7 Buildings

What is covered in this chapter?

Buildings are a big user of energy, through the building materials and through heating, cooling, lighting, and use of equipment in the buildings. They contribute almost 20% to global greenhouse gas emissions, when emissions from the electricity used in buildings are included. At the same time the opportunities for energy savings and CO_2 reduction are enormous. And most of these savings pay for themselves. Modern techniques now allow net zero energy buildings to be built. This chapter will investigate these possibilities and try to find out why these opportunities have not been taken advantage of and what could be done about that.

Developments in the buildings sector

Buildings are the basic infrastructure of human societies. Housing is a fundamental human need. Unfortunately many people on this planet do not yet have an adequate house. One out of three people living in cities in developing countries lives in a slum[1]. The average number of people in Pakistan per room is three, while this is 0.5 for many countries in Europe and the USA[2]. World population will grow by several billion people over the next 50 years. They all need proper housing. Factories, offices, schools, shops, and theatres also require buildings. And these buildings require energy: energy to build them, to heat and cool them, to cook food, to heat water, and to run the appliances and equipment used in buildings (see Box 7.1).

Box 7.1 China's building boom

China is currently adding about 2 billion (= two thousand million) square meters of building floor space every year, about half for residential and half for commercial buildings, a growth rate of about 7%. Most of these new buildings are in cities (urban population is now about 40%, will rise to 60% by 2030). An important driver for the increase in residential buildings is the official government target of increasing the living space per urban person to 35 m^2 by 2020 (now 26 m^2) and the trend towards smaller households (from 4.5 people in 1985 to 3.5

now and to 3 by 2030). Building codes were introduced in 1986, revised in 1995, differentiated according to climate, and revised again in 2006. Compliance with building codes is poor: from 60% in the North to 8% in the South.

The buildings sector used about 35% of total primary energy (including electricity and heat from central supply) in 2005, two-thirds from traditional biomass. This is expected to be only about one-third in 2030. Natural gas and electricity use in the buildings sector are expected to grow by about 6% per year till 2030. Natural gas supply to cities for household use is a government priority. Heating, cooling, and appliances are the biggest energy consumers. About 80% of urban households own an air conditioner now and almost all urban households have a refrigerator, a washing machine, and one or more televisions. Appliances are generally less efficient than comparable European models. Policies on efficiency standards for appliances and phasing out of residential electricity subsidies are in place.

(Source: IEA,WEO 2007)

Energy

The building sector uses almost 40% of the final energy[3] (final energy = energy as used, not including the losses due to electricity production). This share varies from region to region: about 20% in Australia and New Zealand to more than 50% in Sub-Saharan Africa. Residential buildings are responsible for about three-quarters of this energy use, varying from slightly more than 50% in North America to about 90% in most developing countries[4]. Commercial buildings are responsible for one-quarter. Buildings currently use more than 50% of all electricity generated[5].

Residential energy use per person differs enormously across countries. An average Ethiopian used less than one-hundredth of the energy of a Western European or North American in 2003[6]. And an average Chinese person used about one-third the energy of a Western European and a quarter of a North American. Traditional biomass (firewood, crop residues, cow dung, etc.) is still a very big energy source for household heating and cooking in developing countries. In China it provided 65% of all final energy used in the building sector in 1999 (and 80% in rural areas)[7].

What is the energy used for?

In industrialized countries heating and cooling typically use something like 40% of all residential energy, appliances 30%, and lighting and water heating about 10% each. In developing countries these shares are very different. In colder climates heating is by far the biggest use and given limited use for lighting and appliances, water heating is also pretty important.

For commercial buildings the picture is different: appliances, computers, and other equipment take a much higher share (could be 40–50%), lighting could be in the order of 20%, and a relatively lower share is accounted for by heating and cooling (more like 20%). Again, there is a marked difference in developing countries, where space heating

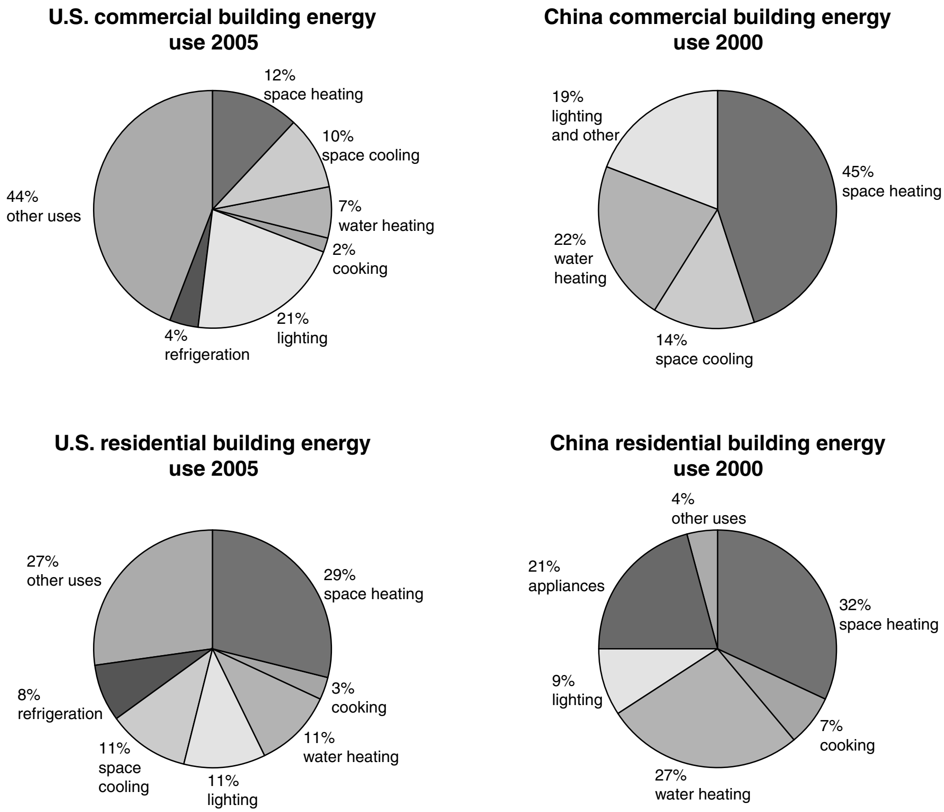

Figure 7.1 **Share of energy used for different purposes in residential and commercial buildings in the USA and China.**

Source: IPCC Fourth Assessment Report, Working Group III, fig 6.3.

and cooling is the dominant usage, followed by water heating. Figure 7.1 gives some breakdowns for the USA and China.

Climatic conditions of course have a major impact. Figure 7.2 shows the different energy use patterns for different climatic zones in the US. The shift from heating to cooling needs is clearly visible.

How do buildings compare?

There are large differences in energy use between buildings in the same climatic zone. The average heating energy use per unit of floor space in Germany for instance is about 220kWh per square metre per year. In Central and Eastern Europe the average is 250–400kWh/m^2/year. Buildings designed according to the 'passive solar house' concept use about 15kWh/m^2/year. A selection of existing office buildings in Malaysia, Singapore,

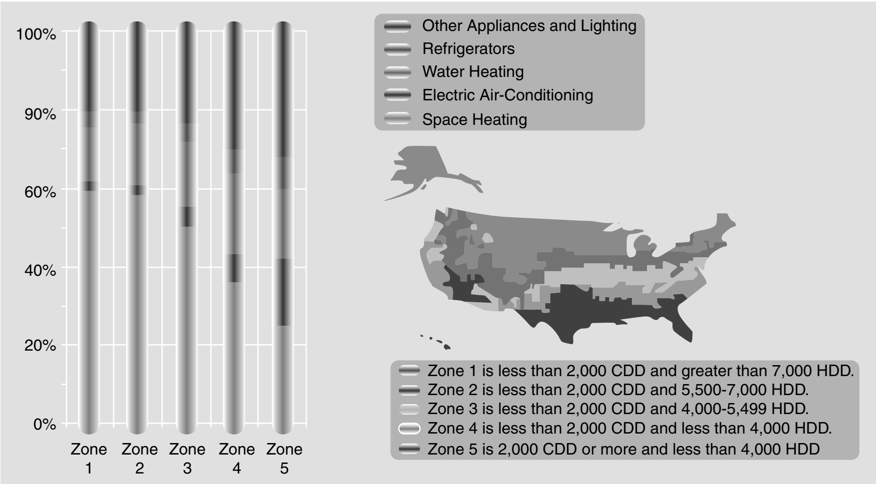

Figure 7.2 **Energy consumption shares in US residential buildings.**

Source: UNEP, Buildings and climate, 2007, fig 2.15. See Plate 13 for colour version.

Thailand, and the Philippines showed a range of 80–250kWh/m^2/year[8]. This means there is a huge potential for reducing energy demand.

Future energy use

Energy use in the building sector is projected to increase by about 40% in the period until 2030. Most of this growth is expected to happen in developing countries, where large expansions of the housing and building stock will be needed. Building energy use in industrialized countries will stabilize or even decline. The share of electricity in the energy use in buildings is expected to double, making it by far the most important energy source for buildings. Centrally supplied heat (from urban heating networks) will remain relatively small (less than 5% of the energy used).

What are the greenhouse gas emissions?

Direct greenhouse gas emissions from the building sector are responsible for 8% of global greenhouse gas emissions or 3.9GtCO_2-eq per year (for 2004 numbers, see Figure 7.3). CO_2 from energy covers 80% of the emissions, CH_4 10%, and the rest is N_2O and fluorinated gases[9]. Here only the emissions of HFCs are included, because emissions of the fluorinated gases CFCs and HCFCs (accounting for 1.3GtCO_2-eq/year) do not fall under the Kyoto Protocol. They are being phased out under the Montreal Protocol however. Table 7.1 gives a summary.

When all emissions from electricity and heat used in buildings, but produced elsewhere, are also included then the share of the building sector goes up to 23%[10].

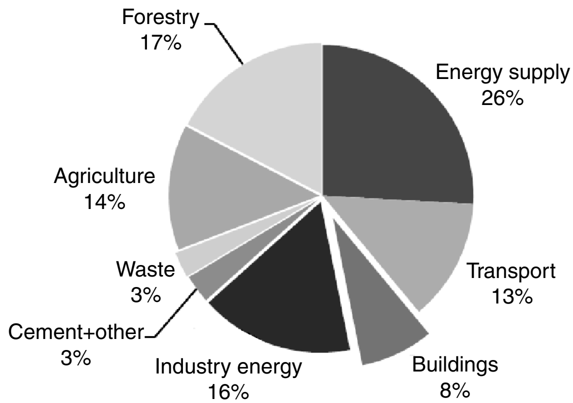

Figure 7.3 **Buildings sector contribution to direct global greenhouse gas emissions in 2004. Indirect emissions from the sector are about 14%, bringing the total of direct and indirect emissions to 22%.**
Source: IPCC Fourth Assessment Report, Working Group III, ch 1.

Table 7.1. Contribution of different greenhouse gases to emissions from buildings: data for 2004

Gas	Source	Emission ($GtCO_2$-eq/year)
CO_2	Heating, cooking	3.2
CO_2	Externally supplied electricity and heat	7.1
CH_4	Gas and biomass burning	0.4
N_2O	Gas and biomass burning	0.1
HFCs	Refrigeration, air conditioning, and insulation	0.2
CFCs and HCFCs (non-Kyoto gases)	Refrigeration, air conditioning, and insulation	1.3

Source: IPCC Fourth Assessment Report, Working group III, ch 1 and IEA, WEO 2007.

As for the share of energy use, residential buildings are responsible for about three-quarters of emissions on average. Regional differences are large. Developed countries are responsible for 70% of emissions, developing countries 30%. Sub-Saharan Africa covers only 6% of the total.

Without new policies total building sector emissions are projected to increase by 50–100% by 2030.

How can we reduce energy use and greenhouse gas emissions?

Energy use by and greenhouse gas emissions from buildings can be reduced in the following ways:

- by reducing energy needs
- by using energy more efficiently

- by changing the energy source
- by changing materials that emit fluorinated gases
- by changing behaviour

Reduce energy needs

The energy needs of a building are to a large extent determined by its design. Orientation to the sun, daylight entry, shading, insulation, and use of natural ventilation are some of the critical variables that determine the heating and cooling requirements. They are set at the design stage. As indicated above there are enormous differences in energy use between buildings in different places today. Several houses have been built according to the so-called 'passive house standard'[11], where energy use for heating and cooling is 75–90% lower than in a standard new-built house[12]. Typical heating energy requirements are 15 kWh/m^2/year. This is achieved with maximizing use of incoming solar radiation through glass windows in winter and minimizing it in summer, storing incoming solar heat in thick walls, very good insulation, airtight design with mechanical ventilation with heat recovery, natural ventilation, and proper orientation to the sun (see Figure 7.4).

Insulating properties of several building elements have improved enormously over time. Replacing windows with double or triple insulating windows reduces the heat loss by 45–55%. Coated double glazed windows only have 25–35% of the heat loss of regular double glazed windows[13]. Reflecting glazing can reduce incoming solar radiation by 75%. The newest windows have the capacity to become more reflecting when temperatures go up[14].

Ventilation systems have become much more advanced. Uncontrolled ventilation in buildings in cold climates can be responsible for half the total heat loss of a building. Advanced controlled ventilation systems can reduce this heat loss by a factor of 5–10. In warm climates cooling requirements can be reduced enormously by making use of natural ventilation, assisted by some small fans and exhaust ventilators. In California such houses

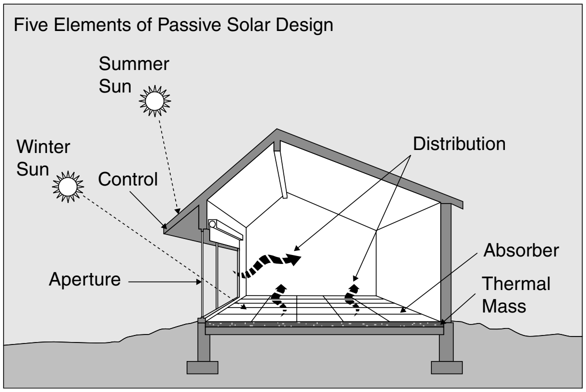

Figure 7.4 **Schematic drawing of passive solar design.**
Source: US Department of Energy, http://apps1.eere.energy.gov/consumer/your_home/designing_remodeling/index.cfm/mytopic=10270.

Figure 7.5 **Use of insulated daylight panels to reduce the need for electric lighting.**
Source: http://www.inhabitat.com/2006/09/06/green-building-101-design-innovation/.

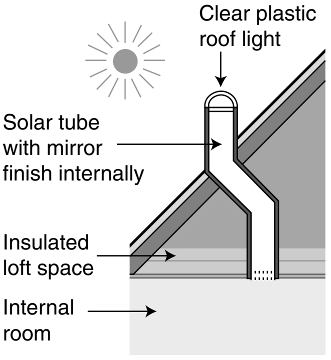

Figure 7.6 **Solar tube to pipe light to enclosed rooms in a building.**
Source: www.lowenergyhouse.com.

are able to keep temperatures below 26°C with night-time mechanical ventilation only for 40% of the time[15].

Better use of daylight can save a lot of lighting energy. Many office building are designed in such a way that in most workplaces electric light is a necessity, even on a sunny day. Through proper design of office buildings 40–80% of lighting energy can typically be saved by making better use of daylight (see Figure 7.5).

Advanced technologies are now available to ‘pipe’ light from outside into enclosed rooms in a building[16] (see Figure 7.6).

Costs

Halving heating and cooling needs compared to current building standards is possible without net additional costs. The saved energy pays for the extra measures taken. Still, in many instances the additional upfront investment required or aesthetical considerations by architects are a reason not to take these economically rational decisions.

Many of the design features described here are of course only achievable in a new building, and from now until 2030 many new houses will be built. According to the UN '*An estimated 21 million new housing units are required each year, in developing countries, to accommodate growth in the number of households between 2000 and 2010. 14 million additional units would be required each year for the next 20 years if the current housing deficit is to be replaced by 2020*[17].'

And that is only part of new construction. In developed countries urban renewal projects will lead to knock-down of old buildings and construction of new ones, together providing a big opportunity for energy saving and CO_2 emission reduction. It would even be attractive to demolish older, energy inefficient buildings well before their economic lifetime, because the energy embedded in the construction of a building is normally only 15–20% of the total energy used over the lifetime[18].

For existing houses and commercial buildings the possibilities for energy conservation are somewhat more limited and more expensive, but a lot can be done at low cost. Insulation of walls of existing buildings by filling of wall cavities with spray foam or rock wool, of floors with insulating foils, and of roofs and lofts with foam or rock wool can be done in many buildings. Care should be taken to use available climate friendly blowing agents when applying foam, because HFC or HCFC blowing agents would add to the GHG emissions[19].

Use energy more efficiently

Heating, cooling, lighting, and running refrigerators, washing machines, TVs, computers, etc. require energy in the form of electricity, gas, oil, coal, or (traditional) biomass. How efficient is that energy used? And how much can CO_2 emissions be brought down?

Space heating

Space heating in industrialized countries and urban areas of developing countries is done with gas, oil, or electricity. Except when very low carbon electricity is available, electric heating is inefficient and leads to high CO_2 emissions. First turning fossil fuel into electricity, losing about 60% of the energy, and then converting electricity into heat, again with a substantial loss of energy, is not a good idea. And most electricity is produced with fossil fuels, guaranteeing high CO_2 emissions from electric heating.

Modern gas fired building heating installations have reached an efficiency of more than 97% due to advanced burner design and recovery of waste heat. On average, installations being used today have an efficiency of 60–70%. With an average lifetime of a central heating boiler of about 15 years, big reductions in energy use and CO_2 emissions can be achieved by replacing those with advanced high efficiency installations. The newest, most efficient boilers earn the additional cost back well within their lifetime. It even makes sense to replace boilers before the end of their economic lifetime.

Heat pumps

In places where there is no way of replacing electric heating with modern gas fired systems, heat pumps can be used to improve energy efficiency. The heat pump is a sort of 'reverse refrigerator' that transfers heat into the house from the surrounding air or the soil. Since the soil is relatively warm in winter time compared to air, it is attractive to draw the heat from the soil. Heat pumps can also work the other way around in summer, cooling the building. Since the soil remains substantially cooler than the air, 'pumping' the heat into the soil in summer is more energy efficient. Given the energy losses when producing electricity, the overall efficiency of heat pumps is lower than that of modern gas fired heaters, except in cases where low carbon electricity is available. By doubling as air conditioners, heat pumps can also eliminate emissions of fluorinated gases from traditional air conditioners[20] (see Figure 7.7).

District heating

An efficient way to heat a building is to use waste heat from a power plant via a district heating system. The power plant then becomes a combined heat and power plant (CHP, see also Chapter 5). Of course the heat will have to be transported via a pipe network. This limits the scope for district heating to a radius of about 50 km around a power plant. There are many cities where that condition applies and district heating with CHP is applied in many cities already.

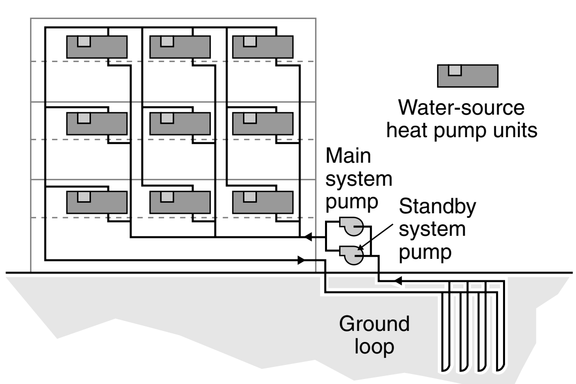

Figure 7.7 **Ground source heat pump system for building heating and cooling.**
Source: redrawn from http://www.geo4va.vt.edu/.

Micro CHP

Yet another alternative that is being installed in some places is the so-called micro combined heat and power installation (micro CHP). It is an installation that produces both electricity and heat for a small building. They are normally gas fired. Because of their very high efficiency, the overall efficiency for heat and electricity is often better than electricity from the grid and a separate heater. In terms of CO_2 emissions this also holds, except in cases where grid based or decentralized electricity is from renewable sources.

Rural areas

In rural areas of developing countries the situation is quite different. About 3 billion people in rural areas depend on wood, charcoal, crop residues, cow dung, and coal (particularly in China) for heating and cooking, although many of these people live in tropical areas where no heating is required. This practice causes severe indoor air pollution and causes disease and premature death. In terms of contribution to greenhouse gas emissions the picture is mixed. Much of the heating fuel is renewable, although wood consumption in many areas is not sustainable[21].

There are not many low carbon alternatives for rural energy in the short term. A lot of work has been done on the development of efficient cook stoves. Results are mixed. Efficiency has been shown to be 10–50% better, but penetration is limited, new cook stoves were not always working properly, and costs were not always low enough. The impact on women and children (reduced time for fuel gathering and less indoor pollution) is bigger than on CO_2 emissions. Biogas installations (see Chapter 5) do have a good potential to provide renewable cooking fuels. Capacities of these installations are generally not sufficient however to cover heating needs. Solar and small electric cookers have some potential. For the time being more efficient heating stoves are the only short term solution.

Air conditioning

Full mechanical air conditioning is becoming the norm for cooling of buildings. In urban areas of developing countries it is one of the first things households want to have if they can afford it. In cooler areas of industrialized countries it is also becoming more common to have air conditioning, where this used not to be necessary. The world production of small air conditioners for instance increased by 25% between 1998 and 2001.

Air conditioners come in a range of sizes and types, from small room size wall mounted units, to so-called split system units for homes and small buildings to large cooling devices for use in larger residential and commercial buildings. Their energy efficiency generally improves with size. Big centrifugal chillers are about 2–3 times as efficient as small room air conditioners. Further improvement of energy efficiency is possible[22].

Figure 7.8 **Window-mounted air conditioners in apartment building.**
Source: Shutterstock.com, © Phaif, image #15585142.

Air conditioners generally use a halo-carbon refrigerant. More than 90% of the installations use HCFC-22. As this substance will be phased out in the near future under the Montreal Protocol, a shift to HFCs, a powerful greenhouse gas controlled by the Kyoto Protocol, is noticeable[23] (see also Chapter 2). Leaks in some installations and repair or service work lead to an emission of HFCs of about 0.2 $GtCO_2$-eq per year. Alternatives in the form of refrigerants that have a zero or lower global warming contribution are available. For supermarket cooling systems the combined effect of choosing more energy efficient cooling equipment and a change of the refrigerant can lead to a 60% reduction in overall CO_2 equivalent emissions[24].

There are other, much lower energy alternatives by moving from air conditioners to low energy cooling techniques. One approach is to mechanically assist air flows through buildings using cooler night-time air or using (cool) underground inlet ducts. Another is to cool the inlet air by evaporating water directly in it or cool the incoming air with an evaporative cooling driven heat exchanger. Energy savings in the order of 90% compared to traditional air conditioners are possible. In areas with hot and humid air the drying of the air by over cooling consumes a lot of energy. Desiccants can reduce this energy use by 30–50%. Figure 7.9 shows a schematic diagram of a building where several energy reducing measures have been taken, including a small sized centrifugal chiller as the main cooling machine on the roof.

Light[25]

Lighting consumes roughly 20% of global electricity, 10% of the total energy use in residential buildings, and 20% in commercial buildings. The total energy used for lighting is about one-third used in residential and two-thirds in industrial and commercial buildings. Lighting is responsible for about 1.9 $GtCO_2$ per year, which is 70% of the emissions from all passenger vehicles. Traditional so-called incandescent lamps represent 80% of lamps sold, 30% of all lighting energy, but only 7% of delivered

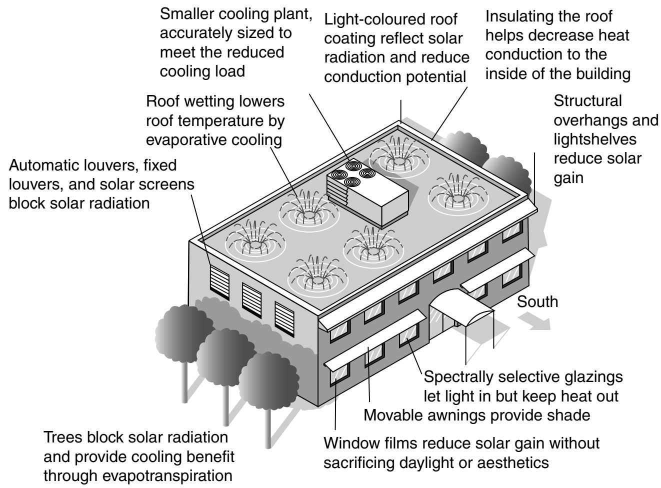

Figure 7.9 **Combination of measures to reduce the cooling requirements and energy use for cooling, including a small size centrifugal chiller on the roof.**

Source: Madison Gas and Electric, http://www.mge.com/business/saving/madison/pa_14.html.

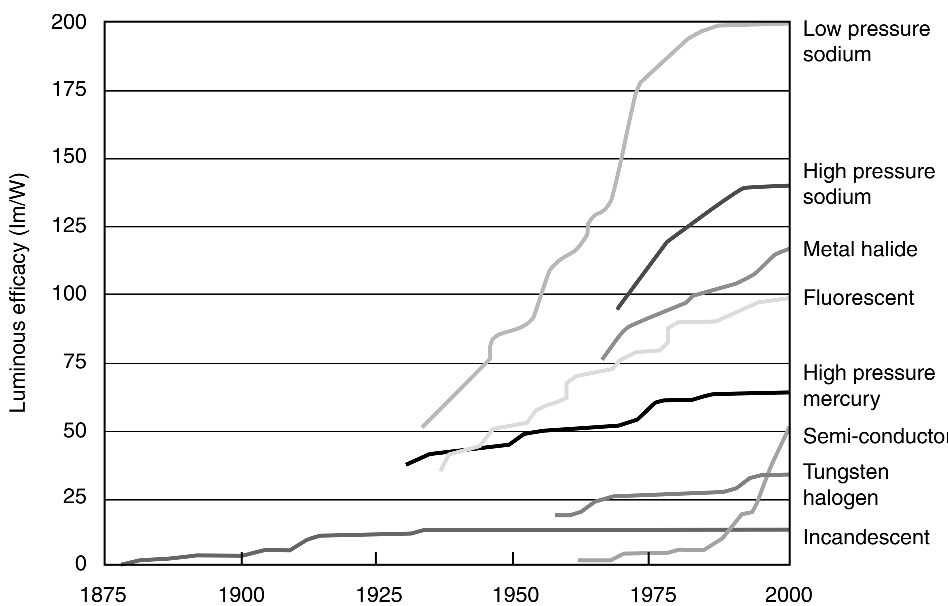

Figure 7.10 **Efficiency of different lamp types over the years. Efficiency is expressed in light delivered (lumen) per Watt.**

Source: Light's Labour's Lost, International Energy Agency, 2006.

light. This is a complex way of saying they are very inefficient but are still widely used. Penetration of more efficient fluorescent tubes, compact fluorescent, and halogen lamps is limited: in the best European country about one in three light bulbs in households was efficient. For a comparison of the efficiency of lamps see Figure 7.10.

The potential for reduction of energy use and emissions is considerable. Reductions of 75–80% are possible in residential buildings, primarily by shifting from incandescent light bulbs towards compact fluorescent lamps (CFLs) and (in the future) LED (light emitting diode) lamps. The use of sensors to switch light on when people are present (and daylight is not enough) and off when they have left is an important way to assist people to save on energy.

In commercial buildings, where lighting is already more efficient, a further 50% improvement is possible through use of more efficient lamps, sensors, and use of local, so-called task lights. And this on top of a further 20–40% reduction by minimizing the need for lighting by designing buildings to make better use of daylight.

About one third of the world population depends on kerosene, paraffin, or other hydrocarbon fuel for lighting. Only 1% of all lighting is provided in this way, but it represents 20% of the lighting related CO_2 emissions and 3% of the world's oil consumption. Together with efforts to provide electricity to the 1.6 billion people that do not have it now, efficient fluorescent lamps allow people to use a minimum of electricity, which is an expensive commodity for many poor people. Bringing the costs of these CFLs down is therefore of prime importance.

Appliances

In 11 large OECD countries the electricity used by refrigerators, freezers, ovens, washing machines, dryers, computers, etc. (in short: household appliances) is more than 40% of the total residential primary energy use. In developing countries this share is much lower, although in several countries, for example amongst China's urban population, the penetration of electrical appliances is increasing strongly. In commercial building the share of equipment in the total energy use is normally higher than in residential buildings. Figure 7.11 gives an overview for the average electricity used by appliances in US households.

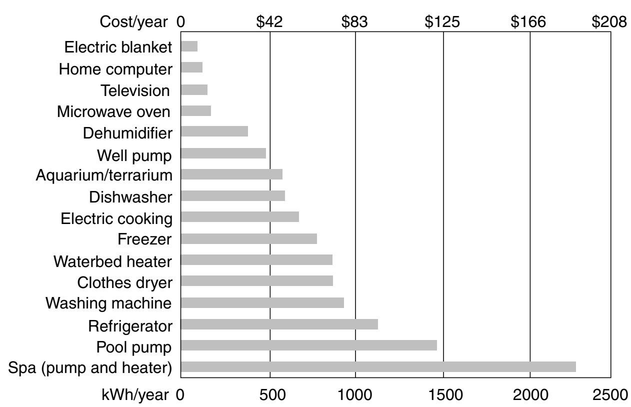

Figure 7.11 **Energy use of a typical appliance per year and its corresponding cost based on national averages for US households. For example, a refrigerator uses almost five times the electricity the average television uses.**

Source: US Department of Energy, http://www1.eere.energy.gov/consumer/tips/appliances.html.

How much efficiency improvement is possible?

Efficiency of appliances has improved considerably over the years. Refrigerators sold in the US today use less than 400 kWh per year, while those sold in the late 1970s used about 1800 kWh. Due to the lifetime of appliances there is a significant difference between the average appliance in use and the new models on the market. In the UK in 2005 average energy use of washing machines was 1.24 kWh per washing cycle. The best machines for sale used about 0.85 kWh[26]. And then there is the difference in appliances for sale today: the most efficient use 50–80% less energy than the worst ones, as is for instance shown by the energy labels used in the EU (see Figure 7.20).

Unfortunately efficiency is not the only thing. The volume of refrigerators tends to increase with income and is influenced by cultural aspects: in the US they are much bigger than in Europe. In the US the best standard size refrigerators use less than 400 kWh per year; in Europe the figure is about half this, because of smaller size.

So-called 'standby power', the electricity consumed when appliances are switched off but still in sleeping mode, is becoming a big contributor to electricity consumption. In the US it is now more than all refrigerators combined, due to the sheer volume of appliances that are kept plugged in (see Box 7.2).

Box 7.2 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 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. 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), labelling, voluntary agreements, quality marks, incentives, tax rebates, and energy efficient procurement policies – are applied globally to reduce the standby consumption in buildings, but most of them capture only a small share of this potential. The international expert community has been urging a one Watt target. In 2002, 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. As of mid-2006, the only mandatory standard regarding standby losses in the world has been introduced in California, although in the USA the Energy Policy Act of 2005 directed the USDOE to evaluate and adopt low standby power standards for battery chargers.

(Source: taken from IPCC Fourth Assessment Report, Working group III, box 6.4)

Further efficiency improvements are possible, through innovation and by removing inefficient appliances from the market.

Change the energy source

Changing to low carbon energy sources is an obvious way to reduce CO_2 emissions. As far as electricity is concerned the options are discussed in Chapter 5, including PV cells mounted on building roofs and small scale wind turbines. PV cells integrated in building materials will be considered below as will solar water and space heating. Combining renewable energy generation by buildings with energy needs reduction and energy efficiency improvements can lead to so-called 'net zero energy' buildings that produce all the energy that is needed.

PV integrated building materials

Photovoltaic panels, mounted on the roof of a building, are now a common thing. There are many building materials on the market however where PV cells are integrated in the building material itself. PV Roof tiles for flat roofs and PV slates and shingles for slanted roofs are commercially available (see Figure 7.12). South facing facades of buildings are ideal for PV integrated wall tiles, but also for PV sunshades (see Figure 7.13).

Solar water heating

Solar water heaters absorb heat from the sun, either in an insulated dark flat panel (flat panel type) or in pipes that are insulated with a double vacuum wall like a thermos can

Figure 7.12 PV integrated roof slates.

Source: www.newagesolar.com.

Figure 7.13 PV integrated sunshades as part of the building design.
Source: Power Glaze, www.romag.co.uk.

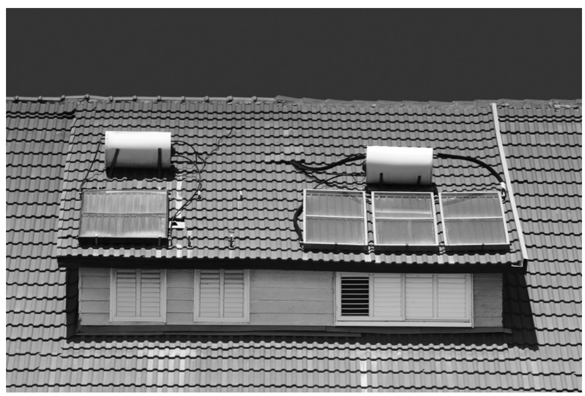

Figure 7.14 Flat panel solar water heaters providing 80% of the hot water needs of the house.
Source: © mtsvn/shutterstock.com, image # 14253103.

(vacuum tube type, see Figures 7.14 and 7.15). For swimming pools unglazed plastic collectors are often used, particularly in the USA.

China is now by far the biggest market for solar water heaters, with about 65% of all installed capacity in the world. The EU has 13%, followed by Turkey (6%), Japan (4%), Israel (3%), and Brazil (2%)[27]. Local building codes are a very strong driver for installation of solar water heaters. In Israel for instance there are strict national regulations and in a number of other countries stimulation programmes and municipal building codes have contributed to a significant penetration (see Figure 7.16.). The total installed capacity of solar heaters is of the order of 220 million m^2. Annual growth rates are of the order of 20%. The heat produced however is still less than 5% of all heat used in the buildings sector[28]. More than 50 million households worldwide have a solar heater system.

Costs of solar water heaters in China are typically 200–300US$ each, while systems in Europe vary from US$700 to US$2300. Prospects for solar water heating as a

Figure 7.15 **Vacuum-tube solar water heater.**

Source: www.himfr.com.

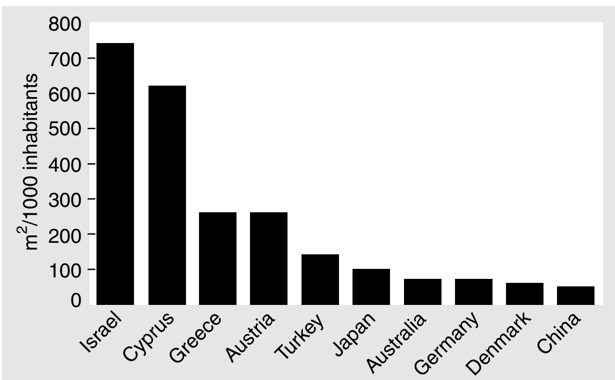

Figure 7.16 **Solar water heaters (m^2 per 1000 inhabitants).**

Source: REN21, Renewables 2005.

contribution to CO_2 emission reduction are modest at a global scale, although growth of these systems could be strong when adequate policies are put in place in many countries. Especially in tropical and subtropical developing countries the need for drastic expansion of the housing stock provides excellent opportunities at low costs.

Solar space heating and cooling

Passive solar heating has already been discussed above. The same principle as for solar water heaters can be used to provide additional solar space heating, albeit with much larger solar collectors, which is the reason why this technology is not applied widely yet.

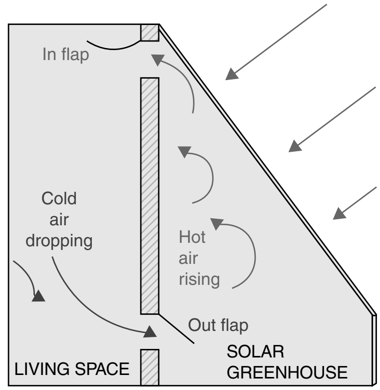

Figure 7.17 **Schematic diagram of solar greenhouse attachment for space heating.**
Source: http://jc-solarhomes.com/passive_solar.htm.

A more attractive form of solar space heating is the attachment of glass extensions (a greenhouse actually) to buildings that act as a greenhouse and capture heat. By controlling air flow from the glass extension the adjacent house can be (partially) heated (see Figure 7.17).

Solar heating and cooling can benefit from seasonal storage. Excess heat captured in summer can be stored for instance in the groundwater under the building. In winter this warm water can be used for heating again

Zero-energy and Energy-plus buildings

By combining all elements of reducing energy needs through the passive house concept (see above), energy efficiency improvements, and use of solar energy, buildings can be constructed that use no external energy or are even net energy producers. The US Department of Energy database contains seven examples of commercial zero or net positive energy buildings in the US[29]. Box 7.3 describes a new energy-plus office building in Paris. There are additional costs involved, but part of these will be earned back due to lower energy bills.

Box 7.3 Energy Plus office building in Paris

The 'Energy Plus' office building, to be located outside of Paris, is designed to produce all its own energy for heating, lighting, and air conditioning. This zero-energy building, according to the designers, will be the greenest office building ever created. It will accomplish this by having more solar panels on its roof than any other building – producing enough energy to power the entire building and still feed extra back into the grid. Its unique cooling system will take cold water from the river Seine and pump it around the building – eliminating the need for a traditional air conditioner. The 70 000 m^2 building will also utilize cutting edge insulation, reducing amount of electricity consumption per square meter of office space per year to 16 kilowatts, the lowest in the world for a building of its size. The building is expected to house up to 5000 people. It's expected to cost approximately 25–30% more than a traditional office building. It was designed by Skidmore Owings Merrill, the architectural firm behind New York's upcoming Freedom Tower.

(Source: http://www.metaefficient.com/architecture-and-building/the-energy-plus-building-produces-all-its-own-power.html)

Change behaviour

Behaviour is an important driver of energy use and greenhouse gas emissions in buildings. Setting the temperature, switching off lights, purchasing lighting and appliances, decisions to invest in insulation or PV panels, buying green electricity, etc. are all human decisions that determine energy use and emissions. We know from research that, for similar houses (i.e. similar design, insulation, and other features) and composition of families, energy use can vary by a factor of 2.

Most of the actions that people can take to reduce energy use in buildings have a net benefit. In other words, they save money. However, only a small percentage of people react 'economically' to these existing financial incentives for installing insulation or energy efficient heating and cooling equipment or appliances. There are many reasons for this seemingly irrational behaviour, which is not so irrational actually. Lack of motivation, lack of time, lack of information, and competing issues that people have to attend to are important. There are also limitations to what individuals can do. People that rent a home or an apartment have only a limited influence on the insulation of the building and the efficiency of the heating and cooling facilities. Scarcity in the housing market often reduces the choices and location is often more important. Figure 7.18 gives an example, based on research in the UK, of willingness and ability to act. When ability is low, attempts to change people's behaviour will of course fail. And when willingness is absent, prospects are not good either.

Willingness and ability are not enough to change behaviour. It is well known that people who say they are very concerned about climate change are not doing all the things they could. So changing behaviour is about creating the additional incentives to turn willingness into action. Information campaigns have traditionally been the preferred instrument to change behaviour. They often were focused on motivating people, in other words increasing their willingness. That explains the limited success of such campaigns. If action is not made easier, behaviour will not really change. There is another complicating factor: consumers are not all the same. There are distinct groups with different values and preferences: environmentally conscious people, trendsetters, rationalists, ill informed followers, conservationists, hedonists, etc. They react differently to campaigns. Effectiveness of behavioural change campaign is also affected by culture. In Japan for instance information campaigns seem to work much better (see Box 7.4).

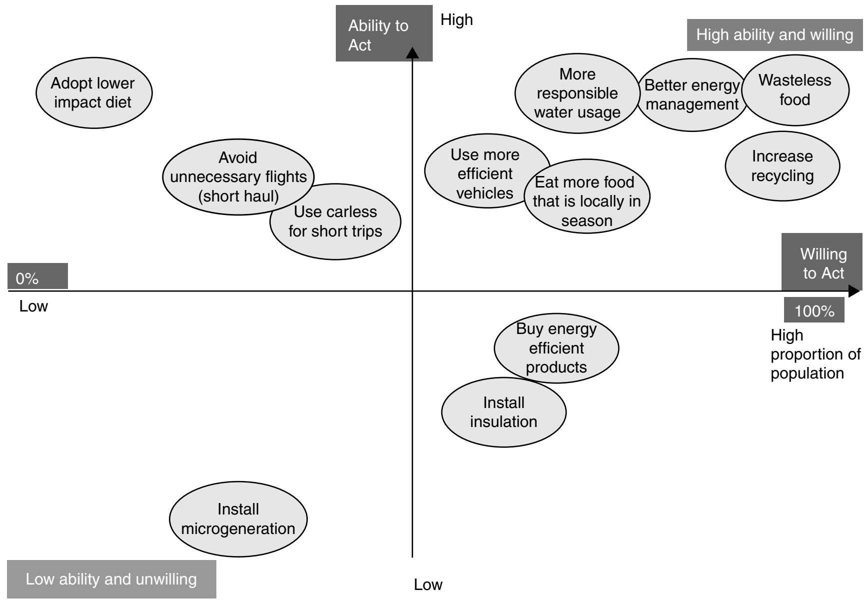

Figure 7.18 **Willingness and ability of people to change environmental behaviour.**
Source: UK DEFRA, A framework for pro-environmental behaviours, January 2008.

An important lesson from research and practice on behavioural change is that 'hard' measures, such as appliance standards, building codes, automatic power off features, bans on certain energy wasting equipment, and things like motion detecting light switches, free compact fluorescent lamps and subsidies on efficient appliances, supported by 'soft' information instruments, work best. In that way information about the need for change is combined with a practical and easy way to actually change behaviour[30].

Box 7.4 **Japan Cool Biz campaign**

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°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, an MOE survey of 562 respondents 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 approximately 460 000 tonnes in 2005, which is equivalent to the amount of CO_2 emitted from about 1 million Japanese households for 1 month. MOE will continue to encourage offices to set air conditioning in offices at 28°C and will continue to promote 'Cool Biz'.

(Source: IPCC Fourth Assessment Report, Working Group III, box 6.5)

How does this all fit together?

Many studies have been performed in specific regions on how much reduction of energy and CO_2 emissions can be realized and at what cost levels. Because studies assume different combinations of measures, different electricity and fuel prices, different economic criteria when calculating cost, and not all regions are adequately covered, only a rough estimate of the global potential can be given. Overall, total emissions can be reduced by about 30% in 2030, compared to what they would have been otherwise, at zero costs or at a profit ('negative costs'). An additional 10% can be reduced for costs up to US$100/tonne CO_2 avoided. Both numbers are an underestimate, because most studies have looked at only a part of the attractive options available and ignored many of the higher cost options since so much can be done at low costs. That corresponds to a minimum of about 4.5 and 5.6 Gtonnes of CO_2 per year by 2030, at zero and US$100/tonne, respectively. These are the reductions achievable for the total building stock. Given the 50–100 year lifetime of buildings a lot of the reductions have to be achieved through retrofitting of existing buildings. For new buildings, about a 75% reduction can be realized, compared with current practice, at little or no extra costs[31]. Accepting 20–30% higher initial costs would bring zero energy buildings within reach as discussed above. Pushing the new construction to very low or zero energy use is needed to bring the overall building emissions down.

The potential differs from region to region. Most of the reductions can be found in developing countries, in light of the expected population growth and the building activity in these countries. Of the total reduction potential developing countries cover about 45%, OECD countries about 35%, and former Soviet Union countries about 20% (a high share compared to the size of the population, caused by a long neglect of energy conservation in these former centrally planned economies).

How to realize this large potential?[32]

With the large potential for reductions at negative cost, the building sector seems to be ideal for realizing energy and CO_2 reductions without specific policy. There is such a strong economic argument, things should happen automatically, shouldn't they? The reality is very different. The savings that can be made are not happening and even with specific policy actions it is extremely difficult to get measures implemented. Why is that?

Barriers

The most important reasons are summarized in Table 7.2. Financial barriers to a large extent have to do with the problem of making higher initial investments acceptable.

Table 7.2 Barriers that hinder the penetration of energy efficient technologies and practices in buildings

Barrier categories	Definition	Examples
Financial costs/benefits	Ratio of investment cost to value of energy savings	Higher upfront costs for more efficient equipment Lack of access to financing Energy subsidies Lack of internalization of environmental, health, 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, lack of awareness, and lifestyle Corruption

Source: IPCC Fourth Assessment Report, Working Group III, table 6.5; *Source Carbon Trust, 2005.*

Individual decisions are often driven by initial capital investment rather than overall costs that include energy costs during the use of the building, lack of financial incentives for delivering excess PV electricity back to the grid, and lack of attractive financing for energy efficiency investments. The relative costs of more energy efficient or renewable energy options are often a disadvantage as a result of low or subsidized (fossil fuel) energy prices.

Hidden costs primarily emerge from uncertainty about the performance and reliability of alternative options, the cost of collecting the necessary information or of getting approval for alternative solutions.

A typical example of a market failure is the so-called ‘split incentive’ situation, where owners/landlords have little incentive to put in additional investment to save energy, while tenants (that have a good incentive) are not in a position to make the investments. Other examples are regulations that prohibit the installation of some energy saving or renewable energy options, or policy priorities to keep rents affordable (meaning limiting the capital investments). It also covers lack of information about energy use, options for reduction and costs, or lack of time to investigate how measures can be taken; this applies to architects, builders, and owners.

Behavioural and institutional barriers include the issues of personal choice and behaviour mentioned above, as well as real world issues such as non-payment and corruption, preventing rational decisions to be made (see above).

Policies

In light of the multitude of barriers it is no surprise that an effective policy to realize energy and CO_2 reduction needs to be based on multiple policy instruments, each addressing specific barriers. For a sector with a large number of decision makers (down to individual home owners or tenants) effectiveness of policy instruments is a function of reaching these decision makers. A package of many different kinds of information, financial incentive, and other measures still would only reach a fraction of these decision makers. In such a situation regulatory approaches are usually the most effective. The most effective are building codes and legislation requiring utilities to invest in energy savings and to pay adequately for electricity delivered back to the grid by decentralized solar PV. They can address a whole range of barriers at the same time[33]. For reducing fluorinated gas emissions from air conditioners and refrigeration regulation is also an effective approach.

Building codes

Building codes come in two different styles: the *prescriptive style* where specific provisions for insulation, windows, and heating/ cooling systems are prescribed; and the *performance style*, where standards for the energy performance of whole buildings are specified, leaving flexibility for architects and builders. The first type is easier to enforce, making it attractive for countries with limited enforcement expertise, but provides no incentive for further improvements. The second allows for optimizing

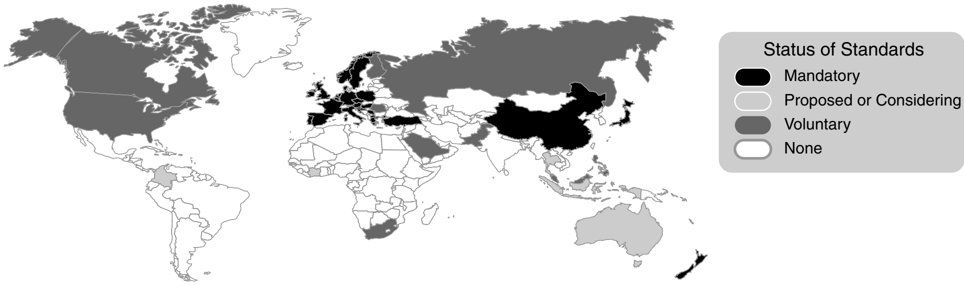

Figure 7.19 **Status of building codes around the world.**
Source: UNEP. Buildings and Climate Change: Status, Challenges and Opportunities, 2007.

design in light of the specific situation and gives more room for introducing new technologies, but requires more sophisticated expertise to ensure compliance.

Building codes are often limited to new buildings, although requirements in relation to remodelling of existing buildings can extend their influence. They also need to be renewed regularly, to adopt the latest developments in building technology, use of renewable energy, and energy savings. And they need to be enforced, which is not always done (see Figure 7.19 and Box 7.5). This is a well-known weak spot. Harmonizing building codes across countries, which is for instance done in the EU, is a very effective way to push possible energy and emission savings.

Box 7.5 **EU Directive on Energy Performance of Buildings**

One of the most advanced and comprehensive pieces of regulation targeted at the improvement of energy efficiency in buildings is the European Union Directive on the Energy Performance of Buildings (European Commission, 2002). The Directive introduces four major actions. The *first action* is the establishment of 'common methodology for calculating the integrated energy performance of buildings', which may be differentiated at the regional level. 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 due to the slow turnover and renovation cycle of buildings, and considering that 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), and in the case of public buildings to require the public display of energy performance certificates. 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'. It is estimated that CO_2 emission reductions to be tapped by implementation of this directive by 2010 are 35–45 million tCO_2-eq at costs below 20EUR/tCO_2-eq, which is 16–20% of the total cost-effective potential associated with buildings at these costs in 2010.

(Source: taken from IPCC Fourth Assessment Report, Working group III, box 6.3)

Demand side management

In the USA, Demand Side Management (DSM) programmes, run by electric utilities, have been very successful. They operate on the basis of regulatory requirements imposed on utilities to first invest in energy savings, before expanding power plant capacity. At first sight that looks to be against the interest of these utilities. Why would they put money into selling less electricity? The crucial element is the rule that energy saving investments can be recovered via the electricity tariffs. So customers pay for it, but less than what they would have paid if investments had been put in new power plants. These programmes are implemented through utility based incentive programmes or direct investments in energy savings in buildings. This policy approach is spreading to other countries now. The UK has introduced the Energy Efficiency Commitment legislation for instance[34].

Appliance standards and labelling

Legally based appliance standards are in place in many countries. The US programme applied in 2004 to 39 residential and commercial products. Experience with this programme is very positive: costs are low (in the order of US$2 per household), and standards are effective (estimated reduction of 10% in 2020 compared to business as usual and more than US$1000 savings per household). Standards can speed up the improvement of energy efficiency, provided they are regularly strengthened. In that respect the Japanese 'Top-Runner' programme is very interesting. Performance of the best-in-class equipment is automatically becoming the standard 3 years later. This is a built-in mechanism to stimulate innovation by companies[35].

Labelling of appliances, heating/cooling and lighting equipment, and whole buildings is becoming quite popular. Figure 7.20 shows how efficiency of refrigerators in the EU improved over time, and how consumer preference shifted. Labels make it easier for people who are motivated to buy an efficient appliance. It does not change behaviour of those who are not sensitive to energy conservation.

Financial incentives

Supplementary policies are needed to take care of barriers that cannot be removed through building codes. The obstacle of higher initial investments, for example, one of

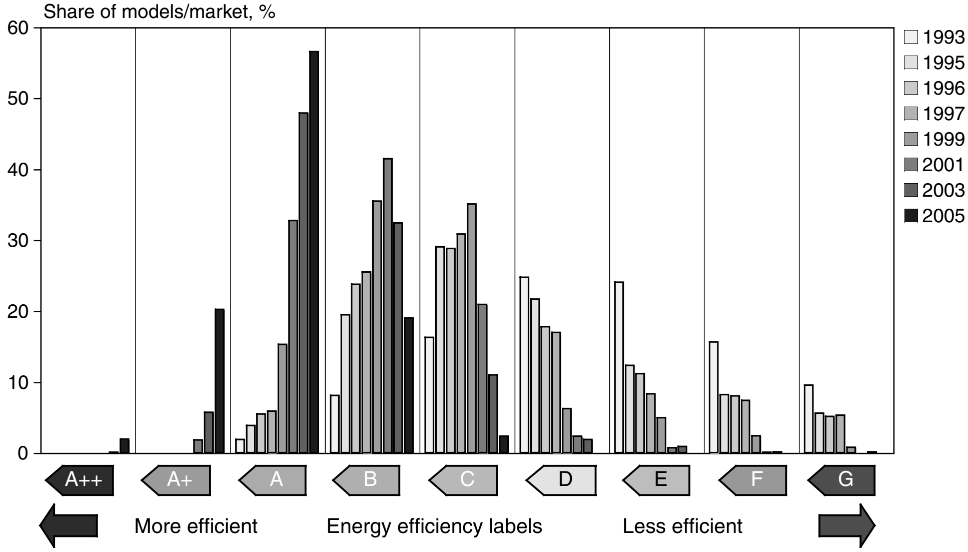

Figure 7.20 **The EU labelling system and the shift in sales of refrigerators over time.**
Source: IPCC, Fourth Assessment Report, Working Group III, figure 6.5.

the more important factors that make people resist strengthening building codes and refraining from cost-effective energy saving measures in existing building. This can effectively be addressed through financial incentives. They can take the form of upfront subsidies (often called rebates), taxes on energy based on the carbon content to make energy and CO_2 savings financially more attractive, or tax deductions (tax credits). All of these are widely used.

Surprisingly, many countries still subsidize fossil fuel based energy. So the first priority should be to remove these subsidies. Given the political sensitivity of removing subsidies, alternative forms of support for poor households, such as installing energy saving features free of charge to lower electricity bills, would be needed.

Feed-in tariffs for solar PV panels, making it attractive to deliver electricity back to the grid, are used in many countries. So-called 'net metering' is becoming popular. If you deliver electricity from a solar PV equipped building back to the grid, the meter turns backwards; meaning you receive as much for a kWh delivered back as for a kWh consumed from the grid (see also Chapter 11).

In several countries low interest mortgages are available for energy saving investments in buildings. Effectiveness of these financial incentive policies varies.

The specific design and the presence of other policies have a large impact on effectiveness. In terms of cost effectiveness caution is warranted. Government expenditures can be in the region of US$30–100 per tonne of CO_2 avoided[36], although the savings by owners and tenants could still make these policies cost effective for the national economy as a whole. Avoiding complex and overlapping incentives helps to make these policies more effective.

Energy Service Companies

A somewhat different approach that is showing good results in the commercial buildings sector is the promotion of so-called Energy Service Companies (ESCOs). These companies contract with businesses to reduce energy consumption and get paid on the basis of achieved results. This is an ideal way to take the burden of energy conservation out of the hands of busy managers of small and medium sized companies and institutions. In the USA the turnover of ESCOs in 2006 was of the order of US$2 billion[37].

The building sector challenge

With an abundance of technical options to reduce greenhouse gas emissions from buildings at low to negative costs, the real challenge is to find effective ways to realize this potential. A tailored approach with a mixture of instruments is needed. But above all the focus of policy should be shifted towards regulatory instruments. These also hold the best opportunities to induce behavioural change, if 'soft' information instruments are closely aligned with and supporting the introduction of 'hard' instruments.

Notes

1. UN Habitat, State of the World's Cities 2008–2009, 2008.
2. http://www.nationmaster.com/graph/peo_per_per_roo-people-persons-per-room.
3. Price et al. Sectoral trends in global energy use and greenhouse gas emissions, LBL, report LBNL-56144, July 2006.
4. See UNEP, Buildings and Climate Change: status, challenges and opportunities, Nairobi, 2007, fig 2.10.
5. IEA, WEO 2006, ch 9.
6. See Earth Trends, Residential energy data 2003; http://earthtrends.wri.org.
7. Tonooka Y et al. Journal of Asian Architecture and Building Engineering, vol 1(1), February 2002, 1–8.
8. See note 4.
9. Here only the emissions of HFCs are included, because other fluorinated gas emissions of CFCs and HCFCs do not fall under the Kyoto Protocol. CFCs and HCFCs are good for 1.3$GtCO_2$eq/year. They are being phased out under the Montreal Protocol however.
10. IPCC Fourth Assessment Report, Working Group III, ch 1 and IEA WEO, 2007.
11. This is different from 'zero net energy' houses, that generate some of their own energy; see section on 'Changing the energy source'.
12. For mid-latitude (40–60 degrees North) regions the 'Passive House standard' is 15kWh/m^2/year maximum energy use for space heating and cooling and 120kWh/m^2/year for all appliances, water heating, and space heating/cooling together, see http://www.passivhaus.org.uk/index.jsp?id=668.

13. see Smith PF. Architecture in a climate of change: a guide to sustainable design, Elsevier, 2nd edition, 2005, page 65.
14. IPCC Fourth Assessment Report, Working Group III, ch 6.4.2.2.
15. IPCC Fourth Assessment Report, Working Group III, ch 6.4.2.3 and 6.4.4.
16. IPCC Fourth Assessment Report, Working Group III, ch 6.4.10.
17. http://www.habitatforhumanity.org.uk/lea_need.htm.
18. See note 4, page 8.
19. See for a detailed description of climate friendly insulation the IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, 2005, chapter 7.
20. IPCC Fourth Assessment Report, Working Group III, ch 6.4.3.
21. In estimates of global CO_2 emissions it is assumed that 90% of traditional biomass is from sustainable sources; this means that 10% of it is not and should be counted when emissions are calculated.
22. IPCC Fourth Assessment Report, Working Group III, ch 6.4.4.3.
23. HCFC-22 is also a greenhouse gas. It has a Global Warming Potential that is slightly higher than that of HFC-134a (the most used replacement). A shift to HFCs therefore does not improve the warming effect of emissions much.
24. See IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System, 2005, chapter 5.
25. IEA, Light's Labour's Lost, 2006 and IPCC Fourth Assessment Report, Working Group III, ch 6.4.9.
26. See UK National Energy Foundation, http://www.nef.org.uk/energysaving/labels.htm.
27. see Renewable Energy Network 21, Renewables 2007 Global Status Report, 2008, www.ren21.net.
28. IEA Solar Heating and Cooling programme, Solar Heat Worldwide, 2008.
29. See http://zeb.buildinggreen.com/.
30. See DEFRA, A framework for pro-environmental behavior, 2008; CE, Energy conservation behavior, 2006; Policy Studies Institute, A green living initiative, http://www.green-alliance.org.uk.
31. IPCC Fourth Assessment Report, Working Group III, ch 6.5.
32. IPCC Fourth Assessment Report, Working Group III, ch 6.7.
33. IPCC Fourth Assessment Report, Working Group III, ch 6.8.
34. IPCC Fourth Assessment Report, Working Group III, ch 6.8.3.1 and 6.8.3.6.
35. Joakim Nordqvist, Evaluation of Japan's Top Runner programme, AID-EE, 2006.
36. IPCC Fourth Assessment Report, Working Group III, ch 6.8.3.3.
37. IPCC Fourth Assessment Report, Working Group III, ch 6.8.3.5.