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Chapter 6 Mitigation options for residential and commercial[1] buildings

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[1] The category of non-residential buildings is referred to by different names in the literature, including commercial, tertiary, public, office, and municipal. In this chapter we consider all non-domestic buildings under the “commercial” sector.

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Executive Summary

The buildings sector was responsible for 7.85 Gt carbon dioxide (CO_2) emissions in 2002, 33% of the global total. These figures do not include the approximately 1.5 $GtCO_2$ eq emissions from halocarbons.[2] The most common SRES scenarios project considerable growth of these emissions to 11 GT (B2 scenario) and 15.6 $GtCO_2$ (A1 scenario) by 2030 (IPCC, 2000), with the share of the sector remaining at app. 34% of total. In these and many other scenarios, the largest growth is expected in Asia, with the Middle East and North America following.

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 GHG gases.[3] This chapter devotes most attention to improving energy efficiency in new and existing buildings, which encompasses the most diverse, largest and most cost-effective mitigation opportunities in buildings. In addition, buildings can contribute indirectly to reducing carbon emissions in multiple ways, including by the choice of type of building and location in reducing sprawl and thus personal transport.

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. 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 lends considerable confidence to this view. A significant portion of 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).

While there are methodological challenges in aggregating potential GHG reductions to a global level due to limited research and differing assumptions used in the existing studies, we have made a best estimate for the global economic potential. Our calculations suggest that, globally, by 2020, approximately 1.6 and 1.4 billion tons of CO_2 eq can be avoided annually through mitigation measures in the residential and commercial sectors, respectively. Using the A1 and B1 SRES Scenarios as the baseline, this estimate represents a reduction of 21% and 27%, respectively for all buildings in 2020. Due to the limited number of demand-side end-use efficiency options considered by the studies and the exclusion of the positive integration effects, the real potential is likely to be higher. There are, however, substantial barriers that need to be overcome and a faster pace of well-enforced policies and programs pursued for energy efficiency and decarbonization to achieve these reductions in CO_2 emissions.

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[2] The IPCC Special Report "Safeguarding the Ozone Layer and the Global Climate System," Metz, *at. al.,* 2005) estimates that emissions of halocarbons contributed 2.5 $GtCO_{2eq}$ emissions in 2002. About 1.5 Gt of these CO_{2eq} are due to refrigerants and blowing agents for use in buildings (refrigerators, air conditioners, and insulation). Projections show the emissions due to these uses remaining about constant in 2015, with a substantial decline in contribution of CFCs as the bank of these chemicals declines and increases in emissions of HCFCs and HFCs. We devote little attention to halocarbons in this chapter, even though they are of considerable significance, because they are treated comprehensively in Metz, *et al., 2005.*)

[3] Fuel switching is largely the provence of Chapter 4, energy supply. Non-CFC gases are treated extensively in the IPCC Special Report (Metz, *et.al.,* 2005) and are discussed only briefly in this chapter.

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. There is a broad array of widely accessible and cost-effective technologies and know-how that can abate GHG emissions in buildings to a significant extent that have not as yet been widely adopted. These include passive solar design, high-efficiency lighting and appliances, solar water heaters, insulation materials and techniques, high-reflectivity building materials, and multiple glazing. The largest savings in energy use for new buildings (75% or higher for specific buildings) 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. The largest reductions for individual buildings occur in buildings that have not yet been constructed, especially because of the opportunity to treat the building and its energy-using equipment as a whole system. However, over the whole building stock the largest portion of carbon savings by 2030 is in retrofitting existing buildings and replacing energy-using equipment with more advanced low-energy alternatives.

For new and existing commercial buildings, emerging areas for energy savings include the application of controls and information technology to continuously monitor, diagnose, and communicate faults and systems approaches to reduce the need for ventilation, cooling, and dehumidification. In residential buildings, emerging areas include advanced windows, passive solar design, eliminating leaks in buildings and ducts, and energy-efficient appliances. Controlling standby and idle power consumption and advanced lighting systems are important in both 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, increased access to energy services, improved indoor and outdoor air quality, as well as increased comfort, health and quality of life. In developing countries, safe and high-efficiency cooking devices and high-efficiency electric lighting not only abate substantial GHG emissions, but reduce mortality and morbidity due to indoor air pollution by millions of cases annually worldwide.

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 labelling, pricing measures and financial incentives, utility demand-side management programs, 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, providing assistance to the building design process, 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. Because culture and occupant behaviour are major determinants of energy use in buildings, these policy approaches need to go hand in hand with programs that increase consumer access to information, awareness and knowledge.

There is a wide range of low-cost options to curb CO_2 emissions in buildings. A review of 11 studies assessing the costs of GHG mitigation in buildings worldwide showed that up to 62% of the GHG emissions in the buildings of developing countries and economies in transition, and up to 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$20/tonne CO_2 eq. are considered, higher savings are possible. Efficient lighting technologies are among the most promising GHG abatement measures in buildings in almost all countries, in terms of both cost-effectiveness and size of potential savings. In developing countries, cook stoves and solar water heaters follow in terms of cost-effectiveness, while heating-related measures have the next lowest costs in economies in transition, including insulation of walls, roofs, windows, and floors, as well as improved heating controls for district heat. In developed countries, appliance-related measures are typically identified as the next most cost-effective, with cooling-related equipment upgrades ranking high in the warmer climates according to the size of savings.

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. Devoting international aid or other public and private funds aimed at sustainable development to energy efficiency and renewable energy initiatives in buildings can achieve a multitude of development objectives and result in a long-lasting impact.

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

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. Renewable and low-carbon energy can be supplied to buildings or generated on-site by distributed generation technologies. 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. This chapter devotes most attention to energy efficiency in new and existing buildings, as fuel switching is largely covered elsewhere in this report (Chapter 4) and non-CO_2 GHGs are treated in depth in an IPCC special report (Metz, *et al.*, 2005).

A very large number of technologies are commercially available and tested in practice that can substantially reduce energy use while providing the same 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 (Harvey, 2006) by reducing uncontrolled infiltration, increasing insulation in walls, using highly insulated windows and passive solar design. 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 much higher than necessary. 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 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 describe several scenarios of 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 GHG emissions from buildings, and a review of studies that have estimated potential savings. The last section addresses policies and programs to achieve energy efficiency improvements in buildings.

6.2 Trends in the Buildings Sector

The buildings sector was responsible for 7.85 Gt carbon dioxide (CO_2) emissions in 2002, 33% of the global total. Carbon dioxide emissions from energy use in buildings grew from 1971 to 2002 at an annual rate of 1.8%, about equal to overall growth rate of CO_2 emissions from all uses of energy. CO_2 emissions for commercial buildings grew 0.8% per year more rapidly than those for residential buildings during the period. The largest regional increases in CO_2 emissions for commercial buildings were from North America (30%), Centrally Planned and Other Asia (27%) and OECD Pacific (20%). The largest regional increase in CO_2 emissions for residential buildings were from Asia (Centrally Planned and Other) accounting for 40% and Middle East/North Africa with 20%.

During the past five years (since the previous IPCC report), CO_2 emissions from energy use in residential buildings has increased much slower than the 30-year trend (annual rate of 0.1% versus trend of 1.4%) and emissions associated with commercial buildings have growth faster (3.0% per year in last five years) than the 30-year trend (2.2%)%.

6.3 Scenarios of Carbon Emissions Resulting for Energy Use in Buildings

Figures 6.1 and 6.2 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 sub-sectors and ten world regions (Price, *et al.*, 2006). These scenarios show a range of buildings related CO_2 emissions: from 7.85 $GtCO_2$ emissions in 2002 to 11.4 and 15.6 $GtCO_2$ emissions in 2030 (B2 and A1 respectively), representing an app. 34% share of total CO_2 emissions in both scenarios. 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: North America and Centrally Panned Asia. In Scenario A1 (which shows rapid economic growth, especially in developing nations), all of the increase in CO_2 emissions occurs in the developing world: Centrally Planned Asia, Other Asia, Middle East/North Africa, Latin America, and Sub-Saharan Africa, in that order. Overall, average annual CO_2 emissions growth is 1.3% in Scenario B2 and 2.5% in Scenario A1 over the 28-year period.

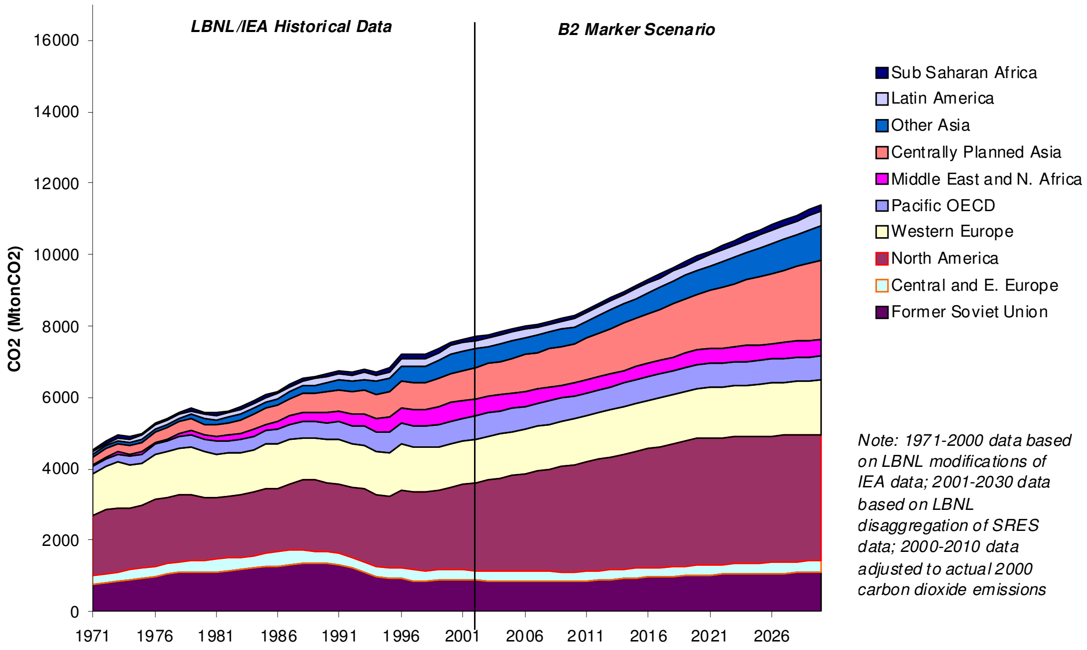

Figure 6.1: *CO_2 emissions resulting from buildings energy use: B2 marker scenario*

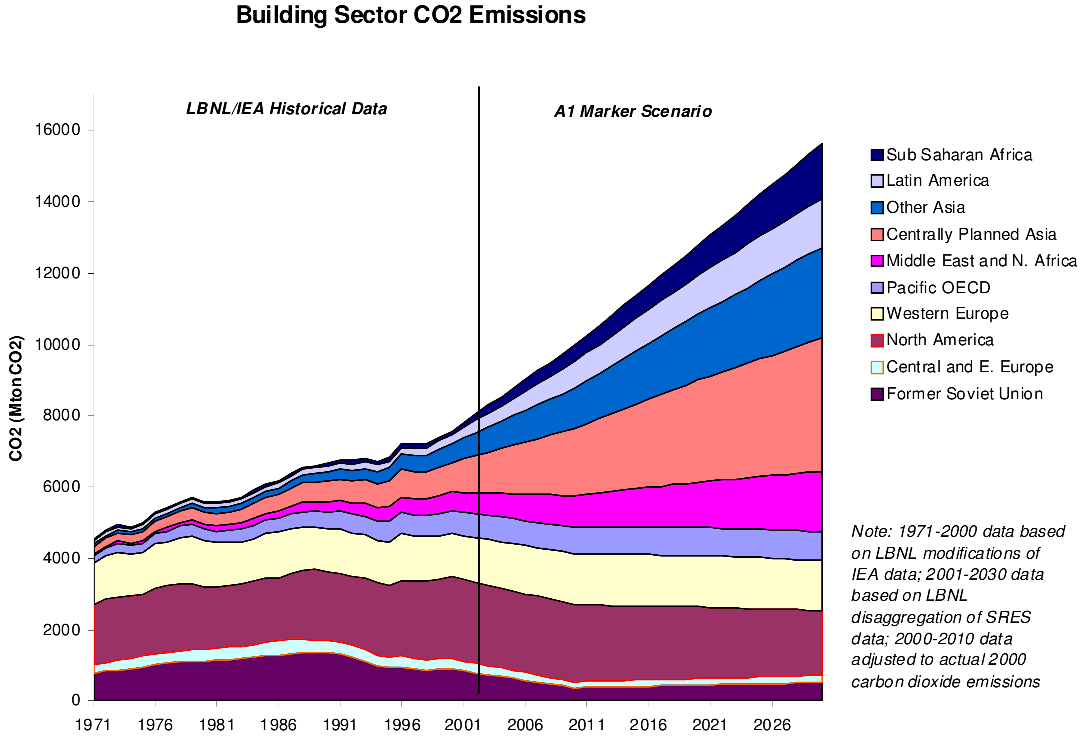

Figure 6.2: *CO_2 emissions resulting from buildings energy use: A1 marker scenario*

6.4 GHG mitigation options in buildings and equipment

In this section we describe the extensive array of technologies that can be used to abate GHG emissions in new and existing residential and commercial buildings. 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

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.

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, optimizing 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 (evaporative cooling and radiative cooling to the night sky) can be used.

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.

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 behaviour

The energy use of a building also depends on the behaviour 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). Levermore (1985) found a variation of 40% gas consumption and 54% electricity consumption in nine identical children's homes in a small area of London. When those in charge of the homes knew that their consumption was being monitored, the electricity consumption fell. Behaviour 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 (Ueno, *et al.*, 2006).

6.4.1.6 System approaches to energy efficiency and the critical role of the design process

Evaluation of the opportunities to reduce energy use in buildings can be done at the level of individual energy-using *devices* or at the level of building *systems* (including building energy management systems and human behaviour). Energy efficiency strategies focused on individual energy-using devices or design features are often limited to incremental improvements. Examining the building as an entire system can lead to entirely different design solutions. This can result in new buildings that are no more expensive than conventional buildings, but with much increased energy efficiency.

The systems approach in turn requires an integrated design process (IDP), in which the building performance is optimized through an iterative process that involves all members of the design team from the beginning. The steps in the most basic IDP for a commercial building include (i) selecting a high-performance envelope and highly efficient equipment, properly sized; (ii) incorporating a building energy management system that optimises the equipment operation and human behaviour, and (iii) fully commissioning and maintaining the equipment (Todesco, 2004). These steps alone can usually achieve energy savings on the order of 35-50% for a new commercial building, compared to standard practice, while utilization of more advanced or less conventional approaches has often achieved savings on the order of 50-80% (Harvey, 2006).

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 (i) the insulation levels in the walls, ceiling, and ground or basement floor, including factors such as moisture condensation and thermal bridges that affect insulation performance; (ii) the thermal properties of windows and doors; and (iii) 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.

Improvements in the thermal envelope can reduce heating requirements by a factor of 2 to 4 compared to standard practice, at a few percent of the total cost of residential buildings, and at little to no net incremental cost in commercial buildings when downsizing of heating and cooling systems is accounted for (Demirbilek, *et al.*, 2000; Hamada *et al.*, 2003; Hastings, 2004; Jakob, 2006; Harvey, 2006). 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 the most stringent 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 solar gains and internal heat gains from equipment, occupants, and lighting.

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 (openable) windows are available with heat flows that have only 25-35 percent of the heat loss of standard non-coated 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 up to 75%, thus reducing cooling loads. In spite of these technical improvements, costs of glazing and windows remained constant or even dropped in real terms (Jakob and Madlener 2004). Spectrally selective windows can maximize the transmission of visible sunlight to replace artificial lighting while minimizing increased cooling requirements from solar heat gain.

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 to 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 to 10 compared to standard practice in most jurisdictions in North America, Europe and the cold-climate regions of Asia (Harvey, 2006, Chapter 3).

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). 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 labour 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). Aggressive envelope measures combined with optimisation of passive solar heating opportunities, as exemplified by the European Passive House Standard, have achieved reductions in purchased heating energy by factors of 5 to 30 (i.e., achieving heating levels less than 15 kWh/m^2/yr even in cold climates, compared to 220 and 250-400 kWh/m^2/yr for the average of existing buildings in 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.

Heating systems used primarily in industrialized countries

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 vapour in the exhaust is condensed in a separate heat exchanger. Condensing boilers are increasingly used in Western Europe due to regulation of new buildings that require higher-efficiency systems.

Hydronic systems (in which water rather than air is circulated), 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 are a fundamentally different type of means of providing space conditioning. They 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 to 35ºC can be used in floor radiant heating systems, compared to 70 to 90ºC in conventional hot-water heating systems. For a heat pump with a COP of 2 to 2.5, this is increased to 3.5 to 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 to 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. Heat pumps driven by mechanical power from a gas engine (rather than by electricity) have attained a COP of 1.5 which is comparable in terms of primary energy use to an electric heat pump with a COP of 4.5 if the electricity is generated with an efficiency of 33%.

Coal and biomass burning stoves in rural areas of developing countries

Worldwide, about three billion people use solid fuels - biomass and, mainly in China, coal-in household stoves to meet their cooking, water heating, and space heating needs.. 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 estimates of energy use and associated GHG emissions are uncertain.[4] 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).

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[4] 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.

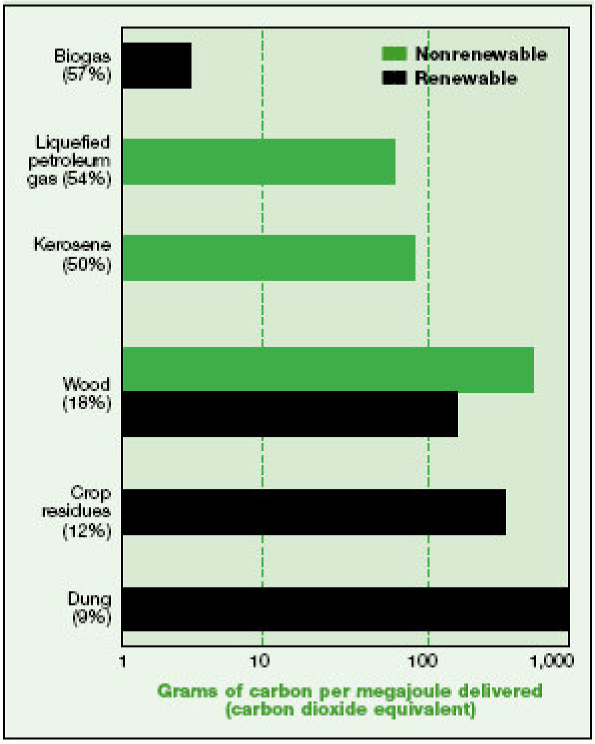

Figure 6.3: *GHG emissions from household fuels*
Note: includes warming potential from all GHGs emitted: CO_2, *CH_4, CO, non-methane hydrocarbons, and nitrous oxide. Weighted by stove distribution in India. Numbers in parentheses are average stove energy efficiency. Source: Goldemberg et al., 2000*

Worldwide, most household stoves use simple designs and local materials that are inefficient and highly polluting and contribute to the overuse of local resources. Studies of China and India have found that if only the Kyoto Protocol basket of GHGs is considered, biomass stoves 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, and in many cases even higher emissions than from stoves burning coal briquettes (see Figure 6.3). 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. In most climates, they include: (i) orienting a building to minimize the wall area facing east or west; (ii) clustering buildings to provide some degree of self shading (as in many traditional communities in hot climates); (iii) using high-reflectivity building materials; (iv) increasing insulation; (v) providing fixed or adjustable shading; (vi) using selective glazing on windows with a low solar heat gain and a high daylight transmission factor, and avoiding excessive window area (particularly on east- and west-facing walls); and (vii) 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 *et al.* (1998) 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. For Toronto, Akbari and Konopacki (2004) calculated potential savings in cooling energy use of about 25% for residential buildings and 15% for office and retail buildings through similar measures.

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 (2006, Chapter 6) and Levermore (2000). Highlights are presented below.

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, providing 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 multi-story commercial buildings in more temperate climates in North America, notably in the new San Francisco Federal Office Building (McConahey, *et al.*, 2002). Natural ventilation can be supplemented with mechanical ventilation as needed.

Night-time ventilation

In climates with a minimum diurnal temperature variation of 5 to 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.,* (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.

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.

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 an indirect-direct evaporative cooler that was 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 to 95%; estimated cooling energy savings for a modular school classroom are 89-91% (DEG, 2004).

Other passive cooling techniques

Underground earth-pipe cooling consists of cooling ventilation air by drawing outside air through a buried coil. Good performance depends on the climate having a substantial annual temperature range.

Desiccant dehumidification and cooling involves using a material (desiccant) that removes moisture from air, saving energy for dehumidification and enabling lower energy cooling methods. Solid desiccants are a commercially available technology. The energy used for dehumidification can be reduced by 30 to 50% compared to a conventional overcooling/reheat scheme (50 to 75% savings of conventional sources if solar energy is used to regenerate the desiccant) (Fischer, *et al*., 2002; Niu, *et al.,* 2002). In hot-humid climates, desiccant systems can be combined with indirect evaporative cooling, desiccant systems, providing an alternative to refrigeration-based air conditioning systems (Belding and Delmas, 1997).

6.4.4.3 Air conditioners and vapour-compression chillers

Air conditioners used for houses, apartments, and small commercial buildings have a COP ranging from 2.2 to 3.8 in North America and Europe, depending on operating conditions. More efficient mini-split systems are available in Japan, ranging from 4.5 to 6.2 for 2.8-kW. 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 up to 7.9. Thus, 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 inefficient split-unit air conditioner in each room of each apartment unit. A limitation of chiller-based central cooling systems for many applications is that they require a chilled-water piping system and space for the central facility, and metering and billing of individual apartments to discourage waste.

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 in climates with seasonal heating 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 produce substantial reductions in annual HVAC energy use.

Greater gains in efficiency can be achieved by recognizing that water, as a heat transfer fluid, is 25 to 100 times more effective 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 to 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 vapour, 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 to 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.

6.4.5.2 Alternative HVAC systems in commercial buildings

In the following paragraphs we describe two alternatives to conventional HVAC systems in commercial buildings that together can reduce the HVAC system energy use by 30 to 75%. These savings are in addition to the savings arising from reducing heating and cooling loads.

Radiant chilled-ceiling cooling

A room may be cooled by chilling a large fraction of the ceiling using circulating water through pipes or lightweight panels. 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 to 20°C rather than at 5 to7°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 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, Ireland and 67% of the time in Milan, Italy if the chilled water is supplied at 18°C (Costelloe and Finn, 2003).

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^{o}C *vs*. ~13^{o}C in a conventional mixing ventilation system).

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).

6.4.6 Building energy management systems (BEMS)

BEMSs are computer and distributed microprocessor based monitoring, data storage and communicating control management systems for individual, or groups of, buildings and their systems (Levermore, 2000). The BEMS can be centrally located and communicate over telephone or internet links with remote buildings having "outstations" so that one energy manager can manage many buildings remotely. As *management* systems the savings they produce depend on how well they are used.

With temperature, occupancy and lighting sensors and energy meters connected to a BEMS, faults can be detected, automated fault detection can be employed (Katipamula, 1999), and energy efficiency can be maintained (Burch, 1990). With the advent of inexpensive, wireless sensors and advances information technology, extensive monitoring via the Internet is possible.

Estimates of energy savings vary considerably: up to 27% (Birtles and John, 1984); between 5% and 40% (Hyvarinen, 1991; Brandemuehl, 1999, 1998; Levermore, 2000); up to 20% in space heating energy consumption and 10% for lighting and ventilation; and 5% to 20% (Roth, *et al.*, 2005).

6.4.6.1 Commissioning

Proper commissioning of the energy systems in a commercial building is a key to its efficient operation (Koran, 1994; Kjellman, 1996; Roth, *et al.*, 2005; IEA, 2005). 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.

Retro-commissioning involves analysing 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. Retro-commissioning improve energy performance (15-20% is a typical result) and/or to address known problems (e.g. indoor air quality).

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.

6.4.6.2 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 is currently under development (Brambley, *et al.,* 2005). Post-occupancy evaluation (POE) is a useful complement to ongoing monitoring of equipment, also useful for ensuring that the building operates efficiently. A UK study of recently constructed buildings found that the use of POE identified widespread energy wastage (Bordass, *et al.*, 2001a,b).

6.4.7 Cogeneration and District Heating/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 without major distribution losses, then significant savings in primary energy use are possible - beyond what can be achieved by optimising the design of a single building. 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) and central production of cold water; 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 to 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 upgrades 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 that involve the simultaneous production of electricity and useful heat. It can be done at the scale of individual buildings using microturbines or at the scale of district heating systems using either a simple gas turbine or combined gas and steam turbines. The ratio of electricity to useful heat, electrical efficiency, and the overall efficiency are lowest for microturbines (0.5 to 0.75, 25 to 30%, and 60 to 70%, respectively) and highest for combined-cycle cogeneration (1.1 to 1.6, 47 to 55%, and 88 to 90%, respectively)(Goldstein, *et al*., 2003). For cogeneration to provide an improvement in efficiency, a use has to be found for the waste heat. Buildings with high-performance envelopes have minimal heating loads even in cold climates, so this centralized combined-cycle cogeneration connected to district heating networks is favoured due to the higher electricity/heat output ratio of combined-cycle plants and the need to pool heat loads to match the larger size of combined cycle plants.

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, if a district-heating network is 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). Efficiency gains through centralized heating and cooling can also occur due to the greater efficiency of larger equipment and the greater opportunity to optimise operation (Shimoda, *et al.*, 2005). In the last decade technological innovations and a changing economic and regulatory environment have resulted in a renewed interest in distributed generation. There are different types of distributed generation technologies including traditional internal combustion engines (diesel engines), gas turbines, micro-turbines, fuel cells, photovoltaics, wind turbines, etc.

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, 2006, 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 because of 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 solar energy provides 30 to 95% of total annual heating and hot water requirements under German conditions (Lindenberger, *et al.*, 2000).[5] Sweden has been able to switch a large fraction of its building heating requirements to biomass energy (plantation forestry) by switching from fossil fuels to biomass as the fuel for its district heating systems (Swedish Energy Agency, 2004). To directly heat individual buildings with this biomass energy would not have been feasible. Similarly, Denmark has been able to utilize biogas from farm manure for heating purposes in some of its district heating systems (Ramage and Scurlock, 1996). In 1997, there were 369 district heating plants in Austria powered by biomass (Faninger, 2000). The world's first hybrid solar/biomass district heating plant was installed in Austria in 1994, and by 1998, 12 hybrid solar/biomass plants were in operation in Austria with solar collector areas ranging from 225 m^2 to 1250 m^2 (Faninger, 2000).

6.4.8 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 some 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 heating and cooling energy needs of buildings as constructed under normal practice can either be eliminated or satisfied through passive solar design. 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. 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.

6.4.8.1 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,

[5] Existing and planned solar-assisted systems in Germany, Sweden, Denmark, Netherlands, and Austria are described in Lottner *et al.* (2000), Schmidt *et al.*(2004), Fisch *et al.* (1998), Heller (2000), and IEA (2000), while information on a Canadian system is available at www.dlsc.ca.

shading devices, skylights). BiPV systems 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$0.30-0.40/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). Estimates of the percent of present total electricity demand that could be provided by BiPV ranges from about 15% (Japan) to almost 60% (USA).

6.4.8.2 Solar thermal energy for heating and hot water

Most solar thermal collectors used in buildings are either flat-plate or evacuated-tube collectors.[6] 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, 2002a). "Combisystems" are solar systems that provide both space and water heating. Depending on the size of panels and storage tanks, and the building thermal envelope performance, 10 to 60% of the combined hot water and heating demand can be met at central and northern European locations. Costs of solar heat have been 9-13 eurocents/kWh for large domestic hot water systems and 40-50 eurocents/kWh for combisystems with diurnal storage (Peuser, *et al.*, 2002).

Worldwide, over 132 million m^2 of solar collector surface for space heating and hot water were in place by the end of 2003. China accounts for almost half of the total (51.4 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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6.4.9 Domestic hot water

Options to reduce fossil or electrical energy used to produce hot water include (i) use of low-flow water fixtures, more water-efficient washing machines, cold-water washing, and (if used at all) more water-efficient dishwashers (50% typical savings); (ii) use of more efficient and better insulated water heaters or integrated space and hot-water heaters (10-20% savings); (iii) use of tankless (condensing or non-condensing) water heaters, located close to the points of use, to eliminate standby and greatly reduce distribution heat losses (up to 30% savings, depending on the magnitude of standby and distribution losses with centralized tanks); (v) recovery of heat from warm wastewater; (vi) use of air-source or exhaust-air heat pumps; and (vii) use of solar thermal water heaters (providing 50-90% of annual hot-water needs, depending on climate). The integrated effect of all of these measures can frequently reach a 90% savings. Heat pumps using CO_2 as a working fluid are an attractive alternative to electric-resistance hot water heaters, with a COP of up to 4.2 (Saikawa, *et al.*, 2001).

6.4.10 Lighting Systems

[6] See Peuser *et al.* (2002) and Andén (2003) for technical information.

Lighting energy use can be reduced by 75 to 90% compared to conventional practice through (i) use of daylighting with occupancy and daylight sensors to dim and switch off electric lighting; (ii) use of the most efficient lighting devices available; and (iii) use of such measures as ambient/task lighting.

6.4.10.1 High efficiency electric lighting

Continuous improvements in the efficacy[7] of electric lighting devices have occurred during the past 5-10 years, and can be expected to continue to occur. 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), and compared to about 10 lumens/Watt for incandescent lamps. Advances have also occurred in occupancy-sensor technology (Garg and Bansal, 2000). Compact fluorescent lamps (CFLs) provide 60 to 70 lumens/watt. CFLs can be purchased for as low as $2 (U.S) in many countries - a significant drop during the last few years. Altogether, a reduction in residential lighting energy use of a factor of 4 to 5 can be achieved compared to incandescent/halogen lighting.

For lighting systems providing uniform lighting in commercial buildings, the energy required can be reduced by 50% or more compared to T12 systems through use of efficient lamps (T5 or recent T8), ballasts, and reflectors, occupancy sensors, and lighter colour finishes and furnishings. A further 40 to 80% of the remaining energy use can be saved in perimeter zones through daylighting (e.g., Rubinstein, *et al*., 1998; Bodart and de Herde, 2002). A simple strategy to further reduce energy use is to provide a relatively low background lighting level, with local levels of greater illumination at individual workstations. This strategy is referred to as *task/ambient lighting,* and is popular in Europe. Not only can this alone cut lighting energy use in half, but it provides a greater degree of individual control over personal lighting levels.

About one third of the world's population depends on fuel-based lighting (such as kerosene), contributing to the major health burden from indoor air pollution in developing countries. A CFL is about 1000 times more efficient than a kerosene lamp. Efforts are underway to promote replacement of kerosene lamps with CFLs in India and China.

Recent advances with the light-emitting diode (LED) technology significantly improved the cost-effectiveness, longevity and overall viability of stand-alone PV-powered lighting (IEA 2006b).

6.4.11 Daylighting

Daylighting systems involve the use of natural lighting for the perimeter areas of a building. Such systems have light sensors and actuators to control artificial lighting. They may also include other features to improve lighting performance (described below). 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 (2000) provides a comprehensive sourcebook of conventional and less conventional techniques and technologies for daylighting. These include: (i) light shelves (horizontal reflective surfaces placed near the upper part of the window, on the inside or outside, in

[7] Ratio of light output in lumens of light to input power in watts.

order to reflect light onto the ceiling while shading the lower part of the window to prevent glare and overheating); (ii) automatic Venetian blinds, whose tilt angle is varied in order to compensate for changing outdoor light levels and changing solar position; (iii) 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; (iv) prismatic panels, light-directing louvers, and laser-cut panels (all of which act by reflecting onto the ceiling the light falling on the window); and (v) 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 to 80% in the daylighted perimeter zones of office buildings (Rubinstein and Johnson, 1998; Bodart and Herde, 2002; Li and Lam., 2003). The management of solar heat gain through daylighting also leads to a reduction in cooling loads. Lee, *et al.* (1998) 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 to 75% in summer. Monitored reductions in summer daily cooling loads, for a southeast-facing office in this Oakland, California building, were 5 to 25%, with even larger reductions in peak cooling loads.

Ullah and Lefebvre (2000) reported measured savings of 13 to 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 (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). Another impediment 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.

6.4.12 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) This equipment is more than 40 percent of total residential primary energy demand in 11 large OECD nations [8] (IEA, 2004). The largest growth in electricity demand has been in miscellaneous equipment (home electronics, entertainment, communications, office equipment, and small kitchen equipment), which has been evident in all industrialized countries since the early 1980s. Such miscellaneous equipment now accounts for 70% of all residential electricity use in the 11 large OECD nations (IEA, 2004, Figure 5-11). Appliances generally constitute a smaller fraction of residential energy demand in developing countries. However, the rapid increase in appliance saturation in China, especially in urban areas, demonstrates the expected rise in importance of appliances in the developing world as economies grow (LBNL, 2004).

On a primary energy basis, appliances are undoubtedly a larger portion of total energy use for commercial than for residential buildings. In the United States, for example, appliances account for almost 75 percent of total energy consumption in commercial buildings. Miscellaneous equipment and lighting combined account for more than half of total energy consumption in commercial buildings in the United States and Japan (Koomey, *et al.*, 2001, Murakami, *et. al.*, 2006).

The most efficient appliances require a factor of two to five less energy than the least efficient appliances available today. For example, in the US, the best horizontal-axis clothes-washing machines use less than half the energy of the best vertical-axis machines and less than one-fifth the energy permitted under the current US standard for top-loading machines (FEMP, 2002), while 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) and about 50% of energy used in the late 1980s. Prototype refrigerator/freezers of standard US size use less than 400 kWh/yr (Brown *et al.*, 1998). However, this is still in excess of the average energy use by refrigerators in Sweden, The Netherlands, Germany, and Italy in the late 1990s (IEA, 2004).

Standby and low power mode 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 (Calwell and Reeder, 2002) and highly inefficient circuit designs that draw unnecessary power in the resting or standby modes - has caused this equipment to be responsible for a large fraction of the electricity demand growth in both residential and commercial buildings in many nations. 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

[8] Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom, and the United States.

computer chips that reduce electricity use in low-power mode, and 3) repeated reminders to users to turn equipment off during non-working hours.

The cookstove, already referred to in Section 6.4.3.2.2 for heating, is a major energy-using appliance in developing countries. We have noted the particular concern about emissions of products of incomplete combustions described in that section. Three billion people in developing countries depends on biomass, such as wood, dung, charcoal and agricultural residues, to meet their cooking energy needs. Otions available to reduce domestic cooking energy needs including: 1) improved efficiency of biomass stoves; 2) improved access to clean cooking fuels, both liquid and gaseous; 3) access to electricity and low-wattage and low-cost appliances for low income households; 4) non-electric options such as solar cookers; 5) efficient gas stoves; and (6) small electric cooking equipment such as microwaves, electric kettles or electric fry.

6.4.13 Energy savings through retrofits

There is a large stock of existing, inefficient buildings, most of which will still be here in 2025 and even 2050. Our long-term ability to reduce energy use depends critically on the extent to which energy use in these buildings can be reduced when they are renovated. The equipment inside a building, such as the furnace or boiler, water heater, appliances, air conditioner (where present), and lighting is completely replaced over time periods ranging from every few years to every 20-30 years. The building shell - walls, roof, windows, and doors - last much longer. There are two opportunities to reduce heating and cooling energy use by improving the building envelope: (i) at any time prior to a major renovation, based on simple measures that pay for themselves through reduced energy costs and potential financial support or incentives; and (ii) when renovations are going to be made, including replacing windows and roofs.

Renovations themselves are rarely done in order to save energy, and some of the energy-saving measures that might be taken during renovation might be done because of other benefits that they provide (such as providing more uniform temperatures and addressing moisture problems). Thus, some of the energy-savings measures might not be justifiable based on energy-cost savings alone, but can still be worthwhile. The time when the building envelope is upgraded is a good time to replace the heating system, as this provides an opportunity for downsizing the system, or for switching to a more efficient heating system. Conversely, if the heating or cooling system needs to be replaced, that could be a good time to undertake needed renovations if accompanied by an improved thermal envelope, as the cost savings on a down-sized heating and cooling equipment can offset a portion of the cost of the renovation. Deeper energy savings can be achieved through solar-retrofits of buildings. Examples of conventional and solar retrofits are given below.

6.4.13.1 Conventional retrofits of residential buildings

Cost-effective measures that can be undertaken without a major renovation of residential buildings include: sealing points of air leakage around baseboards, electrical outlets and fixtures, plumbing, the clothes dryer vent, door joists, and window joists; weather stripping of windows and doors; and adding insulation in attics or wall cavities. A Canadian study found that the cost-effective energy savings potential ranges from 25-30% for houses built before the 1940s, to about 12% for houses built in the 1990s (Parker, *et al.*, 2000). In a carefully-documented retrofit of 4 representative houses in the York region of the UK, installation of new window and door wood frames, sealing of suspended timber ground floors, and repair of defects in plaster reduced the rate of air leakage by a factor of 2.5-3.0 (Bell and Lowe, 2000). This, combined with improved insulation, doors, and windows, reduced the heating energy required by an average of 35%. Bell and Lowe (2000) believe that a reduction of 50% could be achieved at modest cost using well-proven (early 1980s) technologies, and a further 30-40% reduction through additional measures.

Studies summarized by Francisco, *et al*. (1998) indicate that air-sealing retrofits alone can save an average of 15-20% of annual heating and air conditioning energy use in US houses. Additional energy savings would arise by insulating ductwork in unconditioned spaces. Rosenfeld (1999) refers to an "AeroSeal" technique that he estimates is already saving $3 billion/yr in energy costs in the USA. Without proper sealing, homes in the USA lose, on average, about one-quarter of the heating and cooling energy through duct leaks in unconditioned spaces - attics, crawl spaces, basements.

In a retrofit of 4003 homes in Louisiana, the heating, cooling, and water heating systems were replaced with a ground-source heat pump system. Other measures were installation of attic insulation and use of compact fluorescent lighting and low-flow showerheads. Space and hot water heating previously provided by natural gas was supplied instead by electricity (through the heat pump), but total electricity use still decreased by one third (Hughes and Shonder, 1998).

External Insulation and Finishing Systems (EIFSs) provide an excellent opportunity for upgrading the insulation and improving the air-tightness of single and multi-unit residential buildings, as well as institutional and commercial buildings. This is because of the wide range of external finishes that can be applied, ranging from stone-like to a finish resembling aged plaster. A German company manufacturing some of the components used in EIFSs, undertook a major renovation of some of its own 1930s multi-unit residential buildings. The EIFSs in combination with other measures achieved a factor of eight measured reduction in the heating energy use. An envelope upgrade of an apartment block in Switzerland after retrofitting reduced the heating requirement by a factor of two, while replacing an oil-fired boiler at 85% seasonal average efficiency with an electric heat pump having a seasonal average COP of 3.2 led to a further large decrease in energy use. The total primary energy requirement decreased by 75%.

6.4.13.2 Conventional retrofits of institutional and commercial buildings

There are numerous published studies showing that energy savings of 50 to 75% can be achieved in commercial buildings through aggressive implementation of integrated sets of measures. These savings can often be justified in terms of the energy-cost savings alone, although in other cases full justification requires consideration of a variety of less tangible benefits. In the early 1990s, a utility in California sponsored a $10 million demonstration of advanced retrofits. In six of seven retrofit projects, an energy savings of 50% was obtained; in the seventh project, a 45% energy savings was achieved. For Rosenfeld (1999), the most interesting result was not that an alert, motivated team could achieve savings of 50% with conventional technology, but that it was very hard to *find* a team competent enough to achieve these results.

Other, recent examples that are documented in the published literature include:

- A realized savings of 40% in heating+cooling+ventilation energy use in a Texas office building through conversion of the ventilation system from one with constant to one with variable air flow (Liu and Claridge, 1999);

- A realized savings of 40% of heating energy use through the retrofit of an 1865 two-story office building in Athens, where low-energy was achieved through some passive technologies that required the cooperation of the occupants (Balaras (2001);
- A realized savings of 74% in cooling energy use in a one-story commercial building in Florida through duct sealing, chiller upgrade, and fan controls (Withers and Cummings, 1998));
- Realized savings of 50-70% in heating energy use through retrofits of schools in Europe and Australia (CADDET 1997);
- Realized fan, cooling, and heating energy savings of 59%, 63%, and 90%, respectively, in buildings at a university in Texas, roughly half due to standard retrofit and half due to adjustment of the control-system settings (which were typical for North America) to optimal settings (Claridge, *et al*., 2001).

6.4.13.3 Solar retrofits of residential, institutional, and commercial buildings

The retrofit examples described above, while achieving dramatic (35-75%) energy savings, rely on making incremental improvements to the existing building components and systems. More radical measures involve re-configuring the building so that it can make direct use of solar energy for heating, cooling, and ventilation. The now-completed Task 20 of the IEA's *Solar Heating and Cooling (SHC)* implementing agreement was devoted to solar retrofitting techniques.

Solar renovation measures that have been used are installation of roof- or façade-integrated solar air collectors; roof-mounted or integrated solar DHW heating; transpired solar air collectors, advanced glazing of balconies, external transparent insulation; and construction of a second-skin façade over the original facade.

Table 6.1 provides information on a number of solar renovation projects completed in Europe under IEA SHC Task 20. Further information can be found in the indicated references or in Voss (2000b).

Table 6.1: *Summary information on solar renovation projects performed as part of International Energy Agency's Solar Heating and Cooling Programme, Task 20. DHW=domestic hot water, TI=transparent insulation*

Location	**Building description**	**Dates**		**Measures implemented**	**Space heating energy use (kWh/m²/yr)**		**Investment (EUR/ m² floor area)**	**Cost of saved energy (EUR/kWh)**
		Built	**Renov.**		**Before**	**After**		
Jambes, Belgium	8-story apartment	1976	1990s	Glazed balconies	64	47		
Perwez, Belgium	Single-family row houses	1800s	1990s	Added 2-level greenhouse on SE façade	Almost 40% savings			
Aalborg, Denmark	8 apartments in 4-story building	1900	1996	Preheat ventilation air in ventilated solar walls, roof-integrated DHW solar collectors, demand-controlled ventilation, low-e glazing	230	70	2780[9]	
Freiburg,	Multi-family	1950s	1989	Standard insulation of all	225	43		

[9] High cost due to intensive demonstration of advanced technologies.

Germany	(8 units)			façades, roof, and cellar; low-e blinds, 120 m^2 TI on SE and SW façades with adjustable shading				
Freiburg, Germany	Multi-family Villa Tannheim	1912	1995	Insulation, new windows, 53 m^2 TI on west façade for space heating and DHW, no shading.	225	75[10]	633	0.22
Zaandam, Netherlands	384 apartments in 14-stories	1968	1997	Solar DHW, glazed balconies, TI walls	145	80	59	
Gardstensbergen, Gothenburg, Sweden	11-story residential	1975	1990s	Insulation, new windows, roof-integrated DHW solar preheating, glazed balconies, TI	270	160	60	
Rannebergen, Gothenburg, Sweden	188-unit apartment building	1975	1990s	Roof-mounted solar air collector	40% savings			
Hedingen, Switzerland	11-unit multi-family	1971	1994	Standard insulation of all façades, roof, and cellar. New low-e windows, 63 m^2 TI on south façade with adjustable shading	245	140	86	0.36
Niederurnen, Switzerland	12 apartments in 4 stories	1971	1996	Insulation, new windows, TI on SW façade with external blinds	175	105	79	0.43

Sources: Boonstra and Thijssen (1997), Haller et al. (1997), Voss (2000a)

6.4.14 Tradeoffs between embodied energy and operating energy

The replacement of materials that require significant amounts of energy to produce (such as concrete and steel) with materials requiring small amounts of energy to produce (such as wood products) will reduce the amount of energy embodied in buildings. Whether this reduces energy use on a lifecycle basis, however, depends on the effect of materials choice on the energy requirements for heating and cooling over the lifetime of the building and whether the materials are recycled at the end of their life (Börjesson and Gustavsson, 2000; Lenzen and Treloar, 2002). For typical standards of building construction, the embodied energy is equivalent to only a few years of operating energy, although there are cases in which the embodied energy can be much higher (Lippke, *et.al.,* 2004). Thus, over a 50-year time span, reducing the operating energy is more important than reducing the embodied energy.

It most circumstances, the choice that minimizes operating energy use also minimizes total lifecycle energy use. In some cases, the high embodied energy in high-performance building envelope elements (such as krypton-filled double- or triple-glazed windows) can be largely offset from savings in the embodied energy of heating and/or cooling equipment, so a truly holistic approach is needed in analysing the lifecycle energy use of buildings.

6.4.15 Tradeoffs involving energy-related emissions and halocarbon emissions

[10] A 75% savings in space heating, along with a 50% savings in DHW energy use.

Issues pertaining to stratospheric ozone and climate are comprehensively reviewed in the recent IPCC/TEAP report (Metz, *et al*., 2005). We provide here a brief summary.

Halocarbons (CFCs, HCFCs, HFCs) are involved as a working fluid in refrigeration equipment (refrigerators, freezers, cold storage facilities for food), heating and cooling of buildings (heat pumps, air conditioners, chillers) and as an expanding agent used in foam insulation for refrigerators, pipes, and buildings. The CFCs and HCFCs lead to loss of stratospheric ozone, and all three groups are greenhouse gases. Global Warming Potential (GW_p) is highest for CFC, which are banned by the Montreal Protocol because of their effect on the atmospheric ozone layer. Most HCFCs are being phased out, also for reasons of ozone depletion. The GW_p of HCFCs is lower than CFCs and that of HFCs is lower than HCFCs. Projected emissions of HCFCs and HFCs are, nonetheless, sufficiently high that 2015 scenarios of halocarbon use in buildings show almost the same emissions as in 2002 (about 1.5 $GTCO_2$ eq emissions). For the coming decade or longer, the bank of CFCs in the stock of air conditioners is so large that particular attention needs to be given to recovering these CFCs.

Lifetime emissions of refrigerants from cooling equipment, per unit of cooling, have fallen by a factor of 10 during the past 30 years. For HFC refrigerants in heat pumps (which will be the only permissible halocarbon refrigerant by 2010 in developed countries), the climatic impact of halocarbon emissions from heat pumps is estimated to be 2 to 10% of the total impact (including energy use) for a 4 kW_c unit, and 20 to 30% for a 56 kW_c unit, in both cases assuming that 50 to 70% of the remaining refrigerant is recovered at the end of a 15-year operating life (Peixoto, *et al*., 2005). Non-halocarbon refrigerants can entail efficiency penalties of 40-50% if the heat pump is not optimised for the alternative refrigerant, but as low as 15% in some circumstances or with a slight efficiency benefit in other circumstances if the heat pump is fully optimised. Thus, both the performance of the heat pump and the impact of halocarbon emissions need to be considered in evaluating the climatic impact of alternative choices for refrigerants.

The climatic impact of air conditioners and chillers is overwhelmingly related to the energy used to power them. For leakage of HFC refrigerants at rates of 1 to 2% (best practice is about 0.5%/yr) and recovery of 85% of the refrigerant at the end of a 15-year life, refrigerant leakage accounts for only 1 to 2% of the total impact on climate of the cooling equipment (Piexoto, *et al*., 2005). At 50% end-of-life recovery, the refrigerant accounts for 10% of the total impact. This example demonstrates the importance of end-of-life recovery, which is highly uncertain for HCFs at present. Refrigerant emissions per unit of cooling have fallen by a factor of 10 over the past 30 years.

For spray and solid foam insulation starting from uninsulated conditions, the climatic benefit of reduced heating energy use is many times the climatic effect of leakage of the blowing agent from the insulation when HFC blowing agents are used (Ashford, *et al*., 2005). However, when halocarbon-blown foam insulation is used to augment already high levels of insulation, the heating-energy-related climatic benefit of the additional insulation can be less than the climatic effect of halocarbon emissions (Harvey, 2007). That is, the additional insulation can be counterproductive from a climatic point of view. For this application, non-halocarbon foam insulation or non-foam insulation is appropriate.

6.4.16 Summary of mitigation options in buildings

Table 6.2 shows the summary of a selection of key technological opportunities in buildings for GHG abatement in five world regions compared based on three criteria. Eighteen typical technologies were selected from ones described in section 6.4. As economic and climatic conditions in regions largely determine the applicability and importance of technologies, countries were divided into three economic classes and two climatic types. The three criteria include the maturity of the technology, cost/effectiveness, as well as appropriateness. Appropriateness include climatic, technological, climatic as well as cultural applicability. For example, direct evaporative cooling is ranked highly appropriate in dry and warm climate but while it is not appropriate in humid and warm climates. The assessment of some technologies depends on other factors, too. For instance, the heat pump system depends on the energy source and whether it is applied to heating or cooling. In these cases, variable evaluation is indicated in the table.

***Table 6.2:** Applicability of energy efficiency technologies in different regions*

Energy Efficiency Technology	Developing Countries						OECD						Economies in Transition, Continental		
	Cold Climate			Warm Climate			Cold Climate			Warm Climate					
	Technol o-gy stage	Cost/ Effectiveness	Appropriateness	Technology stage	Cost/ Effectiveness	Appropriateness	Technology stage	Cost/ Effectiveness	Appropriateness	Stage of Technology	Cost/ Effectiveness	Appropriateness	Technology stage	Cost/ Effectiveness	Appropriateness
Structural insulated panels (Insulation)	•	•	•	•	·	·	●	•	•	•	•	•	•	●	●
Multiple glazing layers	●	•	•	•	•	·[1]-•[2]	~	●	●	●	●	•	●	●	●
Passive solar heating	●	•	•	•	•	·	●	•	●	●	•	•	●	•	●
Heat Pumps	•[3]	·	·	•-●[4]	•[5]-·[6]	•[7]-·[8]	●[9]	•	•	~[10]-●[11]	●[12]-•[13]	●[14]-•[15]	●[16]	•	•
Biomass derived liquid fuel stove	●	•	●	•	·	·	~	•	●	~	•	·	~	●	●
High-reflectivity bldg. materials	·	·	·	•	●	•	●	•	•	~	•	●	●	•	•
Thermal mass to minimize daytime interior temperature peaks	~	●	•	~	●	●[17]-·[18]	~	●	•	~	●	●[19]-·[20]	~	●	●
Direct evaporative cooler	·	·	·	~	●	●[21]-·[22]	·	·	·	~	●	●[23]-·[24]	·	·	·
Solar thermal water heater	~	●	●	●	●	●	~	●	●	~	●	●	~	●	●
Cogeneration	●	•	•	•	·	·	~	•	●	~	•	•	●	•	●
District Heating &Cooling System	●	•	•	·	·	·	~	•	●	●	•	•	●	•	●
PV	●	•	•	·	·	·	~	•	●	●	•	•	●	•	•

Air to air heat exchanger	⬤	●	⬤	⬤	●	⬤	⬤	⬤	⬤	⬤	⬤	⬤	⬤	●	⬤
High efficiency lamp	~	●	⬤	~	●	⬤	μ	⬤	⬤	μ	⬤	⬤	⬤	●	⬤
Light shelves	⬤	●	⬤	⬤	●	⬤	⬤	●	⬤	⬤	●	⬤	⬤	●	⬤
Variable speed drives for pumps and fans	~	●	●	~	●	●	~	●	●	~	●	●	~	●	●
Advanced control system based on BEMS	⬤	●	●	⬤	●	●	⬤	●	●	⬤	●	●	⬤	●	●

Notes: 1 For heat block type, 2. For Low-E, 3. Limited to ground heat source etc, 4. For air-conditioning, 5 .For cooling, 6. For hot water, 7 .For cooling, 8. For hot water, 9. Limited to ground heat source, etc., 10. For cooling, 11. For hot water, 12. For cooling, 13. For hot water, 14. For cooling, 15. For hot water, 16. Limited to ground heat source, etc, 17. In arid region, 18. In high humidity region, 19.In arid region, 20. In high humidity region, 21. In arid region, 22. In high humidity region, 23. In arid region, 24. In high humidity region

Evaluation ranks:

Stage of technology	***Cost/Effectiveness***	***Appropriateness***	***Visual representation***
Research phase (including laboratory and development)	*Expensive/Not effective*	*Not appropriate*	•
Demonstration phase	*Expensive/effective*	*Appropriate*	●
Economically feasible under specific conditions	*Cheap/Effective*	*Highly appropriate*	⬤
Mature Market (widespread commercially available without specific governmental support	*"~" Not avaluated*	*"~" Not avaluated*	~
No Mature Market (not necessarily available and not necessarily mature market)			μ

6.5 Potential 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 GHG emissions. This section aims at quantifying the reduction potential these options represent, as well as the costs associated with their implementation.

6.5.1 Recent advances in potential estimations from around the world

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.,* (Brown, 1998). An update of this assessment has been conducted for this report, based on a review of 64 recent studies from 36 countries and 11 country groups, spanning five continents. While the appraisal concentrated on new results since the IPCC exercise between 1996 and 1998, in striving for comprehensive global coverage, a few older studies were also revisited if no recent study was located to represent a geopolitical region. Table 6.3 reviews the findings of a selection of major studies on 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, for methodological aspects of such a comparison exercise).

Table 6.3: *Greenhouse gas emissions reduction potential for residential and commercial sectors*

Country/ region	**Reference**	**Type of potential**	**Description of mitigation scenarios**	**Potential**		**Measures with lowest costs**	**Measures with highest potential**	**Notes**
				Million tCO_2	**Base-line %**			
Case studies providing information for Demand-Side Measures								
EU-15	Joosen and Blok 2001	Economic	25 options: retrofit (insulation); heating systems; new zero & low energy buildings, lights, office equipment & appliances; solar and geothermal heat production; BEMS for electricity, space heating and cooling.	310	21%	1.Efficient TV & video; 2.Efficient re-frigerators & freezers; 3.Lighting Best Prac-tice.	1.Retrofit: insulated windows; 2.Retrofit: wall insulation; 3.BEMS for space heating and cooling.	[1].4%; [4].Fr-ef.; [6].TY 2010.
Canada	ERG: Jaccard, M.K. & Asso-ciates. 2002	Market	Mainly fuel switch in water and space heating, hot water efficiency and the multi-residential retrofit program in households; landfill gas, building shell efficiency actions, and fuel switch in commerce.	22	24%	N.a. (Not listed in the study)	1.Electricity demand reductions; 2.Commercial landfill gas; 3.Furnaces & shell improvements.	[1].10%; [6].TY 2010.
Greece	Mirasgedis et al 2004	Technical	14 technological options: fuel switch, controls, insulation, lights, air conditioning, and others.	13	54%	1.Replacement of central boilers; 2.Use of roof ventilators; 3.Replacement of AC.	1.Shell, esp. insulation; 2.Lighting & water heating; 3.Space heat-ing systems.	[1].6%; [4].Fr-ef; [6].TY 2010;[8]. Res. only.
Estonia	ESE, SEITC 1999	Market	4 insulation measures: 3d window glass, new insulation into houses, renovation of roofs, additional attic insulation.	0.4	2.5% of nation. emis.	1.New insulation; 2.Attic insulation; 3.3d window glass.	1.New insulation; 2.3d window glass; 3.Attic insulation.	[1].6%; [5].BY 1995; [6].TY 2025.
New EU Member States[11]	Petersdorff et al 2005	Technical	Building envelope esp. insulation of walls, roofs, cellar/ground floor, windows with lower U-value; and renewal of energy supply.	62	-	1.Roof insulation; 2.Wall insulation; 3.Floor Insulation.	1.Window replace-ment; 2.Wall insula-tion; 3.Roof insulation.	[1].6%; [4].Fr-ef; [5].BY 2006; [6].TY 2015.
Hungary	Szlavik and Urge-Vorsatz 1999	Economic	25 technological options and measures: building envelope, space heating, hot water supply, ventilation, awareness, lighting, appliances.	22	45%	1.Individual metering of hot water; 2.Water flow controllers; 3.Retrofit windows.	1.Post insulation; 2.Retrofit of windows; 3.Replacement of windows.	[1].3%; [6].TY 2030; [8].Com. - publ. sector
Myanmar	ADB 1998d	Technical	5 options: shift to CFLs, switch to efficient biomass and LPG cook stoves, improved kerosene lamps, efficient air-conditioners.	3	N.a.	1.Biomass cook stoves, 2.Kerosene lamps, 3.CFLs.	1.Biomass cook stoves, 2.LPG cook stoves, 3.CFLs.	[1].10%.

[11] Hungary, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Poland, and the Czech Republic.

Country/ region	Reference	Type of potential	Description of mitigation scenarios	Potential		Measures with lowest costs	Measures with highest potential	Notes
				Million tCO_2	Base-line %			
India	Reddy and Balachandra 2005	Market	Lighting: mixture of incadescents, fluorescent tubes and CFLs, exchange of traditional kerosene and wood stoves and water heaters for efficient equipment.	85	N.a.	1.Efficient packages of lighting; 2.Kerosene stoves; 3.Wood stoves.	1.Wood stoves, 2.Efficient packages of lighting; 3.Kerosene stoves.	[1].N.A.; [5].BY 2000; [6].TY 2010; [8].Res. only.
New Zealand	APEIS 2004	Economic	9 main technological options: energy efficient appliances such as refrigerator and air-conditioners, lights (shift from incadescents to fluorescents), kerosene, electricity and gas water heater, kerosene and gas heater, wall and window insulation, and others.	0.3	16%	Efficient refrigerator, electricity and gas water heater, kerosene and gas heater, lights, air-conditioners (not ranked).	1.Efficient refrigera-tors, 2.Fluorescent lamps, 3.Efficient electric water heater (ranking at negative marginal cost).	[1].5%; [2].Integrated Assessment; [4].Fr-ef.; [8].Residences only.
Indonesia	APEIS 2004	Economic		13	24%			
Russia	APEIS 2004	Economic		204	18%			
Argentine	APEIS 2004	Economic		4	20%			
Brazil	APEIS 2004	Economic		5	37%			
China	ERI and NDRC 2004	Enhanced market	Key policy measures: energy conservation standards, heat price reform, lowest efficient standards & labeling for appliances, energy efficiency projects, etc.	422	23%	N.a. (Not listed in the study)	N.a. (Not listed in the study)	[1].N.a.
Republic of Korea	ADB 1998	Economic	7 options: heating - condensing gas boilers, solar hot water systems, insulation standards; cooling - air conditioners; improved lights - shift to fluorescents and CFLs; efficient motors and inverters.	20	17%	1.Heating: gas boilers, solar hot water, insulation standards; 2.Air-conditioners; 3.Inverters & motors.	1.Improved lights; 2.Motors & inverters; 3.Gas boiler RES, solar hot water system, insulation standards.	[1].8.5%; [5].BY1998.
Ecuador	FEDEMA 1999	Technical	6 main options: improvements of appli-ances, lighting systems, electricity end-uses esp. in rural areas and in the services, solar water heating, public lighting.	7	79%	1.Lights; 2.Electric appliances (esp. rural areas); 3.Electricity end-use in services.	1.Electric appliances (esp. in rural areas); 2.Public lighting; 3. Efficient light systems.	[1].10%; [6].TY 2030.
Thailand	ADB 1998	Economic	3 technological programs: lighting (shift to fluorescents), refrigerator (insulation and compressors), and air-conditioning.	15	31%	1.Lighting, 2.Efficient refrigerators, 3.Air-conditioning.	1.Efficient air-condi-tioning, 2.Efficient re-frigerators, 3.Lighting.	[1].10%; [5].BY 1997; [8].Res. only.
Pakistan	ADB 1998	Economic	Energy efficiency improvements of electric appliances and other end-use devices such as lights, fans, refrigerators, water heaters, and improvement of building design.	7	18%	1.Improved lights, 2.Efficient ceiling fans, 3.More efficient refrigerators.	1.Efficient ceiling fans, 2.Improved lights, 3.Improved building design.	[1].8%; [5].BY 1998.

Country/ region	Reference	Type of potential	Description of mitigation scenarios	Potential		Measures with lowest costs	Measures with highest potential	Notes
				Million tCO_2	Base-line %			
South Africa	De Villers and Matibe 2000; De Villers 2000	Economic	21 options: light practices; new & retrofits HVAC; stoves, thermal envelope; fuel switch in heaters; standards & labeling; for hot water: improved insulation, heat pumps, efficient use; solar heating.	22	71%	1.Energy star equipment; 2.Lighting retrofit; 3.New lighting systems.	1.Hybrid solar water heaters; 2.New building thermal design; 3.Efficient new HVAC systems.	[1].6%; [4].Fr-ef.; [6].TY 2020 (re-calculated).
UK	Defra 2006	Economic	41 options: insulation; low-e double glazing windows; various appliances; heating controls; better IT equipment, more efficient motors, shift to CFLs, BEMS, etc.	46	24% (Res. only)	1.Efficient fridge/freezers; 2.Efficient chest freezers; 3.Efficient dishwashers.	1.Efficient gas boilers; 2.Cavity insulation; 3.Loft insulation.	[1].7%-5%: Res-Com; [4].BL: Johnston 2005; [5].BY 2005.
Australia	Australian Greenhouse Office 2005	Market	Fridges and other appliances, air conditioners, water heating, swimming pool equipment, chillers, ballasts, standards, greenlight Australia plan, refrigerated cabinets, water dispensers, standby.	18	14%	1.Standby programs; 2.MEPS for appliances 1999; 3.TVs on-mode.	1.Packaged air-conditioners; 2.Ballast program in 2003; 3.Fluorescent bulbs.	[1].5%; [5].BY 2005.
Studies providing the information about both supply and demand-side options not separating them								
EU-25	Lechtenbohmer et al 2005	Economic	Improvement in space and water heating, appliances and lighting, cooling/freezing, air-conditioning, cooking, motors, process heat, renewable energies, reduced emissions from electricity generation.	410	37%	N.a. (Not listed in the study)	Res: 1.Insulation; 2.Heating systems, fuel switch, DH&CHP; Com: 1.Energy efficiency, 2.Renewables.	[1].3-5%; [5].BY 2005; [8].Com. includes agriculture.
USA	Koomey et al 2001	Advanced market	Voluntary labelling, deployment programs, building codes, new efficiency standards, government procurement, implementation of tax credits, expansion of cost-shared federal R&D expenditures.	898	37%	N.a. (The study did not examine a GHG potential supply cost curve).	1. Lighting; 2.Space cooling; 3.Space heating.	[1].7%; [5].BY 1997.

Notes specify those parameters which are different from those identified below (the number of a note is the number of the model parameter):
1. Discount Rate (DR) belongs to the interval [3%; 10%] **2**. Most models are Bottom-up (BU) (exceptions are Top-down (TD)) **3**. All models consider CO_2. If a study considered GHGs, CO_2 only was analysed, if the study assessed C, potential was converted into CO_2. **4**. Baseline (BL) is Business as Usual Scenario (BAU) or similar (Frozen efficiency scenario is abbreviated as fr-ef). **5**. Base year (BY) is 2000 **6**. Target year (TY) is 2020. **7**. Costs covered: cost of incremental reduction, abatement costs, costs of avoided or saved or mitigated CO_2, marginal costs. **8**. Estimations are made for Residential (R) and commercial (C) sectors in sum. **9**. Other important notes.

Both the methods and results for quantifying the potential for Greenhouse Gas mitigation in buildings vary widely around the world and from report to report, largely depending on the coverage and assumptions of each study. According to Table 6.4, estimates of technical potential range from 54% of residential CO_2 emissions in Greece in 2010 (Mirasgedis, *et al.,* 2004) to 79% of building-related emissions in Ecuador in 2030 (FEDEMA 1999). The estimates of economic potential in 2020[12] vary from 16% in New Zealand (APEIS IEA 2004) and 17% in the Korean Republic (ADB 1998), where only a limited number of mitigation options were considered, to 71% in South Africa (De Villiers and Matibe 2000, De Villiers 2000), from a very wide range of energy saving and fuel switching options. Estimates of market potential[13] range from 14% in Australia, focusing on electric appliances and equipment only (Australian Greenhouse Office 2005), to 37% in the USA, where a wide range of policies were appraised (Koomey, *et al*., 2001).

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-correcting for as many of the differing assumptions as possible. Our calculations suggest that, globally, by 2020, app. 1.6 and 1.4 billion tons of CO_2 eq. can be avoided annually through mitigation measures in the residential and commercial sectors, respectively. Using the A1 and B1 SRES Scenarios as the baseline, this estimate represents a reduction of 21%, 27%, respectively, 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 the studies and the exclusion of the positive integration effects, the *real potential is likely to be higher*. These figures are very 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, they 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

Various approaches have been used to estimate the costs of GHG mitigation in buildings. Assessing the private plus government costs of achieving energy savings is a difficult task, and only a few studies estimate them. 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 11 studies (ADB 1998 (three studies), De Villers and Matibe 2000, De Villiers 2000, Joosen and Blok 2001, FEDEMA 1999, APEIS IEA 2004, Mirasgedis, *et al*., 2004, Defra 2006, Szlavik and Ürge-Vorsatz 1999) assessing the costs of GHG mitigation in buildings worldwide attests that there is considerable potential for low-cost energy-efficiency improvements in buildings. Up to 62% of the GHG emissions in the buildings of developing countries and economies in transition studied, and up to 25% of those in developed countries, can be captured at *negative cost.*[14]

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[12] Where not specified in the following text, a 2020 target year is considered, and percentage figures refer to potential expressed as the share of GHG emissions in the building stock.

[13] For definitions of technical, economic, market, and enhanced market potential, see Chapter 2 Section 2.1.24.

[14] 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,

If measures with costs up to US$20/t$CO_2$ eq. are considered, some developing countries and economies in transition may eliminate between 17% and 66% of their emissions in this sector; the range of potential that can be tapped at this cost in developed countries is 21-28%. Table 11.3.2 in Chapter 11 provides more detailed information on the GHG abatement potentials in buildings as a function of costs and world regions. It attests that the majority of the abatement potential in buildings as assessed by a large number of studies were identified in the net negative cost category. The table also demonstrates that measures to save electricity in buildings typically offer larger and cheaper options to abate CO_2 emissions than measures related to fuel savings. This is especially true for developing countries located in warmer regions, which have less need for space and water heating.

6.5.3 Supply curves of conserved carbon dioxide

CO_2 conservation supply curves relate the quantity of CO_2 emissions that can be reduced by certain technological or other measures, to the cost per unit CO_2 savings (Sathaye and Meyers 1995). The measures, or packages of measures, are considered in order of growing marginal CO_2 abatement cost, therefore forming a "supply curve" for the commodity of CO_2 reduction.

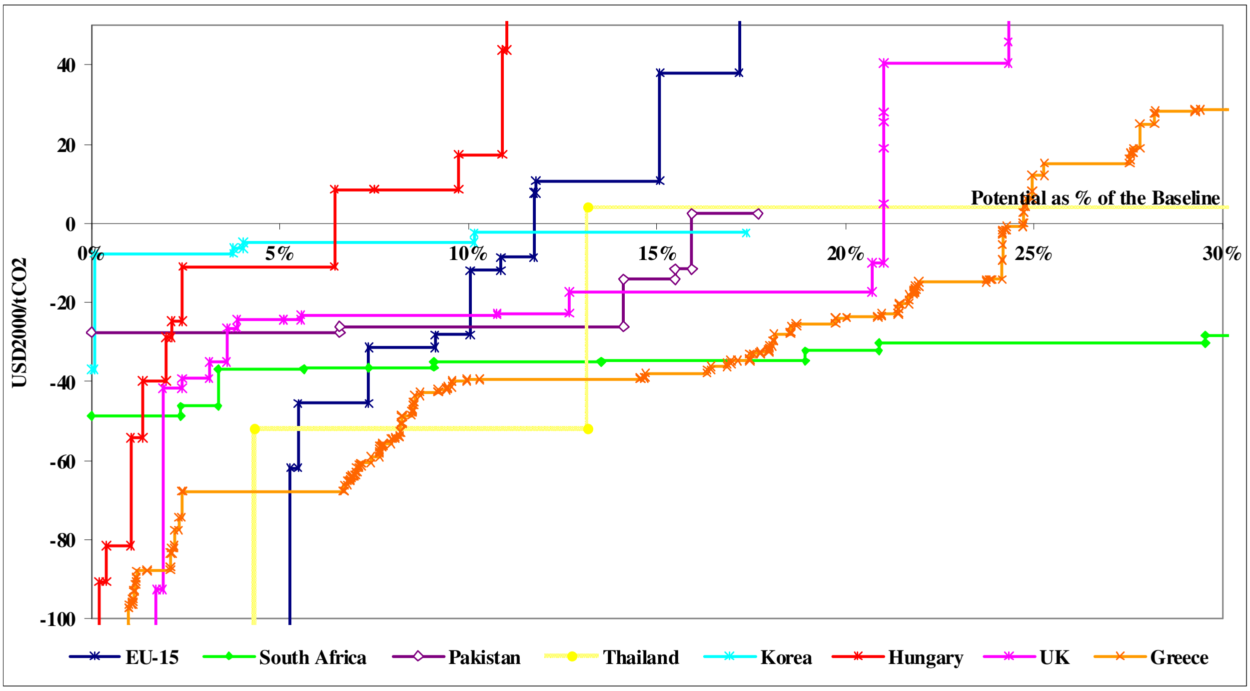

Figure 6.4: *Supply curves of conserved CO_2 for commercial and residential sector in 2020 for different world regions*

* Except for South Africa, United Kingdom, Thailand, and Greece, for which the supply curves are for the residential sector only.

** Except for European Union-15 and Greece, for which the target year is 2010, and Hungary, for which the target year is 2030.

Notes: Each step on the curve represents a type of measure, such as improved lighting or added insulation. The length of a step on the "X" axis shows the abatement potential represented by the measure, while the cost of the measure is indicated by the value of the step on the "Y" axis.

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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).

Sources: Joosen and Blok 2001, ADB 1998, De Villiers and Matibe 2000, De Villiers 2000, ADB1998, ADB 1998, Szlavik and Urge-Vorsatz 1999, DEFRA 2006, Mirasgedis et al. 2004.

Figure 6.4 integrates the findings of eight selected recent studies from different world regions on the potentials for CO_2 abatement as a function of cost. 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 used in the study, the figure attests that opportunities for cost-effective and low-cost CO_2 mitigation in buildings are abundant in each world region. All eight studies covered here identified measures at negative costs. The supply curves of developing countries in focus are characterized with a flat slope and lie, in general, lower than the curves of developed countries. The flat slope justifies the general perception (for instance, which provided the rationale for the Kyoto Flexibility Mechanisms) that there is a higher abundance of "low-hanging fruit" in these countries. More concretely, the net costs of GHG mitigation in buildings in these countries do not grow rapidly even over 30-50% of emissions reductions. For developed countries, the baseline scenario assumes that many of the low-cost opportunities are already captured due to progressive policies in place or in the pipeline.

6.5.4 Most attractive measures in buildings

From a policy-design perspective, it is important to understand which technologies/end-uses entail the lowest unit abatement costs for society, as well as which ones offer the largest abatement potential. This section reviews the most attractive mitigation options in terms of overall potential. Both Figure 6.4 and Table 11.3.2 in Chapter 11 demonstrate that CO_2-saving options are largest from fuel use in developed countries and countries in transition due to their more northern locations and, thus, larger potential for heat-saving measures. Conversely, electricity savings constitute the largest potential in developing countries located in the south, where the majority of emissions in the buildings sector are associated with appliances and cooling. This distribution of the potential also explains the difference in mitigation costs between developing and developed countries. The shift to more efficient appliances quickly pays back, while building shell retrofits and fuel switching delivering approximately a half of the potential in developed countries are more expensive.

While it is impossible to draw universal conclusions regarding individual measures and end-uses, 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 almost all countries. The IEA (2006b) estimates that by 2020, app. 760Mt of CO2 emissions can be abated by the adoption of least life-cycle cost lighting systems globally, at an average cost of USD-161/tCO2. 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) have found heating-related measures to be most cost-effective, including insulation of walls, roofs, windows, and floors, as well 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. Air conditioning savings can be more expensive than other efficiency measures but can still be cost-effective because they tend to displace more expensive peak power.

In terms of the size of savings, improved insulation and district heating in the colder climates and efficiency measures related to space conditioning in the warmer climates come first in almost all studies,[15] along with cook stoves in developing countries. Other measures that rank high in terms of savings potential are solar water heating, efficient lighting, and efficient appliances, as well as building energy management systems.

6.5.5 Energy and cost savings through use of the Integrated Design Process (IDP)

Despite the usefulness of supply curves for policy-making, the methods used to create them rarely consider buildings as integrated systems; instead, they focus on the energy savings potential 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. This suggests that studies relying solely on component estimates may *underestimate* the abatement *potential* or *overestimate* the *costs*, compared with a systems approach to building energy efficiency. Recent published analyses show that, with an integrated approach, (i) the cost of saving energy can go down as the amount of energy saved goes up, and (ii) highly energy-efficient buildings can cost less than buildings built according to standard practice.

6.6 Co-Benefits of Greenhouse Gas Mitigation in the Residential and Commercial Sectors

Co-benefits of mitigation policies are an important decision element for decision makers in the residential sector, but also in the commercial one. Although these co-benefits are often not 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

Climate mitigation through energy efficiency in the residential and commercial sectors will improve local and regional air quality, particularly in large cities, contributing to improved public health (e.g., increased life expectancy, reduced emergency room visits, reduced asthma attacks, fewer lost work days) and avoidance of structural damage to buildings and public works. Beyond the general synergies between improved air quality and climate change mitigation described in Chapter 11 (see 11.8.1), some of the most important co-benefits in the households of developing countries are due to reduced indoor air pollution through certain mitigation measures (Staff Mestl, *et al*., 2005). These benefits are detailed further in sections 6.6.2 and 6.9.1.

6.6.2 Improved health, quality of life, and comfort

In the least developed countries, one of the most important opportunities for achieving GHG mitigation as well as sustainable development in buildings is to focus on the health-related benefits of clean domestic energy services, including safe cooking. Indoor air pollution is a key

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

environmental and public health peril for countless of the world's poorest, most vulnerable people. Approximately 3 billion people worldwide rely on biomass (wood, charcoal, crop residues, and dung) and coal to meet their household cooking and heating energy needs (ITDG 2002). Smoke from burning these fuels contributes to acute respiratory infections in young children and chronic obstructive pulmonary disease in adults that are responsible for nearly all of the 2.2 million deaths attributable to indoor air pollution each year, over 98% of which are in developing countries (Gopalan and Saksena, 1999, UN 2002, Smith, *et al*., 2004). (See Box 6.1). In addition, women and children also bear the brunt of the work of collecting biomass fuel. Clean-burning cookstoves not only save substantial amounts of GHG emissions, but also prevent many of these health problems, and provide many other benefits identified in Box 6.1.

Box 6.1: *Traditional biomass-based cooking has severe health effects on children and women (UN, 2002)*

In South Africa, children living in homes with wood stoves are almost five times more likely than others to develop respiratory infections severe enough to require hospitalization. In Tanzania, children younger than five years who die of acute respiratory infection are three times more likely to have been sleeping in a room with an open cookstove than healthy children. In the Gambia, children carried on their mothers' backs as they cook over smoky stoves contract pneumonia at a rate 2.5 times higher than unexposed children. In Colombia, women exposed to smoke during cooking are over three times more likely than others to suffer from chronic lung disease. In Mexico, urban women who use coal for cooking and heating over many years are subject to a risk of lung cancer two to six times higher than women who use gas. Rural coal smoke exposure can increase lung cancer risks by a factor of nine or more. In India, smoke exposure has been associated with a 50 percent increase in stillbirths.

Cleaner-burning improved cook stoves (ICS), outlined in the previous sections of this chapter, help address many of the problems associated with traditional cooking methods. The benefits derived from ICS are: 1) reduced health risks for women and children due to improved indoor air quality; 2) reduced risks associated with fuel collection; 3) cost-effective and efficient energy use, which eases the pressure on the natural biomass resource; 4) a reduction in the amount of money spent on fuel in urban areas; and 5) a reduction in fuel collection and cooking time, which translates into an increase in time available for other economic and developmental activities.

In developed countries, the diffusion of new technologies for energy use and/or savings in residential and commercial buildings contributes to an improved quality of life and increases the value of buildings. Jakob (2006) lists examples of this type of co-benefit, such as improved thermal comfort (fewer cold surfaces such as windows), and 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 or more (Jochem and Madlener, 2003). In addition, better-insulated buildings eliminate moisture problems associated with, for example, thermal bridges and damp basements, and thus reduce the risk of mould build-up and associated health risks.

6.6.3 Improved productivity and economic competitiveness

There is increasing evidence that well designed, energy efficient buildings often have the co-benefits of having better productivity and occupant health (Fisk, (2000) and (2002), Leaman and Bordass (1999)). Assessing these productivity gains is difficult (CIBSE (1999)) but in a study of 16 buildings in the UK occupants assessed their productivity was influenced by the environment by between -10% to +11% (Leaman and Bordass, (2001).

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. 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). For commercial office buildings that use 10-30% 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 value to shareholders; 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).

6.6.4 Employment creation and new business opportunities

Most studies agree that energy-efficiency investments will have positive effects on employment, by creating new business opportunities and thus jobs via domestically produced energy-efficient technologies and services, and through the economic multiplier effects of 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 the use of energy-efficient technologies helps all sectors of the country to compete internationally, thus contributing to economic development and job creation.

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 energy service company (ESCO) industry revenues in section 6.8.3.4 demonstrate that the energy services business appears to be both a very promising and a quickly growing trade worldwide.

The European Commission (2005) estimates that a 20% reduction in EU energy consumption 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 regional and rural development benefits and contribute to social cohesion because of the decentralized nature of energy-efficiency actions.

6.6.5 Improved social welfare and poverty alleviation

Improving residential energy efficiency 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). 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. The removal of subsidies, 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.*, 2006). 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). In economies in transition, this situation provides an opportunity to redirect social programs that are aimed at compensating for increasing fuel tariffs towards energy-efficiency efforts. In this way resources can be 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).

Fuel poverty, or the inability to afford basic energy services to meet minimal needs or comfort standards, is also found in even the wealthiest countries. In the UK in 1996, about 20% of all households were estimated to live in fuel poverty. The number of annual excess winter deaths, estimated by the UK department of Health at around 30,000, can largely be attributed to inadequate heating (DoH, 2000, Boardman, 1991). Improving energy efficiency in these homes is a major component of strategies to eradicate fuel poverty.

In developing countries, energy-efficient household equipment and low-energy building design can contribute to poverty alleviation through minimizing energy expenditures, therefore making more energy services affordable for constrained incomes (Goldemberg 2000). Clean and efficient utilization of locally available renewable energy sources reduces or replaces the need for energy and fuel purchases, increasing the access to energy services. Therefore, sustainable development strategies aimed at improving social welfare go hand-in-hand with energy efficiency and renewable energy development.

6.6.6 Summary of co-benefits

Additional co-benefits of building-level GHG mitigation through improved energy efficiency and building-integrated distributed generation include improved energy security and system reliability (IEA, 2004), discussed in more detail in Chapter 4. Improving end-use energy efficiency is among the top priorities on the European Commission's agenda to increase energy security, with the recognition that energy efficiency is likely to generate additional macroeconomic benefits because reduced energy imports will improve the trade balances of importing countries (European Commission, 2003).

In summary, investments in residential and commercial building energy efficiency and renewable energy technologies can yield a wide spectrum of benefits well beyond the value of saved energy and reduced GHG emissions. 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 levels 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, health, environment, social welfare, poverty alleviation, and energy security, can provide 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). In developing countries, residential and commercial-sector energy efficiency, and modern technologies to utilize locally available renewable energy forms, can form essential components of sustainable development strategies.

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 and businesses, why are these opportunities not pursued? 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 operation, as well as in the purchase and use of appliances. The Carbon Trust (2005) suggests a classification of these barriers into four main categories: financial costs/benefits; hidden costs/benefits; real market failures; and behavioural/organizational non-optimalities. Table 6.4 gives characteristic examples of barriers that fall into these four main categories. The most important among them that pertain to buildings are discussed below in further detail.

Table 6.4: *Taxonomy of barriers that hinder the penetration of energy efficient technologies/practices in the buildings sector. Based on Carbon Trust (2005)*

Barrier categories	Definition	Examples
Financial costs/benefits	Ratio of investment cost to value of energy savings	Higher up-front costs for more efficient equipment Lack of access to financing Energy subsidies Environmental and health damage and other external costs
Hidden costs/benefits	Cost or risks (real or perceived) that are not captured directly in financial flows	Costs and risks due to potential incompatibilities, performance risks, transaction costs etc. Poor power quality, particularly in some developing countries
Market failures	Market structures and constraints that prevent the consistent trade-off between specific energy-efficient investment and the energy saving benefits	Limitations of the typical building design process Fragmented market structure Landlord/tenant split and misplaced incentives Administrative and regulatory barriers (e.g. in the incorporation of distributed generation technologies) Imperfect information
Behavioural and organizational non-optimalities	Behavioural characteristics of individuals and organizational characteristics of companies that hinder energy efficiency technologies and practices	Tendency to ignore small opportunities for energy conservation Organizational failures (e.g. internal split incentives) Non-payment and electricity theft Tradition, behaviour and lifestyle Corruption

6.7.1 Limitations of the traditional building design process and fragmented market structure

One of the most significant barriers to energy-efficient building design is that buildings are complex systems. While the typical design process is linear and sequential, minimizing energy use requires optimizing the system as a whole by systematically addressing building form, orientation, envelope, glazing area, and a host of interaction and control 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.

Compounding the flaws in the typical design process is fragmentation in the building industry as a whole. 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. As an example, the design of large commercial buildings typically involves architects for the building envelope (roof, walls, and foundation); mechanical and electrical engineers for the HVAC systems and controls; and lighting designers or lighting contractors 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); while the EPB Directive in the EU brings engineers in at early stages of the design process through its performance-based approach.

6.7.2 Misplaced incentives

When intermediaries are involved in decisions to purchase energy-using or 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 often 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. For example, in residential buildings, landlords often provide the AC equipment and major appliances, while the tenant pays the electricity bill. As a result, the landlord is not likely to invest in energy efficiency, since he is not the one rewarded for the investment.

Misplaced incentives can also be caused by fragmented organizational structures in institutions, where agents responsible for investment decisions are different from those benefiting from the energy savings. For example, 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. Similarly, in many countries, the energy bills and other operating expenses of hospitals 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.

Finally, the prevailing selection criteria and fee structures for building designers may emphasize initial costs over life-cycle costs (Jones, *et al.*, 2002; Lovins, 1992). This tends to hinder energy efficiency because initial capital costs are typically higher for high-efficiency building systems (e.g., HVAC or lighting), even though subsequent operating costs are lower and the return on investment very attractive.

6.7.3 Energy subsidies, non-payment, and theft

In many countries, electricity historically has been subsidized to residential customers (and sometimes to commercial or government customers as well), creating a disincentive for energy efficiency. This is particularly the case in many developing countries, and historically in Eastern Europe and the former Soviet Union-e.g., widespread fuel poverty in Russia has driven the government to subsidize energy costs (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 these three countries, while industrial consumers were 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-Kashmir), while in Lebanon 25 percent of the electricity supplied by the country's electric utility has been reported 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. In the United States, it has been estimated to cost utilities billions of dollars each year (Suriyamongkol, 2002). The failure of recipients to pay in full for energy services tends to induce waste and discourage energy efficiency.

6.7.4 Regulatory barriers

A range of regulatory barriers has been shown to stand in the way of building-level distributed generation technologies such as PV, 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 metering policies cause confusion in the marketplace and represent barriers to distributed generation.

Net metering, an option to overcome barriers caused by variations in metering policies, 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 for PV power and other on-site power production (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2003).

6.7.5 Small project size, transaction costs, and perceived risk

Many energy-efficiency projects and ventures in buildings are too small to attract the attention of investors and financial institutions. Small project size, coupled with disproportionately high transaction costs-i.e., costs related to verifying technical information, preparing viable projects, and negotiating and executing contracts-prevent energy-efficiency investments. Conservative, asset-based lending practices of financial institutions, a limited understanding of energy-efficiency technologies on the part of both lenders and their consumers, lack of traditions in energy performance contracting, 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 (Westling, 2003; Bertoldi and Rezessy, 2005; Vine, 2005). High transaction costs and relatively small project size also help explain why energy-efficiency investments in buildings have not benefited from the project-based mechanisms of the Kyoto Protocol-i.e., Joint Implementation and the Clean Development Mechanism (CDM)-despite the potential benefits these mechanisms could provide to developing countries and economies in transition. As discussed in Section 6.8 below, policies can be adopted that can help reduce these transaction costs, thus improving the economics and financing options for energy-efficiency investments.

6.7.6 Imperfect information

Information about energy-efficiency options is often incomplete, unavailable, expensive, and difficult to obtain or trust. In addition, few small enterprises in the building industry have access to sufficient training in new technologies, new standards, new regulations, and best practices. A similar situation exists for building officers in local authorities. 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 their benefits are often not directly observable. For example, households typically receive an electricity bill that provides no breakdown of individual end uses, making it difficult to assess the benefits of efficient appliances or additional thermal insulation. Infrequent meter readings (e.g., once a year, as is typical in many EU countries) provide insufficient feedback to consumers on their energy use and on the potential impact of their efficiency investments. This situation contributes to making energy savings "invisible," and makes energy-use patterns and load profiles hard to understand and to link to energy bill savings.

Trading off energy savings for 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's Directive on the Energy Performance of Buildings (2002/91/EC, see Box 6.2) 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.

6.7.7 Culture, behavior, lifestyle, and the rebound effect

Policies aimed at GHG mitigation focus, to a large extent, on the availability and uptake of technologies that can reduce emissions. However, energy use, and the resulting CO_2 emissions, are bound up in a complex mixture of technologies, infrastructure, individual behaviour, social traditions, and environmental conditions (Shove 2003). Despite globalization and the broad availability of similar energy-using equipment worldwide, patterns of energy use vary greatly across countries. Variation across countries in quantity of energy used per capita-which is large, both at economy and household levels (IEA 1997)-can only partly be explained by weather and wealth. Even in identical houses with the same number of residents, energy consumption has been shown to differ by a factor of two or more (Socolow 1978). These variations, among countries and within countries, among individuals, give some indication of how much energy might be used to support an individual. Cross-country comparisons illustrate some of the potential impacts of lifestyle choices. 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 greatly by country (Chappells and Shove, 2004; IEA, 1997).

From the perspective of social sciences of consumption, two points stand out related to climate change mitigation in buildings. First, human behavior is more than random noise around levels of consumption otherwise determined by technological choices. Studies of formal information, education, and energy consumption feedback programs designed to promote energy savings (McCalley 2006, Shove 2003, Ueno, *et al*., 2006), and the demonstrated successes of some campaigns to save energy in the short term (Bender, et *al.,* 2004, IEA 2005), indicate that behavioral choices have strong systematic effects even under relatively fixed technological conditions. Second, technological choices are sociological as well. Traditionally, policy attention has been market-oriented, focusing on influencing purchase and design choices. Even more influential than these one-time investment decisions, however, are what happens *outside* of formal decision points-leading up to them, shaping them, and after they are taken. These issues encompass how needs are created and how they are fulfilled, collectively resulting in what is termed “societal energy efficiency.” Studies aiming at understanding these issues suggest that retaining and supporting lower-consuming lifestyles may be more effective in constraining GHG emissions than introducing energy-saving behaviors and technologies at the margin (e.g., EEA 2001). These observations do not imply that policy must restrict choices of this sort; there are civil liberties and economic development issues at stake.

The “rebound effect” (when increased energy efficiency is accompanied by increased demand for energy services)-although its importance is debated (Herring 2005)-also points to the potential importance of socially and economically introduced changes that can keep technology-driven energy efficiency from achieving its potential reductions in energy consumption and GHG emissions (Moezzi and Diamond 2005). The better we understand the complex interactions between technologies and human practices, the higher the potential for effective GHG emissions mitigation (Jelsma 2004, Nevius and Pigg 2000), and the more we can design and implement targeted and efficient policies to reduce GHG emissions in buildings.

6.7.8 Limited access to capital and financing

The limited availability of capital as well as limited access of low-income households and small businesses to capital markets also hinders the penetration of energy-efficient technologies in the buildings sector in many countries. Developing countries, in particular, lack the financing to adopt building technologies and practices that reduce GHG emissions (Reddy 2001). Limited availability of capital restricts not only deployment and diffusion but also the development of innovative building technologies. This situation is worsened by a drop in development assistance to developing countries; as a result, 70% of foreign direct investment (FDI)-the largest component of external financing to developing countries- invested in only 10 countries (Heller and Shukla, 2003).

6.7.9 Other barriers

Due to space limitations, not all barriers to energy efficiency identified in Table 6.4 can be detailed here. Other important barriers in the buildings sector include the limited availability of energy-efficient equipment along the retail chain (Brown, Berry, and Goel, 1991); the case of poor power supply in some developing countries interfering with the operation of the electronics needed for energy-efficient end-use devices (EAP UNDP, 2000); and the inadequate levels of energy services-e.g., insufficient illumination levels in schools, or unsafe wiring-in many public buildings in developing countries and economies in transition. This latter problem can severely limit the cost-effectiveness of efficiency investments, since 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.

As this discussion demonstrates, the barriers to reducing energy use and GHG emissions are especially numerous and significant in the buildings sector.

6.8 Policies to Promote GHG Mitigation in Buildings

Preceding sections have demonstrated the high potential for reducing GHG emissions in buildings through cost-effective energy-efficiency measures and distributed (renewable) energy generation technologies. The previous section has demonstrated that even the cost-effective part of the potential is unlikely to be captured by markets due to the high number of barriers. Although there is no quantitative or qualitative evidence in the literature, it is possible that barriers to the implementation of economically attractive GHG reduction measures are the most numerous and strongest in the buildings sector, especially in households. Since policies can reduce or eliminate barriers and associated transaction costs (Brown 2001), streamlined regulation targeted at removing the barriers in the buildings sector may be especially warranted for GHG mitigation efforts.

Table 6.5 reviews the key policy instruments presently applied or planned for fostering energy efficiency and renewable energy utilization in buildings. The first column identifies the key policy instruments grouped by four major categories using a typology synthesized from several sources (including Crossley, *et al.,* (2000), (Verbruggen, 2003), Vine, *et al.,* (2003), Grubb (1991), and IEA (1997)): (i) control and regulatory mechanisms, (ii) economic and market-based instruments, (iii) financial instruments and incentives, and (iv) support and information programs and voluntary action. Sections 6.8.1-6.8.5 describe a selection of the major instruments summarized in the table that complement the more general discussion of Chapter 13, with a focus on policy tools specific to or specially applied for buildings. The rest of Table 6.5 is discussed in section 6.8.5.

Table 6.5: *The impact and effectiveness of various policy instruments aimed to mitigate GHG emission in the buildings sector*

Policy [16]instrument	Examples of countries[17]	Effectiveness	Energy or emission reductions for selected best practices	Cost-effectiveness	Cost of GHG emission reduction for selected best practices18	Impact on sustained innovation	Special conditions for success, major strengths and limitations, co-benefits	References
Control and regulatory mechanisms								
Appliance standards	EU, US, JP, AUS, Br	High	Br: 78 M tCO_2[19] in 1998; De: app. 90 K tCO_2 per year in 1995-2000	High	US: - 83$/$tCO_2$[20]; AUS: -15$/tCO_2 in 2012, US: -65$/$tCO_2$ in 2020; EU: -194$/$tCO_2$ in 2020	High	Factors for success: periodical update of standards, independent control, information, communication and education	IEA 2005, Schlomann et al. 2001, Gillingham et al 2004, ECS 2002, WEC 2002, NAEEEP 2005, IEA 2003
Building codes	SG, Phil, Alg, Egypt, US, UK, Hong Kong, EU	High	HkG: 1% of total electricity saved; US: 88 M tCO_2 in 2000; EU: up to 60% energy savings for new dwellings	Medium/ High	NL: from -189$/$tCO_2$ to -5$/$tCO_2$ for end-users, 46-109$/$tCO_2$ for society	Medium	No incentive to improve beyond target. Only effective if enforced	WEC 2002, Lee/Yik 2004, Schaefer 2000, Joosen et al. 2004, Geller 2006.
Procurement regulations	US, EU, Cn, Mex, Kor, Jp	High	Mex: After 1 year, 4 municipalities saved 3.3 $ktCO_2$ eq.	Medium	Mex: $1M in purchases saves $726,000/year in 4 municipalities; EU: <21$/$tCO_2$	High	Factors for success: Enabling legislation, en-ef labelling and testing. En-ef specifications need to be ambitious.	Borg & Co. 2003; Harris et al. 2005; Van Wie McGrory et al. 2006.
Energy efficiency obligations and quotas	UK, Be, Fr, I, Dk, Ir	High	UK: 1.4 M tCO_2/yr	High	Flanders: -216$/$tCO_2$ for households, -60$/$tCO_2$ for other sector in 2003. UK: -139 $ /tCO_2	High	Continuous improvements neces-sary: new EE measures, savings change, short term incentives to transform markets etc.	UK government 2006, Sorell 2003 Eoin Lees 2006, Collys 2005, Bertoldi Rezessy2006, Defra 2006
Demand-side management programs	US, Sw, Dk, Nl, De, Aut	High	El. savings for US 60 GWhr/yr ~ 15 Mt CO_2/yr	High	Average costs app. -35$/$tCO_2$	High	DSM programmes for commercial sector tend to be more cost-effective than those for residences.	IEA, 2005; Kushler et al 2004

16 For definitions of the instruments see: Crossley et al. (1999), Crossley et al. (2000), EFA (2002), Vine et al. (2003), Thomas et al. (2001) and Wuppertal institute (2002).

17 Selected best practices from countries listed in bold are used for the detailed examples in the following columns. Where possible developing countries were listed.

18 Energy savings were recalculated into emission savings using the following references for the emission factors: Davis (2003), UNEP (2000), Center for Clean Air Policy (2001).

19 Emission Factor 48tCO_2/GWh (Center for Clean Air Policy 2001)

20 Emission Factor 0.556, electricity price 0.05$/kWh.

Economic and market-based instruments								
Energy performance contracting	De, Aut, Fr, Swe, Fi, US, Jp, Hu	High	Fr, S, US, Fi: 20-40% of building's energy saved; US: 3.2 $MtCO_2$/yr	Medium	EU: <22$/$tCO_2$; US: 17 $/$tCO_2$	Medium/ High	Strength: no need for public spending or market intervention, co-benefit of improved competitiveness.	ECCP 2003, OPET network 2004, Singer 2002, IEA 2002, WEC 2002
Co-operative procurement	De, It, UK, Swe, Aut, Ir, Jp, UK, Pol, Sk, Sw	High	Varies, German Telekom: up to 60% energy savings for specific units	High	0: Energy-efficient purchasing relies on funds that would have been spent anyway.	High	Success condition: energy efficiency needs to be prioritized in purchasing decisions	Oak Ridge National Lab, Le Fur B. 2002, Borg & Co. 2003
Energy efficiency certificate schemes	It, Fr (proposed), UK (As white certificate)	High	UK: 1.4$MtCO_2$/yr	High	Fr: expected cost <20€/MWh; UK:-139 $/$tCO_2$	Low/ Medium	No long-term experience. Transaction costs can be high. Adv. institutional structures needed. Profound interactions with existing policies. Benefits for employment.	OPET network 2004, Bertoldi/Rezessy 2006, Eoin Lees 2006, Defra 2006
Kyoto Protocol flexible mechanisms	Cn, Tha, CEE (JI &AIJ)	Medium	CEE: 220 K tCO_2 in 2000	Medium	63 $/$tCO_2$	Low/High (innovation/ techn. transfer)	So far limited number of CDM &JI projects in buildings	ECS 2005; Novikova, Urge-Vorsatz and Liang. Forthcoming
Fiscal instruments and incentives								
Taxation (on CO_2 or household fuels)	Nor, De UK, NL, Dk, Sw	Generally low	De: household consumption reduced by 0.9 %	Medium		medium	Effect depends on price elasticity. Revenues can be earmarked for further efficiency. More effective when combined with other tools.	WEC 2002,Kohlhaas 2005
Tax exemptions/ reductions	US, Fr, Nl, Kor	Medium	US: Com. Bldgs: 968 M tCO_2. New homes 339 M tCO_2	High	Overall B/C ratio - Commercial buildings: 5.4 - New homes: 1.6	Low/High	If properly structured, stimulate introduction of highly efficient equipment and new buildings.	Quinlan et al 2001, Geller and Attali 2005
Public benefit charges	BE, Dk, Fr, Nl, US states	Medium/hi gh	US: 0.1-0.8% of total el. sales saved/yr, av. of 0.4%, 592 tCO_2 savings in 8 states	High in reported cases	From -53$/$tCO_2$ to -17$/$tCO_2$	medium		Western Regional Air Partnership, Kushler et al 2004
Capital subsidies, grants, subsidised loans	Jp, Svn, NL, De, Sw, US, HgK, UK	Medium/hi gh	Svn: 3 programs for residences pre-1970: en. savings of up to 24% for buildings	Medium/H igh	NL: 41-105$/$tCO_2$ for society, -214- -140$/$tCO_2$ for end-user	High	Positive for low-income households, risk of free-riders, may induce pioneering investments	Energy Charter Secret 2002, Martin Y. 1998, Schaefer 2002, Geller 2006, Joosen 2004.

Support, information and voluntary action								
Mandatory labelling and certification programs	US, CAN, AUS, Jp, Mex, Cn, Cr, EU	High	US: 5 M tCO_2 savings 1992-2000	High	-30$/t CO_2 abated	High	Effectiveness can be boosted by combination with other instrument, and regular updates.	WEC 2002, OPET network 2004, Holt/Harrington 2003
Voluntary certification and labelling	De, Sw, US, Tha, Br	Medium/ high	Br: 254 K tCO_2 in 1998	High	Br: 20 $ Million saved	Medium/ low	Little use for existing bdgs. Effective with financial incentives, voluntary agreements and regulations	OPET network 2004, WEC 2002, Geller 2006, Egan et al. 2000
Voluntary and negotiated agreements	Mainly Western Europe, Jp, US	Medium	US: CO_2 emissions reduced by 24 tCO_2 eq. per year	Medium	UK: 54.5-104$/t$CO_2$	Low	Can be effective when regulations are difficult to enforce. Effective if combined with financial incentives, and threat of regulation	Geller 2006, Cotrell 2004: 45
Public leadership programs	NZL, Mex, US, Phil, Arg, Br, Ecur	High	De: 25% public sector CO_2 reduction over 15 years	High	US DOE/FEMP estimates $4 savings for every $1 of public funds invested	Medium to high	Can be used to demonstrate new technologies and practices. Mandatory programs have higher potential than voluntary ones.	Borg & Co. 2003; Harris et al. 2005; Van Wie McGrory et al. 2006, OPET 2004
Awareness raising, education, information campaigns	Dk, US, UK, CAN, Brl, Jp	Medium/High	UK: Energy Efficiency Advice Centers: 10.4 K tCO_2 annually	High	Br: -66$/t$CO_2$; UK: 8$/tCO_2 (for all programs of Energy Trust)	Medium to high	More applicable in residential sector than commercial.	Bender et al. 2004; Dias et al. 2004, Darby 2006; IEA 2005; Lutzenhiser 1993; Ueno et al. 2006, Energy Trust 2005
Mandatory audit and energy mgmt requirement	US; Fr, NZL, Egy, AUS, Cz	High, but variable	High	Medium	US: Weatherization program: 22% saved in weatherized households	Medium .	Most effective if combined with other measures such as financial incentives	WEC 2002
Detailed billing and disclosure programs	Ontario, It Swe, Fin, Jp, Nor, Aus, Cal, Can	Medium	Up to 25% energy savings	Medium		Medium-low	Success conditions: combination with other measures and periodic evaluation. Comparability with other households is positive.	IEA DSM task 2000, Darby 2000, Roberts/Baker 2003, Energywatch 2005

Country name abbreviations: Alg - Algeria, Arg- Argentina, AUS - Australia, Aut - Austria, Be - Belgium, Br - Brazil, Cal - California, Can - Canada, CEE - Central and Eastern Europe, Cn - China, Cr - Costa Rica, Cz - Czech Republic, De - Germany, Ecu - Ecuador, Egy - Egypt, EU - European Union, , Fin - Finland, GB-Great Britain, Hkg - Hong Kong, Hu - Hungary, Ind - India, Irl - Ireland, It - Italy, JP - Japan, Kor - Korea (South), Mex - Mexiko, NL - Netherlands, Nor - Norway, Nzl - New Zealand, Phil - Philippines, Pol - Poland, SG - Singapore, Sk - Slovakia, Svn - Slovenia, Sw - Switzerland, Swe - Sweden, Tha - Thailand, US - United States, Nga - Nigeria.

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

6.8.1.1 Building codes

Building regulations originally addressed questions related to safety and the protection of occupants. Oil price shocks in the 1970s led most OECD countries to extend their regulations to include energy efficiency. 19 out of 20 OECD countries surveyed have such energy standards and regulations, although coverage varies among countries (OECD, 2003).

Building energy codes may be classified as follows: 1) Overall performance-based codes that require compliance with an annual energy consumption level 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, and minimum boiler efficiency. There are also examples of codes addressing electricity demand. Several cantons in Switzerland require specific installed electric loads for lighting ventilation and cooling in new commercial buildings (SIA, 2006); and 3) A combination of an overall performance requirement plus some component performance requirements, such as wall insulation and maximum window area.

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

Prescriptive codes often are easier to enforce than performance-based codes (Australian Greenhouse Office, 2000; City of Fort Collins, 2002; Smith, 2001; U.S. Department of Energy, 2001). However, there is a clear trend in many countries toward performance-based codes that address the overall energy consumption of the buildings. This trend reflects the fact that performance-based policies allow optimisation of integrated design and leave room for creativity of designers and innovative technologies. However, successful implementation of performance-based codes requires education and training-of both building officials and inspectors-and demonstration projects showing that the building code can be achieved without much additional cost and without technical problems (Ecofys, 2006). New information and communication technology (ICT) based design and education tools, including continuous e-learning tools, are examples of tools that can provide good design techniques, continuous learning by professionals, easier inspection methods, and virtual testing of new technologies for construction and building systems.

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 2003 (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. In some countries, the codes may even prohibit the use of certain technologies-e.g., Sweden's prohibition of direct electric resistance heating systems, which has led to the rapid introduction of heat pumps in the last five years.

According to the OECD (OECD, 2003), there is still much room for further upgrading building energy-efficiency codes throughout the OECD member countries. To remain effective, these codes have to be regularly upgraded as technologies improve and costs of energy-efficient features and equipment decline. Setting flexible (e.g., performance-based) codes can help keep compliance costs low and may provide more incentives for innovation.

Box 6.2: *The European Directive on the 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 *common methods for calculating the integrated energy performance of buildings*. This approach includes consideration of 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 methods 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 requirement is a very important action, since 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; it is one of the few policies worldwide to target existing buildings. The third action is to set up *certification schemes for new and existing buildings* (both residential and non-residential) on the basis of the above-mentioned procedures, 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 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.

The European Climate Change Programme (ECCP 2001) estimated that CO_2 emissions to be tapped by implementation of the European Union Directive on the Energy Performance of Buildings by 2010 are 35-45 million tCO_2 eq. at costs below 20 EUR/tCO_2 eq., which is 16-20% of the total cost-effective potential associated with buildings at these costs in 2010. If the costs at 20-100 EUR/tCO_2 are accepted, the Directive is expected to deliver an additional 6 million tCO_2 eq. in 2010.

6.8.1.2 Building certification and labelling 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 and buyer, or between the owner and tenant. Certification and labeling schemes can be either mandatory or voluntary.

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*). The voluntary Energy Star Buildings label in the US and the NF-MI voluntary certificate for houses in France have proven to be effective in ensuring compliance with energy code requirements and sometimes higher performance levels (Hicks, 2000). Switzerland has developed the "Minergie" label for new buildings that have a 50% lower energy demand than buildings fulfilling the mandatory requirements; such buildings typically require roughly 6% additional investment costs (OPET Network, 2004). Several local governments in Japan apply the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) (IBEC, 2006). The Australian town of Canberra (ACT) has a requirement for all houses to be energy-efficiency rated on sale. The impact on the market has been to place a financial value on energy efficiency through a well-informed market place (ACT, 2006).

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, and practicing holistic education, as in Japan.

The education of end-users and raising their awareness about energy-efficiency opportunities is also important. Good explanation (e.g., user-friendly manuals) is often a condition for proper installation and functioning of energy-efficient buildings and components. Since optimal operation and regular maintenance are often as important as the technological efficiency in determining overall energy consumption of equipment, accessible information and awareness raising about these issues during and after purchase are necessary. This need for widespread education is beginning to be reflected in the curricula of some countries: Japan's and Germany's schools increasingly teach the importance of energy savings (ECCJ, 2006, Hamburger-bildungsserver, 2006).

6.8.1.4 Energy audit programs

Energy audit programs assist consumers in identifying opportunities for upgrading the energy efficiency of buildings. Occasionally with financial support from government or utility companies, these programs may 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). The implementation of the audit recommendations 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; Ürge-Vorsatz, 2003). In India, all large commercial buildings have to conduct an energy audit at specified intervals of time (Energy Conservation Act 2001). The EU Directive mandates audits and the display of the resulting certificate in an increasing number of situations (see Box 6.2).

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

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 simpler installation and maintenance. Thus, the barriers to energy-efficient alternatives are also different, to some extent, for appliances, warranting a different policy approach. This section provides an overview of policies specific to appliances, lighting, and plug-in equipment.

Box 6.3: *Global efforts to combat unneeded standby and low-power mode consumption in appliances*

Standby and low-power-mode (LoPoMo) electricity consumption of appliances is growing dramatically worldwide, while technologies exist that can eliminate or reduce a significant share of related emissions. The IEA (2002) estimated that standby power and LoPoMo waste may account for as much as 1% of global CO_2 emissions, and 2.2% of OECD electricity consumption. Lebot, *et al.*, (2000) estimated that the total standby power consumption in an average household could be reduced by 72%, which would result in emission reductions of 49 million tCO_2 in the OECD. Various instruments-including minimum energy efficiency performance standards (MEPS), labeling, voluntary agreements, quality marks, incentives, tax rebates, and energy-efficient procurement policies-are applied globally to reduce the standby consumption in buildings (Commission of the European Communities 1999), but most of them capture only a small share of this potential. The international expert community has been urging a 1-Watt target (IEA 2002). In 2000, the Australian government introduced a "one-watt" plan aimed at reducing the standby power consumption of individual products to less than one watt. To reach this, the National Appliance and Equipment Energy Efficiency Committee has introduced a range of voluntary and mandatory measures to reduce standby-including voluntary labelling, product surveys, MEPS, industry agreements, and mandatory labelling (Australian Greenhouse Office. 2005). As of mid-2006, the only mandatory standard regarding standby losses in the world has been introduced in California (California Energy Commission, 2006).

6.8.2.1 Standards and labelling

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 GHG 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, 2005). Today, S&L programs are among the most cost-effective instruments across the economy to reduce GHG emissions, with typically large negative costs, as demonstrated in the following paragraphs. Products subject to standards or labels cover all end-uses and fuel types, with a focus on appliances; ICT, lighting, heating, and cooling equipment; and other energy-consuming products used in homes and offices, as well as commercial equipment such as motors.

Endorsement labels and comparison labels[21] 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, in order to be effective, labels need to be simple to understand. According to studies evaluating the effectiveness of labels (Thorne, 2002), those that show the annual energy cost savings appear 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, 2003). A downside of the labeling system can be that if standards are not revised from time to time, there is no stimulus to the manufacturers to develop more efficient appliances and the whole market will be able to deliver appliances fitting the highest efficiency class. With time, this might even be counter-productive and efficiency improvement may slow down considerably (Bertoldi et al. 2001). Despite widely divergent approaches, national S&L programs have resulted in significant cost-effective GHG savings, as reported by the following case studies.

The 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 US$1,270 per household of net-present-value savings during the lifetimes of the products affected. Projected annual residential carbon reductions in 2020 due to these appliance standards amount roughly to 9% of projected U.S. residential carbon emissions in 2020 (base case) (Meyers, 2002). In addition, the U.S. ENERGY STAR endorsement label program estimates savings of 13.2 million tCO_2 eq. and US$4.2 billion from the combination of supplier and consumer responses to labeling the 46 product categories covered as of 2004 (EPA 2005), and projects that the program will save 2,1 billion tons of CO_2 by 2010, growing to 5,9 billion tons of CO_2 by 2020 (Webber, *et al.*, 2003). According to the IEA (2003), GHG abatement through appliance standards and labeling will be achieved at a cost of -$65 /$tCO_2$ in North America and -169 €/tCO_2 (i.e., both at substantial *net benefit*) in Europe by 2020.

Japan imposes stringent energy-efficiency standards on equipment through its "Top Runner Program" by distinctly setting the target values based on the most energy-efficient model on the market at the time of the value-setting process. Energy-efficiency values and a rating mark are

[21] 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.

voluntarily displayed in promotional materials so that consumers can consider energy-efficiency when purchasing. In order to accelerate energy savings using the Top Runner approach, the Japanese government is planning to add new items and to regularly strengthen the standards (Murakoshi, 2005).

An evaluation of the impact of the EU appliance-labeling scheme showed a dramatic shift in the efficiency of refrigerators sold in the EU in the first decade of its S&L program, as displayed in Figure 6.5 (Bertoldi, 2000).

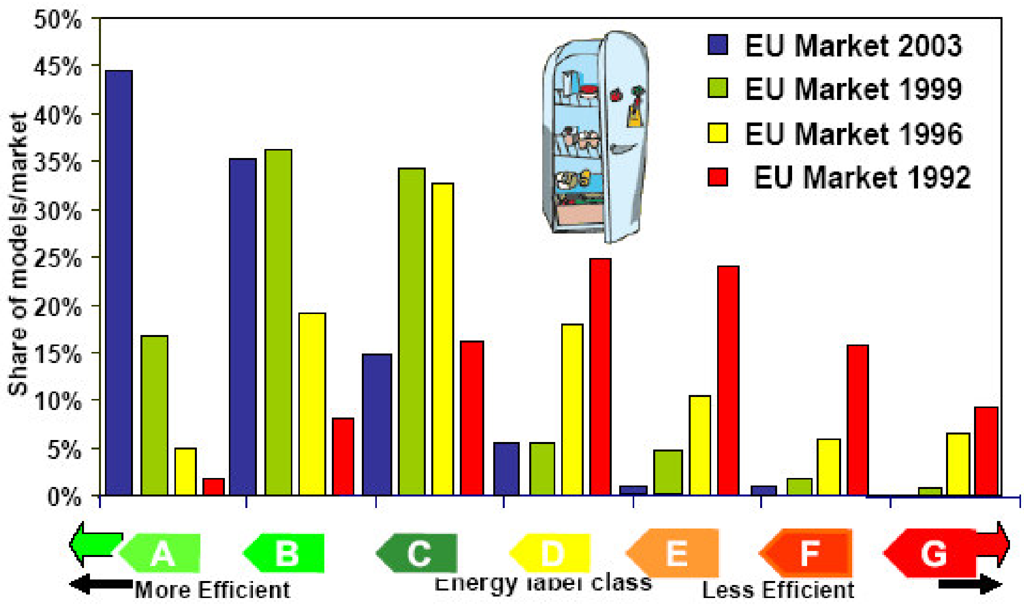

Figure 6.5: *The Impact of the EU Appliance Label on the Market of Cold Appliances.*
Source: Data for 1992-99 are from (IEA, 2003). Data for 2003 are from (Soregaroli, 2003)

A recent IEA report (International Energy Agency, 2003) concludes that, without existing policy measures such as energy labeling, voluntary agreements, and 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, 2004) estimated savings from eight new MEPS 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. 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, 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, 2000). Recently, 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)

In the past few years, strong regional and global S&L efforts have also emerged, offering a 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 IEA (IEA , 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: (i) greater market transparency, (ii) reduced costs for product testing and design, (iii) enhanced prospects for trade and technology transfer, (iv) reduced costs for developing government and utility efficiency programs, and (v) 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, 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 place of, or in conjunction with, mandatory MEPS for equipment to improve the energy efficiency of appliances and equipment. 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 (Rezessy and Bertoldi 2005). Voluntary measures can cover equipment (e.g., cars, electric motors, white goods), industrial processes, and industrial energy management policies and practices (e.g., EU and US programs such as Green Lights). Industry often favors voluntary agreements to avoid the introduction of mandatory standards (Bertoldi, *et al.,* 1999). For the public authorities, voluntary agreements offer a faster approach than mandatory regulation, and are often acceptable if they include the following three elements: (i) commitments by those manufacturers accounting for most of the equipment sold, (ii) quantified commitments to significant improvements in the energy efficiencies of the equipment over a reasonable time-scale, and (iii) an effective monitoring scheme (COM/1999/120). Voluntary agreements are considered especially useful in conjunction with other instruments and if mandatory measures are available as a backup or to encourage industry to deliver the targeted savings.

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 by 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 through the EU's mandatory energy -efficiency standard (COM/1999/120, Jaeger-Waldua, *et al.*, 2004).

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 support energy efficiency and emissions reductions - including effects across other end-use sectors.

6.8.3.1 Utility demand-side management programs

One of the most successful approaches to achieving energy efficiency in buildings has been utility-run demand-side management (DSM) programs. Such programs are implemented on the theory that society benefits when the cost of saving electricity is lower than the cost of building new power plants to supply the electricity. While this is an easy concept to grasp in principle, the creation of utility DSM programs has not been so easy in practice. There are several reasons for this: (1) utilities make profits from selling electricity, not from reducing sales; (2) lower sales combined with costs of implementing DSM produce higher costs of electricity when measured in dollars per kilowatt-hour even if the overall bill is reduced because of lower electricity usage; and (3) utilities are not accustomed to being involved in the customer side of the meter, having expertise in building and maintaining power plants and transmission and distribution lines.

The first of these difficulties can be overcome by regulatory changes in which the utility will receive profits from successful execution of DSM programs. Because electric utilities are regulated to serve the public interest, it is possible to provide substantial incentives to them for DSM programs. The second difficulty relates to distributional issues. Bill-payers who have taken advantage of DSM programs will gain; those who have not will lose. The net for all utility customers will be positive so long as the energy efficiency measures are less expensive than new supply, a condition that has been met easily in the United States where DSM has been used widely. The third is solved over time if the first - utility profitability from the programs - is solved.

The major large-scale experience with utility DSM has been in the United States. It has had an interesting and overall very successful experience. Through the 1980s, utilities resisted DSM for the reasons stated above. As regulatory commissions learned to provide incentives for the programs, DSM programs began in various parts of the United States - primarily the West Coast and New England. It spread, generally slowly, to other parts of the country. Spending on DSM reached a peak of $1.8B in 1993. Spending declined to about half of that level ($900 M in nominal dollars; less in real dollar) by 1998 (York and Kushler, 2005). The primary reason for the decline in spending was the anticipation of restructuring of electric utility markets with the loss of rate recovery from DSM programs. The general view of the industry was that higher prices (per kilowatt hour) would render the utility less competitive in a competitive market. DSM has come back since its low in 1998 to $1.1B in 2000 and $1.35B in 2003 (York and Kushler, 2005). California is more than doubling its expenditure on DSM $700M/year for the next three years, thus assuring that DSM expenditure in the United States will increase substantially.

These programs have had a major impact, even during the years when the investment in DSM declined because of the fact that the savings from investments persist over time. For the United States as a whole, where DSM investments have been 0.5% of revenues, savings are estimated to be

1.9% of revenues. Many of the DSM programs have been evaluated with some care, so these estimates are meaningful. For California, which has done a relatively extensive job of scrutinizing DSM programs, cumulative annual savings are estimated to be 7.5% of sales, while DSM investment has been less than 2% (1.2% in 2003). Overall, DSM has produced an average of about 60,000 annual savings in gigawatt hours for the nation for each of the years 1996 through 2003. At $0.085 per kilowatt hour (average price for residential and commercial customer), this is an annual gross savings to the nation of $5B and a net savings of more than $3.7B.

There are numerous opportunities to expand DSM programs: in the United States, by having other states catch up to the leaders (especially California at present), much more so in Europe, which has little experience with such programs offered by utilities, and over time in developing countries.

6.8.3.2 Energy prices, pricing schemes, energy price subsidies, and taxes

Market-based energy pricing and energy taxes, while often difficult to implement for political reasons, offer a broad incentive for saving energy in buildings. The effect of energy taxes depends on energy price elasticity, i.e., the percent change in energy demand associated with each one percent change in price. In general, residential energy price elasticities are low in the richest countries. Eyre (1998) estimated that, for the UK, long-run price elasticity for the household sector is only -0.19, and Jeeninga and Boots (2001) calculated this figure to be -0.25 for the Netherlands. However, if energy expenditures reach a significant proportion of disposable incomes, as in many developing countries and economies in transition, elasticities-and therefore the expected impact of taxes and subsidy removal-may be higher. Low elasticity means that taxes on their own have little impact; it is behavioural and structural barriers that need to be addressed (Carbon Trust, 2005). To have a significant impact on CO_2 emission reduction, excise taxes have to be substantial. This is only the case in a few countries (Figure 6.6): the share of excise tax compared to total fuel price differs considerably by country. The national foundation of the tax also varies: For example, Italy has a general excise tax, in Sweden the tax consists of environmental levies (energy tax and CO_2 tax), and in Turkey a large part consists of the fuel price stabilization tax (IEA, 2004).

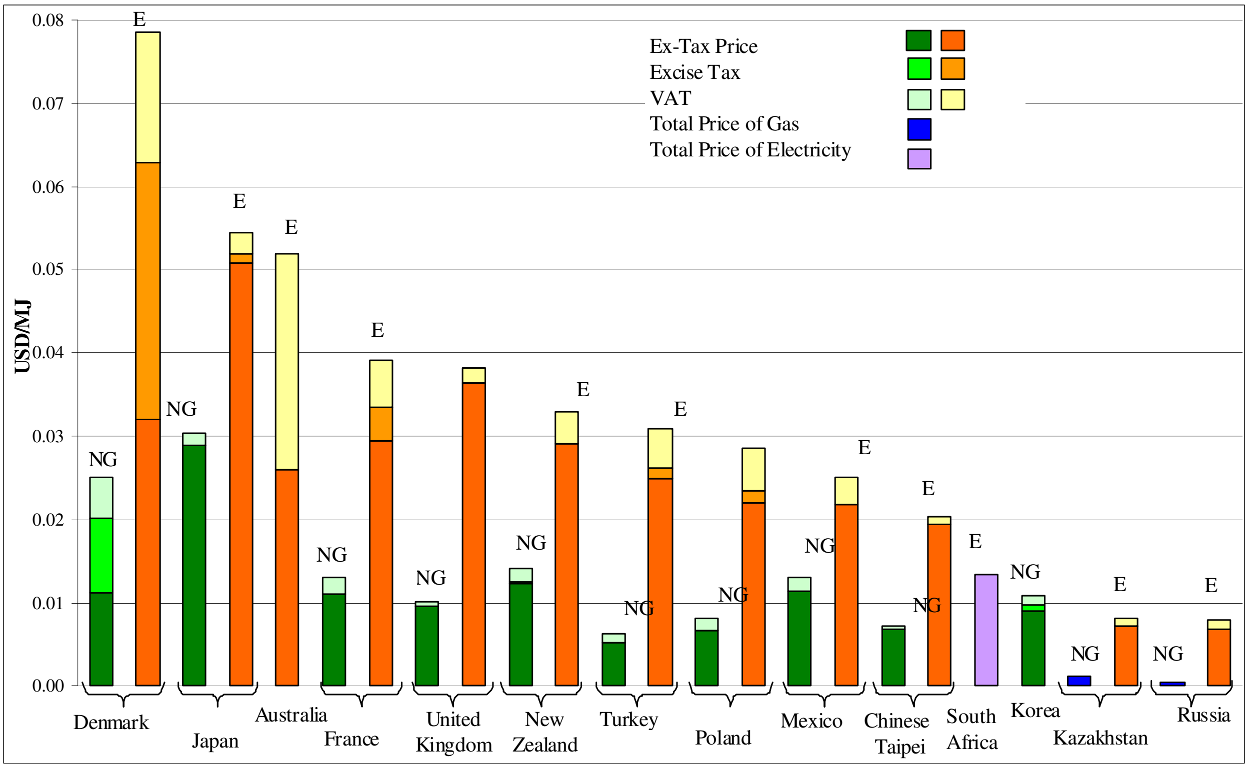

Figure 6.6: *Electricity and gas prices and taxes for households in 2004 (IEA (International Energy Agency), 2006; RAO EES, 2006)*
Notes: Natural gas is abbreviated as NG, electricity is abbreviated as E. Total price is listed when no breakdown avail-able to show taxes

In stark contrast to taxing energy, energy prices are subsidized in many countries. This results in under-pricing of energy, which reduces the incentive to use it more efficiently. Energy subsidies are also typically much larger, per GJ, in developing and transition countries than in most industrial economies Markandya, 2000. The total value of energy subsidies of eight of the largest non-OECD countries (China, Russia, India, Indonesia, Iran, South Africa, Venezuela, Kazakhstan), covering almost 60% of total non-OECD energy demand, was around US$95 billion in 1998 (UNEP, 2002). In 1999, the IEA investigated what could happen if all energy subsidies were removed in those eight countries, and estimated that removing the energy subsidies would reduce primary energy use by 13%, lower CO_2 emissions by 16%, and raise GDP by almost 1%. Table 6.6 summarizes the results for each country (averaging all sectors). In Russia, India, Iran, and Venezuela, the removal of energy subsidies in the residential sector accounts for the bulk of the estimated reduction in CO_2 emissions. For example, in Russia, 70% of the estimated 17% reduction of CO_2 emissions is due to the removal of the subsidies in the price of natural gas for households.

***Table 6.6:** Impact of the removal of energy subsidies in the energy economy of eight countries (IEA (International Energy Agency), 1999)*

Country	**Average subsidy removed (% of market price)**	**Annual economic efficiency gain (% of GDP)**	**Reduction in energy consumption (%)**	**Reduction in CO_2 emissions (%)**
China	11	0.4	9	13
Russia	33	1.5	18	17
India	14	0.3	7	14
Indonesia	28	0.2	7	11
Iran	80	2.2	48	49
South Africa	6	0.1	6	8
Venezuela	58	1.2	25	26
Kazakhstan	18	1.0	19	23
Total selected countries	21	0.7	13	16
Total world	n.a.	n.a.	3.5	4.6

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 over the course of several years, is often accompanied by appropriate social compensation programs, such as grants or tax reductions not tied to energy use. 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 that reduce fuel costs and GHG emissions in the long-term (ERRA 2002). For a number of years, the U.S. government has provided US$1.5-2.0 billion/year in near-term support for energy-efficiency investments to low-income households through the Low-Income Heating Assistance Program (LIHEAP, 2005), and smaller, 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, such as wood, straw, crop residues, and dung. These positive effects, however, can be better achieved through other means-e.g., the introduction of safe and efficient 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, 2002).

6.8.3.3 Investment subsidies, financial incentives, and other fiscal measures

As noted in Section 6.5.5, applying IDP can result in buildings that use 35-70% less energy than conventional designs, at little or no additional capital cost. The design process itself can cost more, due to the greater effort and time required to optimize the design as a whole. Thus, one approach is to provide financial incentives for the design process, rather than financial incentives for the capital cost of the building. This approach has been adopted by Canada in its Commercial Building

Incentive Program (Larsson, 2001), by California in its Savings By Design program, and in Germany under the *SolarBau* program (Reinhart, *et al.*, 2000).

Going beyond IDP, other measures-particularly those that include renewable energy options such as building-integrated PV and/or thermal collectors-entail significant added capital costs. Many developed countries offer incentives for such measures (IEA , 2004). Types of financial support include subsidies, tax reduction (or tax credits) schemes, and preferential loans or funds. Investment subsidies are the most frequently used incentives to achieve energy savings in the buildings sector (IEA , 2004). Capital subsidy programs and tax exemption schemes for both new construction and existing buildings have been introduced in nine OECD countries out of 20 surveyed (OECD, 2003). Several countries (USA, France, Belgium, UK, Netherlands) combine their financial incentive policy for the existing building stock with social policy to assist low-income households (IEA, 2004a; U.S./DOE 2006; Ministry of Housing, Netherlands; 2006). 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 built before 1979 (Boardman, 2004; IEA, 2004). Within the Energy Star Homes program in the U.S., houses that meet the energy-efficiency standard are eligible for a special mortgage, because benefits from energy savings compensate the higher monthly costs (Energy Star, 2006; Nevin and Watson, 1998).

Financial incentives for the purchase of energy-efficient appliances are in place in some countries, including Mexico, the U.S., Belgium, Japan, and Greece (Boardman, 2004; IEA , 2004). Incentives can also encourage connection to district heating, particularly where systems use biomass or geothermal energy (Austria, Denmark, Italy) (Boardman, 2004; IEA , 2004).

There has been limited assessment of the efficiency of these schemes. The cost-effectiveness of subsidy-type schemes can vary widely, depending on program design. Joosen, *et al.*, (2004) have estimated that subsidy programs for residential buildings cost Dutch society USD32-105/tCO_2, whereas this range for the commercial sector was between USD-64 and USD123/tCO_2. According to Barnerjee and Solomon (Barnerjee, 2003), a variety of financial incentives available simultaneously may make the decision process difficult; simplicity of the schemes might be an asset. The authors also suggest that a combination of government financial incentives and private bank loans may be more effective than a government-subsidized loan, as may combining building rating or labelling with a loan-especially when the labelling scheme has public approval.

6.8.3.4 Public sector leadership programs and public procurement policies

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 to recreational facilities. 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 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) (Borg, *et al.*, 2003) found a potential for cost-effective energy savings of 20% or more in EU government facilities and operations. According to the USDOE's Federal Energy Management Program (FEMP), average energy intensity (site energy per square meter) in federal buildings has been reduced by about 25% since 1985 as a result of government policies and initiatives to save energy, while average energy intensity in U.S. 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. 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 establishing public sector energy efficiency as a core element of energy efficiency can substantially enlarge present benefits to climate change. Public sector energy efficiency programs fall into five categories (Harris, *et al.*, 2005): (i) Policies and targets (energy/cost savings; pollution/CO_2 reductions); (ii) Public buildings (energy-saving retrofit and operation of existing facilities, as well as sustainability in new construction), (iii) Energy-efficient government procurement; (iv) Efficiency and renewable energy use in public infrastructure (transit, roads, water, and other public services); and (v) Information, training, incentives, and recognition of leadership by agencies and individuals. The following paragraphs provide selected examples.

The EU Directive on Energy Performance of Buildings discussed above and in Box 6.2, includes special requirements for public building certification. These requirements have helped initiate or expand a number of programs. Among others, the UK has posted on-line benchmarking tools and associated Best Practice Guides for public buildings, offices, and sports centers. 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 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).

Energy-efficient government purchasing and public procurement can be powerful tools 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 (Borg, *et al.*, 2003) 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. Energy-efficient purchasing policies are currently in place in Denmark, the UK, and (with varying degrees of compliance) in several other EU countries. Energy-efficient government procurement policies are also in place in Japan, Korea, Mexico, China, and the U.S. (Harris, *et al.*, 2005). In the U.S., 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 1.1 million tons CO_2 eq. and US$224 million/year in 2010 (after several years of normal stock replacement) (Harris and Johnson, 2000).

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 U.S., 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 annual electricity savings in the U.S. would be 10.8 million tons CO_2 eq, allowing government agencies (and taxpayers) to save at least US$1 billion/year on their energy bills (Harris and Johnson, 2000).

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 and 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.

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

While not a *policy instrument*, ESCOs have become favoured vehicles to deliver energy-efficiency improvements, and are 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 (e.g., space heating, lighting). 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. This is typically executed legally through an arrangement called “energy performance contracting” (EPC). In many 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.

In 2006, the U.S. ESCO market is considered the most advanced in the world; it grew significantly in the 1990s (Goldman, *et al.*, 2005), with revenues reaching about US$2 billion in 2002 (Lin, *et al.*, 2004). Most U.S. ESCO activity (approximately 75%) is in the public sector (schools, universities, government, and hospitals), and the most common projects involve lighting and HVAC measures.

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, with street-lighting projects among the most common demand-side EPC projects, and public buildings the most targeted sector. 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 EPCs to renovate 50% of the total floor area of federal buildings (Unterpertinger, 2005). In Germany, more than 200 EPCs have been signed since the mid-1990s, primarily for public buildings with building "pools" of up to 100 separate buildings (Seefeldt, 2003). In Japan, the ESCO market is growing quickly, with a focus on the commercial and public sectors (office buildings and hospitals) (Murakoshi and Nakagami., 2003). In India and Mexico, ESCOs also have targeted at least 50% of their activity in the public and commercial sectors (Vine, 2005). Most ESCOs do not target the residential sector, although exceptions exist (e.g., in Nepal and South Africa).

ESCOs offer important opportunities for energy-efficiency improvement 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 or regulatory intervention to markets. However, the ESCO industry does not always develop on its own, and policies, programs and initiatives maybe necessary to kick-start the market. 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 countries such as Germany and Austria (Brand, *et al.*, 2003). 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.

6.8.3.6 Energy-efficiency obligations and tradable energy-efficiency certificates

Recognising the shortcomings of the traditional energy policy tools and the fact that they have not achieved the magnitude of energy and carbon savings needed to meet climate stabilization targets, a few new innovative instruments are being introduced or planned in a number of countries. Among them are the so-called "white certificates," a cap-and-trade scheme (or, in some cases, an obligation without the trading element) applied to achieve energy efficiency improvements. The basic principle is an obligation for some category of economic actors (e.g., utility companies, product manufacturers or distributors, large consumers) to meet specified energy savings or program-delivery goals, potentially coupled with a trading system based on verified and certified savings achieved (or expected) for energy-efficiency measures (the "white" certificate) (ECEEE, 2004; Oikonomou, 2004). 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. Energy efficiency obligation programs without certificate trading have been operating in the UK since 1994 and in Flaming (Belgium); white certificate schemes with a trading element were in place in 2006 only in Italy and New South Wales. France and other European countries have announced their intention to introduce similar schemes, and a white certificate scheme is included in the European Commission's Directive on Energy End-Use Efficiency and Energy Services adopted in 2006.

One of the main rationales for implementing tradable white certificate schemes is to reduce the cost of achieving energy savings through the utilisation of the lowest-cost sources of available energy savings (Oikonomou, 2004). Since it is important that the white certificate scheme stimulates *additional* investment in energy efficiency, monitoring and verification are crucial. The relationships among the overall savings target, the cost-effective energy savings potential, and targets for individual companies have to be carefully analyzed. Capturing the often-cited benefit of certificate trading schemes-i.e., minimising the costs of meeting energy savings goals-also 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 transaction 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.

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 the first phase of the program (EEC-1) was 65 TWh and the total delivered savings reached 86.8 TWh. The target has since been increased to 130.2 TWh (Lees 2006). Suppliers must achieve at least half of their energy savings in lower-income households.

6.8.3.7 Technology research, development, demonstration and deployment

Section 6.4 attested that there is a broad array of accessible and cost-effective technologies and know-how that can abate GHG emissions in buildings to a significant extent that have not been widely adopted yet, including high-efficiency lighting and appliances, passive solar and integrated design practices - pointing to the need for the strengthening of policies to promote their deployment. At the same time, several recently developed technologies, including high performance windows, active glazing, vacuum insulated panels, phase change materials to increase building thermal mass, high performance ground source reversible heat pumps, and many other technologies, may be combined with integrated passive solar design and result in a more than 80% reduction of building’s energy consumption and GHG emissions. Large-scale GHG reduction in buildings requires quick and large dissemination and transfer in many countries, including efficient and continuous training of professionals to integrated approach and design, and optimized use of combinations of technologies. Integrated intelligent building control systems, building- or community-level renewable energy generation, heat and coldness networks, coupled to buildings renewable energy capture components and intelligent management of the local energy market need more research, development and demonstration, and could largely develop in the next two decades.

The very large and very diverse stocks of existing buildings with poor energy efficiency and large GHG emissions can benefit from more effort on research and development to ensure adapted technologies becoming available for the very large variety of situations due to history and construction passed materials and techniques

Between 1996 and 2003 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, 2004). Figure 6.7 shows that the U.S. is the leading country in energy research and development for buildings, responsible for half of the total global expenditures. Substantial buildings-related energy-efficiency RD&D is also sponsored in Japan (15% of global energy expenditures).

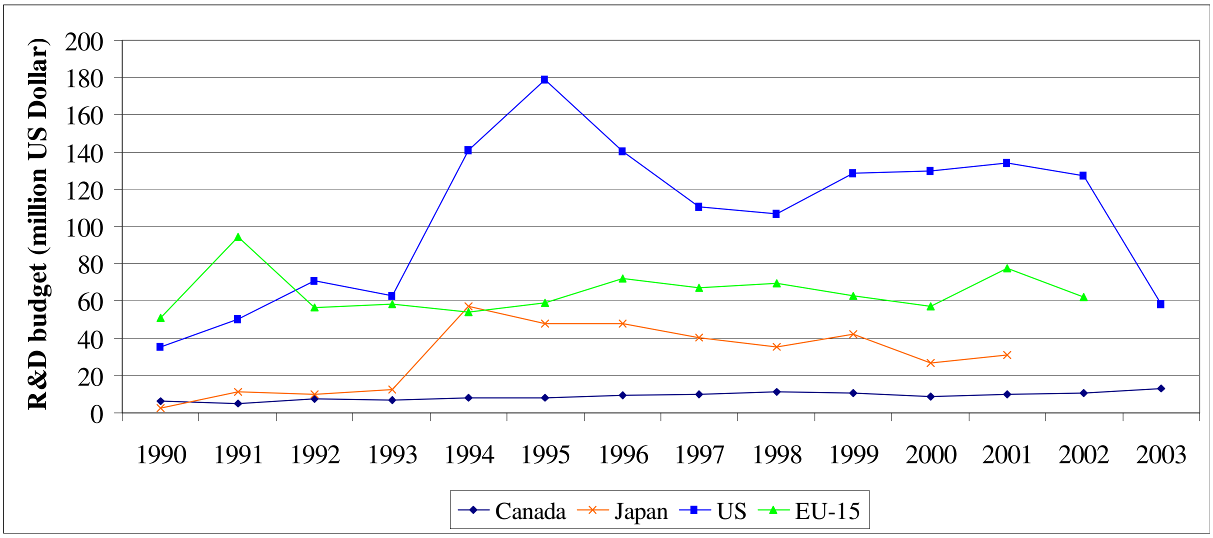

***Figure 6.7:** Annual budget for R&D in energy conservation in the residential and commercial sectors for the period 1990-2003 (IEA 2004c). The data series are not complete for several countries in the IEA RD&D database and the reliability of data is uncertain*

6.8.4 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. Background in this report is in Section 6.4.15, which is in turn a brief summary of Metz, *et al*., 2005).

6.8.4.1 Stationary refrigeration, air conditioning, and heat pump applications

Halocarbon emissions can occur during (re-)filling of compressor installations, leakage in operation, and disposal of refrigerators, air conditioners, and heat pumps. For modern and properly serviced cooling equipment, however, the climatic effect of halocarbon emissions is small (on the order of a few to 5 percent) 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 can no longer be used as a refrigerant for new products, and the industry is switching to alternatives such as HFCs, hydrocarbons, and CO_2 (EC, 2000).

Other existing policies aim at reducing leakage or discouraging the use of refrigerants containing fluorine, of which CFCs are the prime example. Even though new products cannot use CFCs, many existing products do use them as refrigerants and leakage can be very high. Netherlands provides an example of policy to reduce leakage: regulations to minimize leakage rates through improved maintenance, use of qualified personnel, and regular inspection have decreased average refrigerant leakage rates from 30% in 1990 to 4.5% in 1999 (Enviros, 2002). Scandinavian countries provide an example of a policy to reduce fluorine compounds as a refrigerant through high taxes on their production or sale, and legislation in Luxembourg that regulates the choice of refrigerants for all new large cooling systems (Harmelink, *et al.*, 2005). Some countries, such as 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

GHGs 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 improve recovery of refrigerants at the end of life (Harmelink, *et al.*, 2005).

6.8.4.2 Insulating foams and SF_6 in sound-insulating glazing

HFC and HCFC are used as blowing agents to produce foam insulation. Emissions occur during the production, use and disposal of the materials. The Montreal Protocol requires a timed phase-out in the use of HCFC, with industrialized countries achieving 90% phase-out by 2015. As a result, producers are actively exploring alternatives (UNEP, 1987). Foam insulations that use CO_2, water, pentane, or other hydrocarbon-expanding agents in place of halocarbons are increasingly becoming available. In many applications it is already 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 HFCs 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 EU agreed to limit emissions and application of fluorinated gases (EC, 2004). Emissions of HFCs from existing, installed insulation will mainly occur during disposal, over coming decades, leading to a total loss to the atmosphere of the remaining blowing agent unless effective measures for insulation recovery and/or destruction are in place and enforced.

In some countries, SF_6 has been used in high-performance sound-insulating glazing. The same sound-insulation effect can be achieved with an improved, redesigned non-SF_6 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.

6.8.5 Policy options for GHG abatement in buildings: summary and conclusion

Section 6.8 demonstrates that there is a very broad portfolio of policy instruments, programs, and market mechanisms available to enhance GHG mitigation in buildings. Table 6.5 (above) reviews 20 of the most important policy tools used in buildings according to different criteria, such as effectiveness, achieved energy savings, cost-effectiveness, costs per ton of CO_2 abated. Since any instrument can perform poorly if not designed carefully, or if its implementation and enforcement are compromised, the qualitative and quantitative comparisons are based on identified best practices, in order to demonstrate what impact an instrument *can* achieve if applied well. The effectiveness in achieving CO_2 reduction and cost-effectiveness were rated qualitatively based on available literature as well as quantitatively based on one or more selected case studies. Finally, the table lists special conditions for success, major strengths and limitations, and co-benefits.

All of the instruments reviewed can achieve significant energy and CO_2 savings; however, the costs per ton of CO_2 saved diverge greatly. Building code and tax exemption policies achieved the highest CO_2 emission reductions in our sample. Appliance standards, building codes, public benefit charges, and mandatory labelling were among the most cost-effective policy tools in the sample, all achieving significant energy savings at negative costs. Subsidies were revealed as the least cost-effective instrument. Tax reductions appear more effective than taxation. Labelling and voluntary programs can lead to large savings at low costs. Finally, information programs can also achieve significant savings and effectively accompany most other policy measures.

Section 6.8 demonstrates that, during the last decades, many new policies have been initiated. However, so far only incremental progress has been achieved by these policies. In most developed countries, the energy consumption in buildings is still increasing (IEA, 2003). Although some of this growth is offset by increased efficiency of major energy-consuming appliances, overall consumption continues to increase due to the growing demand for amenities, such as new electric appliances and increased comfort. The decoupling of energy use from economic growth is only observed for space heating demand (IEA, 2003). The limited overall impact of policies so far is due to several factors: (i) slow implementation processes (e.g., as of 2006, only ten European countries are on time with the implementation of the EU Buildings Directive); (ii) the lack of regular updating of building codes (requirements of many policies are often close to common building practices, despite the fact that CO_2-neutral construction without major financial sacrifices is already possible) and appliance standards and labeling; and (iii)insufficient enforcement. In addition, Section 6.7 demonstrated that barriers in the building sector are numerous; diverse by region, sector, and end-user group and especially strong.

Therefore, there is no single policy instrument that can capture the entire potential for GHG mitigation. Due to the diverse and strong barriers in this sector, buildings require a diverse portfolio of policy instruments for effective and far-reaching GHG abatement and for taking advantage of synergistic effects. The effectiveness of economic instruments, information programs, and regulation can be substantially enhanced if these 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. In addition, ESCOs can flourish when public procurement legislation accommodates EPCs and includes ambitious energy-efficiency or renewable energy provisions, or in the presence of an energy-saving obligation.

In summary, significant CO_2 and other GHG savings can be achieved in buildings, often at net benefit to society and also meeting many other sustainable development and economic objectives, but this requires a stronger political commitment and more ambitious policy-making than today, including careful design of policies as well as enforcement and regular monitoring.

6.9 Interactions of mitigation options with vulnerability, adaptation, and sustainable development

6.9.1 Synergies with sustainable development

The majority of the countries classified by the UN as least-developed are in Africa (UN 2005). The failure of numerous development strategies in these countries to yield the expected results has been attributed to the fact that the strategies failed to address the core needs of such countries-i.e., economic growth, poverty alleviation, and employment creation (OECD 2001). Often a tension exists between the main agenda of most of these countries (poverty alleviation through increased access to energy) and climate change concerns (emissions resulting from generation, distribution, and consumption of energy); thus, policies formulated around mitigating climate change are generally not given high priority. For instance, security and diversity of supply are the two most important energy concerns in sub-Saharan Africa (SSA). Increased access to modern energy for the mostly rural population has been a priority in recent years. Most countries, therefore, place more policy emphasis on increasing the supply of petroleum and electricity than on renewables or energy efficiency (Karekezi and Ranja, 2002). The success of climate change mitigation policies depends largely on the positive management of these tensions. GHG reduction strategies in developing countries have a higher chance of success if they are "embedded" in poverty eradication efforts, rather than executed independently.

Fortunately, buildings offer perhaps the largest portfolio of options where such synergies can be identified. Matrices in Chapter 12 demonstrate that the impact of mitigation options in the building sector on sustainable development, for both industrialized countries and developing countries, is reported to be positive for all of the criteria used. Both Sections 6.6 above and Box 6.1 discuss many of the opportunities for positive synergies in detail; the next paragraph revisits a few of them.

The dual challenges of climate change and sustainable development were strongly underscored in the 2002 Millennium Development Goals (MDGs). The MDGs have set targets for a reduction in poverty, improvements in health and education, and protection of the environment, and are commonly accepted as a framework for measuring progress toward poverty alleviation (Thomas and Irrek, 2005, Verdict and Wei, 2005, Koppmann, *et al.,* 2005). GHG mitigation strategies are more realizable if they work mutually with MDGs toward the realization of these set objectives. For example, MDG goal 7 is to reduce indoor air pollution, in part by reducing the proportion of people using solid fuels (see sections 6.6.1). GHG mitigation and public health are co-benefactors in the achievement of this goal. Similarly, increased energy efficiency in buildings, or considering energy efficiency as the guiding principle during the construction of new homes, will result in both reduced energy bills-enhancing the affordability of increased energy services-and GHG abatement. If technologies that utilise locally available renewable resources in an efficient and clean way are used broadly, this provides access to "free" energy to impoverished communities for many years and contributes to meeting other MDGs.

However, for the poorest people in both developing countries and industrialised countries, the main barrier to energy-efficiency and renewable energy investments is the availability of financing for the investments. Devoting international aid or other public and private funds aimed at sustainable development to energy efficiency and renewable energy initiatives in buildings can achieve a multitude of development objectives and result in a long-lasting impact. These investments need not necessarily be executed through public subsidies, but may increasingly be achieved through innovative financing schemes, such as ESCOs or public-private partnerships. These schemes offer win-win opportunities, and leverage and strengthen markets (Blair Hamilton, *et al*., 2005). The CDM is also an attractive instrument to ensure the fair transfer of financing from industrialised countries and meet locally identified development goals (Van Vuuren, *et al*., 2003). Since, as of 2006, it has not been used widely for buildings and has often been criticised as delivering only limited sustainable development results the design of future climate regimes may consider placing higher emphasis on alternative architectures that better capture the low-cost GHG abatement opportunities in developing country buildings. Finally, increasing both energy efficiency and building-level renewable energy generation may require the transfer of advanced technologies and know-how such as PV, power storage, fuel cells, high-insulation building materials, IDP, efficient appliances, and solar cooling, from industrialised countries.

With a few exceptions, energy policies and practices in residential and commercial buildings in SSA do not take into consideration efficiency. However, energy efficiency in buildings has recently been recognised as one of the ways of increasing energy security, and benefiting the environment, through energy savings (Winkler, *et al.,* 2002). South Africa, for example, has drafted an energy-efficiency strategy to promote efficiency in buildings (DME 2004). Such policies can be promoted in other SSA countries by linking energy efficiency in buildings directly to the countries' development agendas, by demonstrating how energy efficiency practises contribute to energy security. The positive impacts of these practices, including GHG mitigation, could then be considered as co-benefits.

6.9.2 Interactions of mitigation options with vulnerability and adaptation

In formulating climate change strategies, mitigation efforts need to be balanced with those aimed at adaptation. There are interactions between vulnerability, adaptation, and mitigation in buildings through climatic conditions and energy systems. As a result of a warming climate, heating energy consumption is declining in temperate climates (e.g., Europe, parts of Asia, and North America), but energy use for cooling is increasing globally, which causes a positive feedback loop: More cooling emits more GHGs, therefore exacerbating warming. The combination of climate warming and fuel switching-in both the residential and commercial sectors-from natural gas, oil, and other fuels to electricity is resulting in increases in overall energy demand (and especially electricity demand) (Mansur, *et al.,* 2005). Since, in many countries, electricity generation is largely based on fossil fuels, these deviations may significantly increase the total amount of GHG emissions.

Vulnerability of energy demand to climate is country- and region-specific, since changes in temperature due to climate change and the corresponding adaptation regimes, as well as differences in energy infrastructures and building stock, vary significantly by region. For instance, a temperature increase of 2^{o}C is associated with an 11.6% increase in residential per capita electricity use in Florida, but with a 7.2% decrease in Washington, DC (Sailor 2001). Increased net energy demand translates into increased welfare losses. Mansur *et al.,*(2005) found that, for a 5^{o}C increase in temperature by 2100, the annual welfare loss in increased energy expenditures is predicted to reach $40 billion for US households.

Fortunately, there are many potential synergies where investments in the buildings sector may reduce the overall cost of climate change-in terms of both mitigation and adaptation. For instance, if new buildings are constructed, the design can address both mitigation and adaptation aspects-e.g., using advanced insulation techniques to reduce heating demand in the winter and simultaneously reduce the expected increase in ventilation and air conditioning. If electric appliances are improved in commercial buildings, the savings may double due to reduced electricity demand for air conditioning. Roof retrofits can incorporate increased insulation and storm security in one investment. Heat storage and heat pumps may be used simultaneously for heating and cooling. Active window glazing may achieve better payoffs as the heat-reflecting properties become more important in summers. In addition, the integrated design of well-insulated, air-tight buildings, with efficient air management and energy systems, leads not only to lower GHG emissions, but also to reduced thermal stress and increased comfort to occupants. Furthermore, adaptive comfort, where occupants accept higher indoor (comfort) temperatures when the outside temperature is high, is now incorporated in design considerations, especially for predominantly naturally ventilated buildings.

Policies that actively promote integrated building solutions for both mitigating and adapting to climate change are especially important for the buildings sector. It has been observed that building users responding to a warmer climate generally choose options that increase cooling energy consumption rather than other means, such as insulation, shading, or ventilation, which consume less energy. A prime example of this is the tendency of occupants of existing, poorly performing buildings (mainly in developing countries) to buy portable air-conditioning units. These trends-which clearly will accelerate in warmer summers to come-may result in a significant increase of

GHG emissions from the sector, enhancing the positive feedback process. However, well-designed policies supporting less energy-intensive cooling alternatives can help combat these trends (see Box 6.4). Good urban planning, including increasing green areas as well as cool roofs in cities, has proven to be an efficient way to limit the heat island effect, which also aggravates the increased cooling needs (Sailor 2002).

Box 6.4: *Mitigation and adaptation case study: Japanese dress codes*

In 2005, the Ministry of the Environment (MOE) in Japan widely encouraged businesses and the public to set air conditioning thermostats in offices to around 28^{o}C during summer. As a part of the campaign, MOE has been promoting summer business styles ("Cool Biz") to encourage business people to wear cool and comfortable clothes, allowing them to work efficiently in these warmer offices.

In 2005, a survey of 562 respondents by the MOE (Murakami, *et al*., Forthcoming) showed that 96% of the respondents were aware of "Cool Biz" and 33% answered that their offices set the thermostat higher than in previous years. Based on this result, CO_2 emissions were reduced by app. 460 Mt in 2005, which is equivalent to the amount of CO_2 emitted from about one million Japanese households for one month. MOE will continue to encourage offices to set air conditioning in offices at 28^{o}C and will continue to promote "Cool Biz."

Mitigation and adaptation investments may compete for the same, limited set of financial resources. It is thus essential to identify those measures that address both goals simultaneously. Since the priority of specific mitigation and adaptation measures is very location-dependent, this assessment needs to be performed for each locality. Leveraging market actors and tools such as ESCOs, public-private partnerships (PPP), and the CDM to achieve increased efficiency and the use of renewable energy in buildings may help avoid this conflict. For a summary of these issues, see Chapter 11, Section 11.9.

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