiency (table 2-6), although even the advanced incandescent lamps are still far less efficient than fluorescent lamps. Improved filaments and the use of krypton gas inside the bulb provide a modest efficiency improvement. Other technological improvements on the standard incandescent technology include infrared-reflective coatings and the use of halogen-filled tubes inside the bulb. This halogen lamp offers a modest efficiency gain and a significantly longer life than the standard incandescent.

Table 2-6-Characteristics of Improved Incandescent Lamps

	Standard	Improved	Halogen
Rated energy consumption (watts). .	100	90	100
Rated light output (lumens).	1,750	1,620	1,925
Efficiency (lumens per watt).	17,5	18.0	19.3
Rated life (hours). ... ., ...	750	750	2,250
Retail purchase price (dollars).	0.67	0.90	4.19

NOTE: Data and prices are for lamps available in Washington, DC, in 1991.

SOURCE: Office of Technology Assessment, 1992.



"Laugh if you will, but my kind once ruled the earth."
Drawing by Ziegler; @1991 The New Yorker Magazine, Inc.

Compact fluorescent

Fluorescent lamps are about four times more efficient than incandescent lamps, but their use in residences has been limited by their higher frost cost, unattractive light, and inability to fit in incandescent fixtures. In 1984, however, a lighting manufacturer introduced the compact fluorescent, a lamp providing reasonably attractive light and fitting regular incandescent fixtures yet using the efficient fluorescent technology .[63] The compact fluorescent achieves an efficiency of 61 lumens per watt, or 3.8 times the efficiency of a comparable incandescent (table 2-7), This means that a compact fluorescent can provide the same light as a standard incandescent with just one-fourth of" the energy.[64] In addition, the life Of a compact fluorescent is typically about 10,000 hours, about 13 times as long as a standard incandescent (table 2-7).

Table 2-7—Technical Comparison of Incandescent and Compact Fluorescent Lamps

	Standard incandescent	Compact fluorescent
Rated energy consumption (watts). . . .	75	18
Rated light output (lumens).	1,190	1,100
Efficiency (lumens per watt).	15.9	61.1
Rated life (hours).	750	10,000
Retail purchase price (dollars).	0.67	20.00

NOTE: Data and prices are for lamps available in Washington, DC, in 1991.
SOURCE: Office of Technology Assessment, 1992.

The technical potential for energy savings from using compact fluorescent lamps is considerable. Compact fluorescent are not suitable for all residen-

63 Compact fluorescent are a different size and shape than the standard incandescent and therefore may not fit all lamps or fixtures designed for incandescent.

64 The compact fluorescent shown in table 2-7 supplies slightly less light, as measured in lumens, than the 75-wait standard incandescent. However, lumens arc only one measure of light. Light has several other qualities, including color and shadowing patterns, which may differ for the two technologies shown in table 2-7.

Box 2-E—Introduction to Lighting Technology

Most lighting in the residential sector is performed by standard pear-shaped incandescent lamps. These lamps use a simple filament that produces light when an electric current passes through it. These lamps are simple to install, cheap to manufacture, familiar to consumers, and widely available. Their disadvantages are short life (typically 1,000 hours) and very low energy efficiency. Lighting energy efficiency is typically measured in lumens per watt, where lumens can be thought of as the quantity of light [1] and watts are the electric power input. A typical incandescent lamp achieves only about 18 lumens per watt, far lower than other technologies. The low efficiency is due to much of the energy input being converted to heat, rather than light, which is easily demonstrated by touching a lit incandescent lamp.

Fluorescent lights represent an entirely different approach to producing light from electricity. These lights consist of two components—a ballast, which regulates current and voltage, and the lamp itself. When a fluorescent lamp is switched on, a current is generated between two electrodes in the lamp. Mercury ions in the lamp emit ultraviolet energy in the presence of this current. This ultraviolet energy then strikes the inner walls of the lamp, which are coated with a phosphor powder. This powder then emits radiation seen by the human eye as light. The efficiency of this complex process is quite high--typically about 60 to 80 lumens per watt, or 3 to 5 times as efficient as the incandescent lamp. Fluorescent lamps usually have much longer lives as well—typically 10,000 to 20,000 hours, or 10 to 20 times longer than incandescent. Disadvantages include a higher initial cost due to increased complexity and a differing quality or type of light. In the past, fluorescent light has been perceived as cold or sterile, although recent improvements have narrowed the gap between the quality of light emitted by fluorescent and incandescent lamps. Fluorescent lamps are widely used in commercial buildings.

A third lighting technology is HID, or high intensity discharge. This includes high-pressure and low-pressure sodium lamps, as well as metal-halide lamps. These lamps are very efficient (table 2-E-l), but their use is limited to areas where light quality is less crucial, such as street lighting, parking garages, and warehouses. They typically require several minutes to warm up and are not designed for frequent on-off cycles.

Table 2-E-l—Efficiencies and Lifetimes of Lighting Technologies

Technology	Typical lighting efficiency (lumens per watt)	Typical lifetime (hours)
Incandescent.	17 to 20	750 to 1,000
Fluorescent.	60 to 85	10,000 to 20,000
HID[a].	100 to 125	24,000+

[a]HID - High Intensity Discharge.

SOURCE: Office of Technology Assessment, 1992.

1 One linen on an area of 1 square foot is equivalent to one footcandle. Lumens per watt can be thought of as analogous to miles per gallon for cars-a useful way to compare different technologies, where larger is more efficient.

tial applications, however if compact fluorescent replaced just half of all residential lighting presently supplied by incandescent, electricity consumption would drop 36 terawatt-hours per year, which is approximately equivalent to the combined annual output of six full-size coal-burning powerplants.[65] The payback for a compact fluorescent is 1.7 years for a light used 6 hours per day.[66]

In summary, there are alternative technologies that can significantly reduce lighting energy use. These come at an increased first cost but offer reasonable paybacks—for example less than 2 years for compact fluorescent.

Operation and Design

Improved lighting operation and design—turning off lights when not needed, using automatic (dusk-to-dawn) switches on outdoor lights, and designing fixtures that reflect rather than absorb light--can improve lighting efficiency. These opportunities are difficult to quantify, and their savings potential will depend on the specific situation.

65 In 1990 residential lighting consumed about 105 TWh. Assuming 90 percent of this is consumed by incandescent lamps, and half Of this incandescent lighting is supplied instead with compact fluorescents, 47.3 TWh of incandescent are replaced with 11.3 TWh of compact fluorescent. The net savings is 36 TWh. A 900-megawatt (MW) coal-burning powerplant operating at 80 percent capacity factor produces about 6.3 TWh/yr. Note that half of incandescent lighting energy, not incandescent lights, are replaced with compact fluorescents in this example.

66 Assuming electricity price of 7.8 cents/kWh, O labor costs, and the values shown in table 2-7.

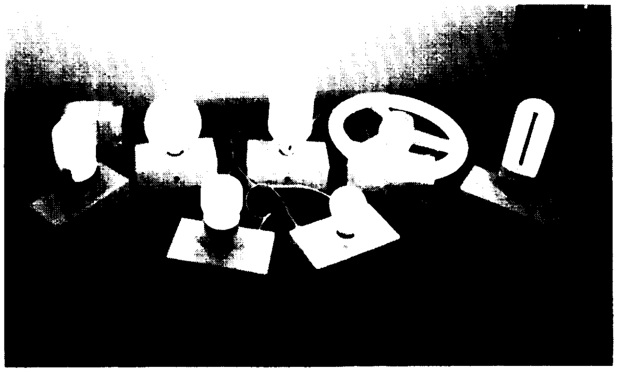


Photo credit: U.S. Department of Energy

Compact fluorescent, which use 75 percent less energy than standard incandescent lamps, are available in a variety of designs.

Lighting in Commercial Buildings

Lighting is the single largest user of electricity in commercial buildings, accounting for about 41 percent of commercial sector electricity use.[67] The lighting technologies currently used in commercial buildings mirror the diversity of the sector itself: standard fluorescent lamps in offices, high-intensity lamps highlighting merchandise in retail stores, a mix of fluorescent and incandescent lamps in restaurants, and so on. This section provides basic information on widely used commercial lighting technologies, their alternatives, and their costs and other attributes.[68]

Lamps

Fluorescent lamps consume about 55 percent of lighting electricity in the commercial sector (table 2-8), Fluorescent lamps vary widely, but many are the familiar 4-foot cylindrical-shaped units. These lamps typically consume 34 to 40 watts of electricity and supply about 3,000 lumens of light. Other popular fluorescent lamps are the 8-foot long cylinders, typically consuming 75 to 100 watts and producing 6,000 to 9,000 lumens; and the U-shaped lamp, typically at 40 watts and 3,000 lumens. Most fluorescent lamps found in commercial buildings are one of these three types.

Table 2-8—Lighting Technologies in Use in Commercial Buildings (1989)

Type of lighting	Percent of floor space[a]	Percent of lighting electricity[b]	Total electricity (TWh per year)
Incandescent. , .	15	41	141
fluorescent.	77	55	190
HID[c].	9	4	14
Total.	100	100	345

[a]The approximate percent of commercial building floor space that is lit predominantly by that technology.
[b]The approximate percent of electricity used for lighting in the commercial sector that is consumed by that technology. Assumes all technologies are used the same number of hours per year, all technologies deliver the same number of lumens per square foot, and the following energy efficiencies: Incandescent 18 lumens per watt, fluorescent 70 lumens per watt, HID 110 lumens per watt.
[c]HID - High Intensity Discharge.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989,* DOE/EIA-0246(89) (Washington, DC: June 1991), p.195. Floor space total does not sum to 100 due to rounding. Total electricity for lighting from OTA 1992; see app. I-B.

There are countless variations on the regular fluorescent technology. Color of light, starting technology, shape of electrical connector, diameter, length, and of course energy consumption can all vary, depending on the specific model and manufacturer. The focus here is on those technologies that can influence energy consumption.

There is some evidence that many older commercial buildings are overlit, meaning that the installed lighting fixtures supply more light than needed.[69] In such buildings the standard 4-foot, 40-watt fluorescent lamp may be replaced with a 'high-efficiency' 34-watt lamp, recognizing that much of the energy savings from this lamp comes from reduced output, not higher efficiency. The reduced wattage lamp described in table 2-9, for example, is filled with a higher fraction of krypton than a standard lamp and is therefore slightly more efficient than the standard lamp. It uses 15 percent less energy, but delivers 12 percent less light (as measured in lumens). Despite their reduced output, these lamps now supply about one-third of the total U.S. market for new 4-foot

67 See app. 1-B fo, sources. This does not include indirect effects on HVAC consumption.

68 Those interested in a more detailed technical discussion of lighting technologies are referred to M.A. Piette, F. Krause, and R. Verderber, Technology *Assessment: Energy-Efficient Commercial Lighting, LBL-27032* (Berkeley, CA: Lawrence Berkeley Laboratory, March 1989).

69 A Usibelli, S. Greenberg, M. Meal, A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-Sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 5-26. The Illuminating Engineering Society (IES) sets recommendations for lighting levels, but there is some evidence that in the past most commercial building lighting systems supplied much more light than the IES recommends.

Table 2-9—Standard and Reduced Wattage Versions of the 4-Foot, 40-Watt (T-12) Fluorescent Lamp

Description	Energy use (watts)	Light output (lumens)	Efficiency (lumens per watt)
Standard.	40	3,250	81
High efficiency, . .	34	2,850	84

NOTE: Both are rapid start, T-1 2 (1.5 inch diameter) lamps with a rated lifetime of 20,000+ hours.

SOURCE: GE Lighting, "Selection Guide for Quality Lighting," Form 9200, 20th cd., Cleveland, OH, 1990, pp. 90-91.

fluorescent lamps.[70] As with all lighting retrofits, however, careful attention is required to maintain a level and quality of light that meets occupant needs.

Several fluorescent lamp technologies offer additional efficiency improvements. Smaller diameter lamps (known as T-8, with a 1 inch diameter) are somewhat more efficient, due to their greater surface-to-volume ratio. Lamps with improved phosphors also offer efficiency gains.

Ballasts

The fluorescent lamp requires a ballast, which regulates the voltage and current received by the lamp. Ballasts consume energy internally and also affect the energy efficiency of the lamp through their voltage and current control. There are two major types of ballast technologies—magnetic and electronic. For many years, ballasts used a simple iron core and aluminum core windings to regulate voltage and current. This magnetic technology was well-proven and in universal use but was relatively inefficient. The use of larger iron cores and copper rather than aluminum windings provides about a 10 percent improvement in energy efficiency,[71] with no change in light output or quality.

The use of electronic (solid-state) ballasts, which control voltage and current electronically, can both increase the energy efficiency of the ballast it self and improve the operation of the lamp through improved

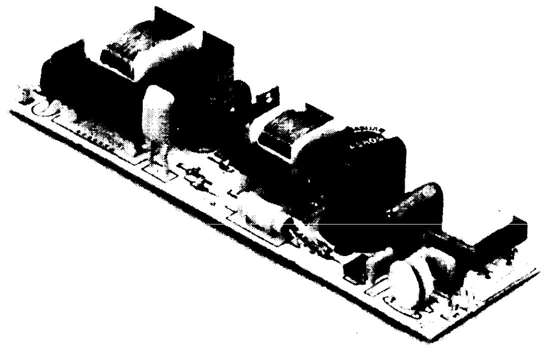


Photo credit: Advance Transformer Co.

Electronic ballasts can cut fluorescent lighting energy use by 20 to *25* percent.

current control. The efficiency of the ballast-lamp system is typically improved 20 to 25 percent when electronic ballasts are used.[72] These ballasts *come* at a higher frost cost—typically about $10 more than an efficient magnetic ballast[73]—but offer typical paybacks of 3 to 4 years.[74] In addition, electronic ballasts are often smaller, lighter, and quieter. Despite their benefits, electronic ballasts have yet to acquire a large market share-less than 4 percent of all ballasts shipped by U.S. manufacturers in 1990 were electronic.[75] Although some early models of electronic ballasts had moderately high failure rates,[76] these ballasts have since been improved and are now routinely offered with long-life warranties. Their reputation for unreliability still persists, however, and may be contributing to their slow market penetration.

In 1988 the U.S. Congress passed the NAECA amendments (Public Law 100-357), which set minimum efficiency levels for balIasts. Standards were set for four types of ballasts, representing about 85

70 A. Lovins and R. Sardinsky, *The State of the Art: Lighting* (Old Snowmass, CO: Competitek, Rocky Mountain Institute, March 1988), p. 122.

7 I A Usibelli,S Greenberg,M. Meal A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-Sector Conservation Technologies, LBL-18543* (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 5-4.

72 Relative to standard magnetic ballasts. R. Verderber, *Status and Application of New Lighting Technologies,* LBL-25043 (Berkeley, *CA:* Lawrence Berkeley Laboratory, June 1988), p.3.

73 The incremental additional first cost of an electronic ballast over an efficient (that is, one meeting the NAECA Amendment Standards) magnetic ballast, based on quotes from manufacturers for large purchase orders in 1991.

74 Assuming $10 incremental first cost, 15 watt *savings,* operation for 10 hours per&y and 250 days per year, and an electricity cost of 7.3 cents/kWh.

75 U S Department of commerce, Bureau of the Census, Current Industrial Reports, "Fluorescent Lamp Ballasts—Summary for 1990, " MQ36C(90)-5, Washington, DC, issued July 1991.

76 R. Verderber, *Status and Application of New Lighting Tech/* ologies,* LBL-25043 (Berkeley, CA: Lawrence Berkeley Laboratory, June 1988), p. 3.

Table 2-10—Alternative Lighting Designs for a Large Office

	Standard design	High efficiency design
Lamps	40-watt fluorescent	34-watt 'miser' fluorescent
Ballasts	Standard magnetic	Dimmable electronic
Fixtures	4 lamp, flat lens	2 lamp, parabolic reflector
Initial cost (per square foot-year)	$2.77	$4.08
Operating cost (per square foot-year)	$0.54	$0.34

NOTE: Electricity price assumed: 7.3 cents per kWh.

SOURCE: Decision Focus Inc., *TAG Technical Assessment Guide,* EPRI P-4463-SR (Palo Alto, CA: Electric Power Research Institute, October 1988), vol. 2, Part 2, pp. 6.29-6.33.

percent of the ballast market.[77] Efficiency levels set by this legislation will probably prevent the use of the very inefficient standard magnetic ballasts, but will allow for the use of improved magnetic ballasts and electronic ballasts.[78]

Fixtures

The design of the entire lighting fixture can significantly influence performance, A poorly designed fixture will absorb light and reduce useful output. Conversely, a well-designed fixture will reflect light to where it is needed, thereby reducing wasted output. Fixtures consist of several parts: the lamp itself, the ballast, the reflector to direct the light in the desired direction, the lens or louver to reduce glare, and the housing. There are thousands of fixtures on the market, each with its own design and characteristics. The quality of light given off by a fixture is difficult to measure, making it difficult to quantify the effectiveness or value of various fixture designs. There are some general design features, however, that clearly contribute to energy efficiency.

The addition of a specular reflector can increase the light output of a fixture. For example, removing two lamps from a four-lamp fixture and then adding a specular reflector will yield about 60 to 80 percent of the initial light output with a 50 percent reduction in energy use, and a payback of usually less than 1 year.[79] Locating fixtures nearer to areas needing light can reduce wasted output. Changing, cleaning, or removing the lens covering fixtures can increase light output.

The potential savings from combining improved fixtures, lamps, and ballasts is significant. For example, an analysis by the Electric Power Research Institute (EPRI) found that the use of commercially available lighting technologies, including electronic ballasts, reflectors, and reduced wattage lamps, reduced energy consumption by 37 percent relative to a standard design with no reduction in light output and with a payback of less than 7 years (table 2-10). Actual installation of similar technologies in an office building in New York City yielded significant savings, with a payback of 6.2 years.[80]

Controls

Lighting controls can reduce lighting energy use by ensuring that lights are used only when and where required. Options include manual or automatic dimming to reduce output when appropriate, manual switches to allow lights to be turned off when not needed, occupancy sensors to switch lights on automatically when a room is occupied, and scheduled switches to turn lights on and off on a prearranged schedule. The economic attractiveness of improved controls are building-specific, as they depend on hours of operation, occupant behavior,

77 U.S. Congress, Senate Committee on Energy and Natural Resources, ''Senate Report No. 100-345 on the National Appliance Energy Conservation Amendments of 1988," May 13, 1988, p. 3.

78 The NAECA amendments set performance standards, rather than technical requirements, so one cannot conclude from the legislation itself exactly which technologies will be used. The performance standards, however, are set at levels that seem to prohibit the least efficient magnetic ballasts. It is interesting to note that, when the NAECA amendments were passed, seven States had already set their own statewide ballast standards, which were then superseded by the Federal standard.

79 Decision Focus Inc., *TAG Technical Assessment Guide*, EPRI P-4463-SR (Palo Alto, CA: Electric Power Research Institute, October 1988), vol. 2, Part 2, pp. 6-27.

80 Based on predicted energy savings and excluding predicted maintenance savings. R. Watson, ''Case Study in Energy Efficient Office Renovation: NRDC'S Headquarters in New York City, " *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1990), p. 3.225.

electricity prices, and other factors. Examples include the installation of occupancy sensors in a section of the World Trade Center, which reduced lighting energy use by 57 percent,[81] and lighting control retrofits in eight commercial buildings that yielded an average 19 percent energy savings, with an average payback of 3.7 years.[82]

Daylighting

The use of natural sunlight, rather than light from electricity, has many attractions. In addition to the electricity savings, daylighting typically offers better views and the feeling of more space, The potential electricity savings are quite high+. g., a 70 percent reduction in perimeter lighting electricity y use,[83] In one case study, a retail/office Space was retrofit with daylighting technologies to provide a more attractive space, and although energy savings were not the primary intent, lighting energy use was reduced 59 percent.[w] There can be increased first costs, however, due to the need for additional windows and, depending on climate, an increased space cooling load.[85] Designing a building to exploit daylighting is complex and can require specialized skills.[86]

WATER HEATING

Water heating accounts for about 15 percent of residential and 4 percent of commercial energy use. Slightly more than half of U.S. households use natural gas to heat water and 37 percent use electricity (table 2-11). In residences, hot water is used for personal washing (in showers and baths), clothes washing, dish washing, and other miscellaneous uses, The bulk of hot water use in the commercial sector is in the service sector—in restaurants, laundromats, and other facilities requiring hot water as part of their business.

Table 2-1 I—Water Heating Fuels in **Residential Buildings (1989)**

Type	Percent of households
Natural gas	52
Electricity	37
Oil	7
Bottled gas	3
Other	1
	100

SOURCE: U.S. Department of Commerce, Bureau of the Census, *American Housing Survey for the United* States *in 1989,* HI 50/89 (Washington, DC: U.S. Government Printing Office, July 1991), p. 42.

Residential Water Heating Technologies

Essentially all U.S. households have hot water service. In single-family homes and in some multifamily buildings, 40 to 50 gallon water heater tanks are used both to heat and to store hot water. Natural gas-fired tanks typically have somewhat higher first (purchase) costs than electric units,[87] and can cost more to install as well, as they require gas service and external ducting.[88] The costs of operation, however, are typically about 50 percent lower for gas-fired tanks (this will vary depending on fuel costs and unit efficiency).

The efficiency of residential-size water heaters has improved in recent years (figure 2-6), due largely to increased tank insulation, smaller pilot lights, and improved heat transfer from combustion gases to the water in the tank. The most efficient commercially available water heaters sold today use thick polyurethane foam insulation, carefully designed heat trans-

8 1M.A. Piette, F. Krause, and R. Verderber, *Technology Assessment: Energy-Efficient Commercial Lighting,* LBL-27032 (Berkeley, CA: Lawrence Berkeley Laboratory, March 1989), p. 5-4.

82 K. Greely, J. Harris, and A. Hatcher, ' 'Measured Energy Savings and Cost-Effectiveness of Conservation Retrofits in Commercial Buildings, " *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1990), p. 3.103, table 3.

83 A. Usibelli, S. Greenberg, M. Mea], A, Mitchell, R. Johnson, G, Sweitzer, F. Rubinstein, D, Arasteh, *Commercial-Sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 6-3, Perimeter refers to the area near the windows in a building, as distinct from the core where daylighting often cannot penetrate.

84 M. A, Piette, F. Krause, and R, Verderber, *Technology Assessment:* Energy *-Efficient Commercial* Lighting, LBL-27032 (Berkeley, CA: Lawrence Berkeley Laboratory, March 1989), p. 5-2.

85 The use of fewer electrical lights will reduce space cooling needs; however, this may be more than offset by the increased heat coming from the sun.

86 A Usibelli S. Greenberg M. Meal, A, Mitchell, R. Johnson, G, Sweitzer, F, Rubinstein, D, Arasteh, *Commercial-Sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 6-2.

87 Natural gas Units are typically about 20 to 30 percent more expensive than comparable electric units, excluding installation and operating costs.

88 Approximately one-third of households in the United States do not have access to natural gas. U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987,* DOE/EIA-0314(87) (Washington, DC: May 1989), p. 35.

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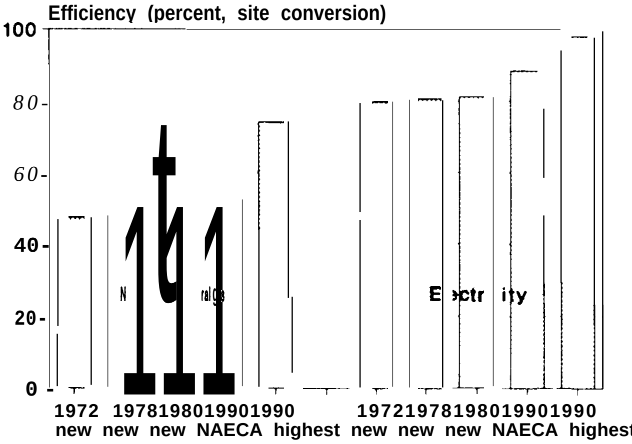
fer surfaces, and electronic ignition, but these features are found only in a few models. As was found for other residential appliances, there is a considerable efficiency difference between the average new water heater and the most efficient commercially available new water heater (figure 2-6).

The costs of the very efficient units are quite high-but it is not appropriate to attribute this additional cost solely to energy efficiency. For example, a 40-gallon gas water heater with an efficiency of 74 percent costs about $780, but this unit has a lifetime warranty,[89] special design to eliminate corrosion, and several other features not found on a $35061 percent efficient unit.[90] According to a sales manager for a water heater manufacturing firm, the main marketing advantage of the highly efficient unit is the warranty and not the energy efficiency.[91] (chapter 3 of this report discusses in more detail how energy-using devices are marketed and selected.)

Other methods of improving water heating efficiency include demand reductions, retrofits to existing units, and technical improvements in new units. The simplest method to reduce energy use for water heating is by reducing consumption of hot water. The largest users of hot water in residences are showers and baths (41 percent of hot water), clothes washing (24 percent), and kitchens (27 percent), with the remainder (8 percent) used in bathroom sinks.[92] Low-flow showerheads can reduce shower flow rates by about 50 percent.[93] Although consumer acceptance of these devices is a concern, designs have improved in recent years and consumer satisfaction is reported to be quite high.[94]

Retrofits to existing hot water systems can reduce their energy use. Popular retrofits include tank wrapping (adding a layer of insulation to the outside

Figure 2-6-Trends in the Efficiency of Water Heaters



NOTES: 'New' is shipment-weighted average of all units shipped in that year. 'NAECA' is the minimum allowable according to the national standard. 'Highest' is the most efficient commercially available.

SOURCES: 1972 to 1980: Pacific Northwest Laboratory, *Residential/ and Commercial Data Book—7hird Edition,* PNL-6454 (Richland, WA: February 1968). 1990 NAECA: Public Law 100-12, for a 50 gallon tank. 1990 highest: Gas Appliance Manufacturers Association, "Consumer's Directory of Certified Efficiency Ratings," October 1990, Arlington VA, pp. 134, 163.

of the hot water tank), reducing tank temperature, and insulating hot water pipes. Adding R-1 1 insulation blankets to water heaters in homes in the Pacific Northwest, at a cost per blanket of about $20, resulted in an average annual savings of 714 kWh per household.[95] A separate study found water heater wrapping to be the most cost-effective building retrofit measure, with an average payback of 0.6 years.[96]

Several new water heating technologies show considerable promise for improved efficiency. Heat pump electric water heaters, which pump heat from an external heat source (usually outside air) into a hot water tank, are commercially available from

89 For example, one company provides a warranty in effect for as long as the original purchaser owns his or her home.

90 Costs and efficiencies from "Sears Spring/Summer 1991 Catalog," Sears Roebuck Co., Downers Grove, IL, pp. 1073-1077.

91 The simple payback considering only the difference in energy efficiency is an unimpressive 15 years.

92 W. Kempton, ''Residenti~ Hot Water: A Behaviorally-Driven System, '' in W. Kempton and M. Neiman (eds.), *Energy Efficiency: Perspectives on Individual Behavior* (Washington, DC: American Council for an Energy-Efficient Economy, 1987), p. 233.

93 Measured data from actual showers in Washington State, as reported in B. Manclark, ''~w-mow Showers Save Water, " *Home Energy,* vol. 8, No. 4, July/August 1991, p. 28. This does not necessarily mean that the use of low-flow showerheads will reduce shower hot water consumption by 50 percent, as people may take longer showers once the low-flow showerhead is installed.

94 In one study, the percent of consumers reporting that they were "very satisfied" with their showerheads went from 37 to 56 percent after replacement of old showerheads with new low-flow units. Ibid., p. 29.

95 M. Brown, D. White, and S. Purucker, *Impact of the Hood River Conservation project on Electricity Use for Residential Water Heating,* ORNL/CON-238 *(Oak* Ridge, TN: Oak Ridge National Laboratory, October 1987), pp. xii, 8.

96 S. Cohen, "Fifty Million Retrofits Later, " *Home Energy,* vol. *7, No. 3,* May/June 1990, p. 16.

Box 2-F—Plastic Tanks: A Technical Advance That May Hinder Energy Efficiency

The natural turnover in appliance stock has allowed newer, more efficient appliances to penetrate the market. Recent developments in materials, however, may decrease turnover and thereby slow the implementation of new, efficient appliances.

Almost all residential-size hot water storage tanks are made of steel. These tanks typically last 10 to 15 years, and when they fail it is almost always due to corrosion of the steel seam. Recently, however, plastic-lined one-piece tanks have appeared on the market. These tanks are available with warranties that are good for as long the purchaser owns the tank, implying that the manufacturer does not expect these units to fail. Although these units are at present quite efficient-with efficiencies of 94 to 97 percent due to the use of thick insulation, heat traps, and other devices-their use may reduce the use of improved technologies such as heat pump water heaters in the future, as the replacement market will shrink drastically. Furthermore as plastic-lined tanks become more popular and less expensive, they may find use in less efficient electric water heaters.

several U.S. firms. The energy efficiency of these units is in the range of 150 to 340 percent.[97] Costs are quite high—about $900 to $2,000[98]-but may drop in the future if production volumes increase.[99] Add-on heat pump units, which can be retrofit to existing water heaters, can also be used, but here again prices are high.[100] Heat recovery water heaters, which capture waste heat from space conditioning equipment, are available for an installed cost of about $550.[101] Performance of these units depends heavily on climate. A prototype condensing gas water heater, which recaptures the latent heat in the combustion gases, has been built with an efficiency of 83 percent.[102]

Table 2-12—Water Heating Fuels in Commercial Buildings

Fuel	Percent[a]
Natural gas	49
Electricity	40
District heat	9
Fuel oil	4
Propane	2

[a]The approximate percent of commercial building floor space whose hot water is supplied by the corresponding fuel. Total sums to more than 100 as some commercial buildings use more than one fuel for hot water. Excludes commercial buildings with no hot water.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Commercial Building Characteristics 1989,* DOE/EIA-0246(89) (Washington, DC: June 1991), p. 150.

Commercial and Multifamily Water Heating Technologies

As in residential buildings, natural gas and electricity are the leading fuels for water heating in commercial buildings (table 2-12).[103] The methods and systems used for heating water in commercial buildings vary widely. Many older buildings have a hot water tank that is heated by a submerged coil, heated in turn by the main space-heat boiler. This design is rarely used in new buildings, as it requires the main boiler to be operated year-round to provide hot water. A second design is a storage tank with a smaller, dedicated boiler. This boiler can provide only hot water or can provide both hot water and space heating as necessary. A third type of system is a commercial tank, which is essentially a large-scale version of a residential tank. This last design is increasingly popular, as it is simple and relatively inexpensive to install.

The options for improvements are similar to those for residential systems. Demand reductions, including repairing leaks and reducing temperature settings, can reduce energy use. Retrofits to systems

97 Efficiencies of over 100 percent are possible as the useful output includes the pumped heat obtained from another source, while the only input is the electricity used to pump the heat from one place to another. Source is EPRI, *Electric Water Heating News*, vol. 4, No. 1, spring 1991, p. 4.

98 Average costs for an integral (i.e., includes tank) heat pump water heater. Ibid.

99 Economies of scale in production require higher sales volumes, yet these volumes will not be achieved as long as prices are high.

100 Probably $450 to $800. EPRI, *Electric Water Heating News*, vol. 4, No. 1, spring 1991, p. 4.

101 Installed costs vary widely, depending on the specific equipment Used and the difficulty of installation. Average value of $550 from Synergic Resources Corp., *Review of Energy-Efficient Technologies in the Residential Sector,* EPRI EM-4436, vol. 1 (Palo Alto, CA: Electric Power Research Institute, February 1986), p. 1-12.

102 E. Hirst, J. Clinton, H. Geller, W. Kroner, Energy *Efficiency in Buildings. Progress and Promise* (Washington, DC: American Council for an Energy-Efficient Economy, 1986), p. 85.

103 Much of this discussion applies to large multifamily buildings as well.

can include those used in the residential sector, such as increasing tank insulation, as well as some more innovative features including electronic ignitions, electronic flue dampers, and boiler tune-ups. For example, the addition of an electric flue damper to a 70-gallon natural-gas-fired water heater tank in a recent field test increased effficiency from 61 to 65 percent, with a payback period of 5.3 years.[104]

New technologies for commercial water heating include the use of heat pumps, heat recovery devices, and other methods for integrating water heating into other heating and cooling systems. For example, a heat recovery heat pump recently installed at a large resort complex in Arizona uses heat from the chillers (space cooling devices) to heat water for the laundry, swimming pool, and spa. The new system replaces a natural-gas water heating system and thereby reduces the annual natural gas costs by about $61,000 per year. The estimated payback for the system is 3.5 years.[105]

FOOD REFRIGERATION/ FREEZING

Keeping food cold requires a significant amount of energy—about 10 percent of residential energy use and about 5 percent of commercial sector energy use[106] The energy efficiency of food refrigeration equipment has improved tremendously in the last 10 to 20 years, and considerable potential for further improvement remains. This section reviews the recent history of refrigeration equipment, the present-day technologies, and the most promising technologies for the future. Residential equipment is emphasized, as it uses the bulk of food refrigeration energy, but commercial technologies are mentioned as well.

Residential Refrigeration and Freezing

Almost every U.S. household has at least one refrigerator, and some-about 14 percent—have two or more.[107] The energy consumption of residential refrigerators tripled from 1950 to 1972, due to increased size (from 7 to 17 cubic feet), addition of energy-cons uming features such as automatic defrost, and reduced insulation.[108] In the 1970s, however, several factors led to a sharp drop in refrigerator energy consumption. Increased energy prices, energy consumption labels (required by the Energy Policy and Conservation Act of 1975, Public Law 94-163), and State-level energy efficiency standards (California set minimum refrigerator energy efficiency standards in 1976) all led to the use of improved, more efficient refrigerator technologies. A number of innovations and improvements, rather than a single technical breakthrough, led to a 55 percent drop in the energy consumption of the typical refrigerator from 1972 to 1990 (table 2-13, figure 2-7). Among these improvements were the use of polyurethane foam rather than fiberglass insulation, more efficient motors and compressors, improved door seals, and improved air flow between cold coils and food compartments.

The typical refrigerator sold today is an 18-cubic-foot, top-mount (meaning the freezer is above the refrigerator), automatic defrost unit using about 900 kWh per year.[109] Although this energy use level is far below that of the typical units sold in the 1970s, it is far above that which the Department of Energy (DOE) has determined to be ''technically feasible' (table 2-13). According to DOE, it is technically feasible to build a refrigerator using less than 500 kWh per year that retains the features expected by consumers-including 18-cubic-foot interior volume and automatic defrost. A 16-cubic-foot manual

[104] R. Nevitt and V. Stefanson, ''Evaluating the Perfo rmance of a New High Efficiency Commercial Tank Water Heater, ' *Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings* (Washington DC: American Council for an Energy-Efficient Economy, 1988), p. 2.155.

[105] EPRI, *Electric Water Heating News*, vol. 3, No. 3, winter 1990-91, pp. 1, 3.

[106] Primary equivalent, see app. 1-B for sources.

[107] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990*, DOE/EIA-0384(90) (Washington, DC: May 199 1), p. 45. The term "refrigerator" refers to a combination refrigerator-freezer, unless noted otherwise.

[108] "Appliance Efficiency on the Fast Track,'' *EPRI Journal*, vol. 12, No. 2, March 1987, p. 33.

[109] Sizes given here refer t. the sum of the refrigerator and freezer volumes. The adjusted volume (AV), defined as refrigerator volume plus 1.63 times freezer volume, is 20.8 cubic feet.

Table 2-13—Trends in the Energy Consumption of Refrigerators

Description	Energy use (kWh/year)	Annual operating cost[a]
1. Average new 1972	1,990	$155
2. Average new 1978	1,440	112
3. Average new 1981	1,200	94
4. Average new 1986	1,070	83
5. Average new 1987	970	76
6. Average new 1990	880	69
7.1990 NAECA standard	960	75
8. 1993 NAECA standard	690	54
9. 1990 technically feasible (DOE)	490	38

[a]Electricity price of 7.8 cents/kwh assumed.

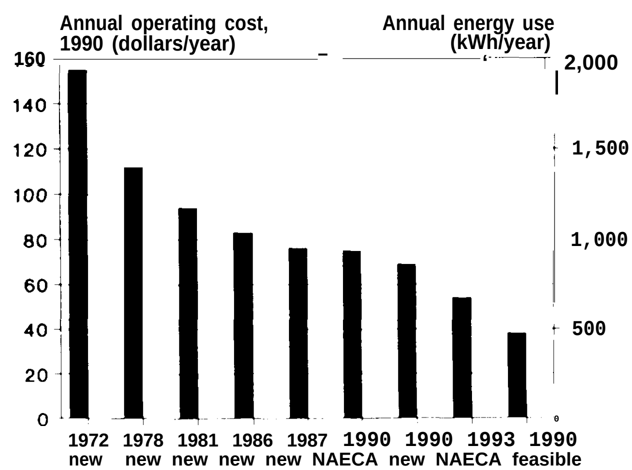
NOTE: Entries 1 to 6 are shipment-weighted averages; 7 to 9 are for top-mount automatic defrost units, no through-the door ice, 18 cubic feet actual volume, 20,8 cubic feet adjusted volume.

SOURCES: 1 to 6: R. Gants, Vice President, Association of Home Appliance Manufacturers, personal communication, Oct. 18, 1991.7 to 9: 54 *Federal Register 47918 (Nov.* 17, 1989).

defrost refrigerator using only about 280 kWh per year is commercially available.[110] The NAECA standards, which include both technical and economic considerations, will require energy use levels no higher than 690 kWh per year by 1993.[111]

Several technologies could further improve refrigerator energy efficiency. Refrigerators use energy to maintain a temperature difference between the food storage area and the surrounding environment; by reducing the amount of heat that penetrates into the refrigerator, one can reduce the energy use. This can be done by improving the insulation surrounding the food storage area. The foam insulation used in refrigerators today has an insulating value of about R-8 per inch.[112] Simply adding more insulation may not be practical, as increasing the external dimensions of the refrigerator makes it difficult to fit the unit in kitchens, while decreasing the internal dimensions reduces the available food storage space. Therefore materials that provide more insulating value while still fitting in the narrow shell of the refrigerator are needed. A further constraint on refrigerator insulation is related to the use of chlorofluorocarbons (CFCS). Foam insulation commonly used in refrigerators contains CFCS, which are being phased out of international production due to their harmful effects on the stratospheric ozone layer.

Figure 2-7—Trends in the Energy Consumption of Refrigerators



NOTES: Operating cost includes energy only. An electricity cost of 7.8 cents/kWh is assumed. 'New' is shipment-weighted average of all units shipped in that year. 'NAECA' is the *maximum* allowable according to the national standard. 'Feasible' is DOE's estimate of the lowest technically feasible unit. Applies to a top-mount automatic defrost unit, no TTD (through-the-door) ice, 18.0 cubic feet actual volume, 20.8 cubic feet adjusted volume.

SOURCES: 1972 to 1990 new: R. Gants, Vice President, Association of Home Appliance Manufacturers, personal communication, Oct. 18, 1991. NAECA: 54 *Federal Register 47918 (Nov.* 17, 1989). Feasible: U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,* DOE/CE-0277 (Washington, DC: November 1989), p. 3-36.

110 Manufacturer's data at 70 degree F ambient temperature, from Sunfrost, Arcata, CA, model RF-19. Actual interior dimensions of 8.0 cubic feet for refrigerator and 8,0 cubic feet for freezer. This unit has larger than usual exterior dimensions, is hand-built, and costs about $2,500. The manufacturer claims that mass-production would drop the per-unit cost to about $1,000. M. Shepard, A. Lovins, J. Neymark, D. Houghton, H. Heede, *The State of the Art Appliances* (Old Snowmass, CO: Competitek, Rocky Mountain Institute, August 1990), p. 76.

111 For a top-mount automatic defrost refrigerator/freezer with an adjusted volume of 20.8 cubic feet.

112 U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,* DOE/CE-0277 (Washington, DC: November 1989), p. 3-4.

Table 2-14—improved Refrigerator Technologies Considered by DOE in Setting the NAECA Standards (partial list)

Double door gasket
Improved insulation
Evacuated panels
High efficiency compressor
Adaptive defrost
Fan and fan motor improvement
Anti-sweat heater switch
Condensor gas heating
Improved evaporator
Improved expansion valve
Two-compressor system
Relocation of components
Variable-speed compressor

SOURCE: U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,* DOE/CE-0277 (Washington, DC: November 1989), p. 3-4.

In an effort to develop insulation that is both compact and CFC-free, much of the recent R&D has focused on the use of vacuums. One such technology, compact vacuum insulation, uses two thin sheets of steel held apart by glass beads, with a vacuum between them.[113] Several prototype panels using this technology have been built, however costs, performance, and feasibility of large-scale production are still uncertain. Other promising vacuum-related technologies under development include powder-filled vacuum panels and silica aerogels, both at about R-20 per inch.[114]

Many other technologies could be considered to improve further the energy efficiency of refrigerators (table 2-14). Improving compressor design, installing separate compressors for the freezer and the refrigerator (dual compressors), and moving the compressor from the bottom to the top of the refrigerator to reduce heat flow from the compressor into the refrigerator, can all improve energy efficiency. Some of the highly efficient technologies provide additional consumer value as well. Vacuum panels, for example, could allow for thinner walls, thereby providing more interior storage space without increased exterior dimensions.

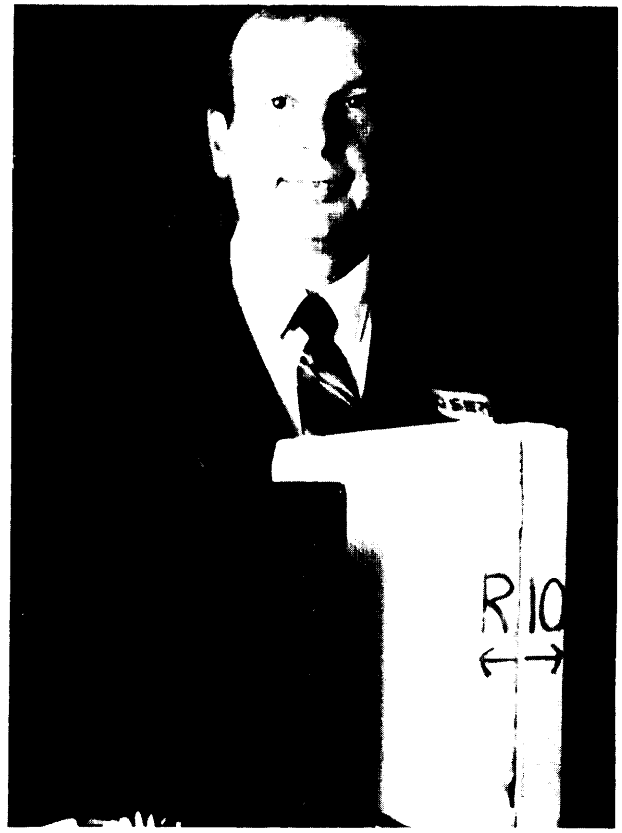


Photo credit: National Renewabie Energy Laboratory

Compact vacuum insulation panels (shown on the left) can provide an insulating value of R-10 in just 1/10 inch. Over 1 inch of standard insulation is required to provide the same insulating value.

Some of these technologies, such as dual compressors, are already in commercial use, and therefore their costs are known. Others, notably vacuum panels, are not yet commercially available, and therefore costs are uncertain. It should be noted, however, that according to DOE it is possible to meet the 1993 NAECA standard through the use of commercially available technologies.115

Approximately 34 percent of U.S. households have separate freezers.[116] As with refrigerators, the energy consumption of freezers has dropped sharply

113 The expected insulating value for this technology is R-10 per 1/10 inch. T. Potter and D. Benson, "Performance Tests of Compact Vacuum Insulation for Refrigerators," *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1990), p. 1.177.

114 U.S. Department of Energy, Technical Support Document: Energy *Conservation Standards for Consumer products: Refrigerators and Furnaces,* DOE/CE-0277 (Washington, DC: November 1989), p. 3-5.

115 Ibid., p. 3-37,

116 In 1987. U.S. Department of Energy, Energy Information Administration, *Annual* Energy *Review 1990*, DOE/EIA-0384(90) (Washington, DC: May 1991), p. 45.

in recent years (table 2- 15). The prospective technologies for residential freezer improvement are quite similar to those for refrigerators.

Commercial Refrigeration and Freezing

In commercial buildings requiring food refrigeration and freezing, such as supermarkets and other retail food stores, refrigeration systems can account for about half of total electricity use.[117] The design and use of this equipment, unlike residential refrigerators, varies widely from site to site. This section reviews some promising technologies for improving the design of this equipment.

Commercial refrigeration systems, like space cooling systems, are used to move heat from one place to another. Energy efficiency opportunities include reducing the amount of heat requiring transfer, capturing the transferred heat and using it to perform useful work, and designing the equipment to move heat more efficiently.

Reducing the amount of heat that needs to be moved, or load reduction, is often the simplest improvement. The addition of plastic strips on refrigerated display cases can reduce energy use by 15 to 45 percent.[118] Glass doors, although more expensive, can reduce energy use by 30 to 60 percent.[119] It is Sometimes thought that these devices will reduce sales by making the product less accessible, and also make product loading more difficult. As with other energy efficiency improvements, the perception that they reduce comfort or convenience is a significant barrier to widespread use.

Heat recovery devices, which capture the waste heat from refrigeration systems and use it for space and/or water heating, are being installed in most new systems. Although they do not contribute to the energy efficiency of the refrigeration system per se, they do capture energy that would otherwise be

Table 2-15-Trends in Energy Consumption of Residential Freezers

Description	Energy use (kWh/year)	Annual operating cost[a]
1. Average new 1972.	1,300	$101
2, Average new 1978.	1,080	84
3. Average new 1987.	780	61
4. Average new 1990.	680	53
5. NAECA 1990 standard.	710	55
6. NAECA 1993 standard.	530	42
7. Technically feasible.	420	33

[a]Electricity price of 7.8 cents/kWh assumed.

NOTE: For an upright manual defrost freezer with an interior volume of 15.1 cubic feet (26.1 cubic feet adjusted volume),

SOURCES: 1 to 4: R. Gants, Vice President, Association of Home Appliance Manufacturers, personal communication, Oct. 18, 1991.5 to 7: 54 *Federal Register 47918, 47919 (Nov. 17, 1989).*

wasted and thereby reduce overall energy use. Their value is limited by the on-site need for heat. For example, a supermarket may have a limited need for hot water, and may need space heating only in winter.

Improvements to the refrigeration system itself offer the largest energy savings. The list of possible technologies is quite long, and just a few of the most promising options are mentioned here. Compressors use much of the energy of commercial refrigeration systems. These compressors operate most efficiently at full load, therefore the use of several, unequally sized compressors in parallel, along with microprocessor controls to match the compressor operation with the load, can reduce energy use 13 to ,27 percent.[120] Variable-speed drive for compressors, along with pressure and temperature controls, could provide significant energy savings.[121] Most refrigeration systems operate at a fixed pressure, set to meet the load on the hottest days. Allowing this pressure to float, or drop to meet actual demand, led to a 23 percent drop in compressor energy use in a recent field test.[122]

117 Battelle-Columbus Division and Enviro-Management and Research, Inc., *DSM Technology Alternatives*, EPRI *EM-5457* (Palo Alto, CA: Electric Power Research Institute, October 1987), p. B-31.

118 A Usibelli, S Greenberg, M. Meal, A. Mitchell, R. Johnson, G. Sweitzer, F. Rubinstein, D. Arasteh, *Commercial-Sector Conservation Technologies,* LBL-18543 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985), p. 3-2.

119 Ibid.

120 Ibid., p. 3-1,

121 Ibid., p. 3-6.

122 G. Wheeler and G. Smith, ‘‘Refrigeration Energy Savings With Floating Head Pressure,’’ *Proceedings of the ACEEE 1988 Summer Study on Energy Efficient in Buildings* (Washington, DC: American Council for an Energy-Efficiency Economy, 1988), p. 4.123

Table 2-1 6-Approximate Energy Consumption of Selected Appliances

Appliance	Approximate annual consumption—1 988, primary trillion Btus	Percent of total sectoral energy use
Residential		
Clothes dryers	480	about 3
Clothes washers[a]	100	less than 1
Dishwashers	70	less than 1
Cooking appliances	570	about 3
Other	740	about 4
Total	1,960	13
Commercial		
Electronic office equipment	260	about 2
Other	1,600	about 12
Total	1,860	15

[a]Does not include energy for water heating.

NOTE: Individual numbers may not sum to totals due to rounding.

SOURCES: Office of Technology Assessment, 1992 (see app. I-B); J. Harris, J. Roturier, L. Norford, A. Rabl, *Technology Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988).

The technical and economic savings potential is well illustrated in a recent field test of advanced commercial refrigeration technologies. An advanced system (utilizing floating pressure, unequally sized compressors, and other innovative technologies) was installed next to a conventional system in a large supermarket in northern California. The two systems were alternately operated in order to measure performance and energy use under the same conditions. Actual energy savings were 23 percent, or about $10,000 per year with the new system. The initial cost premium of the system was estimated at about $20,000, yielding a 2-year payback.[123]

OTHER ENERGY SERVICES

In addition to the previously discussed energy services (space conditioning, lighting, water heating, food refrigeration and freezing), there is a wide range of other energy services in buildings. For the residential sector this includes clothes washing and drying, cooking and cleaning (including dishwashers), home entertainment (notably televisions), and various other uses such as waterbeds and humidifiers. For the commercial sector this includes cooking and cleaning in restaurants, office equipment (computers, copy machines, printers, etc.), clothes washing and drying in laundromats, and so on. These miscellaneous energy services account for about 13 percent of residential energy use and 15 percent of commercial energy use (table 2-16).[124]

For most of these individual appliances the energy use is quite small; however in aggregate their energy use can be considerable. Residential electric clothes dryers, for example, use about 41 TWh of electricity per year,[125] or the combined annual output of 6.5 large coal-burning powerplants.[126] Office electronic equipment uses about 25 TWh per year (1988),[127] or the equivalent of about four large coal-burning powerplants. Furthermore some of these appliances, notably computers in offices, are growing in popularity and may become significant energy users in the future. This section discusses technologies for reducing the energy use of three energy users in the miscellaneous category---clothes washers, clothes dryers, and office equipment (table 2-16).

Clothes Dryers

About 68 percent of U.S. households have clothes dryers,[128] and about 4.5 million new clothes dryers

123 "Putting the Freeze on Refrigeration Costs," *EPRI Journal*, vol. 13, No. 8, December 1988, p. 21.

124 In 1988, using primary conversion factors. See app. 1-B for sources.

125 In 1988. See app. 1-B for sources.

126 Assuming a 900-MW plant operating at 80 percent capacity factor.

127 J. Harris, J. Roturier, L. Norford, A. Rabl, *Technology Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988), p. 3-20.

128 U.S. Department of Energy, Bureau of the Census, *American Housing Survey for the United States in 1989*, H150/89 (Washington, DC: U.S. Government Printing Office, July 1991), p. 40.

are shipped each year.[129] The energy efficiency of dryers increased moderately over the years, showing a 7.8 percent efficiency increase from 1972 to 1980.[130] Technologies are available for greater improvements in dryer efficiency. Some of these technologies are addressed by NAECA (Public Law 100-12) and subsequent DOE rulings. The original NAECA prohibited the use of pilot lights in gas dryers, and subsequent rulings by DOE set minimum efficiency standards for dryers manufactured after May 13, 1994. These standards could be met with the use of automatic moisture or temperature termination and increased insulation, but as they are performance, not prescriptive, standards they do not require the use of any specific technology. Additional technologies considered and rejected by DOE in setting standards include the use of heat-pump clothes dryers (a technology already used for commercial drying), microwave clothes dryers (prototypes do exist),[131] and recycling of exhaust heat. These technologies were rejected for economic, not technical reasons; although DOE found that the life-cycle costs of these appliances were lower than that of dryers without these technologies, they determined that the increased first cost may reduce sales and thereby reduce manufacturers' return on equity. 132

There are other options to reduce dryer energy use. The use of natural gas rather than electricity as the primary fuel for the dryer can be much more financially attractive; gas units typically cost about ***$40 more to*** purchase but about $90 less to operate per year, with a payback period of less than 6 months.[133] Faster spin speeds for washers could help as well, by reducing the amount of water the dryer would need to remove.[134]

Clothes Washers

About 76 percent of U.S. households have electric clothes washers, 135 and about 5.9 million new units are shipped each year.[136] The energy efficiency of washers improved considerably in recent years-by over 50 percent from 1972 to 1989.[137] Most of this efficiency increase came from more cold wash and rinse options, less hot and more cold in the warm water mix, and improved control of washer water level.[138]

As in dryers, there are several technologies that could further increase washer efficiency, some of which are addressed by NAECA and subsequent DOE rulings. The original NAECA legislation required that a cold rinse option be available, and subsequent rulings set minimum efficiency levels effective in 1994 that could be met with the elimination of warm water rinse.[139] One promising technology, the use of horizontal axis rotation, was not included by DOE, because there was insufficient

1291989 U.S. industry shipments minus exports plus imports, from Association of Home Appliance Manufacturers (AHAM), *Major Home* Appliance *Industry Fact Book 1990/91* (Chicago, IL), pp. 11, 15, 17.

130 Units are pounds water removed per kWh consumed. From SAIC, *Trends* in *the Energy Efficiency of Residential Electric Appliances*, EPRI EM-4539 (Palo Alto, CA: Electric Power Research Institute, April 1986), p. 2-18.

131 DOE found that microwave clothes dryers Were "technically feasible" (see 56 *Federal Register 22265 [May 14, 1991]);* however, manufacturers have raised questions of safety and performance (R. Gants, Vice President, Association of Home Appliance Manufacturers, personal communication, Oct. 18, **1991).**

132 See 56 *Federal Register* 22273 (May 14, 1991).

133 Assumptions: electric unit uses 5,800 watts, gas unit Uses 500 watts electricity plus 22,000 Btu/h of natural gas, electricity at $.078/kWh and gas at $5.63/l@ Btu, 6 hours use pcr week. Purchase prices from "Scars Spring/Summer 1991 Catalog, ' Sears Roebuck Co., Downers Grove, IL.

134 By one estimate, removing water mechanically (by spinning) requires only 1/70th the energy required to remove the same amount of water thermally (with heat}. From I. Turiel, D. Berman, P. Chan, T. Chan, J. Koomey, B. Lebot, M. Levine, J. McMahon, G. Rosenquist, S. Stoft, "U.S. Residential Appliance Energy Efficiency: present Status and Future Directions, ' *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy-Efficient Economy, 1990), p. 1.230.

135 U.S. Department Of commerce, Bureau of the Census, *American Housing Survey for* the United States in *1989*, H150/89 (Washington, DC: U.S. Government Printing Office, July 1991), p. 40.

1361989 U.S. shipments minus exports plus imports, from Association of Home Appliance Manufacturers (AI-JAM), *Major Home Appliance Industry Fact Book 1990/91* **(Chicago, IL),** pp. 11, 15, 17.

137 Shipment Weighted average energy factors, as estimated by Association of Home Appliance Manufacturers (AHAM), ibid., p. 29.

138 The bulk of energy use in clothes washers is for water heating.

139 56 *Federal Register* 22267, 22279 (May 14, 1991). Note that the standard could be met with the elimination of warm water rinse but could be met in other ways as well, and according to DOE there are currently models on the market with warm rime that already meet the standard. 56 *Federal Register 22264 (May 14, 199* 1).

information during the public comment period.[140] Higher washer spin speeds (to reduce dryer energy use) were also not considered, as the test procedure for washers does not appear to give credit for reductions in clothes dryer energy use.

Office Equipment

Although the energy use of office equipment is quite small-only about 3 to 4 percent of total commercial electricity use 141—it is growing rapidly and is an important new energy user in office buildings, where it sometimes consumes more energy than lighting. A typical personal computer uses about 100 to 170 watts[142]-about the same as the typical refrigerator. The technology of office equipment changes rapidly, making it difficult to forecast future demand. However one estimate suggests that office equipment energy use could increase 160 to 360 percent by 1995 (relative to 1988).[143]

There are a number of technologies available that could sharply reduce the electricity needs of office equipment. These include greater use of laptops, CMOS chips (which, unlike the traditional NMOS technology, uses almost no power when not in use),[144] liquid-crystal display (LCD) screens, and various alternatives to laser printing. Software allowing computers to shift to a dormant mode after a period of inactivity would help reduce energy use as well. The use of these and other technologies, most of which are already commercially available, could hold office equipment electricity use at about its current level,[145] despite the continued rapid proliferation of computers and other electronic devices.

SUMMARY AND CONCLUSIONS

Recent advances in equipment design have yielded remarkable efficiency improvements, and there is considerable potential for further improvement. For example, while the typical new gas furnace in the 1970s was only 63 percent efficient, new gas furnaces are now available with 97 percent efficiency. New windows are available with an insulating value of R-8-an eight-fold improvement over the old R-1 single-pane window-and window designs in the laboratory suggest R-10 to R-15 may soon be available. Computerized controls can cut commercial building energy use by 10 to 20 percent. Improved design can reduce both energy use and construction costs in large office buildings.

As discussed in chapter 1, there is some disagreement on the amount of energy that could be saved through the use of cost-effective energy efficient technologies. Reasons for this disagreement include differing definitions of cost-effective and different assumptions as to technology costs and performance. There is general agreement, however, on the following points:

- Technical advances have led to impressive improvements in the energy efficiency of energy-using equipment, and further improvement is likely.
- If these efficient technologies were used, energy use in buildings would be reduced considerably.
- A variety of highly energy efficient equipment is commercially available but is not being used,

140 According t. one analysis, a horizontal axis washer uses 61 percent less energy and 39 percent less water than a standard vertical-axis washer (B. Lebot, I. Turiel, G. Rosenquist, "Horizontal Axis Domestic Clothes Washers: An Alternative Technology That Can Reduce Residential Energy and Water Use," Proceedings *of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy -Efficient Economy, 1990), p. 1.155.); however, manufacturers have expressed concerns about retooling costs and consumer preferences.

141 By one estimate, office electronic equipment consumed about 25 TWh/year in 1988. J. Harris, J. Roturier, L. Norford, A. Rabl, Technology *Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988). This corresponds to about 3 percent of commercial sector electricity use, or about 12 percent of office building electricity consumption (for sources, see app. l-B). The U.S. Census Bureau estimates that about 37 million keyboards (including electric typewriters, CRT terminals, and personal computers) were in use in offices in 1988. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United Stares: 1990* (Washington, DC: January 1990), p. 948. Assuming 150 watts per keyboard, 12 hours per day, 250 days per year, and a doubling for printers, copy machines, and other equipment yields about 33 TWh/year or about 4.1 percent of commercial sector electricity use.

142 An IBM XT with a hard disk uses about 115 watts, an IBM AT with a hard disk uses about 165 watts. J. Harris, J. Roturier, L. Norford, A. Rabl, *Technology Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988), p. 3-2.

143 J. Harris, J. Roturier, L. Norford, A. Rabl, *Technology Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988), p. 3-20, scenarios 1995(a) and 1995(b).

144 CMOS stands for complement metal-oxide semiconductor; NMOS stands for n-channel metal-oxide semiconductor.

145 J. Harris, J. Roturier, L, Norford, A. Rabl, Technology *Assessment: Electronic Office Equipment*, LBL-25558 Rev. (Berkeley, CA: Lawrence Berkeley Laboratory, November 1988), p. 3-20, 1995(c) scenario.

even though it would be cost-effective to do so.[146]

- Improved efficiency does not mean reduced comfort or lifestyle changes. More efficient technologies produce the same product—heat, cool, refrigeration, etc.—but with less energy.

Technologies for improving energy efficiency can be conceptualized into three types: 1) those that are cost-effective (but perhaps not used), 2) those available or technically proven but not cost-effective at present fuel prices, and 3) those not yet available or not yet technically feasible. Policy implications for improving or encouraging the use of these three types of technologies differ:

1. The gap between what appears to be cost-effective and what is actually used is due in part to mixed incentives, capital constraints, and other factors. Furthermore, calculations of cost-effectiveness generally do not incorporate environmental and other externalities, and doing so would most likely increase the gap between cost-effective and actual energy use. The barriers to wider use of these technologies may require explicit policy actions, as their existence suggests that the current market structure may not make optimal use of cost-effective energy efficiency opportunities.
2. The gap between the most efficient technologies and the cost-effective technologies can be narrowed by decreasing technology costs (through subsidies, R&D, or market pull[147]), increasing energy costs (through taxes or other fees),[148] or changing the definition of cost-effective.
3. Research and development can further increase efficiency levels or generate new technologies. Existing technologies generally do not approach the theoretical limits for energy efficiency, and the technical frontier for energy efficiency could be pushed well beyond current levels.[149]

The large gap between what is already available on the market and what is actually used suggests that implementation, rather than just technical advancement, is key to increasing energy efficiency. There are many commercially available technologies and methods that can reduce energy use while still providing needed energy services. The key to increasing energy efficiency lies in implementing these technologies, and that in turn requires an understanding of how the market for energy services functions, and how energy-related decisions—selecting and operating energy-using equipment—are made. This is the focus of chapter 3.

146 The studies discussed in ch. 1 use a variety of definitions of cost-effective. Although the savings potential does vary depending on the specific definition used, by most definitions a considerable cost-effective savings potential exists.

147 In many cases, highly efficient technologies are expensive (and therefore not cost-effective) because demand for them is small. Increasing the market demand (market pull) for high efficiency products could reduce costs of these products by taking advantage of economics of scale in production.

148 For example, some argue that cost-effectiveness criteria should incorporate the environmental costs of energy production and use.

149 One might argue that gas furnaces at 97 percent efficiency provide little room for technical improvement, however gas-fired heat pumps could provide space heating at efficiencies of over 100 percent.