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Mitigation options for residential/commercial buildings

Contents

Executive Summary

The buildings sector was responsible for 32% of all CO_2 emissions in 2004. By 2030 this share could grow to 35-42%, comprising 15.6 to 11.8 Gt CO_2 emissions. The largest growth is expected in Asia, as well as in the Middle East/North Africa or North America (Scenarios A1 and B2, respectively).

Greenhouse Gas (GHG) emissions from buildings can be cut in three major ways: by reducing energy consumption in buildings, switching to low-carbon fuels including a higher share of renewable energy, and controlling the emissions of non-CO_2 GHGs. This chapter focuses on opportunities to improve energy efficiency and building-level utilization of renewable energy.

The key conclusion of the chapter is that substantial reductions in CO_2 emissions from energy use in buildings can be achieved over the coming years, because of the considerable experience in a wide variety of technologies, practices, and systems for energy efficiency and an equally rich experience with policies and programs that promote energy efficiency in buildings. These savings can be achieved in ways that reduce life-cycle costs, thus providing reductions in CO_2 emissions that have a net negative cost (generally higher first cost but lower operating cost, for a net savings in 5-7 years or less).

There is some divergence of views about how much savings are possible in buildings by 2030. A typical value is 30%-40% improvement in energy efficiency compared to a business-as-usual baseline. This does not imply the same percentage decline in total energy use or greenhouse gas emissions for buildings over this same period, for several reasons: 1) there is no assurance that policies will be enacted and implemented to achieve such savings, 2) even if they were, slow turnover of buildings and larger, installed equipment would delay some fraction of the savings, and 3) energy demand growth in buildings driven, by a number of factors, may at least partly offset the reduction in energy use resulting from these measures.

For example, Scenario A1 (a scenario that leads to high energy growth) includes 2.5% average annual energy growth in buildings between 2000 and 2030. The potential savings resulting from 30-40% efficiency gains is 1.2% - 1.7% per year (which should be reduced to perhaps 1% per year due to slow turnover of buildings). Thus, in Scenario A1, energy use in buildings would continue to grow at ~1.5% during the period. For Scenario B2, average annual energy use in buildings is 1.5%. In this case, average annual growth in energy use in buildings could be as low as ~0.5%. Converting this to CO_2 emissions would also account for decarbonization of energy sources – primarily electricity for buildings – which for Scenario B2 could lead to very low or negative growth in CO_2 emissions over the period, depending on whether electricity policies favor decarbonization and their effectiveness. The substantial barriers that need to be overcome and the relatively slow pace of policies and programs for energy efficiency and decarbonization will present major challenges to such an achievement.

This chapter reviews a selection of novel and traditional technological options and design approaches that can cut building-related GHG emissions to a significant extent. The largest savings in energy use for new buildings (as high as 50-75%) arise through designing and operating buildings as complete systems. Realizing these savings requires an integrated design process involving architects, engineers, contractors and clients, with full consideration of opportunities for passively reducing building energy demands. Over the whole building stock a large portion of carbon savings by 2030 is in retrofitting existing buildings and replacing energy-using equipment with more advanced low-energy alternatives. Emerging areas for energy savings in commercial buildings include the application of controls and information technology to continuously monitor, diagnose, and communicate faults in commercial buildings; and systems approaches to reduce the need for ventilation, cooling, and dehumidification. In residential buildings, emerging areas include advanced windows, passive solar design, techniques for eliminating leaks in buildings and ducts, and energy-efficient appliances. Controlling standby and idle power consumption as well as solid-state lighting are important in both residential and commercial sectors.

In addition to technological solutions, culture and occupant behavior are also major determinants of energy use and carbon emissions from buildings. Therefore, increasing climate change literacy and consumer access to useful information are also fundamental components of climate change mitigation strategies in the residential and commercial sectors.

Implementing carbon mitigation options in buildings is associated with a wide range of ancillary benefits. These include the creation of jobs and business opportunities, increased economic competitiveness and energy security, social welfare benefits for low-income households, improved indoor and outdoor air quality, as well as increased comfort and quality of life.

A variety of policies have been demonstrated in many countries to be successful in cutting GHG emissions in buildings. Among these are appliance standards, building energy codes, appliance and building labeling, pricing measures and financial incentives, energy efficiency and renewable energy obligations with or without certificate trading, and public sector energy leadership programs including procurement policies. The greatest challenge is the development of effective strategies for retrofitting existing buildings. These and other actions, including continuously tightening building and appliance standards and promoting energy service companies, will all be needed because of the large number of barriers to energy efficiency and distributed low-carbon energy generation in buildings.

With regard to costs, the chapter attests that there is a wide range of low-cost options to curb CO_2 emissions in buildings. A review of 13 studies assessing the costs of GHG mitigation in buildings worldwide showed that up to 41% of the GHG emissions in the buildings of developing countries and economies in transition, and 11–25% of those in developed countries, could be captured by 2020, at a *negative* cost per ton of avoided CO_2. If measures with costs up to US\$25/tCO_2eq. are considered, developing countries and economies in transition may save up to 85% of their emissions in this sector. For industrialized countries, studies suggest that potential energy savings at this cost could range from 14 to 28%[1], but this estimate may be conservative, due to the limited number of truly comprehensive studies.

Support from industrialized countries for the development and implementation of policies to increase energy efficiency of buildings and equipment in developing countries and economies in transition could contribute substantially to reductions in growth of carbon dioxide emissions in the buildings sector and improve the welfare of the population.

In sum, while there are many practical and cost-effective technologies and practices available today – and new options likely to emerge from ongoing research, development, and demonstration, achieving a lower carbon future will require very significant efforts to enhance programs and policies for energy efficiency in buildings and low carbon electricity sources, well beyond what is happening today.

6.1 Introduction

Energy use in the buildings sector constituted approximately 37 percent of total global energy use and was responsible for 32 percent of CO_2 emissions in 2004. This share could grow to 35-42% by 2030. In absolute terms, energy use in buildings will release to the atmosphere 15.6 to 11.8 Gt CO_2 equivalent in 2030, up from 8 Gt in 2004. The significant global role of buildings-related emissions and the rate of their growth attest that measures to curb emissions in residential and commercial buildings need to be an integral part of a strategy to mitigate climate change.

GHG emissions from buildings can be cut in three major ways: by reducing energy consumption in buildings, switching to low-carbon fuels including a higher share of renewable energy, and controlling the emissions of non-CO_2 GHGs. Renewable and low-carbon energy can be supplied to buildings or generated on-site by distributed generation technologies. Since the major fuel used in buildings today is fossil-generated electricity, steps to decarbonize electricity generation can eliminate a substantial share of present emissions in buildings. Chapter 4 describes the options for centralized renewable energy generation, while this chapter covers building-level options for low-carbon electricity generation on-site. However, the central focus of this chapter is on reducing carbon emis-

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[1] Or up to 58% savings, if we include a single study for Hungary.

sions through improved energy efficiency, along with a brief discussion of options for reducing non-CO_2 GHG emissions from buildings.

A very large number of technologies are commercially available and tested in practice that can reduce energy use in buildings while providing needed or desired energy services. In cold climates, heating energy use in residential and commercial buildings can be reduced to very low levels (<10 percent of typical values today) by reducing infiltration, increasing insulation in walls, and using highly insulated windows. Additional approaches using passive solar design are also feasible. Air conditioning energy use can be minimized in hot climates through improved materials, equipment, and system design and operation, especially involving proper choice of windows with appropriate coatings and shading devices, use of reflective materials on roofs, efficient air conditioners, and proper building operation and maintenance (especially for commercial buildings). Numerous energy efficiency improvements are now available for virtually all major appliances, and for the many smaller electronic devices that represent a relatively new and rapidly growing electric load.

In spite of the availability of these technologies – and a wide array of others – energy use in buildings continues to be well above a cost-effective level. There are many reasons for this energy waste in buildings. Most consumers are not aware of energy efficiency opportunities. Even when aware, they are often confronted with high transactions costs in order to find energy-efficient equipment or to design and install efficient energy using systems. The buildings market is highly fragmented, resulting in many small firms responsible for specialized design and construction tasks, with few opportunities for an integrated design approach, little knowledge of energy efficiency techniques, and little incentive to use them optimally.

Countries throughout the world have applied a variety of policies in order to deal with these market imperfections. These include information programs such as energy labels, energy-efficient building codes and equipment standards, utility demand side management, incentives for energy efficiency, energy audits, and building commissioning programs, among others. The past five years have shown increasing application of these policies in many countries in Europe, and growing interest in several key developing and transition economies. In spite of this fact, global CO_2 emissions resulting from energy use in buildings have increased at an average of 3% per year in the five years for which data are available (1997-2002).

The key conclusion of the chapter is that substantial reductions in CO_2 emissions from energy use in buildings can be achieved over the coming years, because of the considerable experience in a wide variety of technologies, practices, and systems for energy efficiency and an equally rich experience with policies and programs that promote energy efficiency in buildings. These savings can be achieved in ways that reduce life-cycle costs, thus providing reductions in CO_2 emissions that have a net negative cost (generally higher first cost but lower operating cost, for a net savings in 5-7 years or less).

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For example, Scenario A1 (a scenario that leads to high energy growth) includes 2.5% average annual energy growth in buildings between 2000 and 2030. The potential savings resulting from 30-40% efficiency gains is 1.2% - 1.7% per year (which should be reduced to perhaps 1% per year due to slow turnover of buildings). Thus, in Scenario A1, energy use in buildings would continue to grow at ~1.5% during the period. For Scenario B2, average annual energy use in buildings is 1.5%. In this case, average annual growth in energy use in buildings could be as low as ~0.5%. Converting this to CO_2 emissions would also account for decarbonization of energy sources – primarily electricity for buildings – which for Scenario B2 could lead to very low or negative growth in CO_2 emissions over the period, depending on whether electricity policies favor decarbonization and their effectiveness.

The substantial barriers that need to be overcome and the relatively slow pace of policies and programs for energy efficiency will provide major challenges to such an achievement. In the sections to follow we first review recent trends in building energy use and then turn to several scenarios for reducing future energy use and associated greenhouse gas emissions. We provide an overview of significant technologies and practices for improving energy efficiency in buildings. This is followed by a discussion of co-benefits from reducing greenhouse gas emissions from buildings, and a review of studies that have estimated potential savings. The last section addresses policies and programs aimed at achieving the potential efficient improvements.

6.2 Trends in the Buildings Sector

Figures 6.1 through 6.4 illustrate trends in energy use and associated carbon dioxide emissions for residential and commercial buildings from 1971/1972 to 2002/2003. Observations from these figures are:

- Energy use and associated carbon dioxide emissions in buildings grew during the period at roughly the same rate as for all sectors (buildings, transportation, industry, and agriculture). Energy use and carbon dioxide emissions grew more slowly for residential buildings (0.1% and 0.3% slower annually) and faster for commercial buildings (0.5 per cent annually for energy and carbon) as compared with global energy use and carbon emissions.
- The largest increase in absolute value of carbon dioxide emissions resulting from residential energy use was in two regions of Asia - trally Planned and Other - h 250 of the 500 MT carbon (MTC) increase; the Middle East/North Africa, 140/500 MTC increase; and North America, 70/500 MTC.
- The largest increase in carbon emissions for commercial buildings were North America, 125/375 MTC increase); Centrally Planned and Other Asia, 125/375 MTC increase; and OECD Pacific, 100/375 MTC.
- For energy use in residential and commercial buildings, the highest average annual growth rates (AAGR) during the period were in the Middle East/North Africa.
- AAGR of carbon dioxide emissions from energy use were lower for residential buildings during the last five years (since the previous IPCC report) than the thirty-year trend (0.1 versus 1.4 percent); during this same period AAGR were higher for commercial buildings than the 30-year trend (3.0 versus 2.2 percent).

INSERT **Figure 6.1** (Primairy energy consumption residential buildings)
INSERT **Figure 6.2** (Energy related CO_2 emissions residential buildings)
INSERT **Figure 6.3** (prim energy cons commercial buildings)
INSERT **Figure 6.4** (energy related CO_2 emissions commercial buildings)

These trends are not surprising considering the factors responsible for growth of energy and associated carbon dioxide emissions. For residential buildings, the largest driver is advances in economic well being in those developing countries that are increasingly able to grow their economies, and thus expand the building stock. For commercial buildings, the most significant driver of increased energy demand is expansion of commerce and related activities (education, health care, recreation). It is not clear why emissions associated with residential buildings have grown so much more slowly than those of commercial buildings during the past five years. The modest emissions growth in North America and the OECD Pacific was almost completely offset by declines in the former Soviet Union and OECD. The result was that 80 percent of the emissions growth during the period – very small compared with the thirty year trend – occurred in just three regions: Centrally Planned Asia, Other Asia, and Middle East/North America.

6.3 Scenarios of Carbon Emissions Resulting for Energy Use in Buildings

Figures 6.5 and 6.6 show the results for the buildings sector of disaggregating two of the emissions scenarios produced for the IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000), Scenarios A1 and B2, into four subsectors and ten world regions (Price *et al.*, 2005a). These scenarios show a range of buildings related CO_2 emissions from 15.6 to 11.8 Gt CO_2 emissions in 2030 (A1 and B2 respectively). In Scenario A1 (which shows rapid economic growth, especially in developing nations), most of the increase in CO_2 emissions occurs in three regions: Centrally Planned Asia, Other Asia, and Middle East/North Africa. In Scenario B2, which has lower economic growth, especially in the developing world (except China), two regions account for the largest portion of increased CO_2 emissions from 2000 to 2030: Centrally Planned Asia and North America. Overall, average annual CO_2 emissions growth is 2.5% in Scenario A1 and 1.5% in Scenario B1 over the 30-year period.

INSERT **Figure 6.5** (Projected Residential energy related CO_2 emissions, A1 scen.)
INSERT **Figure 6.6** (Projected Residential energy related CO_2 emissions, B2 scen.)

6.4 Energy efficiency in buildings and equipment

It is useful, prior to discussing options for reducing specific end-uses of energy in buildings, to review some principles of energy-efficient design and operation that are broadly applicable.

6.4.1 Overview of energy efficiency principles

Delivering an energy-efficient building and maintaining energy-efficient operation depend on both products and processes; both aspect are discussed here. Design strategies for energy-efficient buildings include reducing loads, selecting systems that make the most effective use of ambient energy sources and heat sinks, and using efficient equipment and effective control strategies. An integrated design approach is required to ensure that the architectural elements and the engineering systems work effectively together. This requires early and effective communication within the design team, and appropriate procedures and tools to manage information. Critical to energy-efficient design is the early use of energy performance simulation software and other quantitative analysis tools.

6.4.1.1 Reduce heating, cooling and lighting loads

A simple strategy for reducing heating and cooling loads is to isolate the building from the environment by using high levels of insulation, reducing the glazing area, and minimizing the infiltration of outside air. This approach is most appropriate for cold, overcast climates. A more effective strategy in most other climates is to use the building envelope as a filter, selectively accepting or rejecting solar radiation and outside air, depending on the need for heating, cooling, ventilation and lighting at that time, and using the heat capacity of the building structure to shift thermal loads on a time scale of hours to days.

6.4.1.2 Utilize active solar energy and other environmental heat sources and sinks

Active solar energy systems can provide electricity generation, hot water, and space conditioning. The ground, ground water, aquifers and open bodies of water can be used selectively as heat sources or sinks, either directly or by using heat pumps. Space cooling methods that dissipate heat directly to natural heat sinks without the use of refrigeration cycles include evaporative cooling and radiative cooling to the night sky. These techniques have the potential to replace conventional mechanical cooling systems in all but the hottest and most humid climates (IEA ECBCS Annex 28).

6.4.1.3 Increase efficiency of appliances, heating and cooling equipment, and ventilation

The efficiency of equipment in buildings continues to increase in most industrialized and many developing countries, as it has over the past quarter-century. Increasing the efficiency of appliances, lighting, and other equipment within conditioned spaces reduces energy consumption directly and also reduces cooling loads. Even when the effect of reduced equipment loads is to increase space heating requirements, this often results in substituting fossil fuel or solar energy for electricity, thus reducing primary energy consumption and GHG emissions.

6.4.1.4 Implement commissioning and improve operations and maintenance

The actual performance of a building depends as much on the quality of construction as on the quality of the design itself. Building commissioning is a quality control process that includes design review, functional testing of energy-consuming systems and components, and clear documentation for the owner and operators. Actual building energy performance also depends critically on how well the building is operated and maintained. Continuous performance monitoring, automated diagnostics, and improved operator training are complementary approaches to improving the operation of commercial buildings, in particular.

6.4.1.5 Change behavior

The energy use of a building also depends on the behavior and decisions of occupants and owners. Classic studies at Princeton University showed energy use variations of more than a factor of two between houses that were identical but had different occupants (Socolow, 1978). The behavior of the occupants of non-residential buildings also has a substantial impact on energy use, especially when the lighting, heating, and ventilation are controlled manually.

6.4.1.6 System approaches to energy efficiency

Evaluation of the opportunities to reduce energy use in buildings can be done at the level of individual energy-using *devices*, at the level of building *systems*, and at the level of the *behavior* of building occupants and operators. Energy efficiency strategies focused on individual energy-using devices or design features are often limited to incremental improvements. The effectiveness of this approach is reduced if the building has an inherently energy-inefficient design. Examining the building as an entire system can lead to entirely different design solutions. A systems approach can result in buildings that are no more expensive than conventional buildings, but with much increased energy efficiency, especially if the initial design was faulty [ref].

6.4.2 Thermal Envelope

The term *thermal envelope* refers to the shell of the building as a barrier to unwanted heat or mass transfer between the interior of the building and the outside conditions. The effectiveness of the thermal envelope depends on:

- the insulation levels in the walls, ceiling, and ground or basement floor, including factors such as moisture condensation that affect insulation performance;
- the thermal properties of windows and doors; and
- the rate of exchange of inside and outside air, which in turn depends on the air-tightness of the envelope and driving forces such as wind, inside-outside temperature differences, and air pressure differences due to mechanical ventilation systems or warm/cool air distribution.

Modest improvements in the thermal envelope can reduce heating requirements by a factor of 2-4 compared to standard practice, at little to no net incremental cost when downsizing of heating and cooling systems is accounted for (Demirbilek *et al.*, 2000; Hamada and al., 2003; Hastings, 2004). A number of advanced houses have been built in various countries around the world that use as little as 10% of the heating energy of houses built according to the local national building code (Badescu and Sicre, 2003; Hamada and al., 2003; Hastings, 2004). The best-insulated houses have wall and roof insulation levels that are roughly twice that required by standards in cold-climate countries. Reducing the envelope heat loss by a factor of two reduces the heating requirement by more than a factor of two because of internal heat gains from equipment, occupants, and lighting.

Structural insulated panels, dynamic insulation, evacuated panels, and transparent insulation material (TIM) all have the potential to improve the thermal integrity of the building envelope at lower cost than some conventional insulation materials, or with other benefits. Double façades can serve as a net heat source during winter in cold climates on façades of most orientations. This design approach can also reduce summer heat gain by a factor of three or more by permitting use of external shading devices and passive ventilation under circumstances where these might not otherwise be possible (Manz, 2004).

6.4.2.1 Windows

The thermal performance of windows has improved greatly through the use of multiple glazing layers, low-conductivity gases (argon in particular) between glazing layers, low-emissivity coatings on one or more glazing surfaces, and use of framing materials (such as extruded fibreglass) with very low conductivity. Operable windows are available with heat flows that have only 20-25 percent of the heat loss of standard double-glazed (15 to 20% of single-glazed) windows. Glazings that reflect or absorb a large fraction of the incident solar radiation reduce solar heat gain by ~50%, thus reducing cooling loads. Spectrally selective windows can maximize the transmission of visible sunlight to replace artificial lighting while minimizing increased cooling requirements from solar heat gain.

Electrochromic windows use low voltages (1-5 volts) to cause the window to change from a clear to a transparent state and vice versa. They avoid the trade-off between minimizing winter heating requirements (high solar gain) and minimizing summer air conditioning requirements (low solar heat gain) (Granqvist *et al.*, 1998; Klems, 2001). Simulations of energy use in office buildings with the climate of New York State indicate that electrochromic windows can achieve a savings in combined lighting and cooling electricity use of up to 60%, depending on the building characteristics and window area (Lee *et al.*, 2002).

Another technology currently under development is thermochromic glazing, which changes (reversibly) from opaque at higher temperatures to clear at lower temperatures. This eliminates the need for sensors and controls. It could be employed in skylights to automatically permit penetration of solar radiation when heating is desired (i.e. when the outside temperature is cold) but not when cooling is desired (Inoue, 2003).

6.4.2.2 Air leakage

In cold climates, uncontrolled exchange of air between the inside and outside of a building can be responsible for up half of the total heat loss. In hot-humid climates, air leakage can be a significant source of indoor humidity. In residential construction, installation in walls of a continuous impermeable barrier, combined with other measures, can reduce rates of air leakage by a factor of 5-10 compared to standard practice in most jurisdictions in North America, Europe and the cold-climate regions of Asia (Harvey, 2005b).

In addition to leakage through the building envelope, recent research in the United States has demonstrated that leaks in ducts for distribution of air for heating and cooling can increase heating and cooling energy requirements by 20-40% (Sherman and Jump., 1997; Francisco *et al.*, 2004). . Aeroseal, a technology in early commercial use in the United States, seals leaks by spraying fine particles into ducts. This technology is cost-effective for many residential and commercial buildings; it achieves lower costs by avoiding the labor needed to replace leaky ducts.

6.4.3 Heating Systems

6.4.3.1 Passive solar heating

Passive solar heating can involve extensive sun-facing glazing, various wall- or roof-mounted solar air collectors, double-façade wall construction, air-flow windows, thermally massive walls behind glazing, or preheating of ventilation air through buried pipes. Technical details concerning conventional and more advanced passive solar heating techniques, real-world examples, and data on energy savings are provided in books by Hastings and Hestnes (Hastings, 1994),(Hestnes *et al.*, 2003; Hastings, 2004), produced as part of the International Energy Agency's *Solar Heating and Cooling* Implementing Agreement. Aggressive envelope measures combined with optimization of passive solar heating opportunities, as exemplified by the European standards programs, have achieved reductions in purchased heating energy by factors of 5-30 (i.e., achieving heating levels less than 15 kWh/m^2/yr even in cold climates, compared to 140-170, 220, and 250-400 kWh/m^2/yr for the average of existing buildings in Finland, Germany, and Central/Eastern Europe, respectively (Krapmeier and Drössler, 2001; Gauzin-Müller, 2002; Kostengünstige Passivhäuser als europäische Standards, 2005).

6.4.3.2 Space heating systems

In the industrialized nations and in urban areas in developing countries (in cold winter climates), heating is generally provided by a district heating system or by an on-site furnace or boiler. In rural areas of developing countries, heating (when provided at all) is generally from direct burning of biomass. The following sections discuss opportunities to increase energy efficiency in these systems

6.4.3.2.1 Heating systems used primarily in industrialized countries[2]

Multi-unit residences and many single-family residences (especially in Europe) use boilers, which produce steam or hot water that is circulated generally through radiators. Annual Fuel Utilization Efficiencies (AFUE) values range from 80% to 95% for the boiler, not including distribution losses. Modern residential forced air furnaces, which are used primarily in North America, have AFUE values ranging from 78% to 96% (again, not including distribution system losses). In both boilers and furnaces, efficiencies greater than about 88% require condensing operation, in which some of the water vapor in the exhaust is condensed in a separate heat exchanger. For hydronic heating systems (systems that use water to carry heat), the cooler the return water, the more water vapor that can be condensed and the greater the efficiency. Condensing boilers require larger radiators or radiant floors to provide the increased surface area required to transfer sufficient heat with a reduced temperature difference between the surface and the occupied space. Modern condensing boilers have higher efficiency at part-load, whereas older boilers suffer a significant drop at part-load. Since a boiler operates at part load most of the time, the difference in average efficiency is much larger (by up to one-third) than implied by comparing boiler full-load efficiencies. Condensing boilers are increasingly used in Western Europe due to regulation of new buildings that require higher-efficiency systems.

Hydronic systems, especially floor radiant heating systems, are capable of greater energy efficiency than forced air systems because of the low energy required to distribute a given amount of heat, low distribution heat losses, and absence of induced infiltration of outside air into the house due to poorly balanced air distribution systems.

Heat pumps use an energy input (almost always electricity) to transfer heat from a cold medium (the outside air or ground in the winter) to a warmer medium (the warm air or hot water used to distribute heat in a building). During hot weather, the heat pump can operate in reverse (transferring heat from a hot to a cold medium), thereby providing cooling. In winter, drawing heat from a relatively warm source (such as the ground rather than the outside air) and distributing the heat at the lowest possible temperature can dramatically improve the heat pump efficiency, measured as a coefficient of performance (COP). Distribution temperatures of 30-35ºC can be used in floor radiant heating systems, compared to 70-90ºC in conventional hot-water heating systems. The COP of a conventional heat pump system is 2-2.5. This is increased to 3.5-7.0 for a radiant heating system, with the actual COP depending on the heat-source temperature. Use of the ground rather than the outside air as a heat source reduced measured energy use for heating by 50-60% in two US studies (Shonder *et al.*, 2000; Johnson, 2002). The ground can also serve as a low-temperature heat sink in summer, increasing the efficiency of air conditioning as well.

6.4.3.2.2 Coal and biomass burning stoves in rural areas of developing countries

Worldwide, about three billion people in use solid fuels - biomass and, mainly in China, coal—in household stoves to meet their cooking, water heating, and space heating needs (Figure 6.7). Most of these people live in rural areas with little or no access to commercial sources of fuel or electricity (WEC, 1999). Statistical information on fuel use in stoves used for cooking is sketchy, so any esti-

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[2] The systems discussed are also used in urban areas of developing countries in which space heating is required. This section deals specifically with furnaces, boilers, heat pumps, co-generators, and district heating systems.

mates of energy use and associated GHG emissions are uncertain.[3] The global total for traditional biofuel use - a good proxy for energy use in household stoves - was about 32 EJ in 2002, compared to commercial energy use worldwide of 401 EJ (IEA, 2004d).

INSERT **Figure 6.7** (GHG emissions from household fuels)

Worldwide, most household stoves use simple designs and local materials that are inefficient and highly polluting. Studies of China and India have found that if only the Kyoto Protocol basket of GHGs is considered, biomass stoves using renewably harvested fuels appear to have lower emission factors than fossil-fuel alternatives (Smith, *et al.*, 2000; Edwards, *et al.*, 2004). If products of incomplete combustion (PICs) other than methane and N_2O are considered, however, then biomass stove-fuel combinations exhibit GHG emissions three to ten times higher than fossil-fuel alternatives, even with sustainably harvested fuel, and in many cases higher emissions than from stoves burning coal briquettes. Programs to develop and disseminate more-efficient biomass stoves have been very effective in China, less so in India and other countries (Sinton, *et al.*, 2004; Barnes, *et al.*, 1994; Goldemberg, *et al.*, 2000). In the long term, stoves that use biogas or biomass-derived liquid fuels offer the greatest potential for significantly reducing the GHG emissions associated with household use of biomass fuels.

In summary, current research suggests that biomass stoves are a large contributor to global GHG emissions, although significant uncertainty remains. Biofuel use is not well characterized worldwide, and better estimates are needed of how much of what types of fuels are used. Emissions factors used in models are based mainly on estimates or laboratory emissions tests rather than field tests. Of greatest importance is the improved characterization of PICs, which can have large impacts on the greenhouse. .

6.4.4 Cooling and Cooling Loads

Cooling energy can be reduced by: 1) reducing the cooling load on a building, 2) using passive techniques to meet some or all of the load, and 3) improving the efficiency of cooling equipment and thermal distribution systems.

6.4.4.1 Reducing the cooling load

Reducing the cooling load depends on the building shape and orientation, the choice of building materials, and a whole host of other decisions that are made in the early design stage by the architect and are highly sensitive to climate. In general, recently constructed buildings are no longer adapted to prevailing climate; the same building forms and designs are now seen in Stockholm, New York, Houston, Hong Kong, Singapore and Kuwait. However, the principles of design to reduce cooling load for any climate are well known. They include:

- orienting a building to minimize the wall area facing east or west;
- clustering buildings to provide some degree of self shading (as in many traditional communities in hot climates);
- using high-reflectivity building materials;
- increasing insulation;

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[3] Estimates are available for China and India, collectively home to about one third of the world's population. Residential use of solid fuels in China, nearly all used in stoves, was about 9 EJ in 2002, or 18% of all energy use in the country (NBS, 2004). The corresponding figures for India were 8 EJ and 36% (IEA, 2004). In both cases, nearly all of this energy is in the form of biomass.

- providing fixed or adjustable shading;
- using windows with a low solar heat gain and avoiding excessive window area (particularly on east- and west-facing walls); and
- utilizing thermal mass to minimize daytime interior temperature peaks.

Increasing the solar reflectivity of roofs and horizontal or near-horizontal surfaces around buildings and planting shade trees can yield dramatic energy savings. The benefits of trees arise both from direct shading and from cooling the ambient air. Rosenfeld computed that a very large-scale, city-wide program of increasing roof albedo and planting trees in Los Angeles could yield a total savings in residential cooling energy of 50-60%, with a 24-33% reduction in peak air conditioning loads(Rosenfeld *et al.*, 1998) . For Toronto, Akbari and Konopacki calculated potential savings in cooling energy use of about 25% for residential buildings and 15% for office and retail buildings through similar measures (Akbari and Konopacki, 2004).

6.4.4.2 Passive and low-energy cooling techniques

Purely passive cooling techniques require no mechanical energy input, but can often be greatly enhanced through small amounts of energy to power fans or pumps. A detailed discussion of passive and low-energy cooling techniques can be found in Harvey (Harvey, 2005a).

6.4.4.2.1 Natural ventilation

Natural ventilation reduces the need for mechanical cooling by: directly removing warm air when the incoming air is cooler than the outgoing air, reducing the perceived temperature due to the cooling effect of air motion, night-time cooling of exposed thermal mass, and increasing the acceptable temperature through psychological adaptation when the occupants have control of operable windows. When the outdoor temperature is 30°C, the average preferred temperature in naturally ventilated buildings is 27°C, compared to 25°C in mechanically ventilated buildings (de Dear and Brager, 2002).

Natural ventilation requires a driving force, and an adequate number of openings, to produce airflow. Natural ventilation can be induced through pressure differences arising from inside-outside temperature differences or from wind. Design features, both traditional and modern, that create thermal driving forces and/or utilize wind effects include courtyards, atria, wind towers, and solar chimneys (Holford and Hunt, 2003; Hawkes and Forster, 2002).

Whatever the specific features used to produce air flow, shallow plan and/or low-rise building forms minimize flow resistance and expose all the occupants to cool, fresh air. These forms also have the advantage of increased opportunities for daylighting. Site-specific factors that influence the best approaches to natural ventilation include noise, air-borne particulates, and security concerns. In addition to being increasingly employed in commercial buildings in Europe, natural ventilation is starting to be used in commercial buildings in more temperate climates in North America, notably in the new San Francisco Federal Office Building (McConahey *et al.*, 2002).

6.4.4.2.2 Night-time ventilation

In climates with a minimum diurnal temperature variation of 5-7ºK, natural or mechanically-assisted night-time ventilation, in combination with exposed thermal mass, can be very effective in reducing daily temperature peaks and, in some cases, eliminating the need for air conditioning altogether. Simulations by Springer *et al.* (Springer *et al.*, 2000) indicate that night-time ventilation is sufficient to prevent peak indoor temperatures from exceeding 26°C over 43% of California in houses with an improved envelope and modestly greater thermal mass compared to standard practice in California. For Beijing, da Graça *et al.* (da Graça *et al.*, 2002) find that thermally- and wind-driven night-time ventilation can eliminate the need for air conditioning of a 6-unit apartment building during most of the summer (an extreme outdoor peak of 38°C produces a 31°C indoor peak) if the high risk of condensation during the day due to moist outdoor air coming into contact with the night-cooled indoor surfaces can be reduced. One solution would be to close all openings during the day and dehumidify incoming air sufficiently to prevent condensation. For Shanghai, with its smaller diurnal temperature range, night-time ventilation is sufficient merely to limit peak indoor temperatures to no warmer than peak outdoor temperatures most of the time. (Without any ventilation, peak indoor temperatures would exceed peak outdoor temperatures.)

6.4.4.2.3 Evaporative cooling

There are two methods of evaporatively cooling the air supplied to buildings. In a *direct* evaporative cooler, water evaporates directly into the air stream to be cooled. In an *indirect* evaporative cooler, water evaporates into and cools a secondary air stream, which cools the supply air through a heat exchanger without adding moisture. By appropriately combining direct and indirect systems, evaporative cooling can provide comfortable conditions most of the time in most parts of the world.

Water can be evaporatively cooled in a conventional cooling tower. It can also be cooled by evaporation from a flooded roof surface or from droplets sprayed above, and collected by, a roof or other suitable surface. The evaporative heat loss is supplemented by radiative heat loss to the sky. This process is most effective at night, when the wet-bulb and sky temperatures are lower and there is no solar heating of the surface. Water that is cooler than ~17°C can be circulated through pipes in an exposed ceiling or floor slab, as described in Section 6.4.5.2. Water that is cooler than ~10°C can be used in a conventional heating, ventilating and air-conditioning (HVAC) system in place of water cooled by a chiller. The potential cooling effect of evaporative cooling is greatest in regions of moderate to low humidity, although the availability of water in these regions could be a limiting factor.

6.4.4.2.4 Underground earth-pipe cooling

Ventilation air can be cooled by drawing outside air through a buried coil. The performance of such a system can be characterized by the ratio of the rate of heat removal by the ground to the power used by the fans – analogous to the COP of a heat pump. Good performance depends on the climate having a substantial annual temperature range. Using the system for both heating and cooling, so that heat removed from the ground in the winter is balanced by the heat added in the summer, prevents progressive reduction of the cooling capacity due to heating of the ground over time.

6.4.4.3 Air conditioners and vapor-compression chillers

Air conditioners used for houses, apartments, and small commercial buildings have a COP ranging from 2.2 to 3.5. Chillers are larger cooling devices that produce chilled water (rather than cooled air) and are used in larger commercial buildings. COP generally increases with size, with the largest and most efficient centrifugal chillers having a COP of almost 10, averaged over the range of loads typically encountered. The screw and scroll chillers that are now available as more efficient replacements for the reciprocating chillers used in small to medium sized buildings are not as efficient as large centrifugal chillers but are significantly more efficient than small, window or split-unit air conditioners, even after including the energy consumption of the pumps and the condenser or cooling tower fans, particularly if a cooling tower or an evaporatively cooled condenser is used. Significant energy savings are possible if multi-unit residential buildings are designed with a centralized chiller for air conditioning, rather than designed to accommodate a small split-unit air conditioner in each room of each apartment unit. However, chiller-based central cooling systems require a chilled-water piping system and space for the central facility, as well as metering and billing of individual apartments so as to discourage waste.

6.4.4.4 Absorption chillers and cogeneration

Microturbines (with an electrical power output in the range of 30-500 kW) are, or will soon be, attractive for cogeneration – the simultaneous production of electricity and useful heat - in large individual buildings or groups of buildings (Pilavachi, 2002). Fuel cells may also become economically attractive for cogeneration in buildings by the end of the decade (Ellis and Gurnes., 2002). Since new buildings can be built to require almost no winter heating, even in cold climates, absorption chillers provide the primary means of utilizing the waste heat from on-site electricity generation.

6.4.5 Heating, ventilation, and air conditioning (HVAC) systems

The term HVAC is generally used in reference to commercial buildings. HVAC systems include filtration and, where required by the climate, humidification and dehumidification as well as heating and cooling. However, energy-efficient houses are almost airtight, so mechanical ventilation has to be provided (during seasons when windows will be closed), often in combination with the heating and/or cooling system, as in commercial buildings.

6.4.5.1 Principles of energy-efficient HVAC design

In the simplest HVAC systems, heating or cooling is provided by circulating a fixed amount of air at a sufficiently warm or cold temperature to maintain the desired room temperature. The rate at which air is circulated in this case is normally much greater than that needed for ventilation to remove contaminants. During the cooling season, the air is supplied at the coldest temperature needed in any zone, and reheated as necessary just before entering other zones. A first step in reducing energy use is to minimize simultaneous heating and cooling by eliminating the wasteful reheat. This can be achieved by the use of a variable-air volume (VAV) system in which the flow rate of air to an individual zone varies with the cooling load in the zone, within limits. This in turn helps to minimize the amount of reheating when in cooling mode, which may be most of the year for a commercial building.

Substantial reductions in fan energy also result from the lowering the airflow rate, especially if variable frequency drives (VFD) are used to control the fan speeds. This illustrates another principle: minimize fan and pump energy consumption by controlling rotation speed. Most HVAC systems installed in the last two decades are VAV systems. Converting older, “constant-air-volume” (CAV) systems to VAV operation can reduce total annual HVAC energy use by a factor of 2-3 (Franconi, 1998). Converting the remaining CAV systems to VAV in existing commercial buildings represents a significant energy-saving opportunity in North America.

Greater gains in efficiency can be achieved by recognizing that water, as a heat transfer fluid, is 25-100 times more efficient than air. Thus, another principle of energy-efficient HVAC design is to separate the ventilation from the heating or cooling functions by using chilled or hot water for temperature control, and circulating only the volume of air needed for ventilation. This allows use of

100% outside air (at much lower volumes) rather than recirculating a portion of the indoor air, thereby providing health benefits. The required ventilation airflow – now decoupled from heating or cooling functions – will vary with changing building occupancy. A demand-controlled ventilation (DCV) system uses CO_2 and/or other sensors to adjust the ventilation rate, with 20-30% savings in total HVAC energy use compared to ventilation at a fixed rate based on maximum occupancy (Brandemuehl and Braun, 1999).

Another principle is to separate cooling from dehumidification. In most commercial buildings with air conditioning, dehumidification is accomplished by overcooling the air so as to condense sufficient water vapor, then reheating the air so that it can be supplied at a comfortable temperature. Dehumidification can be decoupled from cooling through a variety of desiccant-based techniques.

An additional principle is to allow the temperature maintained by the HVAC system to vary seasonally with outdoor conditions. A large body of evidence indicates that the temperature and humidity set-points commonly encountered in air-conditioned buildings are significantly lower than necessary (de Dear and Brager, 1998; Fountain *et al.*, 1999). In particular, temperatures up to 28°C are acceptable on hot days, particularly if individually controlled fans are available to create air speeds of about 0.5 m s^{-1} and if natural ventilation through operable windows is allowed. Computer simulations by Jaboyedoff indicate that increasing the thermostat from 24°C to 28°C will reduce annual cooling energy use by more than a factor of three for a typical office building in Zurich and by more than a factor of two in Rome (Jaboyedoff *et al.*, 2004). Simulations by Lin and Deng point to a factor of 2-3 reduction if the thermostat setting is increased from 23°C to 27°C for night-time air conditioning of bedrooms in apartments in Hong Kong (Lin and Deng, 2004.).

Additional savings can be obtained in 'mixed-mode' buildings, in which natural ventilation is used whenever possible, making use of the extended comfort range associated with operable windows, and mechanical cooling is used only when necessary during periods of very warm weather or high building occupancy. In some mixed-mode buildings, red and green lights are used to inform the occupants when windows may be opened. This may be combined with an electronic interlock that prevents the supply of mechanical cooling to zones in which the windows are open.

6.4.5.2 Residential HVAC systems

As discussed in Section 6.4.4.2.3, evaporative cooling can be used as an alternative to compressor cooling in less humid climates. Direct evaporative cooling can be used in arid areas; indirect evaporative cooling extends the region of applicability to somewhat more humid climates. A group in California has developed a prototype indirect-direct evaporative cooler that is due to begin commercial production in early 2006. The COP (cooling power divided by fan power, a direct measure of efficiency) ranges from about 12 when the fan is operating at high speed, to about 40 at low speed. Simulations for a house in a variety of California climate zones indicate savings in annual cooling energy use of 92-95%; estimated cooling energy savings for a modular school classroom are 89-91% (DEG, 2004).

Blowers in forced-air HVAC systems use a substantial amount of electricity. While selecting the most efficient units can reduce this energy use, much greater savings are possible using hydronic systems: radiators for heating or radiant floor panel systems for heating or cooling. With radiant cooling, a relatively high distribution temperature (≥~15°C) is required to avoid the danger of condensation. In some climates, the ventilation air may also require dehumidification.

Evaporatively cooled water can be used with radiant floor cooling systems (Bourne and Hoeschele, 2000). Water is cooled at night and used to pre-cool the slab, allowing it to absorb heat during the daytime. In the absence of a slab, cool water can be stored in an insulated tank and circulated through radiators or baseboard fin-tube convectors. In addition to avoiding the energy consumption of a refrigeration machine, use of evaporatively cooled water in hydronic cooling systems has the advantage of being somewhat self-regulating with respect to condensation risk. Solar-powered absorption chillers are also a potential source of chilled water for hydronic cooling systems. The relatively high chilled water temperature required to avoid condensation risk improves the COP of the chiller.

In houses that are almost completely airtight, fresh air needs to be provided by a mechanical ventilation system when the windows are closed. An air-to-air heat exchanger can capture 60-90% of the heat in the outgoing exhaust air and use it to pre-heat the cold incoming air. Instead of a heat exchanger, a heat pump can be used to extract heat from the exhaust air and, in some cases, meet the entire heating load in this way. Today, almost all new single-family houses in Sweden are equipped with exhaust-air heat pumps (about 4000/yr being installed as of 1997), with another 5000-10,000/yr installed in Germany (Fehrm *et al.*, 2002). The heat exchangers used in indirect evaporative coolers can also provide heat recovery in winter.

6.4.5.3 Alternative HVAC systems in commercial buildings

In the following paragraphs we describe three alternatives to conventional HVAC systems in commercial buildings that together can reduce the HVAC system energy use by 50-75%. These savings are in addition to the savings arising from reducing heating and cooling loads.

6.4.5.3.1 Radiant chilled-ceiling cooling

One effective way to cool a room is to chill a large fraction of the ceiling, either by circulating chilled water through pipes embedded in an exposed concrete ceiling or by circulating chilled water through lightweight panels that form part of a suspended ceiling. Chilled ceiling (CC) cooling has been used in Europe since at least the mid 1970s. In Germany during the 1990s, 10% of retrofitted buildings used CC cooling (Behne, 1999). Significant energy savings arise because of the greater effectiveness of water than air in transporting heat, and because the chilled water is supplied at 16-20°C rather than at 5-7°C. This allows a higher chiller COP when the chiller operates, but also allows more frequent use of “water-side free cooling,” in which the chiller is bypassed altogether[4] and water from the cooling tower is used directly for space cooling**.** For example, a cooling tower alone could directly meet the cooling requirements 97% of the time in Dublin and 67% of the time in Milan if the chilled water is supplied at 18°C (Costelloe and Finn, 2003).

6.4.5.3.2 Displacement ventilation

Conventional ventilation relies on turbulent mixing to dilute room air with ventilation air. A superior system is *displacement ventilation* (DV) in which air is introduced at low speed through many diffusers in the floor or along the sides of a room and is warmed by internal heat sources (occupants, lights, plug-in equipment) as it rises to the top of the room, displacing the air already present. The thermodynamic advantage of displacement ventilation is that the supply air temperature is significantly higher for the same comfort conditions (~18°C *vs.* ~13°C in a conventional mixing ventilation system). This allows the chillers to operate with a higher COP, and increases the amount of time the chillers can be bypassed altogether and outside air directly used without prior cooling. If

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[4] A cooling tower is normally used to cool, through evaporation, the water that cools the condenser of a chiller.

100% outside air is used, i.e. no recirculated air, the airflow rates required for adequate ventilation can be reduced by a factor of 2 or more compared to mixing ventilation, due to the greater effectiveness of DV in removing air contaminants.

DV was first applied in northern Europe; by 1989 it had captured 50% of the Scandinavian market for new industrial buildings and 25% for new office buildings (Zhivov and Rymkevich, 1998). The building industry in North America has been much slower to adopt DV; by the end of the 1990s fewer than 5% of new buildings used under-floor air distribution systems (Lehrer and Bauman., 2003), and most of these were not true DV systems. Overall, DV can reduce energy use for cooling and ventilation by 30-60%, depending on the climate (Bourassa *et al.*, 2002; Howe *et al.*, 2003).

6.4.5.3.3 Desiccant dehumidification and cooling

Solid desiccants can be used to remove moisture from air using a rotating passive desiccant wheel, or through an active desiccant wheel in which the outgoing airflow is heated before it passes through the desiccant wheel so as to more effectively drive moisture from the wheel. A variety of liquid desiccants can also be used to dry air. Full optimization of desiccant dehumidification systems requires sensible-heat exchangers in a variety of possible configurations (discussed in (Harvey, 2005a)). The energy used for dehumidification can be reduced by 30-50% compared to a conventional overcooling/reheat scheme, or by 50-75% if the thermal energy input (which can be supplied by solar energy) is ignored (Fischer *et al.*, 2002; Niu *et al.*, 2002). In hot-humid climates, desiccant dehumidification leads to better control of indoor humidity (Zhang and Niu, 2003), as well as saving energy. When combined with indirect evaporative cooling, desiccant systems provide an alternative to refrigeration-based air conditioning systems (Belding and Delmas, 1997).

6.4.5.4 Control Systems

At a minimum, automated control systems can be used to schedule equipment to operate only when required, with substantial savings. Supervisory control strategies can reduce energy use significantly by changing set points dynamically in response to changes in operating conditions. Optimal control in response to electricity rates can produce significant further energy cost savings, particularly if the cost of energy varies significantly with time of day. Simulation-based estimates of cost savings range from 6% to 30% (Kintner-Meyer and Emery, 1995; Henze, 2003), with the larger cost savings predicted for systems with active thermal storage. However, most of the cost savings result from managing peak loads in response to time of use pricing and demand charges. Cost savings from reduced energy consumption are more modest, ~5-10% for conventional HVAC systems (Brandemuehl, 1998). Integrated control of HVAC, lighting, active façades and on-site generation can achieve major reductions in building energy consumption, peak demands, and energy bills, but the required level of control integration among different systems is still at an early stage of development.

6.4.5.5 Commissioning

Proper commissioning of the energy systems in a commercial building is key to its efficient operation. As noted above, building commissioning is a quality control process that begins with the early stages of design. Commissioning helps ensure that the design intent is clear and readily tested, that installation is subjected to on-site inspection, and that all systems are tested and functioning properly before the building is accepted. A systems manual is prepared to document the owner's requirements, the basis of design and the design intent (including as-built drawings), equipment performance specifications, and control sequences. This allows the owner or property manager to operate the building correctly and helps ensure that future modifications to the building do not conflict with the original design.

Retro-commissioning involves analyzing the performance of an existing building, detecting and remedying equipment faults and operational problems, and adapting the control strategy, as needed, to the current use of the building. The aim of retro-commissioning can be to improve energy performance or to address known problems (e.g. indoor air quality), or both problems.

Commissioning is not yet widely practiced because of a lack of appreciation of its benefits and concern about costs, though this is starting to change. A number of building codes in North America and the U.K. require commissioning of new construction and major renovations [ref]. The concept of commissioning as a separate quality control process is gaining recognition in other countries, in part due to the activities of IEA Energy Conservation in Buildings and Community Systems (ECBCS) Annexes 40 and 47 (IEA Annex 40; IEA Annex 47).

Recent results of building commissioning in the US showed energy savings up to 38% in cooling and/or 62% in heating, and an average higher than 30% (Claridge *et al.*, 2003). A study by Mills *et al.* (2004) reviewed data from 224 US buildings that had been commissioned or retro-commissioned. The study found that the costs of commissioning new buildings were typically outweighed by construction cost savings due to fewer change orders, and that retro-commissioning produced median energy savings of 15% with a median payback period of 8.5 months. It is very difficult to assess the energy benefits of commissioning new buildings due to the lack of a baseline.

6.4.5.6 Operation, maintenance, and performance benchmarking

Once a building has been commissioned, there is a need to maintain its operating efficiency. A variety of methods to monitor and evaluate performance and diagnose problems have recently been developed or are currently under development (Brambley *et al.* 2005). Energy performance benchmarking tools provide a means of comparing a building's overall energy performance to that of other, similar buildings. "Action-oriented" benchmarking is designed to determine whether relatively low-cost retro-commissioning or a capital-intensive retrofit is required to improve the performance of a particular system. Specifications that define instrumentation, data archiving and data visualisation requirements for monitoring commercial building performance, including but not limited to its energy performance, are currently under development [ref]. Also under development are methods and tools for manual or automated detection and diagnosis of equipment faults and operational problems, either during routine operation or during the functional testing performed as part of commissioning or retro-commissioning [ref].

A related issue is the need for more extensive education and training of technicians and building operators whose performance is critical to the efficient operation of complex commercial buildings, systems, and controls. New curricula and computer-based teaching tools are being developed that address controls, troubleshooting, and the new energy-efficient technologies and controls being introduced into commercial buildings [ref].

6.4.6 Domestic hot water

Options to reduce the energy used to heat domestic hot water include: 1) use of low-flow water fixtures, more water-efficient clothes washers, and (if used at all) more water-efficient dishwashers; 2) use of more efficient and better insulated water heaters or integrated space and hot-water heaters; 3) use of tankless water heaters, located close to the points of use, to eliminate standby and greatly reduce distribution heat losses; 4) recovery of heat from warm wastewater; 5) use of recovered heat from exhaust ventilation air using a heat pump, or extraction of heat from the condenser of a chiller (which may also reduce the chiller COP); and 6) use of solar thermal water heaters. Combinations of these measures can produce cost-effective savings greater than 90% of the typical energy use by residential storage water heater systems [ref].

6.4.7 Lighting Systems

Lighting energy use can be reduced by 50-90% compared to conventional practice through: 1) use of daylighting with sensors and controls to dim electric lighting; 2) use of the most efficient lighting devices available; and 3) use of such measures as ambient/task lighting [ref].

Continuous improvements in the efficacy[5] of electric light sources and lighting systems have occurred during the past 5-10 years, and can be expected to continue. The T5 fluorescent lamp and the most recent T8 lamps have an efficacy of about 100 lumens/watt, compared to 80 lumens/watt for older T8 lamps and about 60 lumens/watt for T12 lamps (McCowan *et al.*, 2002). Important advances have also occurred in occupancy-sensor technology (Garg and Bansal, 2002).

For lighting systems providing uniform lighting in commercial buildings, the energy required can be reduced by 50% or more compared to standard practice through use of efficient lamps, ballasts, and reflectors, occupancy sensors, and lighter color finishes and furnishings [ref]. Much larger savings occur where and when daylighting can be used. A simple strategy to further reduce energy use is to provide a relatively low background lighting level along with higher illumination levels at individual workstations. This strategy, referred to as *task/ambient lighting,* is popular in Europe. Task/ambient lighting alone can cut lighting energy use in half, while offering individual control over lighting levels as an added benefit [ref]. Task/ambient lighting is also a good match with daylighting (discussed in the next section).

In addition to their commercial building applications, T8 or T5 fluorescent tubes can be hidden in recessed areas in residential buildings and used for indirect lighting – bouncing light off of ceilings or walls rather than providing direct illumination (Banwell *et al.*, 2004). This provides an efficient alternative to residential recessed lighting using conventional or reflector incandescent lamps, or track lighting using halogen lamps with an efficacy of only 17-19 lumens/watt. Compact fluorescent lamps (CFLs) provide 60-70 lumens/watt, compared to 9-17 lumens/watt for incandescent lamps [ref]. The price of CFLs in North America is now on the order of US$3/lamp, a significant drop during the last few years. CFLs can be used in ceiling downlighting with some modification to the luminaire in place of incandescent or halogen lamps. Altogether, a reduction in residential lighting energy use of a factor of 4-5 can be achieved compared to incandescent/halogen lighting [ref].

6.4.8 Daylighting

Opportunities for daylighting are strongly influenced by early architectural decisions, such as building form; the provision of inner atria, skylights, and clerestories (glazed vertical steps in the roof); and the size, shape, and position of windows. IEA (IEA), 2000) provides a comprehensive sourcebook of conventional and less conventional techniques and technologies for daylighting. These include:

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[5] Lighting efficacy is the ratio of a system's light output in lumens to input power in watts.

- light shelves (horizontal reflective surfaces placed near the upper part of the window, on the inside or outside, in order to reflect light onto the ceiling while shading the lower part of the window to prevent glare and overheating);
- automatic Venetian blinds, whose tilt angle is varied in order to compensate for changing outdoor light levels and changing solar position;
- passive light pipes, consisting of an outside dome that collects light, a pipe that transmits light through internal reflection, and a diffuser at the bottom;
- prismatic panels, light-directing louvers, and laser-cut panels (all of which act by reflecting onto the ceiling the light falling on the window);
- anidolic ceilings, which collect light under overcast conditions from an angular range of about 90º and redirect it into the room over a narrower angular range.

A number of recent studies indicate savings in lighting energy use of 40-80% in the daylighted perimeter zones of office buildings (Rubinstein and Johnson, 1998; Jennings *et al.*, 2000; Bodart and Herde, 2002; Reinhart, 2002; Atif and Galasiu, 2003; Li and Lam., 2003). Daylighting can also lead to a reduction in cooling loads, if solar heat gain is managed. Lee *et al.* measured savings for an automated Venetian blind system integrated with office lighting controls, finding that daily lighting energy savings averaged 35% in winter and ranged from 40-75% in summer. Monitored reductions in summer daily cooling loads, for a southeast-facing office in this Oakland, California building, were 5-25%, with even larger reductions in peak cooling loads (Lee *et al.*, 1998).

Ullah and Lefebvre (Ullah and Lefebvre, 2000) reported measured savings of 13-32% for cooling plus ventilation energy use using automatic blinds in a building in Singapore, depending on the orientation of the external wall. Tzempelikos and Athienitis (Tzempelikos and Athienitis, 2003) simulated the savings in lighting energy expected for offices with automated dimming and shading control on the southwest façade of a new building planned for Montreal. Continuous dimming was predicted to save 83% of the lighting electricity use, while 3-level switching would save almost as much (72%) but at much lower cost. The estimated reduction in peak cooling load was about 40%.

An impediment to more widespread use of daylighting is the lack of “off-the-shelf functionality” for daylighting dimming systems (Turnbull and Loisos, 2000). Dimming systems produced by different manufacturers at present do not conform to any standard performance or communications protocols, so it is difficult to correctly specify and install this essential component of a daylighting system. Although there are dozens of examples of successful and well-documented buildings with good dimming systems, it takes a significant (and often commercially non-viable) amount of expert time to design and commission such systems [ref]. There are good prospects for rapid improvement in this area.

Another impediment to the effective use of daylighting in buildings is the linear, sequential nature of the design process. Based on a survey of 18 lighting professionals in the US, Turnbull and Loisos found that, rather than involving lighting consultants from the very beginning, architects typically make a number of irreversible decisions at an early stage of the design that adversely impact daylighting, *then* pass on their work to the lighting consultants and electrical engineers to do the lighting design (Turnbull and Loisos, 2000). As a result, the lighting system becomes, *de facto*, strictly an electrical design.

6.4.9 Appliances, consumer electronics, and office equipment

Energy use by household appliances, office equipment, and consumer electronics is an important fraction of total electricity use in both households and workplaces (Roth *et al.*, 2002), (Kawamoto *et al.*, 2001)

The most efficient appliances available today require a factor of two to five less energy than the least efficient models. For example, the best horizontal-axis clothes-washing machines use less than half the energy of the best vertical-axis machines [ref]. Refrigerator/freezer units meeting the current US standard (478 kWh/yr) require about 25% of the energy used by refrigerator/freezers sold in the USA in the late 1970s (about 1800 kWh/yr)—less than 50% of energy levels in the late 1980s [ref]. Prototype high-efficiency refrigerator/freezers of standard US size use less than 400 kWh/yr (Brown *et al.*, 1998).

Standby use by consumer electronics (i.e., energy used when the machine is turned off) in a typical household in many countries often exceeds the energy used by a refrigerator/freezer unit that meets the latest US standards. The growing proliferation of electronic equipment such as set-top boxes for televisions, a wide variety of office equipment (in homes as well as offices), and sundry portable devices with attendant battery chargers – combined with inefficient power supplies and highly inefficient circuit designs that draw unnecessary power in the resting or standby modes – has caused this equipment to be responsible for most of electricity demand growth in both residential and commercial buildings in many nations [ref]. Efforts are underway especially at the International Energy Agency and several countries (Australia, Japan, and China, for example) to reduce standby energy use by a factor of 2-3 (Ross and Meier., 2002; Fung *et al.*, 2003). Electricity use by office equipment may not yet be large compared to electricity use by the HVAC system, but (as noted) it is growing rapidly and is already an important source of internal heat gain. The biggest savings opportunities are: 1) improved power supply efficiency in both active and low-power modes, 2) redesigned computer chips that reduce electricity use in low-power mode, and 2) repeated reminders to users to turn equipment off during non-working hours [ref].

6.4.10 Active collection and transformation of solar energy

Buildings can serve as collectors and transformers of solar energy, meeting a large fraction of their energy needs on a sustainable basis without reliance on connection to energy grids, although for climates this may only apply during the summer. As previously discussed, solar energy can be used for daylighting, for passive heating, and as one of the driving forces for natural ventilation, which can often provide much or all of the required cooling. By combining a high-performance thermal envelope with efficient systems and devices, 50-75% of the energy needs of buildings as constructed under normal practice can either be eliminated or satisfied through passive solar design [ref]. Electricity loads, especially in commercial buildings, can be drastically reduced to a level that allows building-integrated photovoltaic panels (BiPV) to meet much of the remaining electrical demand during daytime hours [ref]. Photovoltaic panels can be supplemented by other forms of active solar energy, such as solar thermal collectors for hot water, space heating, absorption space cooling, and dehumidification.

6.4.10.1 Building-integrated PV (BiPV)

The principles governing photovoltaic (PV) power generation and the prospects for centralized PV production of electricity are discussed in Chapter 4. Building-integrated PV (BiPV) consists of PV modules that function as part of the building envelope (curtain walls, roof panels or shingles, shading devices, skylights). With this flexibility, BiPV is increasingly being used as a design element in its own right. The International Energy Agency (IEA) maintains an international demonstration center (www.demosite.ch) and web site (www.pvdatabase.com) with a database of buildings with PV systems. Proponents of sustainable buildings are often very enthusiastic about BiPV systems, which are sometimes installed in new "showcase" buildings even before the systems are generally cost-effective. These early applications will increase the rate at which the cost of BiPVs comes down and the technical performance improves. A recent report presents data on the cost of PV modules and the installed-cost of PV systems in IEA countries (IEA, 2003). Electricity costs from BiPV at present are in the range of US$0.30-0.50/kWh in good locations, but can drop considerably with mass production of PV modules (Payne *et al.*, 2001).

Gutschner *et al.* have estimated the potential for power production from BiPV in IEA member countries (Gutschner and Task-7 Members, 2001). The percent of present total electricity demand that could be provided by BiPV ranges from about 15% (Japan) to almost 60% (USA).

6.4.10.2 Solar thermal energy for heating and hot water

Most solar thermal collectors used in buildings are either flat-plate or evacuated-tube collectors; recent technical discussions can be found in Peuser *et al.* (Peuser *et al.*, 2002) and Andén (Andén, 2003). Integrated PV/thermal collectors (in which the PV panel serves as the outer part of a thermal solar collector) are also commercially available (Bazilian *et al.*, 2001; IEA (International Energy Agency), 2002a). The efficiency of solar collectors (heat delivered to where it is needed divided by incident solar energy) depends on the design of the collector and on the system of which the collector is a part. "Combisystems" are solar systems that provide both space and water heating. Annual average collector efficiencies of 40-55% are feasible for domestic hot water, while combisystems have achieved annual average solar utilization (which accounts for storage losses and heat that cannot be used) of 20-25% (Peuser *et al.*, 2002). Depending on the size of panels and storage tanks, and \the building thermal envelope performance, 10-60% of the combined hot water and heating demand can be met at central and northern European locations.

Worldwide, almost 100 million m^2 of solar collector surface for space heating and hot water was in place in 2003. China accounts for more than half of the total (50.8 million m^2), followed by Japan (12.7 million m^2) and Turkey (9.5 million m^2) (Weiss *et al.*, 2005).

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6.4.11 Community-scale systems: district heating and cooling

Buildings are usually part of a larger community. If the heating, cooling, and electricity needs of a larger collection of buildings can be linked together in an integrated system, then significant savings in primary energy use are possible – beyond what can be achieved by optimizing the design of a single building [ref]. Community-scale energy systems also offer significant new opportunities for the use of renewable energy. These opportunities have implications for the design and operation of individual buildings, and especially for the planning of developments involving more than one building. Key elements of an integrated system can include: 1) district heating networks for the collection of waste or surplus heat and solar thermal energy from dispersed sources and its delivery to where it is needed; 2) district cooling networks for the delivery of chilled water for cooling individual buildings; 3) central production of steam and/or hot water in combination with the generation of electricity (cogeneration), or central production of heat and cold water in combination with the generation of electricity (trigeneration); 4) production of electricity through building integrated photovoltaic (BiPV) panels; 5) diurnal storage of heat and coldness produced during off-peak hours or using excess wind-generated electricity; and 6) seasonal underground storage of summer heat and winter coldness.

A district heating system consists of a network of insulated underground pipes carrying hot water and/or steam, with the hot water or steam produced at or extracted from a limited number of sites. District heat can be economically transported several tens of kilometres (Karvountzi *et al.*, 2002). A district cooling system consists of a network of insulated pipes carrying cold water (typically at 4-6°C) or an alternative thermal-transfer fluid such as an ice-water slurry that is produced centrally.

District heating is widely used in regions with large fractions of multi-family buildings, and has been especially widespread in the former communist countries, providing as much as 60% of heating and hot water energy needs for 70% of the families in transition economies (OECD/IEA 2004). While district heating can have major environmental benefits over other sources of heat, including lower specific greenhouse gas emissions, systems in these countries suffer from the legacies of past mismanagement, and are often obsolete, inefficient, and expensive to operate (Lampietti *et al.* 2002, Ürge-Vorsatz *et al.* 2003). Therefore district heating system retrofits are a top energy policy priority in these countries. According to the IEA (OECD/IEA 2004), making DH more efficient could save 350 million tons of CO_2 emissions in these countries annually, accompanied by significant social, economic, and political benefits.

The greatest potential improvement in the efficiency of district heating systems is to convert them to cogeneration systems in circumstances where this can displace electricity produced from fossil fuel at inefficient central power plants. Combined production of useful heat and electricity leads to a reduction in primary energy use compared to independent heat and power production. However, there can centralized production of heat in a district heat system can be more efficient than on-site boilers or furnaces even in the absence of cogeneration, and in spite of distribution losses [ref]. Furthermore, a district-heating network can be used with heat pumps to upgrade and distribute heat from scattered sources. Examples include sewage in Tokyo (Yoshikawa, 1997) and Gothenberg, Sweden (Balmér, 1997), and low-grade geothermal heat in Tianjin, China, left over after higher-temperature heat has been used for heating and hot water purposes (Zhao *et al.*, 2003).

Chilled water supplied to a district-cooling network can be produced through trigeneration, or it can be produced through a centralized chilling plant independent of power generation. District cooling provides an alternative to separate chillers and cooling towers in multi-unit residential buildings that would otherwise use inefficient wall-mounted air conditioners. In spite of the added costs of pipes and heat exchangers in district heating and cooling networks, the total capital cost can be less than the total cost of heating and cooling units in individual buildings ((Harvey, 2005b), Chapter 15). This arises from the diminishing unit cost of larger units, the fact that total heating or cooling equipment capacity can be reduced due to non-coincident peak demands in different buildings, and the need for less backup capacity. Adequate control systems are critical.

District heating and cooling systems, especially when combined with some form of thermal energy storage, make it more economically and technically feasible to use renewable sources of energy for heating and cooling. Solar-assisted district heating systems with storage can be designed such that 30-95% of total annual heating and hot water requirements are provided under German conditions (Lindenberger *et al.*, 2000). Existing and planned systems in Germany, Sweden, Denmark, The Netherlands, and Austria are described in (Lottner *et al.*, 2000; Schmidt *et al.*, 2004;) (Fisch *et al.*, 1998), (Heller, 2000). (IEA (International Energy Agency), 2000) and (Faninger, 2000). Integrating wind energy systems with district heating and cooling systems allows surplus wind-generated electricity to drive heat pumps and displace fossil fuel. For a scenario in which 50% of Danish electricity demand in 2030 is met by wind, integrated operation of the electricity and heating systems could cut the wasted wind energy potential in half (Redlinger *et al.*, 2002).

6.5 Potentials for and costs of Greenhouse Gas Mitigation in Buildings

The previous sections have demonstrated that there is a plethora of technological, systemic and management options available in buildings to substantially reduce greenhouse gas emissions. From a policy-making perspective, it is important to quantify the reduction potential these options represent, as well as the costs associated with their implementation.

The TAR (IPCC 2001) examines the two main approaches to modeling used for estimating the mitigation potential, namely the Top-Down economic and Bottom-Up technology-rich analytical methods, and reviews their main classes of models, therefore this Assessment does not cover methodological issues, but recent findings related to mitigation costs and potentials in buildings.

Chapter 3 of the TAR (IPCC, 2001), provided an overview of global GHG emissions reduction potential for the residential and commercial sectors based on the work of IPCC (1996) and Brown *et al.* (1998, IEA 1999). It estimated that CO_2 emissions from residential buildings in 2010 can be reduced by 1650 Mt CO_{2eq} at costs ranging from –US$68 to US$15 per ton CO_{2eq} saved. Similarly, CO_2 emissions from commercial buildings can be reduced by 970 Mt CO_{2eq} at costs ranging from –US$110 to US$0 per ton CO_{2eq} saved. The CO_2 emissions abatement potential from the residential and commercial sectors in 2020 was estimated correspondingly at 2160 and 1320 Mt CO_{2eq}.

6.5.1 Recent advances in potential estimations from around the world

An update of this assessment has been conducted for the AR4, based on a review of 56 recent studies from 32 countries and 10 country groups, spanning five continents. While the appraisal concentrated on new results since the IPCC exercise between 1996 and 1998, in striving for a comprehensive global coverage a few older studies were also revisited if no recent study was located to represent a geopolitical region.

Table 6.1 reviews the findings for a selection of major studies of energy savings potential that could be characterized in a common framework. Since the studies apply a variety of assumptions and analytical methods, these results should be compared with caution (see the notes for each row, as well as the TAR, for methodological aspects of such a comparison exercise).

INSERT **Table 6.1** (GHG reduction potential residential and commercial sector)

Both the methods and results for quantifying the potential for GHG mitigation in buildings vary widely around the world and from report to report, largely depending on the coverage of the study and the main assumptions. According to Table 6.1, estimates of technical potential range from 18% of year 2020[6] buildings-related CO_2 emissions in Pakistan, where only a limited number of options were considered, to 99% in South Africa, where supply-side measures such as switching entirely to green electricity were also considered. The estimates of potential savings that are cost-effective vary from 14% of residential emissions in Canada, to 37% for all US buildings and 41% for buildings in Brazil. The enhanced market potential[7] was projected for the case of China at 23% of residential and commercial emissions.

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[6] All figures for potential estimates refer to a 2020 target year, unless otherwise indicated in the last column of Table 6.1.

[7] For a definition of technical, economic, market and enhanced market potential, see Chapter 11.

While there are methodological challenges in aggregating these figures to a global level due to the differing assumptions used in the studies, we have made a best estimate for the global potential suggested by 11 studies from representative countries in four continents. Our calculations suggest that by 2020, globally 1500 and 900 million tons of CO2eq. can be avoided annually through energy efficiency in the residential and commercial sectors, respectively. Accepting the B1 Scenario (Price *et al.* forthcoming) as the baseline, this estimate represents a reduction of 23% of the business-as-usual emissions for all buildings in 2020. Due to the limited number of demand side end-use efficiency options considered by studies, the real potential is likely to be higher. These figures are similar to those reported in the TAR for 2010, indicating the dynamics of GHG reduction opportunities: as previous estimates of additional energy efficiency and GHG reduction potential begin to be captured in a new baseline, these tend to be replaced by the identification of new energy efficiency and GHG mitigation options.

6.5.2 Recent advances in estimating the costs of GHG mitigation in buildings

Studies apply various approaches to estimating the bill for GHG mitigation in buildings. Assessing the private plus government costs of achieving energy savings is a difficult task, and only a few of the studies that estimate energy savings potential also detail the associated costs. In many cases the results of different studies – even for the same country – vary considerably depending on assumptions regarding base-case conditions; the diversity of the building stock and operating practices; the rate of technology diffusion; the shapes of cost, price, and learning curves; and the discount rate adopted for evaluating the various options.

A review of 13 studies assessing the costs of GHG mitigation in buildings worldwide attests that there is a considerable potential for low-cost energy-efficient improvements in buildings. Up to 41% of the GHG emissions in the buildings of developing countries and economies in transition (Thailand, Republic of Korea, Pakistan, South Africa, China, India, Indonesia, Russia, Brazil, Argentine), and 11–25% of those in developed countries (EU-15, Japan, Canada, New Zealand, Australia, Greece), could be captured at negative cost[8] (ADB 1998c, ADB 1998d, ADB 1998k, De Villers and Matibe 2000, Joosen and Blok 2001, FEDEMA 1999, APEIS 2004, Mirasgedis et al 2003). If measures with costs up to US$25/tCO2eq. are considered, developing countries and economies in transition (Ecuador, Thailand, Republic of Korea, Pakistan, South Africa, Hungary) may save between 17% and 85% of their emissions in this sector, while for developed countries (EU-15) the range of potential that can be tapped at this cost is 14%-28%[9] (Urge-Vorsatz and Szlavik 1999, FEDEMA 1999, ADB 1998c, ADB 1998d, ADB 1998k, De Villers and Matibe 2000).

Some studies construct supply curves of conserved energy to illustrate the relationship between cost-effectiveness and the magnitude of potential by the different measures. The following section reviews a selection of recent research.

6.5.3 Supply curves of conserved energy

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[8] For a GHG mitigation measure, the net cost of avoided carbon emissions is the sum of benefits and costs. In the case of energy efficiency measures that result in GHG reductions, the benefit component will include energy cost savings which – in the case of cost-effective energy-saving measures will be greater than the cost of implementing the action, thus resulting in negative cost of conserved carbon. This means that society as a whole benefits from introducing this mitigation action instead of paying for it, as with other carbon mitigation actions (Halsnæs *et al.* 1998)

[9] Or up to 58% savings, if we include a single study for Hungary.

Conservation supply curves characterize the potential savings from a set of energy efficiency measures as a function of the cost per unit of saved energy. Originally developed as an analogue to supply curves for energy production, conservation supply curves recognize that saving energy is in many ways equivalent to supplying it (AIP (American Institute of Physics), 1975; Meier *et al.*, 1983; Rosenfeld *et al.*, 1993). This same framework can be extended to supply curves of avoided GHG emissions, with some measures avoiding carbon at a negative net cost per ton, as discussed above.

[INSERT **Figure 6.8** here] Supply Curves

Figure 6.8 integrates seven selected recent reports on supply curves of conserved carbon from different world regions. The figure underlines the conclusion from the previous section: while the steepness of the curves, i.e. the rate at which the costs of the measures increase as more of the potential is captured, varies substantially by country and by study. While the shape of each supply curve is profoundly influenced by the underlying assumptions and methods, the opportunities for cost-effective and low-cost CO_2 mitigation in buildings are abundant in each world region. Five of the seven studies covered here[10] included measures at negative costs per ton of CO_2; these negative-cost measures represented savings of 10%-41% of total residential and commercial sector CO_2 emissions. Four of the seven studies[11] show that close to 30% of the total building-level emissions can be cut for under US$20/ton of CO_2. The flat slope of six of the seven supply curves suggests that the net costs of GHG mitigation in buildings do not grow rapidly over the range of 30-50% reductions in emissions. One exception is the European Union study, where the baseline scenario assumes that many of the low-cost opportunities are already captured, due to progressive policies in place or in the pipeline.

It is important to note, however, that despite the merits and usefulness of supply curves, these studies rarely view buildings as integrated systems, but rather, focus on the energy savings potential and costs of incremental improvements to individual energy-using devices. As demonstrated in the first part of this chapter, integrated building design cannot only generate savings that are greater than the sum of individual measures, but can also improve cost-effectiveness. For instance, with optimal building design, savings through downsizing of mechanical equipment can often offset the cost of the envelope improvements needed to achieve the downsizing, resulting in significant (30-70%) reductions in energy use often at no net additional upfront cost [ref]. This suggests that studies relying solely on component estimates may underestimate the savings potential or overestimate the costs, compared with a systems approach to building energy efficiency.

6.5.4 Most Attractive Measures in Buildings

Studies applying the bottom-up approach to estimate energy saving potentials prioritize measures according to their cost-effectiveness and/or total potential savings. Table 6.1 summarizes the most promising measures from the key studies reviewed, from both of these perspectives. While it is impossible to draw universal conclusions, the table attests that efficient lighting technologies are among the most promising measures in buildings, in terms of both cost-effectiveness and size of potential savings. In developing countries, efficient cook stoves rank second, while the second-place measures differ in the industrialized countries, by climatic and geographic region. Almost all studies examining economies in transition (typically in cooler climates) found heating-related measures to be most cost-effective, including insulation of walls, roofs, windows and floors, as well as

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[10] Thailand, Pakistan, Korea, So. Africa, and the EU-15.

[11] Excluding the studies for Pakistan, the US, and the EU-15,

as improved heating controls for district heat. In developed countries appliance-related measures are typically identified as the most cost-effective, with cooling-related equipment upgrades ranking high in the warmer climates. In some cases, saving energy may be easier and less costly in manufactured devices than in building shells, because of manufacturing economies of scale and better quality control in the manufacturing of appliances [ref]. However, buildings last longer than appliances and most larger equipment, which allows the added cost of energy-saving features to be amortized over more years of energy cost savings. Air conditioning (AC) savings can be more expensive than other efficiency measures but can still be cost-effective because AC savings displace more expensive peak power [ref].

In terms of the size of savings, efficiency measures related to space conditioning (heating and cooling) come first in almost all studies[12], along with cook stoves in developing countries. Other measures that rank high in terms of savings potential are solar water heating, lighting and appliances, and building energy management systems.

6.6 Co-Benefits of Greenhouse Gas Mitigation in the Buildings Sector

Co-benefits (also referred to as auxiliary benefits or intangible benefits) of mitigation policies are an important decision element for policy analysts and decisions makers. While in many cases these co-benefits may not be quantified, monetized, or perhaps even identified by the decision makers or economic modelers (Jochem and Madlener, 2003), they can still play a crucial role in making GHG emissions mitigation a higher priority. This is especially true in less economically advanced countries, where environmentalism – and climate change specifically – may not have a strong tradition or a priority role in either the policy agenda or the daily concerns of citizens. In these circumstances, every opportunity for policy integration can be of value in order to reach climate change mitigation goals.

6.6.1 Reduction in local/regional air pollution

One of the most important co-benefits of climate policies is the reduction in local or regional air pollution resulting from energy efficiency and/or cleaner energy sources in residential and commercial buildings. Several studies show that such policies will significantly reduce SO_2, NO_x, VOC, and particulate matter emissions (Changhong et al 2005; Van Vuuren et al 2005; Mirasgedis et al 2004). These air pollutants cause significant impacts on humans and the natural environment such as: 1) increased deaths and morbidity, 2) reduced agricultural yields, 3) damage to forests and ecosystems, and 4) deterioration of buildings and historical monuments. According to a study for the DG Research, European Commission (2003), the external health costs from lignite-based electricity generation in Germany amount to almost 1 Eurocent/kWh and 0.34 Eurocents/kWh in the case of natural gas. Furthermore, in 2000, three million life-years – equivalent to about 288,000 premature deaths – were lost in the European Union due to particulate concentrations in the air (European Commission, 2005). Climate mitigation through energy efficiency in the residential and commercial sectors will also improve local and regional air quality, particularly in large cities, contributing to improved public health (increased life expectancy, reduced emergency room visits, reduced asthma attacks, reduced lost work days, etc.) and avoidance of structural damage to buildings and public works.

6.6.2 Improved quality of life and comfort

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[12] Note that several studies covered only electricity-related measures, and thus excluded some heating options.

In many cases the diffusion of new technologies for energy utilization and/or savings in residential and commercial buildings contribute to an improved quality of life and increased value of buildings. Jakob (2006) lists examples of this type of co-benefits, such as improved thermal comfort (fewer cold surfaces such as windows), the substantially reduced level of outdoor noise infiltration in residential or commercial buildings due to triple glazed windows or high-performance wall and roof insulation. The value of these co-benefits may amount to the same order of magnitude as the economic value of the energy saved [ref].

6.6.3 Improved productivity and economic competitiveness

Improving energy efficiency can translate directly into improved economic efficiency through increased productivity and retail sales. It has been shown that high quality, energy-efficient space conditioning and lighting enhance employee productivity and reduce absenteeism in offices, factories, and schools, and can increase sales in retail environments (GreenBiz, 2005; Makower, 2005). In a study by the California Energy Commission, daylighting was positively and significantly linked to higher retail sales – as much as 40% higher, compared with non-daylighted stores (GreenBiz, 2005; Makower, 2005).

Improved economic efficiency in the private sector enhances international competitiveness. For commercial office buildings that use 10% to 30% more energy than necessary, cutting energy use (and costs) by 30% will yield the same bottom-line benefits as a 3% increase in rental income or a 5% increase in net operating income (GreenBiz, 2005; Makower, 2005). Improved energy management of a company also increases its shareholders value; some investors are starting to recognize the added market value of good energy management, as an indicator of overall management quality, reputation, and other factors (GreenBiz, 2005; Makower, 2005).

More examples of both comfort and productivity, as co-benefits of energy efficiency in the tourism sector, are described in Box 6.1.

Box 6.1. *GHG mitigation in buildings can foster tourism*

Tourism has a significant role in the context of climate change policy in some parts of the world due to its economic importance as well as its high energy consumption. In Mexico tourism generated more foreign currency to the economy than oil in 1998, and was the second largest employer after agriculture (Clancy, 1999; Guenette, 2000). The energy demand of international tourists in New Zealand's buildings accounts for 1360 MJ for accommodation and 860 MJ for tourist attractions (Becken et al 2000). The growth of tourism inevitably fuels energy demand growth for hospitality services (Tulsie, 2001). Special policies optimized at mitigating GHG emissions in catering, entertainment, and lodging facilities may be warranted in many parts of the world.

Many tourism facilities within the Wider Caribbean region suffer from inappropriate energy use models transferred from temperate areas without suitable modification to local climate and other circumstances. Numerous measures are available, often at low or no cost, to reduce energy waste and hence cut carbon emissions from the tourism sector. Examples include signage and notes to remind tourists to participate in energy conservation by moderate use of hot water, maintaining moderate air-conditioning operation, using of natural ventilation and passive solar architectural solutions, installation of solar water heaters, designing hotels and resorts with open-air (non-conditioned) public spaces, keycard-enabled power supply in rooms, motion detectors for room and corridor lighting, re-engineering of kitchen areas, and low-energy or solar-powered lighting (*e.g.,* for pathway lights) (Island Resources Foundation, 1996).

It is important to recognise that almost all measures that can reduce carbon-dioxide emissions in tourist establishments improve comfort and amenity and reduce operating costs, therefore fostering the competitiveness and attractiveness of the facility for clients. Hence, policies and measures to help the development of the tourist industry can go hand-in-hand with GHG emissions control efforts.

6.6.4 Energy security

The promotion of energy-efficient technologies and renewable energy sources constitutes an important mechanism for addressing both GHG emissions and energy security concerns (IEA 2004). Next to energy security increase, energy efficiency is likely to generate larger macroeconomic benefits because reduced energy imports will improve the trade balances of import countries (European Commission, 2003).

6.6.5 Employment creation and new business opportunities

Employment is also an important issue associated with energy efficiency and climate mitigation policies, given the high unemployment levels in many countries. Most studies agree that energy efficiency investments will have positive effects on employment in each country, by creating new business opportunities and thus jobs via domestically produced energy-efficient technologies and services, and through the economic multiplier effects of re-spending in other ways the money saved on energy costs (Jochem and Madlener, 2003; Laitner et al 1998).

Further, a national policy that promotes both the production and use of energy-efficient technologies helps all sectors of the country to compete internationally, thus contributing to economic development and job creation (Jochem and Madlener, 2003).

Providing energy efficiency services has proven to be a lucrative business opportunity. Experts estimate a market opportunity of €5-10 billion in energy service markets in Europe (Butson, 1998). The figures on ESCO industry revenues in the section on ESCOs, below, demonstrate that the energy services business appears to be both very promising and quickly growing trade.

The European Commission (2005) estimates that the proposed 20% reduction of present energy consumption in the EU by 2020 can potentially create (directly or indirectly) as many as one million new jobs in Europe. The strongest effects are expected in the area of semi-skilled labor in the buildings trades, which also affords the strongest regional policy effects (Jeeninga *et al.*, 1999; European Commission, 2003). The German Council for Sustainable Development (Council for Sustainable Development, 2003 cited in European Commission, 2005) estimates that more than 2,000 full-time jobs could be created for each million tons of oil equivalent that will be saved as a result of measures and/or investments specifically taken to improve energy efficiency, as compared to equivalent investments in energy production. Energy efficiency can also contribute to positive regional and rural development benefits and social cohesion effects because of the decentralized nature of energy efficiency actions.

6.6.6 Improved social welfare

Improved energy efficiency helps reduce energy bills. Reducing the economic burden of utility bills is an important co-benefit of energy efficiency for less affluent households. This is especially true in former communist countries where energy subsidies have been removed. This, combined with a general decline in welfare and economic security, high inflation levels, and spreading unemployment, has caused energy expenditures to be a major burden for much of the population (Ürge-Vorsatz *et al.*, forthcoming). As a result, payment arrears and fuel theft have become major problems, indicating the magnitude of the challenge in making energy services affordable in these countries (World Bank, 1999; Suriyamongkol, 2002).

Fuel poverty, or the inability to afford basic energy services to meet minimal needs or comfort standards, is not limited to the developing countries or economies in transition, but is also found in even the wealthiest countries. In the UK, a household in fuel poverty is defined as spending more than 10% of income on energy services (Boardman 1991). In 1996, around 4.3 million UK households (equivalent to around 20%) were estimated to live in fuel poverty. The number of excess winter deaths in the UK is estimated by the UK department of Health at around 30,000 p.a., which can largely be attributed to inadequate heating (DoH 2000, Boardman ibid).

Improving residential energy efficiency, especially for space heating, helps households cope with the burden of paying utility bills and helps them afford adequate energy services. One study estimated that an average EU household could save €200-1000 per year in utility costs through cost-effective improvements in energy efficiency (European Commission, 2005). Along the same line, in economies in transition social programs to compensate for increasing fuel tariffs can be partly redirected or otherwise linked to energy efficiency efforts, and with resources invested in long-term bill reduction through energy efficiency instead of one-time subsidies to help pay current utility bills (Ürge-Vorsatz *et al.*, 2005).

6.6.7 Summary of co-benefits

In summary, an investment in residential and commercial building energy efficiency can yield benefits well beyond the value of saved energy and reduced GHG emissions. Many of the co-benefits of GHG mitigation through efficiency are also associated with very near-term effects, whose value can be seen much sooner than the long-term gains from climate change mitigation. Several climate mitigation studies focusing on the buildings sector maintain that, if co-benefits of the various mitigation options are included in the economic analysis, their economic attractiveness may increase considerably – along with their priority in the view of decision makers (Jakob et al 2002; Miresgedis et al 2004; Georgopoulou et al 2003). Strategic alliances with other policy fields, such as employment, competitiveness, environment, social welfare, and energy security, give a broader societal support for climate change mitigation goals, and may improve the economics of climate mitigation efforts substantially through sharing the costs or enhancing the dividends (European Commission, 2005).

6.7 Barriers to Adopting Building Technologies and Practices that Reduce GHG Emissions

The previous sections have demonstrated the significant cost-effective potential for CO_2 mitigation through energy efficiency in buildings. The question often arises: if these represent profitable investment opportunities, or revenues foregone by households, why are these opportunities not taken advantage of? If there are profits to be made, why do markets not capture these potentials?

Certain characteristics of markets, technologies, and end-users can inhibit rational, energy-saving choices in building design, construction and appliance purchase and use. These are discussed below.

6.7.1 Limitations of the traditional building design process

One of the most significant barriers to energy-efficient building design is that buildings are complex systems. Minimizing energy use requires optimizing the system as a whole by systematically addressing building form, orientation, envelope, glazing area, and a host of interactions and controls issues involving the building's mechanical and electrical systems. This is more evident in larger, commercial buildings but is present to some degree even in smaller residential and non-residential buildings. In contrast, the typical design process is linear and sequential. An alternative, called the *integrated design process (IDP),* is being promoted in a number of countries and by the International Energy Agency (E-Source, 1998; Torcellini *et al.*, 1999; IEA, 2000c, 2002c; Balcomb *et al.*, 2002; Poel *et al.*, 2002; Löhnert *et al.*, 2003; Lewis, 2004; de Wilde and van der Voorden, 2004). With an IDP and conventional technologoies, savings of 35-50% in total energy use can be achieved at little to no incremental upfront cost (Harvey 2006). When combined with advanced technologies, savings of 50-80% compared to typical new buildings have been achieved.

6.7.2 Fragmented market structure

Compounding the flaws in the traditional design process is fragmentation in the building industry as a whole. This fragmentation distinguishes the challenges to a low-GHG emitting future in the buildings sector from those in the transportation, industrial, and power generation sectors. Assuring the long-term energy performance and sustainability of buildings is all the more difficult when decisions at each stage of design, construction, and operation involve multiple stakeholders.

The design of large commercial buildings typically involves an architect for the building envelope (roof, walls, and foundation); mechanical and electrical engineers for the heating, ventilation, and air-conditioning systems and controls; and lighting designers or sometimes lighting contractors themselves for the lighting systems. This division of responsibilities often contributes to sub-optimal results (e.g., under-investment in energy-efficient approaches to envelope design because of a failure to capitalize on opportunities to down-size HVAC equipment). In Switzerland this barrier is being addressed by the integration of architects into the selection and installation of energy-using devices in buildings (Jefferson, 2000).

The realty and financial industries are also part of the buildings sector; under the right circumstances they can positively influence the uptake of energy-efficient and climate-friendly building products (Farhar, Collins, and Walsh, 1996). The insurance industry may become an advocate of low-GHG buildings in response to the increased property damage liabilities from extreme climatic events that may be associated with global warming, a fact that has been recognized by the Australian insurance industry (Coleman, 2004).

6.7.3 Misplaced incentives and administrative hurdles

When intermediaries are involved in decisions to purchase energy-saving technologies this limits the consumer's role and often leads to an under-emphasis on investments in energy efficiency. This problem of misplaced incentives occurs when a third party is in a position to act on behalf of a consumer but does not fully reflect the consumer's own costs and benefits. Decisions about the energy features of a building (e.g., whether to install high-efficiency windows or lighting) are often made by people who are not responsible for the energy bills. For example, landlords often provide the air-conditioning equipment and major appliances, while the tenant pays the electricity bill. As a result, the landlord is not rewarded for investing in energy efficiency. Some institutions face analogous situations: in many countries, the energy bills and other operating expenses of hospitals, for example, are paid from central public funds while investments expenditure must come either from the institution itself or from the local government (Rezessy *et al.* 2006). In the case of municipal institutions further administrative hurdles arise from the rules of public budgeting and complicated procurement procedures. For example requiring separate calls for tender for project design and for construction may discourage or further complicate rational decisions on energy-efficient features.

Similarly, the prevailing selection criteria and fee structures for building designers may emphasize initial costs over life-cycle costs (Jones, *et al.*, 2002; Lovins, 1992). Projects are often awarded to the team that designs the lowest-first-cost building. This tends to hinder energy efficiency because initial capital costs are typically higher for high-efficiency heating, ventilation, and air-conditioning systems, even though subsequent operating costs are lower and the return on investment very attractive.

6.7.4 Energy subsidies, non-payment and theft

Electricity historically has been subsidized to residential customers in many countries (and sometimes to commercial or government customers, also). This is particularly the case in many developing countries, and historically in Eastern Europe and the former Soviet Union, although the practice is not restricted to these regions. For example, widespread fuel poverty in Russia has driven the government to subsidize energy costs, which creates a disincentive for energy efficiency (Gritsevich, 2000). Energy pricing that does not reflect the long-term marginal costs of energy, including direct subsidies to some customers, hinders the penetration of efficient technologies (Alam *et al.*, 1998).

However, the abrupt lifting of historically prevailing subsidies may also have adverse effects. After major tariff increases, non-payment has been reported to be a serious issue in some countries. In the late 1990s collection rates in Albania, Armenia, and Georgia were around 60% of billings. Household consumers were the main source of concern in Albania, Georgia, and Armenia, while industrial consumers posed the biggest source of non-payment in Russia and Ukraine (World Bank, 1999; Suriyamongkol, 2002). Besides non-payment, electricity theft has been occurring at a large scale in many countries – estimates show that distribution losses due to theft are as high as 50 percent in some states in India (New Delhi, Orissa, and Jammu-Kashimir), while in Lebanon 25 percent of the electricity supplied by the country's electric utility, Electricité du Liban, has been reported as stolen by unauthorized taps on power cables (EIA, 2004). Electricity theft does not appear to be a problem limited to developing countries or economies in transition. Electricity theft in the United States has also been estimated to cost utilities billions of dollars each year (Suriyamongkol 2002 and references herein). The failure of recipients to pay in full for energy services tends to induce waste and discourage energy efficiency.

6.7.5 Regulatory barriers

A range of regulatory barriers has been shown to stand in the way of building-level distributed generation technologies such as photovoltaics, reciprocating engines, gas turbines, and fuel cells (Alderfer, *et al.*, 2000). In many countries, these barriers include variations in environmental permitting requirements, which impose significant burdens on project developers. Similar variations in net metering policies cause confusion in the marketplace and represent barriers to distributed generation. Net metering allows customers with small generating facilities to use a single meter to measure both power drawn from the grid and power fed back into the grid from on-site generation. Customers in effect receive retail prices for the excess electricity they generate. When combined with time-of-use pricing, this can result in an attractive value proposition for photovoltaics and other onsite power production (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2003).

6.7.6 Small project size, transaction costs and perceived risk

Many energy efficiency projects and ventures are too small to attract the attention of large financial institutions. Small project size, coupled with disproportionately high transaction costs – i.e., costs related to verifying technical information, preparing viable projects, negotiating and executing contracts – result in energy efficiency investments not made for lack of project financing. Conservative, asset-based lending practices of financial institutions, a limited understanding of energy efficiency technologies on the part of both lenders and their consumers, volatile prices for fuel (and in some markets, electricity), and small, non-diversified portfolios of energy projects all increase the perception of market and technology risk by these actors. In turn, these perceptions of high risks and small market sizes discourage lenders from investing the time and resources to learn how to finance energy efficiency projects (Westling, 2003; Bertoldi and Rezessy, 2005; Vine 2005).

High transaction costs and relatively small project size help explain why energy efficiency investments in buildings have not become beneficiaries of the project-based mechanisms of the Kyoto Protocol, i.e., Joint Implementation and the Clean Development Mechanism, despite all the potential benefits these mechanisms could provide to developing countries as well as economies in transition through adding the value of GHG credits to the inherent economic benefits of the energy efficiency projects themselves.

As discussed later, policies can be adopted that can help to reduce these transaction costs, thus improving the economics and financing options for energy efficiency investments.

6.7.7 Imperfect information

Information about energy efficiency options is often incomplete, unavailable, expensive, and difficult to obtain or trust. This insufficient knowledge is compounded by uncertainties associated with energy price fluctuations, which lead to high hurdle rates (i.e., the expected rate of return on a potential investment that is required by the investor) and a slow pace of technology diffusion (Hassett and Metcalf, 1993).

While information for most goods and services is imperfect, it is particularly difficult to learn about the performance and costs of energy-efficient technologies and practices, because the benefits are often not directly observable. For example, households typically receive a monthly electricity bill that provides no breakdown of individual end uses, making it difficult to assess the benefits of efficient appliances or additional thermal insulation. This makes energy savings “invisible,” boosts technical risk perception and concerns over the safety and reliability of equipment, and makes energy use patterns and load profiles hard to understand and to link to energy bill savings.

Properly trading off energy savings versus higher purchase prices for many energy-efficient products involves comparing the time-discounted value of the energy savings with the present cost of the equipment—a calculation that can be difficult for purchasers to understand and compute, even assuming one could accurately predict energy costs. This is another reason why builders generally minimize first costs, in the belief that the higher cost of more efficient equipment may not translate into a higher rental income or resale value for the building. In an attempt to reflect the economic value of energy efficiency in construction, purchase, and rental decisions, the European Commission has introduced the Directive on the Energy Performance of Buildings (2002/91/EC, see Box 6.2). The Directive requires, among other provisions, that an energy performance certificate be made available to the owner in case of new construction, or to the prospective buyer or tenant in case of rent or sale.

Box 6.2. *The European Directive on Energy Performance of Buildings*

One of the most advanced and comprehensive pieces of regulation targeted at the improvement of energy efficiency in buildings is the new European Union Directive on the Energy Performance of Buildings, which entered into force in 2003 (Directive 2002/91/EC). The Directive introduces four major actions to substantially increase the energy performance of buildings across the EU.

The first action is the establishment of a *common methodology for calculating the integrated energy performance of buildings*. Such an approach includes, in addition to the quality of building insulation, heating and cooling installations, energy for ventilation, lighting installations, position and orientation of the building, heat recovery, active solar gain, and other renewable energy sources.

The second action is to require Member States to *apply the new methodology to minimum energy performance standards* for new buildings. The Directive also requires that a non-residential building, when it is renovated, be brought to the level of efficiency of new buildings. This latter is a very important action, as new buildings represent a small percentage of the total building stock, and the cycle of major renovations to inefficient older buildings may occur several times before they are finally removed from the stock. This represents a pioneer effort in energy efficiency policy, as one of the few policies worldwide to target existing buildings.

The third mandatory action is to set up *certification schemes for new and existing buildings* (both residential and non-residential) on the basis of the above-mentioned methodology, and in the case of public buildings to require the public display of energy performance certificates, recommended indoor temperatures, and other relevant information. These certificates are intended to address the landlord/tenant barrier, by facilitating the transfer of information on the relative energy performance of buildings and apartments. Information from the certification process must be made available for new and existing commercial buildings and for dwellings when they are constructed, sold, or rented.

The last mandatory action mandates Member States to establish *regular inspection and assessment of boilers and heating/cooling installations*. Regular maintenance of heating and cooling installations is thus recognized as a key opportunity for improving energy efficiency.

6.7.8 Tradition, customs, behavior, and style

Patterns of energy use vary greatly among countries, and within countries, among inhabitants. These patterns have obviously changed markedly over the past few decades, both in developed and developing countries, but are far from convergent. Energy use, being integral to daily life, reflects a complex mixture of individual behavior and technological and social traditions, into which new opportunities, including new technologies, are continually being introduced – with implications for energy consumption that may be difficult to predict (Shove 2003).

Energy use decisions made by individuals, corporations, and social institutions include purchase and design choices, such as the configuration of a building or the energy-efficiency of the appliance model selected in a showroom, as well as what options are even offered on the market (e.g., the sizes and features of refrigerators available for purchase or the designs presented by the builder). In addition to recognizing these formal decision points, social scientists stress that it is crucial to understand the conditions leading up to the purchase or design decision, and what comes after. For example, how does mechanical air conditioning become considered a desired feature, or perhaps an essential one, in a home or office? How will the air conditioner be operated – within what range of temperatures, for what periods of the day, and during what parts of the year? And how will windows be managed in conjunction with mechanical cooling? Finally, how are all these routines and user expectations formed? Some of the most important determinants of energy use are not one-time investment decisions by each individual, but rather a complex blend of influences from lifestyle, culture, legal standards, market conditions, and the legacy of tradition, which collectively might be termed "societal energy efficiency." These routines are somewhat but not entirely amenable to formal information, education, and energy consumption feedback programs designed to promote energy-efficient practices (Bender *et al.* 2004, McCalley 2006, Shove 2003). The better we understand these complex interactions between technologies and human practices, the better the potential for effective GHG emissions mitigation (Jelsma 2004, Nevius and Pigg 2000).

Air conditioning illustrates many of the common elements driving growth in popularity of a new energy end use. Mechanical refrigeration began as a necessity for certain industrial processes. Historians who have studied trends in air conditioning usage cite a number of shifts by which residential air conditioners became standard in US homes (Ackermann 2002, Cooper 1998), with saturations doubling from 23% of the housing stock in 1978 to 47% of the stock in 1997 (U.S. Department of Energy 2000) and 92% of the new single-family homes sold in 2004 (U.S. Bureau of the Census 2005). These shifts included changes in building codes, advertising campaigns promoting cooling, mortgage lending policies, science-based arguments relating air conditioning to health and productivity, changes in building practices facilitated by the availability of air conditioning (including elimination of some passive cooling features such as overhanging roofs, porches, and openable windows), and concomitant social preferences, styles of dress, time schedules, and expectation for being "cool." Noting somewhat different mechanisms, social scientists have examined the growing preference for air conditioning in Japan (Wilhite et al 1996) and in Ghana and Thailand (Agbemabiese et al 1996).

The potential impact of lifestyle and tradition on energy use is most easily seen by cross-country comparisons. For example, dishwasher saturation was 21% in UK residences in 1998 but 51% in Sweden (European Commission 2001). Cold water is traditionally used for clothes washing in China (Biermayer and Lin 2004) whereas hot water washing is common in Europe. And room temperatures considered comfortable vary by country (Chappells and Shove 2004). Cultural differences generally considered outside the realm of energy analysis may be of great importance in determining energy use – for example, the operating hours of commercial buildings. Few stores in France are open on Sundays or after 7:30 p.m. in metropolitan areas, whereas in the US, Sunday closures are the exception and most large stores are open until 9 p.m. (in other words, energy use in the commercial sector in France is more compressed time-wise than in the US). Similarly, there are substantial differences among countries in ideas about how lighting should be used at night, preferred temperatures of food or drink, and in the size and composition of households. Some of the most accessible literature on this topic is framed around the topic of "lifestyles," which has been approached through the rubric of market segmentation as well as in broader sociological or anthropological frameworks (Bin and Dowlatabadi 2005, Jeeninga and Boudewijn 1999, Lutzenhiser 1993).

While more energy-efficient devices and buildings have been appearing on the market for the past thirty years, the demand for energy services has tended to grow, as well (Wilhite et al 1996), through a combination of social shifts and new technological possibilities (Oreszczyn 2004, Shove 2003). Several trends affected electricity use in the EU-15 residential sector from 1985 through 1998: the saturation of major electrical appliances increased, the intensity of use of these appliances generally increased, and the number of households increased while the average number of people per household decreased. The net result was an overall increase in residential electricity consumption of 32% over 14 years (EEA 2001). Increased energy efficiency may be accompanied by increased demand for energy services, a concept economist call "the rebound effect" – especially when the efficiency gains may contribute to the growing demand for energy services that have become less expensive thanks to efficient technologies (Herring 1998, 2005). While debates continue about the size and persistence of the rebound effect, the phenomenon is useful in understanding the relationships between technology-driven energy efficiency on the one hand, and total energy consumption and GHG emissions on the other (Moezzi and Diamond 2005). Differences in social practices across time and among countries can provide valuable clues to supplement a purely technological approach to designing and implementing GHG emissions mitigation strategies.

6.7.9 Power quality and electronics

Several energy-efficient technologies, especially those powered by electricity, require certain technical standards in power supply in order to operate effectively. For instance, compact fluorescent lamps, electronic ballasts, efficient electric motors and other equipment may not function properly, or may fail prematurely, if the power quality is compromised. This problem often prevents the introduction or spread of some energy-efficient appliances and equipment in developing countries and economies in transition, especially those dependent on electronic circuitry for control or to supply low voltage power. For the case of poor power supply interfering with the operation of the electronics needed for energy-efficient end-use devices was identified by EAP UNDP (2000) as one of the top barriers to adopting energy efficiency in India.

6.7.10 Other barriers

Due to space limitations not all barriers to energy efficiency can be detailed here. Other important barriers include the limited availability of energy-efficient equipment along the retail chain (Brown, Berry, and Goel, 1993); the limited access of low-income households and small businesses to capital markets; as well as the inadequate levels of energy services presently provided in many public buildings in developing countries and economies in transition, such as inadequate illumination levels in schools, or poor fire safety of wiring. This latter can severely limit the cost-effectiveness of the efficiency investment, as a proposed efficiency upgrade must also address safety issues and illumination levels, which may offset most or all of the energy and cost savings associated with improved efficiency, and in turn make it difficult to secure financing or pay back a loan from energy cost savings.

6.8 Policies to Promote GHG Mitigation in Buildings

Preceding sections discussed both the potential for reducing GHG emissions in buildings through cost-effective energy efficiency measures and the significant barriers that still exist (varying by country and region) to large-scale implementation of even those technologies that are well understood and generally available today. However, a major change since the IPCC's TAR is that many countries have now implemented a wide range of policies and programs to spur increased energy efficiency. The results of some of these policies and programs can be assessed, even though there remain many important and unresolved policy and program questions. Policy tools described in this chapter complement those in chapter 13; here we concentrate on policies especially applicable to the residential and commercial sectors. Table 6.2 reviews the key instruments available for GHG emissions reductions in buildings. There are several taxonomies used in the literature to classify policy tools, such as in Crossley *et al.* (2000), (Verbruggen and Bongaerts 2003), Vine *et al.* (2003) Grubb (1991), OECD (1994), IEA (1997), Laponche *et al.* (1997). Table 6.2 synthesizes the wisdom from these typologies, and adapts them to buildings.

INSERT **Table 6.2** (Typology of policy instruments available for GHG emission limitation in buildings)

6.8.1 Policies and programs aimed at building construction, retrofit, and installed equipment and systems

6.8.1.1 Building codes

Building regulation was first introduced to impose minimum standards to assure structural safety and protect occupants from life-threatening problems. However, after the oil price shocks in the 1970s, most OECD countries extended the coverage of building regulation to include the energy efficiency of buildings. As a result, most OECD countries[13] now have energy efficiency standards in their building regulations, although coverage varies between countries (OECD, 2003).

Building energy codes may be classified as follows: 1) Overall performance-based building energy codes that require compliance with an annual energy consumption or energy cost budget, calculated using a standard method. This type of code provides flexibility but requires well-trained professionals for implementation. 2) Prescriptive codes that set separate performance levels for major envelope and equipment components such as minimum thermal resistance of walls, maximum window heat/loss gain, minimum boiler efficiency, etc. 3) A mix of an overall performance requirement plus some component performance requirements such as wall insulation and maximum window area.

Energy codes for new buildings are often considered as the main driver for improved energy efficiency in new buildings. However, the implementation of codes in practice needs to be well prepared and to be monitored and verified. Control of compliance is often claimed to be difficult, and varies among countries and localities (Smith et al; DOE 2001; XENERGY, 2001; City of Fort Collins, 2002; OECD, 2003; Ürge-Vorsatz *et al.*, 2003).

There is a clear trend toward more performance-based codes that address the overall energy consumption of the building. Prescriptive codes often are easier to enforce than performance based codes (Australian Greenhouse Office, 2000; DOE, 2001; Smith and McCullough, 2001; City of Fort Collins, 2002). In particular, small contactors may prefer the simplicity of prescriptive code requirements. Education and training, including training of building officials, are considered to be key factors for the success of building codes.

In addition to new construction, energy efficiency in existing buildings is also increasingly addressed by public policies in many countries. For instance, the EU Commission introduced the Directive on the Energy Performance of Buildings in late 2002 (see Box 6.2), which standardized and strengthened building energy efficiency requirements for all EU Member States. To date, most codes for existing buildings include requirements for minimum levels of performance of the components used to retrofit building elements or installations. This may even extend, such as in Sweden, to strict prohibition of direct electric resistance heating systems, which has led to the rapid introduction of heat pumps in the last five years [ref].

According to the OECD (OECD, 2003), there appears to be much room for further upgrading of buildings energy efficiency standards throughout the OECD member countries. Moreover, in order for building standards to remain effective, they have to be regularly upgraded as technologies improve and incremental costs of energy-efficient features and equipment decline. Flexible setting of standards can help keep compliance costs low and may provide more incentives for innovation.

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[13] An OECD study **OECD**, 2003: *Environmentally Sustainable Buildings - Challenges and Policies.* found that 19 out of 20 countries surveyed had legislated mandatory building standards.

6.8.1.2 Building certification and labeling systems

The purpose of building labeling and certification is to overcome barriers relating to the lack of information, the high transaction costs, the long lifetime of buildings, and the problem of displaced incentives between the builder *vs* buyer or the owner *vs* tenant. Certification and labeling schemes can be either mandatory or voluntary.

In 2001, four European countries mandated the certification of buildings regarding their energy performance (OECD, 2003). With the introduction of the EU Directive on the Energy Performance of Buildings (see Box 6.2), building certification is to be instituted throughout Europe. Voluntary certification and/or labeling systems have also been developed for building products such as windows, insulation materials, and HVAC components in North America, the EU, and a few other countries (Menanteau, 2001, *Hicks T. et al., 2000, McMahon, 2001, Thorne, 2002*).

The Energy Star Buildings label in the US and the quality certificate for single-family houses in France (NF-MI) have proved to be effective in ensuring good compliance with energy code requirements and sometimes higher performance levels (Hicks, 2000). (Hicks, 2000). The experience in Denmark is significant: up to 70% of new single-family houses were labeled and energy costs were lower by 20% [ref]. These houses cost slightly more than non-labeled houses but the typical return on investment for buyers was estimated to be as low as seven years (OPET Network, 2004).

6.8.1.3 Education and training

Lack of awareness of energy-savings opportunities among practicing architects, engineers, lighting specialists, and interior designers is a major impediment to the construction of low-energy buildings. This in part reflects inadequate training at universities and technical schools, where the curricula often mirror the fragmentation seen in the building design profession. There is a significant need, in many countries, to create comprehensive, integrated programs at universities to train future architects and engineers in the design of low-energy buildings, with parallel programs at technical schools to train technical specialists. The value of such programs would be significantly enhanced if they had an outreach component to upgrade the skills and knowledge of practicing architects and engineers – for example, by assisting in the use of computer simulation tools as part of the integrated design process (Section 6.7.1).

6.8.1.4 Energy audit programs

Energy audit programs provide consumers with technical assistance on opportunities for upgrading the energy efficiency of buildings. Often with financial support from government or utility companies, these programs provide trained energy auditors to conduct on-site inspections of buildings, perform most of the calculations for the building owner, and offer recommendations for energy efficiency investments or operational measures, as well as other cost-saving actions (e.g., reducing peak electrical demand, fuel-switching, or changing to a different utility tariff). The implementation of the audit results can be voluntary for the owner, or mandated, such as in the Czech Republic and Bulgaria, which require that installations with energy consumption above a certain limit conduct an energy efficiency audit and implement the low-cost measures (Ürge-Vorsatz *et al.*; Ürge-Vorsatz *et al.*, 2003). In India, according to the Energy Conservation Act of 2001, all commercial buildings with a connected load of 500 kW or contract demand of 600 kVA have to conduct an Energy Audit in the specified manner and intervals of time (Energy Conservation Act 2001).

6.8.1.5 Financial incentives

As noted in Section 6.7.1, applying the integrated design process (IDP) can lead to buildings that use 35-70% less energy use than conventional designs, at little to no additional capital cost. However, the design process itself can cost more, due to the greater effort and time required in order to optimize the design as a whole and to explore a number of alternative designs. Thus, one approach is to provide financial incentives for the design process, rather than financial incentives to the capital cost of the building. This approach has been adopted in Canada in its Commercial Building Incentive Program (CBIP) (Larsson, 2001), in California in its *Savings By Design* program (www.savingsbydesign.com) and in Germany under the *SolarBau* program (Reinhart *et al.*, 2000).

Going beyond integrated design, other measures, particularly with renewable energy options such as building-integrated photovoltaic and/or thermal collectors, entails significant added capital costs. These have been supported through subsidies in several countries [ref]**.**

Capital subsidy programs and tax exemption schemes for both new construction and retrofit of existing building have been introduced in nine OECD countries out of 20 surveyed (OECD, 2003). Only three countries reported using tax exemption schemes; five introduced premium loan schemes for new buildings, and three offered loans for retrofitting existing stock.

There is limited assessment of the efficiency of these schemes. According to Barnerjee and Solomon (Barnerjee and Solomon, 2003), the variety of financial incentives, very often of several kinds at the same period, may make the decision process difficult, suggesting that simplicity of the schemes is an asset. The same authors suggest that a combination of government financial incentives and private bank loans may be more effective than a government-subsidized loan, since the separate incentive program is a more visible and attractive market signal than a relatively small reduction in the loan rate (Barnerjee and Solomon, 2003). The same increased impact is observed for when building rating or labeling are combined with a loan, especially when the labeling scheme is publicly approved (Barnerjee and Solomon, 2003).

6.8.1.6 Importance of policies aimed at the energy efficiency improvement of existing buildings

The majority of policies for improving building energy performance target new construction. However, as the source of most GHG emissions from buildings, will be the existing building stock, at least for the next two decades, more emphasis is needed on effective policies and programs directed toward the existing stock. Since most OECD countries have not tried to apply mandatory efficiency standards to existing buildings, non-regulatory instruments are expected to play a more important role here than they do in new construction (Hasegawa, 2003).

Economic instruments and information tools could enhance each other's effectiveness if they are appropriately combined for both new and existing buildings. A typical example is the co-ordination of energy audit programs with economic instruments, such as energy taxes and capital subsidy schemes. Owners of buildings are in a better position to take advantage of such economic incentives if they have ready access to the results of a high-quality energy audit of their facility.

6.8.2 Policies and programs aimed at appliances, lighting, and office/consumer plug loads

The previous section reviewed policy instruments designed to improve energy efficiency and reduce carbon emissions related to the building shell and HVAC systems. Appliances, equipment (including information and communication technology), and lighting systems in buildings typically have very different characteristics from those of the building shell and installed equipment, including lower investment costs, shorter lifetimes, different ownership characteristics, and less expertise needed for installation and maintenance. Thus, the barriers to energy-efficient alternatives are also somewhat different for appliances. This section provides an overview of policies specific to appliances, lighting, and plug-in equipment.

6.8.2.1 Standards and labeling

Energy efficiency performance standards and labels (S&L) for appliances and lighting are increasingly proving to be effective vehicles for transforming markets and stimulating adoption of new, more-efficient technologies and products. S&L programs were first used successfully to reduce energy consumption in the mid-1970s. Since the 1990s, driven by greenhouse gas reduction as well as energy efficiency goals, 57 countries have legislated efficiency standards and/or labels, applied to a total of 46 products as of 2004 (Wiel and McMahon, 2005). Products subject to standards or labels cover all end-uses and fuel types, with a focus on appliances, information technology, lighting, heating and cooling equipment, and other energy-consuming products used in homes and offices, as well as commercial and industrial equipment such as motors and electric transformers (which are addressed in other chapters).

Endorsement labels and comparison labels[14] induce manufacturers to improve energy efficiency and provide the means to inform consumers of the product's relative or absolute performance and (sometimes) energy operating costs. Appliance labeling is an efficient information and marketing tool to motivate clients but labels need to be simple to understand. According to studies evaluating the effectiveness of labels (Thorne and Egan, 2002), those that show the annual energy cost savings appeared to be more effective than labels that present life-cycle cost savings. A number of stars, or an A, B, C rating can also be effective, although the criteria need to be regularly reviewed and updated. Consumers tend to find rating/labeling systems endorsed by public authorities credible (Barnerjee and Solomon, 2003). Despite widely divergent approaches, national S&L programs have resulted in significant savings, as reported by the following case studies.

The United States (US) program of national, mandatory energy-efficiency standards began in 1978. By 2004, the program had developed (and, in 17 cases, updated) 39 residential and commercial product standards. The total federal expenditure for implementing the US appliance standards adopted so far (US$2 per household) is estimated to have induced investment in energy-saving features equal to US$930 per household, which in turn produces US$2,200 per household gross savings in fuel costs and contributes US$1,270 per household of net-present-value savings to the U.S. economy during the lifetimes of the products affected. Projected annual residential carbon reductions in 2020 due to these appliance standards are approximately 37 million tons of carbon, an amount roughly equal to 9% of projected US residential carbon emissions in 2020 (base case) (Meyers, 2002). The U.S. ENERGY STAR endorsement label program estimates savings of 560 trillion EJ and US$4.1 billion from the combination of supplier and consumer responses to labeling the 34 products covered as of 2002 and projects that the program will save 11 quadrillion Btu (quads) by 2010, growing to 31 quads by 2020 (Weber *et al.*, 2003).

The first evaluation of the impact of the recent EU appliance labeling scheme showed that the sales-weighted average energy efficiency of refrigeration products improved by 29% between 1992 and late 1999, with about one-third of the impact attributable to labeling (Bertoldi, 2000). The dramatic shift in the efficiency of refrigerators sold in the EU in the first decade of its S&L program is displayed in Figure 6.9.

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[14] Endorsement labels define a group of products as "efficient" when they meet pre-specified criteria, while comparison labels allow buyers to compare the efficiency of products based on factual information about their absolute or relative performance, either on a continuous scale or by assigning models to discrete categories.

INSERT **Figure 6.9** (Impact of EU label on market of cold appliances)

A recent IEA report (ADD REF, 2003) concludes that if it had not been for the implementation of existing policy measures such as energy labeling, voluntary agreements, and minimum energy performance standards (MEPS), electricity consumption in OECD countries in 2020 would be about 12% (393 TWh) higher than is now predicted. The report further concludes that the current policies are on course to produce cumulative net cost savings of €137 billion in OECD-Europe by 2020. As large as these benefits are, the report found that much greater benefits could be attained if existing policies were strengthened.

A study of *China's* energy-efficiency standards (Fridley and Lin, 2004) estimated savings from eight new minimum energy-performance standards and nine energy efficiency endorsement labels that were implemented from 1999 through 2004 for appliances, office equipment, and consumer electronics. The study concluded that during the first 10 years of implementation, these measures will have saved 200 terawatt hours (TWh) (equivalent to all of China's residential electricity consumption in 2002) and 250 megatons of CO_2 (almost 70 megatons of *carbon*). New standards and labels in the next two years are expected to more than double this amount.

Among other countries, Korea shows similar evidence of the impact of labeling, as does the EU (KEMCO, 2003). During the 1990s, Thailand developed a portfolio of 19 demand-side management measures, including voluntary labeling programs for refrigerators and air conditioners. From 1994 to 2000, the Thai government spent US$0.22 per capita for this program expense, which in turn induced consumer spending of US$2.44 per capita on energy-enhancing features that saved Thai consumers a net US$0.91 per capita and resulted in an 860 kiloton reduction in CO_2 emissions (Singh and Mulholland, 2000). Five years ago, Australia transformed its S&L program in order to aggressively improve energy efficiency – as described in the first work plan for the Australian Program (National Appliance and Equipment Energy Efficiency Committee, 1999) (see Box 6.3).

***Box 6.3.** Australia Adopts World's Best Practices in Standards and Labeling*

For decades, experts had identified the huge untapped potential for energy efficiency and highlighted market information failures as a major stumbling block. Many countries (Australia included) chose to try to unlock those benefits through a national program of energy efficiency standards and labeling for appliances. In 2000, the Australian scheme introduced a new strategy of matching the most stringent appliance energy performance requirements mandated by any of Australia's trading partners. This move to adopt the "world best regulatory practice" was a direct response to program experience and has helped overcome many of the problems of a program that focused on domestic manufacturing alone.

By monitoring efficiency developments overseas and matching the best requirements for specific products, the Australian program has succeeded in achieving cost-effective energy savings for Australian consumers, as a partnership between government and industry. The program now regulates 16 product types and has announced plans to cover up to 50 product types by 2010. The Australian program is projected to reduce CO_2 emissions by 9.6 Mt annually over the first Kyoto period (2008-2012) and save over AUS$4.8 billion during this same five-year period (using a 10% discount rate, or AUS$16 billion undiscounted) (NAEEEP 2005). The program will achieve GHG abatement at a community benefit (not a cost) of AUS$23 per ton.

In the past few years, strong regional and global S&L efforts have also emerged, offering more coordinated pathway to promote S&L and improve the cost-effectiveness and market impact of the programs. One of these pathways is regional harmonization. The International Energy Agency (IEA (International Energy Agency), 2000) identifies several forms of multilateral cooperation, including: *collaboration* in the design of tests, labels, and standards; *harmonization* of the test procedures and the energy efficiency thresholds used in labels and standards; and *coordination* of program implementation and monitoring efforts. Such cooperation has the following five potential benefits: 1) greater market transparency, 2) reduced costs for product testing and design, 3) enhanced prospects for trade and technology transfer, 4) reduced costs for developing government and utility efficiency programs, and 5) enhanced international procurement. Other examples show that such harmonization is increasing rapidly, aided by broad agreements on economics and trade such as the North American Free Trade Agreement (NAFTA), Asian-Pacific Economic Cooperation (APEC), and the EU (Wiel and McMahon, 2003). However, while easing certain trade restrictions, harmonization of standards and testing methods can have the unintended consequence of overcoming cultural and other differences that affect consumer preferences, possibly leading to increased levels of energy consumption (Biermayer and Lin 2004, Moezzi and Iyer 2002).

6.8.2.2 Voluntary agreements

Voluntary agreements, in which the government and manufacturers agree to a mutually acceptable level of energy use per product, are being used in addition to mandatory standards to improve the energy efficiency of appliances and equipment. Voluntary agreements can be especially useful in conjunction with other instruments – and if the mandatory measures are available as a backup measure to encourage industry to deliver the targeted savings. The European Union (EU) has championed many such arrangements. In the European context the voluntary approach includes a wide range of industry actions such as industry covenants, negotiated agreements, long-term agreements, self-regulation, codes of conduct, benchmarking, and monitoring schemes. These voluntary approaches differ in relation to their form, legal status, provisions, and enforceability (Rezessy and Bertoldi 2005).

Voluntary measures can cover both equipment (e.g., cars, electric motors, white goods, etc.), industrial processes, and industrial energy management policies and practices (e.g. EU programs such as GreenLights or Motor Challenge). In particular, voluntary agreements have been used in place of or in conjunction with mandatory minimum efficiency standards for equipment. Industry often favors voluntary agreements to avoid the introduction of mandatory standards (Bertoldi, *et al.* 1999).

According to manufacturers, voluntary agreements provide more flexibility than mandatory (minimum) standards, since “fleet-average” efficiency targets can be met by selling more high-efficiency models. In addition, manufacturers prefer a pro-active process, which favors cost-effective solutions and allows manufacturers to have a role in setting quantified criteria, (Menanteau, 2001). For the public authorities, voluntary agreements offer a faster approach and are often acceptable if they include the following three elements: 1) commitments by those manufacturers accounting for most of the equipment sold, 2) quantified commitments to significant improvements in the energy efficiencies of the equipment over a reasonable time-scale, and 3) an effective monitoring scheme (COM/1999/120).

Successful voluntary agreements have been established in the EU for the reduction of standby losses in TVs and VCRs and the reduction of energy consumption of washing machines (Rezessy and Bertoldi, 2005, COM/1999/120). Other, less ambitious agreements have been established for dishwashers, electric motors, and electric storage water heaters. In the case of washing machines, the combination of the mandatory labeling scheme and a voluntary agreement resulted in the same degree of efficiency improvements achieved for refrigerators and freezers (COM/1999/120, Jaeger-Waldua *et al.*, 2004).

Voluntary agreements, under certain conditions, are a useful policy instrument, especially in conjunction with other instruments and if mandatory measures are available as a backup or to encourage industry to deliver the targeted savings.

6.8.3 Cross-cutting policies and programs that support energy efficiency and/or CO_2 mitigation in buildings

This section reviews a range of policies and programs that do not focus specifically on either buildings and installed equipment, or on appliances and smaller plug-in devices in buildings, but may act on several levels to support energy efficiency and emissions reductions – including effects across other end-use sectors as well as buildings.

6.8.3.1 Energy prices, subsidies and taxes

Market-based energy pricing and energy taxes, while often difficult to implement for political reasons – offer the broadest incentive for saving energy in buildings. Figures 6.10, 6.11, and 6.12 present energy prices of several fuels in households in 2003 (IEA, 2004a). Only a few countries have a substantial excise tax on electricity and natural gas for households. In Denmark, 10%-15% of the excise tax consists of an environmental tax, while the remainder is mainly general excise tax. In the Netherlands, the energy tax was partly used in the past to finance energy subsidy schemes to stimulate energy efficiency measures. More countries have an excise tax included in the price of light fuel oil for households. The share of excise tax compared to total fuel price differs considerably by country. The national foundation of the tax also varies: for example, in Italy it is a general excise tax, in Sweden it consists of environmental levies (energy tax and CO_2 tax), and in Turkey a large part consists of the fuel price stabilization tax (IEA, 2004b).

INSERT **Figure 6.10** (Electricity prices households)
INSERT **Figure 6.11** (Natural gas prices households)
INSERT **Figure 6.12** (Light fuel prices households)

Energy prices are subsidized in many countries; this under-pricing of energy reduces the incentive to use it more efficiently. Government actions lower the price of energy to consumers either by regulating retail prices to some or all consumers, or by providing subsidies to energy producers (IEA, 2002b; UNEP OECD/IEA, 2002). The form of subsidy varies among developing, transition, and industrialized economies. The bulk of subsidies in developing and transition countries are paid to consumers, while producer subsidies are most common in industrialized countries (Markandya, 2000).

Energy subsidies are typically much larger, per GJ, in developing and transition countries than in most industrial economies [ref]. The total value of energy subsidies of eight of the largest non-OECD countries[15], covering almost 60% of total non-OECD energy demand, was around US$95 billion in 1998 (UNEP OECD/IEA, 2002). End-use prices in these countries were about one-fifth below market levels. In 1999 the IEA investigated what could happen if all energy subsidies were removed (IEA (International Energy Agency), 1999). They found that removing energy subsidies in those eight countries would reduce primary energy use by 13%, lower CO_2 emissions by 16% and raise GDP by almost 1%. Table 6.3 summarizes the results for each country (averaging all sectors). In Russia, India, Iran and Venezuela, the removal of energy subsidies in the residential sector is responsible for the bulk of the estimated reduction in CO_2 emissions. For example, in Russia, 70% of the estimated 17% reduction of CO_2 emission is due to the removal of the subsidies in the

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[15] China, Russia, India, Indonesia, Iran, South Africa, Venezuela, Kazakhstan.

price of natural gas for households. In most other countries, removing energy subsidies in the power generation sector has a greater impact (IEA, 1999).

INSERT **Table 6.3.** (Subsidy rates and impact of the removal of energy subsidies in the energy economy of several countries)

While it may be economically and environmentally desirable, it is a socially sensitive task to remove end-user subsidies, especially in the residential sector. Since the bulk of these subsidies are found in countries with low incomes and high fuel-poverty rates, the removal of this social support, especially in countries with existing high levels of subsidies, can cause a substantial financial burden for families and even institutions. This in turn can lead to bankruptcy, increased payment arrears, and generally increased social tensions (Ürge-Vorsatz 2003, Aistra 2002, ERRA 2002). Therefore, a drastic subsidy removal, even if introduced during the course of several years, is often accompanied by appropriate social compensation programs, such as grants or tax reductions not tied to energy use [ref]. One potentially important form of alternative compensation – although not frequently used to date – is assistance to low-income households to invest in energy-saving measures since these reduce fuel costs and GHG emissions in the long-term (ERRA 2002, p4). For a number of years, the US government has provided US$1.5-2.0 billion/year in near-term support to low-income households through the Low-Income Heating Assistance Program (LIHEAP, 2005), and somewhat smaller but still substantial longer-term grants to “weatherize” many of these same households with efficiency measures that help reduce monthly fuel and electricity bills (Schweitzer and Berry, 1999).

Some forms of energy subsidies can have positive energy and environmental effects. For example, subsidies on oil products and electricity in developing countries reduce deforestation and also reduce indoor pollution as poor rural households switch away from traditional energy sources as wood, straw, crop residues, and dung. These positive effects, however, can be better achieved through the introduction of, for instance, safe cookers and heaters utilizing these renewable sources; the challenge is to design and reform energy subsidies so they favor the efficient and environmentally sound use of energy systems (UNEP OECD/IEA, 2002).

6.8.3.2 Investment schemes and fiscal measures

As discussed above, many developed countries offer incentives for energy efficiency measures (IEA, 2004b). Types of financial support include subsidies, tax reduction (or tax credits) schemes, and preferential loans or funds. Subsidies are the most frequently used incentives to achieve energy savings in the buildings sector (IEA, 2004b).

Energy policies in countries with a cold or moderate climate concentrate on the retrofit of existing buildings. There are schemes for insulation of the building envelope and replacement of old heating boilers by energy-efficient new heating systems. In addition to incentives targeted to individual energy-saving measures, packages of measures in renovation projects may be eligible for financial support (e.g. Germany). Several countries combine their energy policy for the existing building stock with the social policy to assist low-income households (United States, France, Belgium, United Kingdom, the Netherlands) [ref].

Financial incentives for energy-efficient appliances are in place in a limited number of countries (United States, Belgium, Canada, Denmark, Japan, Greece, the Netherlands) (Argiriou and Mirasgedis, 2003, Boardman, 2004; IEA, 2004b). Incentives can also encourage connection to district heating particularly where systems use, biomass or geothermal (Austria, Denmark, Italy)

(Boardman, 2004; IEA, 2004b). Increasingly, eligibility requirements for financial support are tied to CO_2 emission reduction. For example, the German Climate Protection Program for Existing Buildings offers subsidies provided that the measures reduce annual CO_2 emissions by at least 40 kg per square meter of floor space in buildings which were built before 1979 (Boardman, 2004; IEA, 2004b).

Table 6.4 presents an overview of selected financial support measures from the IEA database on climate change policy and measures (Boardman, 2004; IEA, 2004b). Incentives for renewable energy systems (PV and solar hot water systems, heating system on biomass) and incentive programs with limited funding of low expected impact were excluded.

INSERT **Table 6.4.** (Selection of financial support measures for sustainable energy measure in buildings, in several OECD countries)

6.8.3.3 Energy Efficiency Obligations and Tradable Energy Efficiency Certificates

The White Certificate system is a relatively new market-oriented policy instrument, currently applied in Italy and New South Wales (Australia). The basic principle is an obligation for some category of economic actors (utility companies, product manufacturers or distributors, large consumers, etc.) to meet specified energy savings or program-delivery goals, coupled with a trading system based on the savings achieved (or expected) for energy efficiency measures. Energy savings that are verified and certified are the basis for so-called “white” certificates. For example, a utility company may have the choice between either implementing energy-saving projects at their customers’ premises, or buying white certificates from others in order to comply with their obligations; failure to meet the energy-savings quota would result in a penalty. If an organization is able to achieve more savings than required, it has the option to sell these extra certificates on an open market. The key stakeholders involved in this new market concept are electricity and natural gas distribution utilities, ESCOs (energy service companies) and the government (Bertoldi and Rezessy 2004, ECEEE 2004, Bertoldi et al 2005, Oikonomou and Patel, 2004). Some white certificate systems do not have the trading element, such as in the UK.

The main reason for the implementation of White Certificates is the reduction of the cost of achieving energy savings, estimated to average around 2.6 eurocents/kWh h for the residential sector in many EU Member States, compared to an average price for delivered electricity of 3.9 eurocents/kWh (Oikonomou *et al.*, 2004). The certificate market mechanism is expected to identify the lowest-costs sources of available energy savings, and lead to more efficient solutions (Oikonomou *et al.*, 2004). Since it is important that the White Certificates scheme stimulates *additional* investment in energy efficiency, monitoring and verification are crucial. The relation between the overall savings target, the cost-effective energy savings potential, and targets for individual companies has to be carefully analyzed.

In the UK, the Energy Efficiency Commitment (EEC) requires that all gas and electricity suppliers with 50,000 or more domestic customers deliver a certain quantity of “fuel-standardized energy benefits” by encouraging or assisting customers to take energy efficiency actions in their homes. The overall savings target of EEC-1 was 65 TWh and the total delivered savings reached 86.8 TWh. The target has since been increased to 130.2 TWh (Bertoldi and Rezessy in print, Bertoldi et al 2005). Suppliers must achieve at least half of their energy savings in lower-income households. Estimated energy benefits take into account the rebound effect – the likely fraction of energy efficiency savings that are offset by improved comfort – by adjusting the benefits to “comfort factors.” In addition, a “dead-weight factor” is used to account for the effect of energy-saving investments that would have been made anyway (free-riders) (Sorrell, 2003).

In Italy, electricity and gas distributors that serve more than 100,000 customers have mandatory savings targets, expressed in primary energy, that cover the period 2005-2009. Tradable certificates for energy savings are issued to distributors. Although the targets do not refer to specific end-use sectors and/or types of projects, at least half of the target for each year is to be achieved through electricity and gas savings by end-users. To count toward the obligation, energy savings projects must be implemented by distributors (either directly or through a subsidiary company), or by "independent companies operating in the energy services sector" (i.e., ESCOs) ((Bertoldi and Rezessy, in print).

Recently, France, possibly the Netherlands, and other European countries have announced their intention to introduce a White Certificates scheme. Energy efficiency obligations, but without certificates trading, are also in place in the Flemish region of Belgium. White Certificate schemes are included in the European Commission's recently published Recommendation on Energy End-Use Efficiency and Energy Services (COM 2003).

The most commonly cited benefit of certificate trading – minimizing the costs of meeting energy savings goals – depends on the liquidity of the market. There is a trade-off between liquidity (e.g., allowing non-obliged parties to acquire and sell certificates) and manageability and transaction costs. Where transactions costs turn out to be very high, a simple energy savings obligation for electricity and gas distributors, without the complication of trading, may be a better way to deliver the desired outcome (Bertodli et al *in print*). Since the first White Certificate schemes are just starting, it remains to be seen whether this policy instrument will deliver the expected level of savings and at what cost.

6.8.3.4 Research and Development

Since 1996, the annual worldwide research, development, and demonstration (RD&D) budget for energy efficiency in residential and commercial buildings has been approximately US$225-280 million (IEA, 2004c). Figure 6.13 shows that the US is the leading country concerning energy research and development in buildings, responsible for half of the total global expenditures. Substantial buildings-related energy efficiency R&D is also sponsored in Japan (15% of global energy RD&D expenditures for buildings), several European countries and Canada (each responsible for about 5% of the total).

INSERT **Figure 6.13** (R&D budget energy conservation residential and commercial sector)

Buildings energy efficiency research in the US is conducted by the US Department of Energy in two areas: components and system integration. Research and development on building components and materials (envelope, equipment, and appliances) provide the basis for considerable past and anticipated energy savings in buildings (DOE (U.S. Department of Energy), 1998). Improved and/or new energy-efficient concepts for lighting, windows, refrigeration and thermal distribution are the main research fields. Systems integration R&D activities analyze the building components and systems, and integrate them ways that help achieve optimal energy performance of the building. This whole-building approach is concentrated for now in the residential sector, and has currently a higher priority for the USDOE than research on separate building equipment and materials (Belzer *et al.*, 2002). This tendency is also observed in the research of other European countries (IEA (International Energy Agency), 2004d). Characteristic of Japanese RD&D is the focus on control systems and reduction of standby power consumption, along with energy-efficient lighting and high-performance water heating/cooling systems (METI, 2002).

In the US there is also significant RD&D on energy efficiency in buildings conducted outside the federal sector, notably at the state level in California, New York, as well as several other states. These state programs, generally supported by a small utility bill surcharge or state budgeted funds, in the aggregate represent about the same level of RD&D funding for energy efficiency buildings as the USDOE budget itself. Typically, the state programs focus on research that is more applied and near-term. These state-level organizations have joined together to plan and sometimes co-sponsor energy efficiency RD&D projects (see www.asertti.org).

6.8.3.5 Public sector leadership programs

Government agencies - and ultimately taxpayers - are responsible for a wide range of energy-consuming facilities and services. These range from government office buildings, schools, and health care and recreational facilities to car and truck fleets, public transit, street lighting, and water and sanitation systems. Collectively, these public sector activities represent a significant share of all economic activity - typically 10–20% of gross domestic product (GDP) in both industrial and developing countries - and a similar share of building floorspace, energy use, and greenhouse gas emissions (Harris *et al.*, 2005).

The government itself is often a country's largest consumer of energy and largest buyer of energy-using equipment. The US federal government spends over US$10 billion/year for energy-using equipment, and is the world's largest buyer of most energy-using products (Harris and Johnson, 2000). Government's strong presence as an energy consumer and purchaser of buildings, appliances, and equipment mirrors its position in the economy as a whole. For the EU-15, expenditures by government at all levels (excluding social transfer payments) averaged about 18.5% of GDP as of 2001 (Revelin 2003). The pattern is similar in the US, where total government spending (federal, state, local) accounts for 18% of GDP. Available indicators of employment and building floorspace show similar patterns (Harris *et al.*, 2005).

6.8.3.5.1 Energy savings and market impacts

Government policies and actions thus can contribute, both directly and indirectly, to energy savings and associated greenhouse gas reductions (Van Wie McGrory *et al.*, 2002). Direct savings result from improved energy efficiency in government facilities and operations; these savings can be significant. A recent study for several EU countries (PROST) found a cost-effective potential for energy savings of 20% or more in EU government facilities and operations (Borg *et al.*, 2003). The US Department of Energy's Federal Energy Management Program (USDOE/FEMP) tracks energy use in federal buildings based on the agencies' annual reports. Since 1985, average energy intensity (site energy per square meter) has been reduced about 25%, while average energy intensity in all commercial buildings has stayed roughly constant (USDOE/FEMP, 2005 and USDOE/EERE, 2005).

Indirect impacts occur when government takes seriously its opportunity for market leadership. Government can serve as a market leader in two ways. First, government buying power can create or expand demand for energy-efficient products and services. Second, but equally important, visible government energy-saving actions can serve as an example for others. This section presents a few examples of government sector energy savings and market leadership; additional information is at www.pepsonline.org.

Within the EU and other OECD countries, government agencies at all levels have acted to reduce their own energy use, stimulate market demand for efficient products and services, and provide an example to others. However, additional actions and emphasis are needed to establish public sector energy efficiency as a core element of energy efficiency and climate change policy. Public sector energy efficiency programs fall into five categories (Harris *et al.*, 2005):

- Policies and targets (energy/cost savings; pollution/ CO_2 reductions; measurement and verification; tracking and reporting)
- Public buildings (energy-saving retrofit and operation of existing facilities, as well as sustainability in new construction)
- Energy-efficient government procurement
- Efficiency and renewable energy use in public infrastructure (transit, roads, water, and other public services)
- Information, training, incentives, and recognition of leadership by agencies and individuals

Two of these program categories are discussed in more detail, below.

6.8.3.5.2 Public Buildings

The EU Directive on Energy Performance of Buildings, discussed above and in Box 6.2, calls for energy certification of all buildings at key life-cycle stages, but adds special requirements for public building certification:

"Public authority buildings and buildings frequently visited by the public should set an example by taking environmental and energy considerations into account and therefore should be subject to energy certification on a regular basis..." (Directive 2002/91/EC)

These requirements have helped initiate or expand a number of programs. The UK has posted online benchmarking tools and associated Best Practice Guides for public buildings, offices, and sports centers (http://projects.bre.co.uk/gpg286/). UK policy requires all new and refurbished government buildings to be rated under the British Research Establishment Environmental Assessment Method (BREEAM), which includes credits for energy efficiency and reduced CO_2 emissions. New government buildings must achieve a BREEAM rating of "Excellent," while major refurbishments require a "Good" rating (UK/DEFRA, 2004). In Denmark, all government buildings must report total energy and water usage annually, while larger public buildings (using over 10,000 kWh/year) post their metered electricity consumption on-line; this open disclosure is intended to focus the attention of both facility managers and political leaders on energy efficiency (Danish Government, 2005).

In the US, a recent law requires new federal buildings, beginning in 2006, to be designed for energy performance 30% better than that required by current commercial and residential building codes (US Congress, 2005). In addition, federal, state, and local agencies participate actively in the US Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system, which like the BREEAM rating in the UK includes criteria for energy efficiency. A recent review showed that federal projects accounted for 16 out of 149 total LEED-certified buildings, or roughly 11% - compared with only about 1–2% of the total building stock, or new construction, represented by federal buildings (Payne and Dyer, 2004).

6.8.3.5.3 Public procurement

Energy-efficient government purchasing can be a powerful tool for accelerating the market entry of new energy-saving technologies, expanding the market to competitively drive down costs of these technologies, and helping set the stage for periodic upgrading of appliance efficiency standards (Borg *et al.*, 2003; Harris et al, 2003; Harris et al, 2004).

The PROST study concluded that, for the EU as a whole, public sector investments of about €80 million/year in program management and incremental purchase costs for buying energy-efficient products could reduce annual government energy costs by up to €12 billion/year (Borg *et al.*, 2003). Energy-efficient purchasing policies are currently in place in Denmark, the UK, and (with varying degrees of compliance) in several other EU countries and municipalities.

Energy-efficient government procurement policies are also in place in Japan, Korea, Mexico, China, and the US (Harris *et al.*, 2005). In the US, since 1992 a series of administrative policies have called for energy-efficient purchasing by federal agencies. In 2005, Congress passed a law mandating that all federal agencies specify and buy efficient products that qualify for the ENERGY STAR label, or (in cases where that label does not apply) products designated by USDOE FEMP as being among the top 25th percentile of efficient products (US Congress, 2005). Federal purchasing policies are expected to save an estimated 15.6 PJ/year and US$224 million/year in 2010 (after several years of normal stock replacement) (Harris and Johnson, 2000).[16]

Public procurement policies can have their greatest impact on the market when they are based on widely harmonized energy efficiency specifications that can send a strong market signal to manufacturers and suppliers (Borg *et al.*, 2003). In the US, several state and municipal governments have helped to fuel market changes by adopting the federal efficiency criteria for their own purchases (Harris *et al.*, 2004). If agencies at all levels of government adopt these same criteria, estimated electricity savings in the US would be 18 TWh/year, allowing government agencies (and taxpayers) to save at least US$1 billion/year on their energy bills (Harris and Johnson, 2000).

Danish policy requires all national government agencies to use efficiency criteria developed by the Danish Energy Savings Trust (DEST), which are in turn based on criteria set by the Danish A-Club and the US-based ENERGY STAR labeling programs (Danish EPA, 2003; DEST, 2005; and Danish Government, 2005). New policies under consideration may extend these procurement requirements to municipal governments; some have already adopted the efficiency criteria voluntarily.

These examples show that the public sector offers a significant potential for energy saving in its own facilities and operations, and that its influence on the broader market can be amplified through coordinated action, harmonized technical specifications, and by bringing government-sector energy efficiency policies and actions to the attention of both the demand and supply sides of the market.

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[16] Both estimates may be conservative, since this study was carried out prior to enactment of the 2005 law, was based on fewer products than are now covered by ENERGY STAR and FEMP, and assumed federal costs for electricity and fuel lower than current levels.

6.8.3.6 Promotion of energy service companies (ESCOs) and energy performance contracting (EPC)

While not a *policy instrument*, Energy Service Companies (ESCOs) have become favored *vehicles* to deliver energy efficiency improvements, promoted by a number of policies. An ESCO is a company that offers energy services, such as energy analysis and audits, energy management, project design and implementation, maintenance and operation, monitoring and evaluation of savings, property/facility management, energy and/or equipment supply, and provision of energy services (space heating, lighting, etc.). ESCOs guarantee the energy savings and/or the provision of a specified level of energy service at lower cost by taking responsibility for energy efficiency investments or/and improved maintenance and operation of the facility. In some cases, the ESCO's compensation is directly tied to the energy savings achieved. ESCOs can also directly provide or arrange for project financing, or assist with financing by providing an energy (cost) savings guarantee for their projects. Finally, ESCOs often retain an ongoing operational role, provide training to on-site personnel, and take responsibility for measuring and verifying the savings over the term of the project loan.

While the initial ESCO concept started in Europe more than 100 years ago and then moved to North America, today the US market is the most advanced in the world. The American ESCO market has seen a strong growth in the 1990s (Goldman *et al.*, 2002), with revenues reaching about US$2 billion in 2002 (Lin *et al.*, 2004). Most US ESCO activity (approximately 75%) is in the institutional sector (schools, universities, government, and hospitals) with lighting and HVAC measures the most common projects.

The market for energy efficiency services in Western Europe was estimated to be €150 million/year in 2000, while the market potential was estimated at €5-10 billion/ year (Bertoldi *et al.*, 2003; Butson 1998). Recent analysis (Bertoldi *et al.*, 2005; Rezessy *et al.*, 2005) has shown that Germany and Austria are the ESCO leaders in Europe, and that the supply side is attracting the majority of ESCO projects. Street lighting projects are among the most common demand-side ESCO projects. In Germany and Austria, public sector buildings are the most important sector for market penetration of ESCO services. Between 1998 and 2005, 600-700 public buildings were renovated in Austria using energy performance contracting by ESCOs (Unterpertinger, 2005). Austria is now working to replicate this initial effort, using energy performance contracts to renovate 50% of the total floor area of federal buildings (Unterpertinger, 2005). In Germany – the most mature ESCO market in Europe – more than 200 energy performance contracts have been signed since the mid-1990s, primarily for public buildings in the commercial sector with building "pools" of up to 100 separate buildings (Seefeldt, 2003). In Japan, the ESCO market is growing quickly, with a focus on the tertiary sector (office buildings and hospitals) (Murakoshi *et al.*, 2002).

ESCOs are important resources for energy efficiency in buildings, with the potential to greatly facilitate the access of building owners and operators to energy services, technical expertise, and innovative project financing. As private, for-profit businesses, they can play a central role in providing energy services and assuring project financing without burdening public budgets with demand for subsidies or other forms of public support. At the same time, ESCOs may be able to reduce transaction costs as they gain experience with large numbers of similar technologies, facilities, and public or private clients. The commitment of federal agencies and municipal authorities to use ESCOs for their energy efficiency projects, along with supportive policies, loan programs, and public-private partnerships, have been crucial to the successful growth of the ESCO industry in Germany and Austria, for example (Brand *et al.*, 2003).

While sectors targeted by ESCOs vary by country, in most countries ESCOs focus on the commercial, industrial, and municipal sectors (Vine, 2005; Westling 2003). Most ESCOs do not target the residential sector, although exceptions include ESCO activities in Nepal and South Africa [ref]. In India, Japan, and Mexico ESCOs have targeted at least 50% of their activity in the commercial sector (Vine, 2005).

In some cases obligations imposed on electricity companies have fostered the development of ESCO activities, as in the case of Brazil, where power utilities are required to invest 1% of their net operating revenues in energy efficiency.

6.8.4 Policies affecting fuel switching

Fuel switching in the residential and commercial sectors may be encouraged for a variety of environmental, political, and fuel security reasons. The switching of fuels most often takes place from traditional biomass to commercial fuels, from oil and coal to natural gas, or from oil-based fuels to electricity. Since these switches have important consequences for GHG emissions, their rationales need to be understood.

Globally there is increasing use of natural gas in buildings, replacing other fuels (CEPAL 1998, OLADE 2003). For instance, in the Latin American region, with proven natural gas reserves over 10 million m^3, fuel switching from coal or oil to natural gas represents an attractive transitional choice for GHG mitigation (OLADE, 2003). However, other fuel switching options in buildings are not as beneficial for GHG emissions. For instance, there may be significant reductions in energy use – measured at the point of use – through switching from oil-based heating to electrical heating this is sometimes not desirable from a GHG emission perspective, depending on the mix of fuels used for power generation during the heating season. As a result, building energy performance standards may need to consider CO_2 intensity, as well as primary (resource) energy indicators rather than site-energy alone, if GHG mitigation is one of the drivers for such standards.

6.8.5 Policies affecting technology transfer to developing countries

Beyond the responsibility of developed countries for assisting the diffusion of locally appropriate technology choices, the host countries also have their responsibilities to enable the process. For instance, in many developing countries, especially in Latin America, the trading policies partially inhibit this process through high import taxes and fees applied to equipment and technologies, which in some cases reach as high as 46% of the FOB price [additional material to be added.]

6.8.6 Non-Climate/Energy Efficiency Policies Affecting GHG Emissions

Beyond specific policies encouraging GHG reduction, energy efficiency, and renewable energy deployment, there are a large number of other economic, fiscal, and social policies that also affect GHG emissions in the buildings sector. These policies may have a much larger influence on GHG emissions in this sector than some of the specific energy efficiency policies discussed above. This section reviews, as one example, the effects of electricity market restructuring and liberalization.

Electricity markets are undergoing profound changes worldwide, including deregulation, privatization, unbundling, liberalization, and other processes. One of the main impacts is occurring through the effects of market liberalization on electricity prices. A number of authors (Burtraw *et al.*, 2000; Sondreal *et al.*, 2001; Sevi, 2004) suggest that electricity restructuring should result in lower average residential and commercial prices for electricity, particularly in cases where the regulated utilities were relatively inefficient. They point out that lower electricity prices are likely to stimulate higher demand from consumers. This effect depends on electricity price elasticities (i.e., the percent change in electricity demand associated with each one percent change in price). One study for the UK (Eyre, 1998) estimated that long-run price elasticity for the household sector is only -0.19, indicating that energy market liberalization – to the extent it does lead to lower residential electricity rates – may have only a small effect on demand. This is comparable with the findings of a Dutch study (Jeeninga and Boots, 2001)[17] that estimates the long-run price elasticity for electricity in the Netherlands at -0.25. In the US, estimates of price elasticity suggest that if electricity prices fall by 10-15% as a result of restructuring, demand could increase by 1-6% (Palmer, 1999). However, market liberalization will not automatically lower energy tariffs in all countries. Certain areas, such as California at the turn of the decade, have experienced significant price instability and unreliable supply immediately after deregulation (Cabral, 2002).

Restructuring of electricity markets is also expected to produce more widespread use of time-differentiated electricity rates. This form of pricing will encourage a shifting of demand from peak to off-peak periods. The GHG emission implications of this shift depend on the fuels used for peaking (often natural gas) *vs* base load generation. In France, such a shift would produce lower GHG emissions because of the nuclear base-load, while in the US the opposite will be true given its large coal-fired base-load generation (Palmer, 1999; Sevi, 2004).

Several studies also point to a downward trend in utility-funded Demand Side Management (DSM) programs as a result of electricity market liberalization (Eikeland, 1998; Palmer, 1999; Dubash, 2003; Sverrisson *et al.*, 2003; Sevi, 2004). As a result, significant energy and GHG emission savings attributable to these DSM programs efforts will be lost. However, a number of studies also point out that liberalization of electricity markets are sometimes associated with new policy initiatives to support "public benefits" activities such as energy efficiency technical assistance or rebates (Eyre, 1998; Palmer, 1999). For instance in the US, many state laws on utility restructuring and federal proposals for restructuring also include a mechanism for funding DSM initiatives through a public benefits electricity surcharge. Also, the recent California electricity crisis mentioned above resulted in increased funding for energy efficiency programs in order to reduce peak demand and ease the immediate pressures on power plants, transmission capacity, and poorly functioning markets.

Pepermans *et al.* (in print) note that the liberalization of energy markets makes consumers more aware of the value of reliable electricity supply. Since a high level of service reliability also implies high costs for investment and maintenance of the grid and generation infrastructure, reliability levels may initially decrease due to competitive pressures. In such a case, consumers may decide to invest in their own distributed generation units, which could in turn have a significant impact on GHG emissions associated with electricity use in buildings. As noted in Section 6.4.11, these GHG impacts could be either negative (if on-site power generation uses relatively inefficient diesel engines with little or no emissions control), or positive (if low-carbon fuels, such as natural gas or local, sustainably harvested biomass are used in efficient combined-cycle systems with on-site recovery and use of the heat).

In developing countries, different patterns of current energy use and the relative unavailability of electricity distribution infrastructure will likely lead to very different environmental effects of electricity restructuring than are likely in the developed world. The removal of energy cost subsidies in

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[17] Jeeninga, H., and M.G. Boots, 2001: Development of the domestic energy consumption in the liberalised energy market, effects on purchase and use behavior, ECN, ECN-C-1-002, Petten, the Netherlands

many developing nations, as well as the diversification in the level of service and pricing to reflect local costs, could lead to higher electricity prices in many cases. This could enhance the attractiveness of investments in rural electrification (Burtraw *et al.*, 2000) and potentially increasing energy consumption and GHG emissions (along with highly valued services, of course). However, the limited evidence available to date supports the view that without an explicit effort, energy markets restructuring will not support greater access to electricity (Dubash, 2003).

6.8.7 Policies affecting non-CO_2 gases

In the buildings sector, non-CO_2 greenhouse gases (halocarbons) are used as the working fluid in most vapor-compression cooling equipment, and as an expanding agent in some solid-foam and spray-on foam insulation materials. A detailed assessment of these applications is found in Piexoto *et al.* (2005) and Ashford *et al.* (2005), respectively.

6.8.7.1 Stationary refrigeration, air conditioning, and heat pump applications

Halocarbon emissions can occur during (re-)filling of compressor installations, leakage in operation, and when installations are dismantled. For modern and properly serviced cooling equipment, however, the climatic effect of halocarbon emissions is generally insignificant compared to the climate effect of CO_2 emissions associated with the equipment's energy use, and compared to differences in the efficiency of equipment using non-halocarbon instead of halocarbon refrigerants. Due to the international phase-out of the use of CFC and HCFC refrigerants, manufacturers and users had to search for alternatives (UNEP, 1987). In Europe as of 1 January 2004 HCFC may no longer be used as a refrigerant in new installations, and the industry is switching to alternatives such as HFCs, hydrocarbons, and CO_2 (EC, 2000).

Existing policies aim at reducing leakage or discouraging the use of refrigerants containing fluorine. An example of the first policy can be found in the Netherlands where there are regulations to minimize leakage rates, through improved maintenance, use of qualified personnel, and regular inspection. As result of this policy the average refrigerant leakage rate has decreased from 30% in 1990 to 4.5% in 1999 (Enviros, 2002). Examples of the second policy are: substantial taxes for refrigerants containing fluorine in Scandinavian countries, and legislation in Luxembourg that requires all new large cooling systems to use natural refrigerants (Harmelink *et al.*, 2005). Some countries like Denmark and Austria have banned the use of HFCs in selected air conditioning and refrigeration applications. An important policy in preparation is the European directive on limiting the use of certain fluorinated greenhouse gases and setting minimum standards for inspection and recovery (EC, 2004). All medium and large stationary air-conditioning applications in Europe will be required to use certified and trained service personnel and to assure recovery of refrigerants at the end-of-life (Harmelink *et al.*, 2005).

6.8.7.2 Insulating foams

HFC (in the past, also HCFC) can be used as a blowing agent for the production of foam insulation. Emissions occur during the production phase, during disposal, and, at a lower rate, during the product's use. In contrast to refrigeration systems using halocarbons as a working fluid, foam insulation that uses halocarbon blowing agents can have greenhouse gas emissions that exceed the climate benefits of avoided CO_2 due to the heating energy saved by the insulation. Due to the international phase-out in the use of HCFC foam, producers had to search for alternatives (UNEP, 1987). Foam insulations are increasingly becoming available that use CO_2, water, pentane, or other hydrocarbon expanding agents in place of halocarbons.

In many applications it is cost-effective to switch to alternative, non-HFC blowing agents (Harmelink *et al.*, 2005). Besides high costs to obtain HFC, there are indications that producers may avoid HFC to avoid future regulatory risks. Denmark and Austria have introduced legislation to ban the use of HFC for the production of several foams (Cheminfo, 2004). Recently, environmental ministers in the European Union agreed to limit emissions and application of fluorinated gases (EC, 2004). Emissions of HFCs from existing, installed insulation will mainly occur during disposal, several decades from now, generally leading to a total loss to the atmosphere of the remaining blowing agent unless effective measures for their recovery or destruction are in place and enforced.

6.8.7.3 SF_6 in sound insulating glazing

In some countries SF_6 has been used in high-performance sound insulating glazing. The same sound insulation effect can be reached with an improved, redesigned glazing structure (Harnisch and Schwarz, 2003). In some countries this application of SF_6 is already forbidden; at the European level a ban of SF_6 in insulating glazing is in preparation.

***Box 6.4.** Evaluation of the Dutch climate policy*

The Dutch climate policy for the built environment during the period 1995-2002 has been thoroughly evaluated (Joosen *et al.*, 2004). The results are presented in the table below. It is estimated that without policy measures the annual CO_2 emissions in the built environment would have been 7% higher at the end of 2002. In the residential sector the main CO_2 emission reduction is reached through an energy tax. The impact of the energy tax is considerable because it increased the price of natural gas by approximately 55% between 1995 and 2002. The combination of energy subsidies and building standards creates a larger market share for energy-efficient products with a better potential for continuing impact beyond 2002. In the services sector, energy subsidies and fiscal measures are mainly responsible for the CO_2 emissions reduction.

Estimated cost-effectiveness for government, end user and society for various Dutch policy instruments (Joosen *et al.*, 2004) 1 euro 2002 = 0.9 US dollar

Costs in US dollar/ton CO_2 emission reduction			
	Government	End user	Society
Residential sector			
Building standard	4 - 13	-189 - -5	46 - 109
Subsidy (period 1995-2000)	29 - 62	-48 - -5	32 - 62
Subsidy (period 2000-2002)	257 - 290	-214 - -140	41 - 105
Services sector	Government	End user	Society
Building sector	3 - 11	-131 - 16	-46 - 35
Subsidy	7 - 62	-185 - 99	-64 - 123
Long term agreement	54 - 172	-278 - 47	-104 - 35

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