Energy and Energy Efficiency in Buildings: A Global Analysis

Mark D. Levine, Lynn Price and Nathan Martin, Energy Analysis Program
Lawrence Berkeley National Laboratory
Ernst Worrell, Department of Science, Technology & Society, Utrecht University

Recent studies by the authors of this paper show that approximately 33% of global primary energy is consumed by residential and commercial buildings and that demand for energy in this sector may be greater than any other sector in 2020. Growth in buildings energy use between 1971 and 1992 varied widely by region, ranging from 1.9% per year in the industrialized countries to 3.0% per year in Eastern Europe and the former Soviet Union and 5.9% per year in developing countries. Factors that drive energy consumption in buildings (population, economic growth, energy services demanded, and energy intensities) are discussed for each region. Energy efficiency improvements for buildings and the overall technical potential to reduce energy consumption in buildings are outlined. Three scenarios of future energy use in buildings in 2020 project that buildings energy use will grow to about 38% of world primary energy. Under the business-as-usual scenario, buildings energy demand doubles. Adoption of state-of-the-art practices and technologies will lead to buildings energy demand 66% above 1990 levels. Use of ecologically-driven policies and advanced technologies will lead to demand 36% above 1990 levels. There are at least four essential requirements for an energy-efficient future: (1) real increases in energy prices: (2) aggressive energy-efficiency policies; (3) major programs to transfer knowledge, technology, and tools for transforming markets to the developing world; and (4) continued efforts to pursue research and development in technologies and practices to increase energy efficiency in buildings.

INTRODUCTION

Recent studies by the authors of this paper for the World Energy Council, the Intergovernmental Panel on Climate Change, and the United Nations Division for Sustainable Development show that approximately 33% of global primary energy is consumed by residential and commercial buildings and that demand for energy in this sector could be greater than any other sector in 2020 (Levine et al. 1996; WEC 1995; Worrell et al. 1996). These studies grouped countries of the world into three regions: industrialized countries (also referred to as Organization for Economic Cooperation and Development, or OECD, countries), Eastern Europe and the former Soviet Union (EE/FSU), and developing countries[1] in order to assess regional historical building energy demand and to develop scenarios of buildings energy demand for the year 2020. This paper will discuss global and regional energy use in buildings, the potentials for reducing buildings energy use, scenarios of buildings energy use in 2020, and policies to promote buildings energy efficiency.

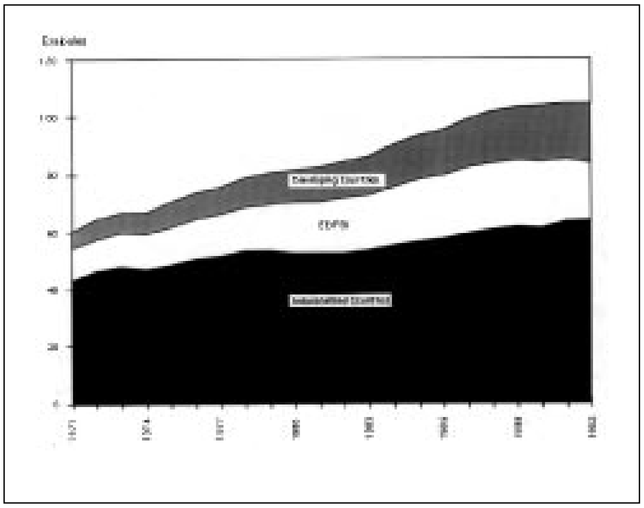
The buildings sector is typically divided into residential and commercial subsectors. Each subsector includes a wide variety of specific energy applications or ''end-use services,'' including cooking, space heating and cooling, lighting, refrigeration and freezing, and water heating. The demand for building services has increased dramatically in recent years and there have been significant changes in the specific technologies that provide these services. This complex interplay of service types, service demand, and technology is the key determinant for estimating future energy demand in the buildings sector.

HISTORICAL TRENDS IN BUILDING SECTOR PRIMARY ENERGY USE

Global primary energy use for buildings increased at an average rate of 2.7% per year between 1971 and 1992 (Figure 1).[2] This growth, however, varied widely by region, ranging from a low of 1.9% per year in the industrialized countries to 3.0% per year in the EE/FSU and 5.9% per year in the developing countries (see Table 1). More recent trends show that since 1988, growth in buildings energy use in developing countries has dropped to 4.0% per year, while annual *declines* of 3.8% were experienced in the EE/FSU region between 1988 and 1992 due to the significant decrease in energy consumption that followed the economic collapse in that region.

Growth in building energy demand is affected by increases in population or economic growth, the type of building energy services demanded, and the energy intensity of the process or technology used to provide those services. Buildings currently account for about a third of global primary energy

Figure 1. *World Primary Energy Use in Buildings by Region, 1971–1992.*



Source: WEC 1995.

consumption (104 EJ), with the largest share of consumption (62%) in industrialized countries. Residential buildings consumption is twice as great as that of commercial buildings. However, these trends are changing quickly. Energy demand in commercial buildings has grown about 50% more rapidly than demand in residential buildings for the past two decades.

Industrialized countries

Population growth in OECD countries was the lowest of the three regions (0.8% per year between 1970 and 1990) and it is projected to drop to 0.5% per year between 1990 and 2020 (UN 1994). Gross domestic product (GDP) per capita grew more rapidly than population, averaging 2.3% annually between 1980 and 1991 (World Bank 1993a).

Residential building energy use in industrialized countries grew 1.4% per year between 1971 and 1992. The number of households grew 1.5% per year faster than population during this time (Schipper & Meyers 1992), leading to increased demand for energy for various residential services, particularly for space heating, central air conditioning, water heating, and energy-intensive appliances (refrigerators, color televisions, and clothes washers). For example, in the U.K., the fraction of residences with central space heating grew from 43% in 1974 to around 65% in 1983 (Ketoff et al. 1987). In 1970, only one-third of new single-family homes in the U.S. had central air conditioning; by 1990 this number had climbed to over three-fourths (U.S. Congress, OTA 1992a).

At the same time, there has been a significant reduction in the energy required to deliver various services, particularly in technologies such as space-heating furnaces, refrigerators, and lighting systems. New refrigerators in the U.S., for example, use about 40% of the energy of new refrigerators sold in the early 1970s (U.S. Congress, OTA 1992a). Since 1973, space-heating intensity (useful energy per m^2 of floor area) has declined in seven OECD countries. Also, the following declines were experienced in appliance stock average unit energy consumption values between 1972 and 1992: refrigerators—17% (U.S.); clothes dryers—13% (U.S.) to 26% (former W. Germany); dishwashers—46% (U.S.) to 63% (former W. Germany); clothes washers—6% (U.S.) to 49% (former W. Germany) (Schipper, Haas & Sheinbaum 1996). One recent analysis found that increases in the number of appliances and relative size of residential homes in nine OECD countries would have raised space-heating energy use by 20–50% (depending on the country) with similar increases for appliances, had these increases not been compensated with increases in efficiency and fuel-switching (Schipper, Haas, & Scheinbaum 1996).

Growth in energy use in industrialized country commercial buildings averaged 2.6% per year between 1971 and 1992, nearly twice the rate of residential buildings. This growth in energy use in commercial buildings was in large part caused by increases in electric heating, computers, and other office equipment as well as growth in commercial floor space (Schipper & Meyers 1992). The United States has the largest amount of commercial floorspace, but growth is highest in such countries as Japan (4.1% per year), Finland (4.1% per year), and Norway (3.6% per year). The average growth in floorspace for a sample of ten OECD countries was 2.3% per year from 1970 to 1990 (Sezgen & Schipper 1995).

Some of the increase in commercial buildings energy demand has been counteracted by improved insulation and more efficient lighting and other equipment. Newer commercial buildings are designed more appropriately for their climate, are better insulated, and have more efficient space-conditioning equipment and lighting. Older buildings are becoming more efficient as improved technologies are incorporated in the course of normal building renovation. A recent survey of U.S. buildings found that some energy-efficiency measures had been installed in 95% of U.S. commercial floorspace (EIA 1994).

Developing countries

Rapid economic growth and population increases in developing countries are bringing large increases in energy consumption in all sectors as countries expand their basic infrastructures. Annual population growth averaged 2.2% in developing countries between 1970 and 1990, but is expected to drop to 1.6% per year to 2020 (UN 1994). Even with such a decline, this projection shows an increase of 60% in the population of developing countries, reaching 6.5 billion

Table 1. World Primary Energy Use in Buildings by Region in Exajoules (1971, 1980, 1990, 1992)

Region and Sector	1971	1980	1990	1992	Avg. Annual Growth Rate (%) 1971–1992
Industrailized Countries					
Residential	28	33	37	38	1.4
Commercial	15	19	24	26	2.6
Total Buildings	43	52	61	64	1.9
Developing Countries					
Residential	5	9	15	16	5.7
Commercial	1	2	4	5	6.7
Total Buildings	6	11	19	21	5.9
EE/FSU					
Residential	2	13	15	13	2.2
Commercial	3	5	8	7	4.9
Total Buildings	11	18	23	20	3.0
World					
Residential	41	54	66	66	2.3
Commercial	19	27	37	38	3.4
Total Buildings	60	81	103	104	2.7

Source: British Petroleum 1994; IEA 1994a.

or 82% of the projected world total of 7.9 billion in 2020 (World Bank 1993a). Economic growth rates vary significantly among the developing countries, with low and sometimes negative growth in GDP/capita in sub-Saharan Africa and Latin America contrasted with the rapid growth seen in India, China, and many of the southeast Asian countries (World Bank 1993a).

Growth in purchased energy consumption for commercial and residential buildings in developing countries grew 6.7% per year and 5.7% per year, respectively, between 1971 and 1992, slightly more than twice the world average. Per capita energy consumption for buildings, particularly in Asia and Latin America, grew faster than either population or GDP.

Residential buildings in developing countries account for 76% of buildings energy consumption, and the share would be even higher if biomass energy were included. As developing country economies mature, increasing urbanization and substitution away from traditional fuels to commercial fuels will also increase purchased energy demand in residential buildings.

Because of the strong correlation between income level and ownership of appliances, demand for energy services such as refrigeration, television, and space conditioning will increase as economies expand. Saturation levels of various residential appliances for selected developing countries are shown in Table 2, indicating that a large potential exists for further adoption in many countries. Air conditioners and refrigerators account for a significant portion of residential electricity use by appliances. Rapid increases in appliance ownership in developing countries are likely in the coming years; such growth will lead to large increases in residential electricity demand (Levine et al. 1996; U.S. Congress, OTA 1992b).

Table 2. *Comparison of Saturation Levels for Residential Appliances in Selected Developing Countries (%)*

Country	Refrig-erator	Color Tele-vision	Air Conditioner	Clothes Washer
Brazil[1]	66	35[2]	4	22
China[3]	19	30	1	34
India	14–40[4]	17–38[4]	0–2[4]	8[5]
Mexico[6]	58	55[7]	6	42
Thailand[8]	63	117	18	22

Sources:
1. Meyers et al. 1990.
2. Jannuzzi & Schipper 1991.
3. Sinton 1995 (based on 1993 data).
4. Tyler et al. 1994 (based on three cities surveyed).
5. Sathaye & Tyler 1991.
6. Masera et al. 1993.
7. Friedmann 1995.
8. Thailand Load Forecast Subcommittee 1993.

Note: For comparison, refrigerator saturation levels in 9 industrialized countries in 1988 were between 106 and 117% (indicating more than one refrigerator per household) and clothes washer saturation levels were between 73 and 99% (Schipper & Meyers 1992).

The energy intensity of appliances used in developing countries is often higher than that of similar appliances used in industrialized countries, implying a significant potential for future savings. Studies in China, Egypt, India, Indonesia, and Mexico have found that the appliances produced locally were significantly less efficient than world standards (Dutt 1993; Levine et al. 1991; Liu 1993). In China, for example, electricity consumption of a new 170-liter refrigerator varied by model from 24 to 32 kWh per month, higher than the average Korean model with consumption of 20 kWh per month (Meyers et al. 1993).

Currently, demand for energy-using services in commercial buildings varies considerably. In India, lighting is estimated to account for 50% of total electricity followed by space conditioning and refrigeration (40%). In Mexico, the share of lighting can be even higher, while in Thailand space conditioning accounts for 40 to 60% of total building energy demand (Busch 1995; de Buen 1995). In most developing countries, the growth in energy use in commercial buildings—expected to continue near the recent levels—is driven by substantial growth in illuminated and air-conditioned commercial floor space.

Eastern Europe and the Former Soviet Union

The economic restructuring that has occurred in the EE/FSU since the late 1980s had a significant affect on buildings energy use in this region. GDP dropped 10% in 1991 and another 4% in 1992 in Eastern Europe. Even larger decreases of 9 and 18% were seen in the former Soviet Union during these years. But recovery has begun in some countries such as the Czech Republic, Hungary, the Slovak Republic, and the Baltics. Economic growth is expected to increase first in Eastern Europe where slight growth was seen in 1993 and 1994, followed by the former Soviet Union (EBRD 1994). Population growth in this region was slightly higher than that of the industrialized countries between 1970 and 1990, but is expected to drop to 0.2% per year to 2020 (UN 1994).

Between 1971 and 1988, residential energy use increased at a rate of 3.9% per year and energy use in commercial buildings increased at 6.6% per year in the EE/FSU, resulting in a 4.7% annual increase in energy used in all buildings over this period. Much of the EE/FSU building stock has inefficient space-conditioning systems and energy-using equipment, as well as poorly insulated building envelopes, and therefore requires more energy to provide the same level of energy services as a similar building in industrialized countries. For example, buildings in the FSU require 50% more energy to heat a square meter of floorspace (after correcting for weather) than buildings in the U.S. (Cooper & Schipper 1991). Building energy use has been affected by the economic restructuring in the region since the late 1980s, leading to an average annual *decline* in buildings energy use of 3.8% was experienced between 1988 and 1992. This decline is expected to be temporary, however, as growth in the number of new buildings and the energy services within those buildings is anticipated for both the residential and commercial buildings sectors.

In the residential sector, the largest end-uses are space heating, water heating, and cooking. The majority of the population in the EE/FSU lives in multi-family housing such as large apartment buildings. The number of residents per household is declining, leading to an increase in energy use per household. For example, the number of residents per unit in Poland dropped from 3.65 to 3.46 between 1978 and 1988. In the Czech Republic, residents per unit dropped from 2.92 to 2.76 between 1980 and 1991 (Meyers et al. 1995). At the same time, there has been a modest increase in per-capita living area thereby driving up the demand for particular end uses such as space heating. Residential living area per capita in the FSU increased 2.3% annually between 1972 and 1987 from 11m^2/capita to 15.5m^2/capita (Cooper & Schipper 1991). Residential floorspace per capita, estimated to be 16 to 17m^2 per person in Poland and the Czech Republic, has also increased at similar rates (Meyers et al. 1995). Per capita floorspace is still significantly less than levels in Europe (25 to 33 m^2 per person), Scandinavia (34 to 45 m^2 per person), or the U.S. (61 m^2 per person), suggesting that large future increases in floorspace and related buildings energy use could take place as the economic growth continues (Meyers et al. 1995; Schipper & Meyers 1992; U.S. Congress, OTA 1993).

Primary energy use in the FSU commercial buildings sector grew at a rate of 3.4% per year between 1970 and 1988, from 2.1 EJ to 3.9 EJ (Cooper & Schipper 1991). In Poland, primary energy use for this sector grew from 0.3 EJ in 1970 to a peak of 0.7 EJ in 1987, at an average growth rate of 5% annually. Consumption dropped by over 9% per year after that, to 0.4 EJ in 1992. In general, the commercial sector in the EE/FSU is poorly lit, has little electrical office equipment, and has equipment that is less efficient than that found in industrialized country commercial buildings (Meyers et al. 1994a; Meyers et al. 1994b; Schipper & Martinot 1993). Commercial sector floorspace in the FSU grew from less than 3.0 m^2 per capita in 1970 to about 5.5 m^2 per capita in 1987, a growth of 1.2% per year (Schipper & Martinot 1993; Schipper & Meyers 1992). Like the residential sector, the per capita floorspace is much lower than the typical 10 to 16 m^2 in Western Europe and 25 m^2 in the U.S. (Schipper & Martinot 1993), suggesting that a large potential exists for growth in commercial sector energy demand. Per capita energy use in the commercial sector in Poland has already begun to rebound and strong growth in the private retail sector driving an expansion of the commercial building stock is expected (Meyers et al. 1994a).

POTENTIAL FOR REDUCING ENERGY USE IN BUILDINGS

There are several categories of efficiency improvement potentials. The *theoretical potential* of energy efficiency improvement for a certain process is determined by thermodynamic laws. The *technical potential* is defined as the achievable savings resulting from the most effective combination of the efficiency improvement options available in the period under investigation. Applying economic constraints, we can also identify an *economic potential* for energy efficiency improvement, which is defined as the potential savings that can be achieved at a net positive economic effect, i.e. the benefits of the measure are greater than the costs over the lifetime of the measure. The *market potential* is defined as the potential savings that can be expected to be realized in practice, and is determined by investment decision criteria applied by investors under prevailing market conditions.

Technical potentials for energy efficiency improvements in buildings

Table 3 presents an overview of the results of selected studies, mostly for industrialized countries, of the technical potential for energy efficiency improvement in residential and commercial buildings. Technical potential savings range from 23 to 76% depending upon the sector, the country or region, and other assumptions. Economic and market potentials, which only include those technologies and practices that are cost-effective and are selected by consumers in the marketplace, are lower. One study of electricity efficiency in residential buildings estimates that 45% of the technical potential during the period 1990 to 2010 is likely achievable in the market (Brown 1994).

Energy-efficient technologies

The technologies to achieve energy efficiency improvements apply to all modern buildings, whether in the industrialized countries, the EE/FSU, or the developing world. Table 4 describes some of the energy efficiency improvements that can be made in buildings worldwide. Below we briefly review the potential for energy savings in building envelopes, heating and cooling equipment, lighting, motors, cooking, and office equipment. We also discuss building energy management systems and building commissioning, operation, and management.

Building envelopes. Energy use can be reduced with building designs that include proper orientation, adequate insulation levels, proper sealing, overhangs, and high-quality windows. Improvements in the thermal characteristics of windows and increases in wall and ceiling insulation in residential buildings in China can reduce energy use by 40% relative to mid-1980s practice while allowing for a considerable increase in indoor temperatures (Huang 1989). A West German study that evaluated homes of different vintage in five building types found an economic potential of 40% of baseline heating energy (Ebel 1990). In the U.S., a government study estimated that energy savings of 30 to 35% could be attained over the 1990–2010 period through retrofits in dwellings built before 1975 (EIA 1990). Adoption of Swedish building practices, which rely heavily on assembly from factory-built components, in the rest of Western Europe and North America would bring a reduction of at least 25% in the space-heating requirements of new dwellings relative to those built in the late 1980s (Schipper & Meyers 1992).

Heating and cooling equipment. Use of condensing technology or high-efficiency heat pumps can reduce energy

Table 3. *Technical Potential for Energy Efficiency Improvement in Residential and Commercial Buildings*

Sector	Potential	Country/Region
Residential		
	48% [1]	U.S.
	27–46% [2]	U.S.
	29% [3]	U.S.
	36% [4]	U.S.
	60% [5]	France, Germany, Italy, The Netherlands, UK
	42–76% [6]	The Netherlands
	31% [7]	Brazil
Commercial		
	23–49% [2]	U.S.
	55% [4]	U.S.
	65% [5]	France, Germany, Italy, The Netherlands, UK
	41–74% [6]	The Netherlands
	60% [8]	Slovak Republic
	38% [7]	Brazil
Residential and Commercial		
	45% [4]	U.S.
	43% [9]	Sweden

Sources:

1. Koomey et al., 1991. Technical potential for electricity relative to frozen efficiency.
2. Faruqui et al., 1990. Technical potential for electricity in the year 2000.
3. EIA, 1990. Technical potential for total energy use in the year 2010.
4. Rosenfeld et al., 1993. Technical potential for electricity in 1989 relative to frozen efficiency.
5. Krause et al., 1995. Technical potential for the year 2020.
6. de Beer et al., 1994. Technical potential for total energy use in the year 2000 and 2015 respectively relative to frozen efficiency.
7. Geller, 1991. Technical potential for electricity in the year 2010.
8. Kaan et al., 1995. Technical potential for fuels (heating) in the near term.
9. Bodlund et al., 1989. Technical potential for electricity relative to frozen efficiency.

Note: Frozen efficiency assumes that equipment and buildings are not retrofit during the analysis period and remain at the same efficiency level until the end of the analysis period or until they are retired. It excludes those efficiency changes that would occur through market forces during the period. In many cases, about half of the energy savings in the technical potential curves might be achieved through market forces over a twenty-year time period. This convention is followed in order to more easily make comparisons between different studies.

use for heating. Technical efficiency improvements for district heating systems include better insulation of pipes that carry heat to and among buildings and improvement of the operation and control of heating systems. Technologies to increase air conditioner efficiency include better thermal insulation, larger and/or improved heat exchangers, higher evaporator coil temperatures, advanced refrigerants, more efficient motors, dual-speed or variable-speed compressors, and more sophisticated electronic sensors and controls (Morgan 1992; Geller 1995). For commercial buildings, large air-conditioning systems using rotary or centrifugal compressors are typically more efficient than systems based on reciprocal compressors or smaller air-conditioning units. Efficiency improvements generally come from improving the efficiency of the chiller, routing and designing ducts to minimize losses, switching to a system using a heat pump, improved controls, improved maintenance, and reducing demand (U.S. Congress, OTA 1992a). For U.S. residential electricity heating and cooling measures, one estimate found a technical savings potential of 12% of total frozen efficiency space conditioning energy use in 2010 (Koomey et al. 1991).

Lighting. Lighting accounts for a significant portion (approximately 10 to 20%) of electricity use in all countries.

Table 4. *Summary of Energy-Efficiency Improvements for Various Buildings Sector End-Use Services*

Service	Technology/Practice	Energy-Efficiency Improvements
Building Envelope	Windows	Use double-glazed windows at a minimum. Low-e coatings reduce heat losses by about one-third; double-pane window with gas-filled spaces and two suspended reflective films inside reduces heat losses by 75 percent; use of thermal breaks to limit conduction losses through the frame.
	Insulation	Adequately insulate ceilings and walls.
	Ducts	Reduce or eliminate leaks.
Space Conditioning	Furnaces	Condensing furnaces are 90 to 97% efficient (compared to U.S. minimum efficiency standard of 78% for new gas-fired warm-air furnaces).
	Heat Pumps	Electric air-source heat pumps are about twice as efficient as electric resistance heaters. Ground-source heat pumps are even more efficient.
	District Heating	Increase insulation of pipes, repair inoperative radiator valves, install thermostats and individual meters; improve operation and control of heating systems.
	Air Conditioners	Use better internal insulation, larger heat exchanges, higher evaporator temperatures, dual-speed or variable-speed compressor motors to reduce on-off cycling, more efficient rotors and compressors, advanced refrigerants, and more sophisticated electronic sensors and controls.
Water Heating	Water Heaters	Increase insulation of water heaters; use electronic ignition for gas water heaters and higher efficiency gas burners. Use air-source, exhaust-air, and ground-source heat pump water heaters.
Refrigeration	Refrigerators	Use of advanced compressors, evacuated panel insulation, and other features lead to refrigerators that consume half as much electricity per volume as those that meet the U.S. 1993 appliance standards.
Clothes Washing/Drying	Clothes Washers	Change from vertical-axis to horizontal-axis technology, reducing energy use by about two-thirds. Increasing spin speed during the spin-dry cycle of a clothes washer can reduce drying energy use by 30 to 50%.
	Clothes Dryers	Use heat pump dryers, leading to savings of 70% over conventional dryers.
Cooking	Biomass Stoves	Improved biomass stoves can reduce the fuel used for cooking a standard meal by 30 to 40%. An additional 50% fuel savings results from switching to kerosene stoves. Solar ovens can also replace biomass stoves.
Lighting	Compact Fluorescent Lamps	Replace incandescent lamps with CFLs which require 75% less electricity.
	Fixtures	Use specular reflective surfaces inside a fluorescent lamp fixture, increasing light emitted and allowing for removal of lamps (delamping).

continued

Table 4. *Summary of Energy-Efficiency Improvements for Various Buildings Sector End-Use Services* (continued)

Service	Technology/Practice	Energy-Efficiency Improvements
	Ballasts	Electromagnetic ballasts reduce ballasts losses to about 10% (vs. 20% of magnetic ballasts). Solid-state electronic ballasts increase the efficiency of the ballast/lamp system by approximately 20 to 25%.
	Lighting Control Systems	Savings of 10 to 15% with photocell controls, 15 to 30% with occupance sensors, and up to 50% in perimeter zones with daylighting dimming systems. Also use multi-level switches, timers, and task lighting.
Motor Power	Variable Speed Drives	Savings of 15 to 40% over a standard motor depending on application.
	Energy-Efficient Motors	Savings of 2 to 15% over a standard motor depending on the motor size.
	Specifying and Maintenance	Optimal sizing of motors, pumps, fans, compressors, and cables can reduce losses. A good maintenace program can reduce motor electricity by up to 10 to 15%.
Energy Management	Building Energy Management Systems	Systems range from point-of-use timers to complex microprocessor-based systems that minimize unnecessary equipment operation and provide other functions such as economizer cycling or varying supply air or water temperatures and limiting peak electric loads by selectively switching off or cycling loads.
Building Performance Assurance	Advanced Energy Management Systems	Recent building performance case studies suggests that typical savings of about 15%, and as much as 40% of annual energy use can be gained by compiling, analyzing, and acting upon energy end-use data.

Source: Claridge et al. 1994; Levine et al. 1996; Levine et al. 1995.

Studies of economic potential energy savings for lighting in commercial buildings in different countries have produced a range of savings estimates: 35% for the U.S. (Atkinson et al. 1992); between 36 and 86% for five countries in Western Europe (Nilsson and Aronsson 1993); 70% in Thailand (Busch et al. 1993); 22% in Brazil (Jannuzzi et al. 1991); and 35% in India (Nadel, Kothari & Gopinath 1991).

Motors. Motors are the largest end user of electricity in most countries. An analysis for the U.S. estimated that electric motor energy use in industry and buildings can be reduced by 16 to 40% by applying a variety of the measures discussed, especially variable-speed drives (Nadel et al. 1991). Another study estimated an even higher savings potential (for motors in all sectors) of 44 to 60% (Lovins et al. 1989).

Cooking. Cooking is the largest home energy use in most developing countries, but a relatively minor end use in the industrialized countries and the EE/FSU. In the industrialized countries, there is relatively limited potential (10 to 20%) to improve the technical energy efficiency of primary cooking devices. In developing countries, use of improved wood-burning stoves can reduce the fuel used for cooking a standard meal by 30 to 40% (Leach and Gowan 1987; Levine et al. 1996). Switching to a kerosene stove results in an additional 50% fuel savings (Dutt and Ravindranath 1993).

Office equipment. It is estimated that energy-saving power management software for personal computers, monitors, printer, copiers, and fax machines can save 22% of projected U.S. commercial sector electricity use by these products in 2010. Use of advanced technologies such as LCD screens and CMOS (Complementary Metal Oxide Semiconductor) chips coupled with the use of less energy-intensive printers can lead to savings of almost 60% (Koomey et al. 1995).

Building energy management systems. Building energy management and control systems regulate the operation of heating, ventilation, air conditioning, and lighting in buildings. It is estimated that computerized energy-management equipment typically provides 10 to 20% energy savings (Geller 1988). A study in Texas identified potential annual energy savings of 23% of total building energy costs in 35 commercial buildings and 104 schools (Liu et al. 1994).

Building commissioning, operation, and maintenance. A major problem in all commercial buildings—even those that are designed and built to be energy-efficient—is that they rarely perform as intended. There is a need to test buildings before or during early occupancy to verify that the design and equipment are performing correctly (''commissioning''). Periodic monitoring and maintenance to assure continued correct performance is required during the lifetime of the building. Period monitoring can save between 15 and 30% of annual energy use (Claridge et al. 1994).

SCENARIOS OF GLOBAL BUILDINGS ENERGY USE

Three scenarios for buildings energy use during the period 1990-2020 were developed (see Table 5) (WEC 1995). The business-as-usual scenario assumes continued use of the mix of current technologies and reflects current trends. The state-of-the-art scenario assumes the replacement of existing stock with the current most efficient technologies available. The ecologically driven/advanced technology scenario assumes a more rapid uptake of current state-of-the-art technologies and adoption of some advanced technologies that are not yet commercially available.

Under the business-as-usual scenario, global buildings energy use grows at a rate of 2.4% per year, increasing from 103 EJ in 1990 to 207 EJ in 2020. Of the doubling in energy use in buildings projected to occur by 2020, 21 EJ is in the industrialized countries, 45 EJ is in the EE/FSU, and 38 EJ is in developing countries.

In the state-of-the-art scenario, energy demand in buildings increases from 103 EJ in 1990 to 171 EJ in 2020, at a rate of 1.7% per year. Average annual growth is 0.8% for industrialized countries, 2.7% for EE/FSU, and 2.8% for developing countries. Overall, 41% of energy growth occurs in the EE/FSU, 36% in developing countries, and 23% in the industrialized countries.

In the ecologically driven/advanced technology scenario, world energy demand in buildings grows at a rate of 1.0% per year, from 103 EJ in 1990 to 140 EJ in 2020. Annual growth rates are 0.4% for industrialized countries, 1.7% for EE/FSU, and 1.9% for developing countries.

Similar scenarios have been developed for energy use in the industrial, transport, and agricultural sectors (see Table 6) (Worrell et al. 1996). Under the business-as-usual and ecologically driven/advanced technology scenarios, buildings energy use grows from 33% of world primary energy use in 1990 to 38% in 2020. In contrast, industrial energy use drops from 44% in 1990 to 37% in 2020.[4] Thus, these scenarios suggest that energy use for buildings may be greater than energy use in the industrial sector in 2020.

The highest average annual growth rates are seen in the transport sector. Annual growth in the buildings sector is expected to be higher than growth in the industrial sector, the agricultural sector, and in the world as a whole. Relatively high average annual growth rates are seen in both the EE/FSU and in the developing countries in all three scenarios. In the developing countries, this growth is based on growing populations and increased residential and commercial construction. In the EE/FSU, high growth in this sector a result of a shift from a heavy industrial to a more consumer-based economy, with considerable growth in the number and floor area of residential and commercial buildings in the region.

ENERGY-EFFICIENCY POLICY INSTRUMENTS

Both the state-of-the-art and the ecologically driven/advanced technology scenarios rely upon increased use of energy-efficient technologies and practices to keep buildings energy use below the doubling expected under the business-as-usual scenario. To realize the energy savings inherent in such scenarios, there are at least four essential requirements: (1) real increases in energy prices; (2) effective use of energy efficiency policies; (3) major programs to transfer knowledge, technology, and tools for transforming markets to the EE/FSU and developing countries; and (4) continued efforts to pursue research and development in technologies and practices to increase energy efficiency in buildings.

Real increases in energy prices

Typically worldwide consumer energy prices do not reflect the full costs of energy production, transmission, and distribution (as well as environmental costs) because these prices are often subsidized. In 1991, world fossil fuel subsidies reduced consumer energy prices by 20 to 25%. Subsidies are greatest in the developing countries and in EE/FSU, with the bulk of global fossil fuel subsidies in the latter region (Kozloff and Shobowale 1994). Between 1979 and 1991, electricity prices in developing countries were on average

Table 5. ***Estimated Primary Energy Consumption in Residential and Commercial Buildings for Three Scenarios for the Year 2020 (in EJ)***

Sector/Region	Energy 1990	Business-as-Usual Energy 2020	Business-as-Usual Growth (%/yr)	State-of-the Art Energy 2020	State-of-the Art Growth (%/yr)	Ecologically Driven/ Advanced Technology Energy 2020	Ecologically Driven/ Advanced Technology Growth (%/yr)
Residential							
Industrialized countries	37	44	0.7	42	0.5	39	0.3
EE/FSU	15	42	3.5	32	2.6	24	1.6
Developing countries	15	43	3.6	32	2.6	25	1.7
Total	66	129	2.3	106	1.6	87	0.9
Commercial							
Industrialized countries	24	38	1.4	35	1.1	30	0.6
EE/FSU	8	26	4.0	19	2.9	14	1.9
Developing countries	4	14	4.3	11	3.4	8	2.3
Total	37	79	2.6	65	1.9	53	1.2
All Buildings							
Industrialized countries	61	82	1.0	77	0.8	69	0.4
EE/FSU	23	68	3.7	51	2.7	38	1.7
Developing countries	19	57	3.7	43	2.8	33	1.9
TOTAL	103	207	2.4	171	1.7	140	1.0

Source: WEC 1995.

40% lower than electricity prices in industrialized countries. The disparity grew over the period from an average difference of 2.3 cents/kWh (1986 US$) between 1979 and 1984 to an average difference of 3.4 cents/kWh between 1985 and 1991. A survey of electricity prices of over 60 developing countries found that electricity subsidies grew during the 1980s (World Bank 1990). In 1991, the average electricity price in developing countries was 4 cents/kWh while the marginal costs were about 10 cents/kWh (Heidarian and Wu 1994). Comparison of retail electricity prices to the marginal costs of supply found ratios of 50 to 60% in China, 66% in Brazil, 29% in Poland, and 63% in Mexico in the late 1980s (Bates 1993).

Energy prices in some areas are beginning to more closely reflect costs in response to commercialization of the electricity industry and investment by independent power producers (Anderson 1995). For example, Thailand has essentially eliminated across-the-board subsidies, electricity prices in Korea have reached the level of costs, and energy prices in Poland are being adjusted to reflect full economic costs (World Bank 1993b; Larsen and Shah 1992; Polish Ministry of Industry and Trade 1992). In Chile, energy prices rose following power sector privatization and reforms that eliminated government intervention in setting prices. In Colombia, Peru, Jamaica, Costa Rica, and Bolivia, privatization of part or all of the energy supply industry is currently taking place, and is expected to lead to deregulation of electricity prices in these countries (Bacon 1995). After many years of trying, the Chinese government initiated significant energy price reforms starting in 1993. By 1994, 90% of all coal was no longer subject to price regulations, and the price of this coal reflected most of the supply costs. In 1993, electricity price reforms in China led to prices for new power projects based on the cost of generation plus a return on capital. This change, plus higher prices for power from exist-

Table 6. Estimated World Primary Energy Consumption for Three Scenarios for the Year 2020 (in EJ)

Sector	Energy 1990	Business-as-Usual Energy 2020	Business-as-Usual Growth (%/yr)	State-of-the-Art Energy 2020	State-of-the-Art Growth (%/yr)	Ecologically Driven/ Advanced Technology Energy 2020	Ecologically Driven/ Advanced Technology Growth (%/yr)
Buildings	103	207	2.4	171	1.7	140	1.0
Industry	136	205	1.4	173	0.8	139	0.1
Transport	61	137	3.3	108	2.3	82	1.2
Agriculture	9	16	2.1	13	1.3	12	0.8
Total	309	566	2.0	465	1.4	371	0.6

Source: Worrell et al. 1996.

ing power plants, means that electricity prices may in time approach deregulated, marginal costs (Wang, Sinton & Levine 1995).

The international lending organizations, led by the World Bank, have been strong proponents of energy price deregulation in developing countries. The largest hurdle to such price increases involves the impact on low-income consumers. This is a serious problem in many developing countries, since low-income urban families often spend a substantial portion of their income on energy. Recent surveys in urban areas of developing countries show the poorest 20% of the population spending 20% of their income on energy (Barnes et al. 1994). The impacts of higher energy prices on the urban poor can be mitigated in several ways. A low tariff for the lowest consumption block can be instituted, the so-called ''lifeline rate'' in the U.S. Subsidies for energy efficiency improvements can be targeted at low-income urban dwellers. Such subsidies could moderate an increase in energy services. Because the lowest income population consumes a relatively small proportion of total energy in developing countries, revenue obtained from energy price increases would be expected to far exceed any subsidies to the low-income consumers.

Energy efficiency policies

Energy efficiency policies include use of financial incentives (direct subsidies, low-interest loans, and tax credits), building codes, appliance standards, information programs, utility integrated resource planning (including demand-side management), and market-aggregation (or market-pull) programs. Such policies accelerate adoption of energy-efficient technologies by addressing factors that often hinder implementation (Levine et al. 1996; Worrell et al. 1996).

Financial incentives to increase energy efficiency account for the majority of public-sector spending on energy efficiency in most countries. For example, in the U.S., 84% ($230 million in 1991) of the Department of Energy's budget is spent on grants for retrofits to existing buildings (U.S. Congress, OTA 1992a). Most countries provide large incentives for electricity supply, leading to lower energy prices and disincentives to investment in energy efficiency. Recently electric utilities in some industrialized countries have provided targeted financial incentives for specific energy efficiency measures (e.g., energy-efficient lighting retrofits for commercial buildings). Other financial incentives have been provided from government and utility funds to provide a ''carrot'' for the rapid commercialization of energy-efficient technology (e.g., more efficient refrigerators).

Building codes, which require minimum levels of energy efficiency in new construction, were adopted in at least 30 countries as of 1992 (Janda and Busch 1993). Such codes range from voluntary goals to specific, comprehensive requirements directed toward savings in all areas of buildings energy use.

Appliance energy efficiency standards have been aggressively pursued in the U.S. Since the passage of the National Appliance Energy Conservation Act (NAECA) in 1987, the federal government has mandated standards for such products as refrigerators, water heaters, furnaces and boilers, central air conditioners and heat pumps, room air conditioners, clothes washers, dryers, dishwashers, oven, and lighting ballasts. The standards already in place are expected to reduce energy consumption in the U.S. by 1.1 EJ/year by the year 2000 with a cumulative savings of 45 EJ by 2015 (McMahon, Pickle, and Turiel 1996).

Information programs are designed to assist energy consumers in understanding and employing technologies and practices to use energy more efficiently. These programs aim to increase consumers' awareness, acceptance, and use of particular technologies or utility energy-conservation programs. Examples of information programs include educational brochures, hot lines, videos, home energy-rating systems, design-assistance programs, audits, energy-use feedback programs, and labeling programs. Such programs tend to be most effective when coupled with other types of policies (e.g., financial incentives).

Utility integrated resource planning (IRP), which has been applied primarily in industrialized countries, is used to assess all options for meeting energy service needs, including utility-sponsored end-use efficiency or demand-side management (DSM) programs. DSM programs in the U.S., which are now on the decline due to the current restructuring efforts, have promoted a wide variety of end-use efficiency measures that are less costly than energy supply additions. Thailand launched a multi-sectoral DSM program to invest US$ 189 million over five years (estimated to be half the cost of new supply) that is aimed at saving as much as 1400 MW of peak demand and 3400 GWh annually (Silver 1996). Utilities in Mexico and Brazil have been active in DSM programs. Brazil's national electricity conservation program (PROCEL) is estimated to have saved the equivalent of a 250 MW power plant (Tavares 1995).

An innovative policy mechanism to transform the market toward the production and consumption of more efficient products is ''*market aggregation,*'' or the organized use of buyer demand to stimulate new supplies of a product or service. NUTEK, the Swedish National Board for Industrial and Technical Development, has successfully undertaken several technology-procurement projects for more efficient refrigerator-freezers, laundry equipment, high-performance windows, computer monitors, office lighting, electronic ballasts and other products (Harris 1995; Lewald and Bowie 1993). In the U.S., recent activities include a Federal ''Procurement Challenge,'' which directs all federal agencies to purchase energy-efficient products that are in the top 25% of the market. In the U.S., a series of ''green'' programs have been developed and implemented by the federal government to encourage consumers and/or manufacturers to purchase or produce more efficient technologies (U.S. EPA 1994).

Programs to transfer knowledge, technology, and tools to the EE/FSU and developing countries

Efforts to promote energy efficiency have illuminated the need for closer collaboration between countries, especially in the areas of technological innovation, strengthening of local capacity, and increased training and information. Technological solutions from industrialized countries may not be applicable to EE/FSU and developing countries without additional applied research and development (R&D). The technical operating environment in these countries is often different from that of industrialized countries. For example, poorer power quality, higher environmental dust loads, and higher temperatures and humidity require different energy efficiency solutions than successful solutions in industrialized country conditions. Technologies that have matured and been perfected for the scale of production and market conditions in the industrialized countries are not necessarily the best choice for the smaller scale of production or different operating environments often encountered in other countries.

Another important arena for cooperation between countries involves the development and strengthening of local technical and policy-making capacity in developing countries. There is inadequate attention to the development of institutional capacity and technical and managerial skills needed to make and implement energy efficiency policy. In some cases, new institutions (such as the energy-efficiency centers that have been created in Russia, Eastern Europe, and China) are needed to make certain that energy efficiency and alternative energy investments are treated equally with traditional supply investments and make it possible to ''bundle'' a large number of demand-side investments into a large investment so that they can attract capital (Gadgil & Sastry 1992).

Finally, there is a great need for increased training and information for EE/FSU and developing countries. Training efforts need to address all major elements of energy efficiency, including in-depth studies in engineering, economics, public policy, and management. Such training needs to be both theoretical and practical. Substantial assistance from industrialized countries in creating and conducting training coursed may be necessary.

Research and development for energy-efficient technologies and practices

Research and development (R&D) is the process that generates and refines new energy-efficient technologies. Different stages of R&D can be distinguished: basic research, applied research, experimental work, and demonstration (OECD 1993). In general, only large industries and governments have the resources and interest to conduct R&D. The buildings industry, in contrast, is highly fragmented. For example, single-family residential construction firms in the United States alone number more than 90,000 (U.S. Congress, OTA 1992a). This fragmentation makes it difficult for the industry to pool its resources to conduct R&D. There is, however, R&D carried out by suppliers to the construction industry (e.g., insulation and window manufacturers, heating, ventilation, and cooling (HVAC) equipment, and appliance manufacturers).

Government-sponsored R&D has played a key role in developing and commercializing energy-efficient technologies. Low-e windows, electronic ballasts, and high-efficient refrigerator compressors are examples of widely use technologies whose origins can be traced to public-sector funding of research. Maintaining public support for energy-efficiency R&D is essential to ensure the availability of the next generation of energy-efficient technologies.

Currently, widespread cutbacks in energy R&D, both public and private, threaten the continuity of the R&D effort. Between 1977 and 1992, public non-defense energy R&D funds decreased by 65% in the U.S. and by 33% in other OECD countries (Williams & Goldemberg 1995). Private energy R&D is expected to decline, particularly as a result of utility and industry efforts to reduce costs to compete in more open markets. In 1990, less than 6% of the energy R&D budget of IEA countries was spent on energy conservation and 6% was spent on renewable energy, while spending on nuclear fusion (46%), nuclear fission (11%) and fossil energy (18%) dominated (IEA 1994b).

Williams and Goldemberg (1995) assert that R&D should be a *sustained activity*, because it takes large resources to build up a knowledge infrastructure, and the key to success is so-called ‘‘tacit knowledge’’ (unwritten knowledge obtained by experience), which is easily lost (Dosi 1988). They also advocate a *diversified portfolio*, as not all R&D will lead to commercialization. Giving priority to relatively small-scale technologies like energy efficiency and renewables allows a diversified portfolio with limited budgets. A diversified portfolio also makes it possible to meet the different R&D demands of industrialized and developing countries. Finally, they believe *long-term research* should be protected against the often more costly demonstration and commercialization initiatives. Sustainable energy policies should secure continuity of R&D funds by appropriate funding mechanisms, by public funding of valuable R&D that it is not executed by industry, and cost-sharing of R&D (U.S. DOE 1995) where both private and public benefits are produced.

CONCLUSIONS

Recent studies found that without increased use of energy-efficient technologies and practices, global primary energy use for buildings will double by 2020. These studies also found that by 2020, global buildings energy demand is likely to be greater than energy use in any of the other sectors, including the industrial sector which has typically dominated world energy use.

Even aggressive scenarios that include the use of advanced technologies coupled with ecologically-driven policies are not expected to keep buildings energy use at 1990 levels due to the high demand growth expected in the developing countries and the EE/FSU. However, the ecologically driven/advanced technology scenario shows reductions in energy growth of 65% from a business-as-usual case. Realizing such savings will require aggressive use of energy-efficiency policies, major programs to transfer knowledge, technology, and tools for transforming markets to the EE/FSU and developing countries, and continued efforts to pursue research and development in technologies and practices to increase energy efficiency in buildings.

ACKNOWLEDGMENTS

This work was supported by the Deputy Undersecretary of the Office of Policy, Planning, and Analysis of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ENDNOTES

1. We recognize that these divisions hide significant regional differences, especially in the category of developing countries. Future work will further disaggregate these three regions, more closely grouping countries in terms of level of economic development.

2. Unless otherwise noted, all energy data in this section exclude traditional fuels (crop wastes, dung, etc.) and include losses from electricity generation, transmission, and distribution. Converting the end use of energy into its primary equivalent is a difficult accounting task since each country has a different fuel mix, which is transformed, transported, and consumed. Many of the energy-consumption statistics cited in the study are based on end-use consumption statistics collected by the International Energy Agency (IEA). We assigned an average approximation for the conversion of electricity. We use a conversion factor for primary energy into electricity of 3.1 for OECD countries and 3.5 for non-OECD countries. Such an approximation inaccurately reflects the situation of many individual countries. Also, the assignment of one conversion factor for the whole time period of the study does not capture improvements of generation efficiency. In future analyses, we intend

to modify this assumption and include the effects of efficiency improvements in electricity generation.

3. 1 EJ = 23.833 Mtoe = 1/1.054 quadrillion Btu.

4. For the state-of-the-art scenario, buildings and industrial energy use are both 37% of world primary energy use in 2020.

5. For more information on subsidies and efforts at price reform, see Worrell et al. 1996.

REFERENCES

Anderson, D. 1995. ''Energy Efficiency and the Economists: The Case for a Policy Based on Economic Principles.'' *Annual Review of Energy and the Environment* 20, 495–511.

Atkinson, B., McMahon, J.E., Mills, E., Chan, P., Chan, T.W., Eto, J.H., Jennings, J.D, Koomey, J.G., Lo, K.W., Lecar, M., Price, L., Rubenstein, F., Sezgen, O., and Wenzel, T. 1992. *Analysis of Federal Policy Options for Improving United States Lighting Energy Efficiency: Commercial and Residential Buildings*. Lawrence Berkeley National Laboratory Report No. LBL-31469. Berkeley, California.

Bacon, R.W. 1995. ''Privatization and Reform in the Global Electricity Supply Industry.'' *Annual Review of Energy and the Environment* 20, 119–143.

Barnes, D.F., Openshaw, K., Smith, K.R., and Van der Plas, R. 1994. ''What Makes People Cook with Improved Biomass Stoves?'' World Bank Technical Paper Number 242, Washington D.C.

Bates, R.W. 1993. ''The Impact of Economic Policy on Energy and the Environment in Developing Countries.'' *Annual Review of Energy and the Environment* 18, 479–506.

Bodlund, B., Mills, E., Karlsson, T., and Johansson, T.B. 1989. ''The Challenge of Choices: Technology Options for the Swedish Electricity Sector.'' In Johansson, T.B., Bodlund, B., and Williams, R.H. (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications*. Lund, Sweden: Lund University Press.

British Petroleum. 1994. *BP Statistical Review of World Energy.* London: British Petroleum.

Brown, R. 1994. ''Estimates of the Achievable Potential for Electricity Efficiency Improvements in U.S. Residences.'' In *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings (Vol. 7).* Washington, D.C.: American Council for an Energy-Efficient Economy.

Busch, J.F. (Lawrence Berkeley National Laboratory). 1995. Personal communication.

Busch, J.F., du Pont, P., and Chirarattananon, S. 1993. ''Energy-Efficient Lighting in Thai Commercial Buildings.'' *Energy: The International Journal.* 18 (2): 197–210.

Claridge, D., Haberl, J., Liu, M., Houcek, J., and Athar, A. 1994. ''Can You Achieve 150% of Predicted Retrofit Savings? Is It Time for Recommissioning?'' In *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings (Vol. 5).* Washington D.C.: American Council for an Energy-Efficient Economy.

Cooper, C. and Schipper, L. 1991. *The Efficiency of Energy Use in the USSR.* Lawrence Berkeley National Laboratory Report No. LBL-29830. Berkeley, California.

de Beer, J.G., van Wees, M.T., Worrell, E., and Blok, K., 1994. *ICARUS-3: The Potential of Energy Efficiency Improvement in the Netherlands up to 2000 and 2015*. Utrecht, The Netherlands: Department of Science, Technology & Society, Utrecht University.

de Buen, O. (Lawrence Berkeley National Laboratory). 1995. Personal communication.

Dosi, G. 1988. ''The Nature of the Innovative Process.'' In Dosi, G., Freeman, C., Nelson, R., Silverberg, G., and Soete, L. (eds.), *Technical Change and Economic Theory.* London: Pinter Publishers.

Dutt, G. 1993. *Energy End Use—An Environmentally Sound Development Pathway.* Manila: Asian Development Bank.

Dutt, G. and Ravindranath, N.H. 1993. ''Bioenergy: Direct Applications in Cooking.'' In Johansson, T.B. et al. (eds.) *Renewable Energy: Sources for Fuels and Electricity*, Washington D.C.: Island Press.

Ebel, W. 1990. *Energiesparpotentiale im Gebauedebestand.* Darmstadt, Germany: Institut für Wohnen und Umwelt.

EBRD (European Bank for Reconstruction and Development). 1994. *Transition Report: Economic Transition in Eastern Europe and the former Soviet Union*. London: EBRD.

EIA (Energy Information Administration). 1990. *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*. United States Department of Energy, SR/NES/90-02. Washington, D.C., USA.

EIA (Energy Information Administration). 1994. *Commercial Buildings Characteristics: 1992*. (DOE/EIA-0246(92). Washington, D.C.: U.S. Government Printing Office.

Faruqui, A., Mauldin, M., Schick, S., Seiden, K., and Wikler, G. 1990. *Efficient Electricity Use: Estimates of Maximum Energy Savings*. Palo Alto, Calif.: Electric Power Research Institute.

Friedmann, R. (Lawrence Berkeley National Laboratory). 1995. Personal communication.

Gadgil, A.J and Sastry, M.A. 1992. ''Stalled on the Road to the Market: Analysis of Field Experience with a Project to Promote Lighting Efficiency in India.'' *Energy Policy* 22 (2): 151–162.

Geller, H.S. 1995. ''Progress in Energy Efficiency of Residential Appliances and Space-Conditioning Equipment.'' *Energy Sources: Conservation and Renewables*. American Institute of Physics, New York.

Geller, H.S. 1991. *Efficient Electricity Use: A Development Strategy for Brazil.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Geller, H.S. and Miller, P. 1988. *1988 Lighting Ballasts Efficiency Standards: Analysis of Electricity and Economic Savings*. Washington D.C. and Berkeley CA: American Council for an Energy-Efficient Economy, Report No. A883.

Harris, J. 1995. *Innovative Market Mechanisms for Climate Change Technologies*. Lawrence Berkeley National Laboratory Draft Report. Berkeley, California.

Huang, Y.J. 1989. *Potentials for and Barriers to Building Conservation in China.* Lawrence Berkeley National Laboratory Report No. LBL-27644. Berkeley, California.

International Energy Agency, 1994a. *Energy Statistics and Balances (OECD 1960–92/non-OECD 1971–92)*. Paris: International Energy Agency.

International Energy Agency, 1994b. *Energy Policies of IEA Countries: 1993 Review*. Paris: IEA/OECD.

Janda, K.B. and Busch, J.F. 1993. *Worldwide Status of Energy Standards for Buildings*. Lawrence Berkeley National Laboratory Report No. LBL-33587, Berkeley, California.

Jannuzzi, G.D.M., Gadgil, A., Geller, H., and Sastry, M.A. 1991. ''Energy-Efficient Lighting in Brazil and India: Potential Issues of Technology Diffusion.'' In *Proceedings of the 1st European Conference on Energy-Efficient Lighting*. Stockholm, Sweden.

Jannuzzi, G.D.M. and Schipper, L. 1991. ''The Structure of Electricity Demand in the Brazilian Household Sector.'' *Energy Policy* 19 (9): 879–891.

Kaan, H.F., Svobodova, M., van der Linden, N.H., and Kosdy, M. 1995. *Conservation Stimulation Programme for the Slovak Republic, Phase 2: Energy Conservation in Buildings*. Petten, The Netherlands: Netherlands Energy Research Foundation.

Ketoff, A., Bartlett, S., Hawk, D., and Meyers, S. 1987. *Residential Energy Demand in Six OECD Countries: Historic Trends and Future Directions*. Lawrence Berkeley National Laboratory Report No. LBL-22642. Berkeley, California.

Koomey, J., Atkinson, C., Meier, A., McMahon, J.E., Boghosian, S., Atkinson, B., Turiel, I., Levine, M.D., Nordman, B. and Chan, P. 1991. *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector*. Lawrence Berkeley National Laboratory Report No. LBL-30477. Berkeley, California.

Koomey, J., Piette, M.A., Cramer, M., and Eto, J. 1995. ''Efficiency Improvements in U.S. Office Equipment: Expected Policy Impacts and Uncertainties.'' Lawrence Berkeley National Laboratory Report No. LBL-37383. Berkeley, California.

Kozloff, K. and Shobowale, O. 1994. *Rethinking Development Assistance for Renewable Electricity*. Washington, D.C.: World Resources Institute.

Krause, F., Olivier, D., and Koomey, J. 1995. *Negawatt Power: The Cost and Potential of Electrical Efficiency Resources in Western Europe*. Prepared for the Dutch Ministry of Housing, Physical Planning, and Environment. El Cerrito, Calif.: International Project for Sustainable Energy Paths.

Larsen, B. and Shah, A. 1992. ''World fossil fuel subsidies and global carbon emissions.'' Background paper for *World Development Report 1992.* Policy Research Working Paper Series, WPS 1002. World Bank, Washington, D.C.

Leach, G. and Gowen, M. 1987. *Household Energy Handbook.* Washington D.C.: The World Bank.

Levine, M.D., Akbari, H., Busch, J., Dutt, G., Hogan, K., Komor, P., Meyers, S., Tsuchiya, H., Henderson, G., Price, L., Smith, K.R., and Siwei, L. 1996. ''Mitigation Options for Human Settlements.'' Chapter 22 in: The *IPCC Second Assessment Report. Vol. 2 Scientific and Technical Analyses of Impacts, Adaptations and Mitigation of Climate Change.* Cambridge, UK: Cambridge University Press.

Levine, M.D, Gadgil, A., Meyers, S., Sathaye, J., Stafurik, J., and Wilbanks, T. 1991. *Energy Efficiency, Developing*

Nations, and Eastern Europe. Washington, D.C.: International Institute for Energy Conservation.

Levine, M.D., Koomey, J.G., Price, L., Geller, H., and Nadel, S. 1995. ''Electricity and End-Use Efficiency: Experience with Technologies, Markets, and Policies Throughout the World.'' *Energy: The International Journal* 20 (1): 37–61.

Lewald, A. and Bowie, R. 1993. ''What Is Happening with the Swedish Technology Procurement Program?'' In Ling, R. and Wilhite, H. (eds.) *Proceedings of the 1993 ECEEE Summer Study: The Energy Efficiency Challenge for Europe*. Oslo: ECEEE.

Liu, F. 1993. *Energy Use and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Lawrence Berkeley National Laboratory Report No. LBL-33867. Berkeley, California.

Liu, M., Houcek, J., Athar, A., Reddy, A., Claridge, D., and Haberl, J. 1994. ''Identifying and Implementing Improved Operation and Maintenance Measures in Texas LoanSTAR Buildings.'' In *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings (Vol. 5)*. Washington, D.C. and Berkeley, CA: American Council for an Energy-Efficient Economy.

Lovins, A., Neymark, J., Flanigan, T., Kiernan, P., Bancroft, B., and Shepard, M. 1989. *The State of the Art: Drivepower*. Snowmass, Colorado: Rocky Mountain Institute.

Masera, O., Friedmann, R., and de Buen, O. 1993. *Residential Energy Use in Mexico: Structure, Evolution, Environmental Impacts, and Savings Potential*. Lawrence Berkeley National Laboratory Report No. LBNL-34174. Berkeley, California.

McMahon, J.E., Pickle, S.J., and Turiel, I. 1996. ''Assessing Federal Appliance and Lighting Performance Standards.'' In *1996 ACEEE Summer Study on Energy Efficiency in Buildings.* Asilomar, CA: American Council for an Energy-Efficient Economy.

Meyers, S., Khrusch, M., L'Heureux, M.A., Martinot, E., Salay, J., Schipper, L., Chyrczakowski, S., and Voracova, Z. 1995. *The Residential Space Heating Problem in Eastern Europe: The Context for Effective Strategies*. Lawrence Berkeley National Laboratory Report No. LBID-2095. Berkeley, California.

Meyers, S., Salay, J., and Schipper, L. 1994a. ''Energy Use in a Transitional Economy: The Case of Poland.'' *Energy Policy* 22 (8): 699–713.

Meyers, S., Schipper, L., and Salay, J. 1994b. ''Energy Use in Poland: An International Comparison.'' *Energy* 19 (6): 601–617.

Meyers, S., Goldman, N., Martin, N., Friedmann, R. 1993. ''Prospects for the Power Sector in Nine Developing Countries.'' *Energy Policy* (21) 11: 1123–1132

Meyers, S., Tyler, S., Geller, H., Sathaye, J., and Schipper, L. 1990. *Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries*. Lawrence Berkeley National Laboratory Report No. LBL-29678. Berkeley, California.

Morgan, D. 1992. ''Energy Efficiency in Buildings: Technical Options.'' Congressional Research Service (CRS) Report No. 92-121 SPR. Washington D.C.: Library of Congress.

Nilsson, P.-E. and Aronsson, S. 1993. ''Energy-Efficient Lighting in Existing Non-Residential Buildings: A Comparison of Nine Buildings in Five Countries.'' *Energy: The International Journal* 18 (2): 115–122.

Nadel, S., Kothari, V. and Gopinath, S. 1991. *Opportunities for Improving End-Use Electricity Efficiency in India.* Washington D.C. and Berkeley, Calif.: American Council for an Energy-Efficient Future.

Nadel, S., Shepard, M., Greenberg, S., Katz, G., and de Almeida, A.T. 1991. *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities.* Washington D.C. and Berkeley, Calif.: American Council for an Energy-Efficient Economy.

OECD (Organization for Economic Cooperation and Development). 1993. *Frascati Manual: Proposed Standard Practice for Surveys of Research and Experimental Development.* Paris: OECD.

Polish Ministry of Industry and Trade. 1992. *Energy Policy of Poland and the Draft Programme to the Year 2010*. Energy Information Center, Warsaw.

Rosenfeld, A.H., Atkinson, C., Koomey, J., Meier, A., Mowris, R.J., and Price, L. 1993. ''Conserved Energy Supply Curves for United States Buildings.'' *Contemporary Policy Issues* 11: 45–68.

Sathaye, J. and Tyler, S. 1991. ''Transitions in Household Energy Use in Urban China, India, The Philippines, Thailand, and Hong Kong.'' *Annual Review of Energy and the Environment* 16: 295–335.

Schipper, L. and Martinot, E. 1993. *Electricity Demand in Former Soviet Republics: Constraints and Opportunities.*

Prepared for the International Energy Agency, Office of Long-Term Co-operation and Policy Analysis.

Schipper, L. and Meyers, S. with Howarth, R. and Steiner, R. 1992. *Energy Efficiency and Human Activity: Past Trends, Future Prospects*. Cambridge, UK: Cambridge University Press.

Schipper, L., Haas, R., and Sheinbaum, C. 1996. ''Recent Trends in Residential Energy Use in OECD Countries and Their Impact on Carbon Dioxide Emissions: A Comparative Analysis of the Period 1973–1992.'' *Mitigation and Adaptation Strategies for Global Change.* Forthcoming.

Sezgen, O. and Schipper, L. 1995. *Comparison of Commercial Sector End-Use Energy and Electricity Use in OECD Countries: Growth of Electricity Use*. Lawrence Berkeley National Laboratory Report No. LBL-36999. Berkeley, California.

Silver, D. (International Institute for Energy Conservation, Asia). 1996. Personal communication.

Sinton, J.E. (Lawrence Berkeley National Laboratory). 1995. Personal communication.

Tavares, P C. 1995. ''The Brazilian Electric Energy Conservation Program— PROCEL'' Presentation to the Annual Meeting of the ESMAP Consultative Group, The World Bank, May 24–25, Washington D.C.

Thailand Load Forecasting Subcommittee. 1993. *Load Forecast for the Thailand Electric System*.

Tyler, S., Sathaye, J., and Goldman, N. 1994. ''Special Issue: Energy Use in Asian Cities,'' *Energy: The International Journal* 19 (5).

United Nations, 1994. *Annual Populations, 1950–2050* (diskette), NY: U.N. Population Division.

U.S. Congress, Office of Technology Assessment, 1992a. *Building Energy Efficiency*. (OTA-E-518). Washington, D.C.: U.S. Government Printing Office.

U.S. Congress, Office of Technology Assessment, 1992b. *Fueling Development*. (OTA-E-516). Washington, D.C.: U.S. Government Printing Office.

U.S. Congress, Office of Technology Assessment, 1993. *Energy Efficiency Technologies for Central and Eastern Europe*. Washington, D.C.: U.S. Government Printing Office.

U.S. DOE (Department of Energy). 1995. *Energy R&D: Shaping Our Nation's Future in a Competitive World*. Washington, D.C.: U.S. DOE.

U.S. Environmental Protection Agency. (1994) *The Climate is Right for Action: Voluntary Programs to Prevent Atmospheric Pollution*. EPA 430-K-94-004, Washington, D.C.: EPA.

Wang, Q., Sinton, J.E., and Levine, M.D. 1995. *China's Energy Conservation Policies and their Implementation, 1980 to the Present and Beyond.* Draft Lawrence Berkeley National Laboratory Report. Berkeley, California.

Williams, R.H. and Goldemberg, J. 1995. *A Small Carbon Users' Fee for Accelerating Energy Innovation* (review draft). Princeton, New Jersey: Center for Energy and Environmental Studies, Princeton University.

World Bank. 1990. *Review of Electricity Tariffs in Developing Countries During the 1980s.* Energy Development Division, Industry and Energy Department, World Bank, Washington, D.C.

World Bank, 1993a. *World Development Report 1993*. Oxford, U.K.: Oxford University Press.

World Bank, 1993b. *Energy Efficiency and Conservation in the Developing World: the World Bank's Role*. World Bank Policy Paper, World Bank, Washington, D.C.

World Energy Council. 1995. *Efficient Use of Energy Utilizing High Technology: An Assessment of Energy Use in Industry and Buildings*. Prepared by Levine, M.D., Martin, N., Price, L., and Worrell, E. London: WEC.

Worrell, E., Levine, M., Price, L., Martin, N., van den Broek, R., Blok, K. 1996. *Potentials and Policy Implications of Energy and Material Efficiency Improvement: A Report to the United Nations Division for Sustainable Development.* Utrecht, The Netherlands: Department of Science, Technology & Society, Utrecht University.