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This chapter has been allocated 40 template pages, currently it counts 56 pages (excluding this page and the bibliography), so it is **16 pages over target**. Reviewers are kindly asked to indicate where the chapter could be shortened.

Colour explanations

Turquoise highlights are inserted comments from Authors or TSU i.e. [AUTHORS/TSU: …]

Chapter 9: Buildings

Contents

Executive Summary

In 2009 buildings accounted for 32% of total global final energy (IEA, 2012) *[high agreement, robust evidence]*, approximately 30% of total energy related CO_2 emissions (including electricity-related ones) *[high agreement, medium evidence]*, approximately two-thirds of halocarbon *[medium agreement, medium evidence]*, 25–33% of black carbon emissions *[medium agreement, medium evidence]*. The substantial new construction taking place in developing countries represents both a significant risk and opportunity from a mitigation perspective. At the same time, the over 2 billion *[high agreement, medium evidence]* presently not having access to modern energy carriers start using electricity, which determines building-related emission development fundamentally in such countries.

There is a large [29% of 2030 business-as-usual energy use] cost-effective potential for [mitigating GHGs] energy savings in existing and new buildings [throughout the world]. *[high agreement, medium evidence*] Analysis shows that technological improvement replenishes the potential for efficiency improvement, so that the potential for cost-effective energy efficiency improvement has not been diminishing *[medium agreement, robust evidence]*. The technology solutions to realize this potential exist and are well documented. In new construction low-carbon, energy-non-intensive materials with GHG storage capacity, durable and energy-efficient buildings determine indirect emissions fundamentally *[high agreement, robust evidence]*. Recent developments in technology and know-how enable the construction and retrofit of very low- and zero-energy buildings, often at little marginal investment cost, typically paying back well within the building lifetime *[high agreement, robust evidence]*. Passive design [both modern and traditional] offers important cost savings and CO_2 mitigation potentials compared to the use of energy active systems *[high agreement, robust evidence]*. In existing buildings savings are on cost-optimal retrofit solutions for the given functional and architectural characteristics and the location of the building *[high agreement, robust evidence]*. Depending on the design and actual usage, ICT can be both a driver to more energy consumption, as well as an opportunity to optimize and decarbonize other sectors *[high agreement, robust evidence]*. There is positive savings evidence about low-energy buildings, however not about how a large-scale implementation of these can occur, in order to fulfil mitigation potentials *[high agreement, limited evidence]*.

Strong barriers hinder the market uptake of these cost-effective opportunities, and large potentials will remain untapped without strong policies *[medium agreement, robust evidence]*. Market forces are not likely to achieve the necessary transformation fast enough without external stimuli *[medium agreement, robust evidence]*. Policy intervention, plus new business and financial models are essential to overcome first-cost hurdles *[medium agreement, robust evidence]*. There is a broad portfolio of effective policy instruments available to remove these barriers, with many of them being implemented widely also in developing countries saving emissions at large negative costs *[high agreement, robust evidence]*. Overall, the history of energy efficiency programmes in buildings shows that 25-30% efficiency improvements have been available at costs substantially lower than marginal supply *[medium agreement, medium evidence]*. The dynamic development in building-related policies in some developed countries has been demonstrating the effectiveness of such instruments: total energy use trends have turned around to start decreasing in some countries *[high agreement, robust evidence]*. As many new buildings will be added to the stock in developing countries, including energy intensive appliances, adequate building codes and energy requirements on eco-design are necessary to address mitigation objectives *[medium agreement, medium evidence]*. For existing stock, especially in developed nations, energy efficiency measures applied during the process of retrofitting can make it economical *[high agreement, medium evidence]*. Building codes can be enforced with strong energy efficiency requirements, tightened over time and appropriate to local climate conditions *[medium agreement, medium evidence]*. Information on energy performance made public influences the market *[medium agreement, medium evidence]*.

There is no evidence that pricing instruments deliver change in building energy efficiency *[low agreement, limited evidence]* and experience shows that pricing is less effective than programs and regulation *[medium agreement, medium evidence]*. Also, there are financial instruments, policies and other opportunities available to improve the efficiency in buildings, but their results have shown to be still insufficient *[medium agreement, medium evidence]*. Combined, these can provide better results in both improved energy access and promotion of energy efficiency *[medium agreement, medium evidence]*.

Some effective existing policies and especially financial mechanisms take into account the long life times and renovation cycles, for both new and existing buildings *[high agreement, robust evidence]*. Application of conventional practices may lead to locking-in carbon intensive options for several next decades until the next renovation cycle, especially those allied with poor management and inadequate use *[medium agreement, robust evidence]*. For instance, analysis shows that even if today's most ambitious policies in buildings are implemented, approximately 80% of 2005 final building energy use can be "locked in" as compared to a scenario where today's best practice buildings become the standard *[medium agreement, medium evidence]*. In order to provide enough time for the construction industry and market to develop, important factors are the avoided lock-in effect and the promptly enabled ambitious policy frameworks *[high agreement, robust evidence]*. This includes all points of the policy chain including building codes, best practices, adequate low-C materials over lifecycle, management, as well as enforcement *[high agreement, robust evidence]*.

Beyond technologies and architecture, lifestyle has a major effect on energy use (and thus emissions) in buildings potentially causing 3-5 times differences *[high agreement, limited evidence]*. In developed countries, evidence indicates that behaviours informed by awareness of energy and climate issues can reduce demand by up to 20% in the short term and 50% by 2050 *[medium agreement, medium evidence]*. There is a high risk of emerging countries following the same path as developed economies, which may lead to doubling total energy use by world buildings *[medium agreement, medium evidence]*. Alternative development paths that provide high levels of building services at much lower energy inputs, incorporating traditional lifestyles, architecture and construction techniques exist and can help avoiding such trends *[high agreement, robust evidence]*. Behavior and lifestyles can be either guided or influenced with elaborated strategies *[high agreement, medium evidence]*. Better energy indicators include those related to sufficiency and not only efficiency *[high agreement, robust evidence]*. Reducing demand includes meeting needs for space effectively, including promoting density, high space utilization, and efficient occupant behaviors *[high agreement, robust evidence]*.

Beyond the direct energy cost savings, many mitigation options in this sector have significant and diverse co-benefits that offer attractive entry points for mitigation action into policy-making even in countries/jurisdictions where financial resources for mitigation are limited *[high agreement, robust evidence]*. These include, but are not limited to, energy security, air pollution and health benefits; productivity, competitiveness and net employment gains; increased social welfare, alleviated energy and fuel poverty, decreased need for energy subsidies and exposure to energy price volatility risks; increased value for building infrastructure, improved comfort and services *[high agreement, medium evidence]*. These often substantially exceed the climate and energy benefits but are rarely recognised as such and thus internalised by policies *[medium agreement, medium evidence]*. There are tools to quantify and monetize co-benefits e.g. proper lifecycle accounting; however without more integration into the decision-making processes such effects are not realized *[high agreement, medium evidence]*.

In a holistic approach the whole lifespan of the building is considered, and includes master planning, life cycle analysis, and integrated building design to obtain the broadest impact possible in the building industry, although misinformation and simplified techniques are risks to this understanding *[high agreement, robust evidence]*. Actions in the buildings sector are presently fragmented, requiring more standardization and uniformization *[high agreement, robust evidence]*. To this end, an improved and more comprehensive database on real building energy use is an important tool *[high agreement, robust evidence]*. Continuous monitoring and dynamic modification of performance and dynamic of codes allows catching up with efficiency improvements and co-benefits *[high agreement, robust evidence]*. There was an impressive strengthening of energy provisions of building codes in the last 10 years; significant further strengthening is planned or contemplated *[medium agreement, robust evidence]*. Delivering low-carbon options raises major challenges for education, capacity building and training *[high agreement, robust evidence]*.

The chapter, in harmony with the whole AR5, uses emission decomposition by identities as the main organising framework. According to this framework, *mitigation options* include (i) *carbon efficiency*, e.g. Building integrated renewable energy systems (BiRES); (ii) *energy efficiency of technology*, e.g. high-performance building envelope (HPE), efficient appliances (EA), efficient lighting (EL), efficient HVAC systems (eHVAC); (iii) *system and infrastructure efficiency* e.g. passive house standard (PHS), nearly/net zero energy buildings (NZEB), integrated Design Process (IDP), urban planning (UP), district heating/cooling (DH/C), commissioning (C) and (iv) *service demand reduction* e.g. behavioural change (BC) and lifestyle change (LSC).

Indicative potentials for carbon efficiency are of 29% CO_2 cost-effective emissions of 2030 BAU (AR4). For System/ (infrastructure) efficiency, there are figures for PHS (cca 70-80% energy savings per building compared to energy use before retrofit (9.3.3.2), NZEB (up to 80%/bldg. compared to energy use before retrofit (9.3.3.5), and IDP (potential of 70% of 2050 baseline (Table 9.6.1) *[medium agreement, medium evidence]*

In terms of *associated direct costs*, can be cited (i) for carbon efficiency, BiRES entails : technology and installation costs; for (ii) for system/ (infrastructure) efficiency, PHS has: 8% compared to standard houses (9.3.3.2), IDP has large savings at low cost (9.3.3.3) and DH/C has infrastructure costs, for both retrofit & new; and (iii) for service demand reduction (BC), there are administrative costs of programmes & awareness campaigns. *[high agreement, medium evidence]*

Concerning *co-benefits, co-risks and co-costs*, are to mention reduction of air pollution (NZEB), increased value for building infrastructure and property premium (HPE, CB), the lock-in effect (CR), energy security, net employment gains, social welfare, lower fuel poverty, lower need for energy subsidies, lower exposure to energy price volatility risks, health benefits, productivity, comfort (PHS, CB) and misinformation through simplified techniques (CR) *[medium agreement, medium evidence]*

Policies cover a wide range of options in carbon efficiency (carbon tax, carbon cap & trade); energy efficiency of technology (building codes, preferential loans, grants, ESCOs, EPCs, MEPS, suppliers' obligations, white certificates, energy tax, public procurement); system/ (infrastructure) efficiency (e.g. Incorporating Integrated Design Process into Urban Planning); and service demand reduction (awareness raising, education, energy audits, energy labelling, building certificates & ratings) *[high agreement, robust evidence]*.

The identity decomposition Chapter 9 chooses to apply for assessing the literature rests on the general identity framework described in Chapter 6. Building-related emissions and mitigation strategies have been decomposed by different identity logics. Commonly used decompositions include into CO_2 intensity, energy intensity, structural changes and economic activity (Isaac and Van Vuuren, 2009a; Zhang et al., 2009) as well as the IPAT (Income-Population-Affluence-Technology) approach(MacKellar et al., 1995; O' Mahony et al., 2012) have used the factors CE – carbon coefficient; FS – fossil fuel substitution effect; RE – renewable energy penetration effect; EIR – residential intensity effect; HN – household number effect, and after finding that the most significant effect in recent decades in Ireland was from the intensity effect, subdivided EIR further into to thermal performance (Cint) and other forms of technological replacement (Cffse) and (Crepe). In this assessment, the review focuses on the main decomposition logic described in Chapter 6, adopted and further decomposed into four key identities to drive emissions:

$$CO_2 emissions = CI * TEI * SEI * A$$

Where CO_2 are the emissions from the building sector; CI is the carbon intensity; TEI is the technological energy intensity; SEI is the structural\systemic energy intensity and A is the activity. For a more precise interpretation of the factors, the following conceptual equation demonstrates the different components:

$$CO_2 = \frac{CO_2}{FE} * \frac{FE}{UsefulE} * \frac{UsefulE}{ES} * \frac{ES}{pop} * pop$$

in which UsefulE is the useful energy for a particular energy service (ES), as occurring in the energy conversion chain, and pop is population (GDP is often used as the main decomposition factor for commercial building emissions). Because ES is often difficult to rigorously define, and UsefulE and ES are either difficult to measure or little data are available, this chapter does not attempt a systematic quantitative decomposition, but rather focuses on the main strategic categories for mitigation based on the equation:

$$CO_2 mitigation \approx CarbonEfficiency \times TechnologicalEfficiency \times \\ Systemic/InfrastruralEfficiency \times DemandReduction$$

whereby carbon efficiency entails fuel switch to low-carbon fuels, building-integrated renewable energy sources and other supply-side decarbonisation; technological efficiency focuses on the efficiency improvement of individual energy-using devices; systemic/infrastructural efficiency encompass all efficiency improvements whereby several energy-using devices are involved, i.e. systemic efficiency gains are made, or energy use reductions due to architectural, infrastructural and systemic measures; finally, demand reduction composes of all measures that are beyond technological efficiency and decarbonisation measures: impacts on floorspace, service levels, behaviour, lifestyle, use and penetration of different appliances, etc. The four main emission drivers and mitigation strategies can be further decomposed into these more distinct sub-strategies, but due to the limited space in this report and in order to maintain a structure that supports convenient comparison between different sectoral chapters, we focus on these four main identities during the assessment of literature in this chapter and this decomposition serves as the main organising/conceptual framework for Chapter 9. Table 9.1 summarises the main findings of the chapter by these four main identities.

Table 9.1: Summary of the chapter's main findings organised by major mitigation strategies (identities)

	Carbon efficiency	Energy efficiency of technology	System/ (infrastructure) efficiency	Service demand reduction
Mitigation options	Building integrated RES (BiRES)	High-performance building envelope (HPE) Efficient appliances (EA) Efficient lighting (EL) Efficient HVAC systems (eHVAC)	Passive house standard (PHS) Nearly/net zero energy buildings (NZEB) Integrated Design Process (IDP) Urban planning (UP) District heating/cooling (DH/C) Commissioning (C)	Behavioural change (BC) Lifestyle change (LSC)
Potential (indicative)	Cost-effective potential of 29% CO_2 emissions of 2030 BAU (AR4)		PHS: cca 70-80% energy savings/bldg. compared to energy use before retrofit (9.3.3.2) NZEB: up to 80%/bldg. compared to energy use before retrofit (9.3.3.5) IDP: potential of 70% of 2050 baseline (Table 9.6.1)	
Potential (illustrative examples)	Roof built solar HW panels: 68% of 2011 energy demand (ES, Table 9.6.1)	HPE: 29% energy savings relative to 2005 (T:ES; Garrido-Soriano et.al. 2012) EL/com.: 50% of 2009 energy demand (Northern Europe; Table 9.6.1) EA/res.,com.: 35% of 2030 baseline energy use (China; Table 9.6.1) EHVAC, EL, EA, HPE: 50% CO_2 reduction relative to 2005 (UK; Table 9.6.1)	NZEB-retrofit/res.: multi-story 90% heating energy use reduction, single family houses up to 75% (DK; 9.3.4.1) NZEB-retrofit/com.: expected 75% reduction in energy intensity (U.S.; 9.3.4.2) NZEB-retrofit/new & old: potential of IDP 43% of 2050 baseline, with changes in UP & infrastructure of 54% of 2050 baseline (US; Table 9.6.1) NZEB-new/res.: 65% of 2050 baseline energy use (CH;Table 9.6.1)	BC: developed countries: 20% energy demand reduction by 2030 and 50% by 2050 (9.3.7.7) BC/res.: recommendations from home energy audits: 21% energy savings p.a. (LT; Table 9.6.1) LSC/res.: energy savings 44% p.a. (LT; Table 9.6.1)
Associated direct costs	BiRES: technology and installation cost		PHS: 8% compared to standard houses (9.3.3.2) IDP: large savings at low cost (9.3.3.3) DH/C: infrastructure costs, retrofit & new	BC: administrative costs of programmes & awareness campaigns
Cost-effectiveness: illustrative best practices			NZB-retrofit/res.: 95% savings in heating energy with a payback of 16.9 years (N. America; 9.3.4.1) NZEB-retrofit/multi-res: 93% reduction at payback 20ys (DE; 9.3.4.1)	
Co-benefits, co-risks, co-costs	NZEB: reduction of air pollution	HPE: CB: increased value for building infrastructure, property premium CR: lock-in effect	PHS: CB: energy security, net employment gains, social welfare, lower fuel poverty, lower need for energy subsidies, lower exposure to energy price volatility risks, health benefits, productivity, comfort	CR: misinformation: simplified techniques
Policies	Carbon tax, carbon cap & trade	Building codes, preferential loans, grants, ESCOs, EPCs, MEPS, suppliers' obligations, white certificates, energy tax, public procurement	e.g. Incorporating Integrated Design Process into Urban Planning	Awareness raising, education, energy audits, energy labelling, building certificates & ratings

9.1 Introduction and organising framework

The purpose of this chapter is to update the knowledge on the sector from a mitigation perspective since AR4. The chapter uses a novel conceptual framework, in line with the general analytical framework of AR5 – focusing on identities as an organizing principle.

9.1.1 Summary of AR4 and what's new

AR4 (Levine et al., 2007) has alerted to the fact that the building sector can make significant contributions to the transformation pathways for stabilising climate change.A wide variety of options can save between a half and three-fourths of individual building-related energy use in each climate.While major and numerous barriers hinder the deployment of these solutions, a broad portfolio of policy instruments and packages have demonstrated to successfully and very cost-effectively reduce emissions. Many scenarios indicate that the proliferation of such policies could reduce building global final energy consumption by up to 40% as compared 2010 despite the increases in amenities and floorspace. Since the AR4, recent advances in IT, design, construction and operation know-how have opened new opportunities for a transformative change in building-sector related emissions at socially acceptable costs, or often benefits that can contribute to meeting ambitious climate targets. Building design and activities in buildings are responsible for a significant share of GHG emissions, but these are also be key to mitigation strategies. In 2009, the building sector accounted for approximately 125 EJ or 32% of global final energy consumption and 30% of energy-related CO_2 emissions; 23% of global primary energy use; 30% of global electricity consumption, and approximately 30% of global energy-related CO_2 emissions including electricity-related ones, plus F-gas emissions. The chapter argues that beyond a large emission role, mitigation opportunities in this sector are large, often very cost-effective, and are often associated with significant co-benefits that can exceed the direct benefits by orders of magnitude. The sector has significant mitigation potentials at low or even negative costs. Nevertheless, without strong actions emissions are likely to grow considerably due to several drivers. Specific policies have been effective, several new ones are emerging. The significance of co-benefits has made them increasingly entry points to policymaking.

9.2 New developments in emission trends and drivers

9.2.1 Energy and GHG emissions from buildings

In 2009 buildings accounted for 32% of total global final energy use (IEA, 2012) , being one of the largest end-use sector worldwide as shows Figure 9.1. Figure 9.2 shows the energy use by region and building subsector (residential or commercial). The buildings sector accounted for approximately 30% of total energy related CO_2 emissions (including electricity-related ones) (IEA, 2012), around two-thirds of halocarbon, and 25–33% of black carbon emissions (GEA, 2012).

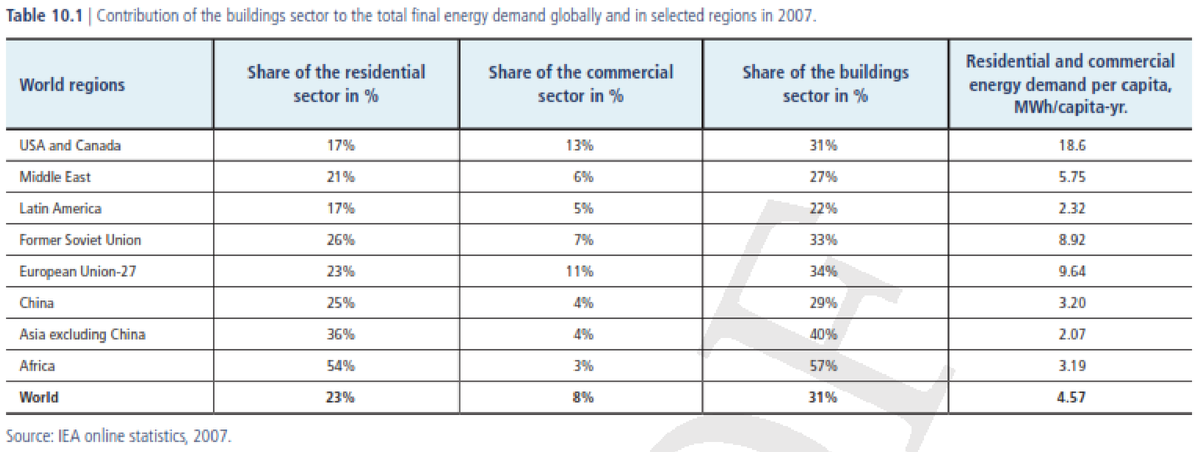

Table 10.1 | Contribution of the buildings sector to the total final energy demand globally and in selected regions in 2007.

World regions	Share of the residential sector in %	Share of the commercial sector in %	Share of the buildings sector in %	Residential and commercial energy demand per capita, MWh/capita-yr.
USA and Canada	17%	13%	31%	18.6
Middle East	21%	6%	27%	5.75
Latin America	17%	5%	22%	2.32
Former Soviet Union	26%	7%	33%	8.92
European Union-27	23%	11%	34%	9.64
China	25%	4%	29%	3.20
Asia excluding China	36%	4%	40%	2.07
Africa	54%	3%	57%	3.19
World	**23%**	**8%**	**31%**	**4.57**

Source: IEA online statistics, 2007.

Figure 9.1 [AUTHORS:This table will be updated from new IEA data and converted into a figure]
Source of this table: (Ürge-Vorsatz, 2012a; GEA, 2012).

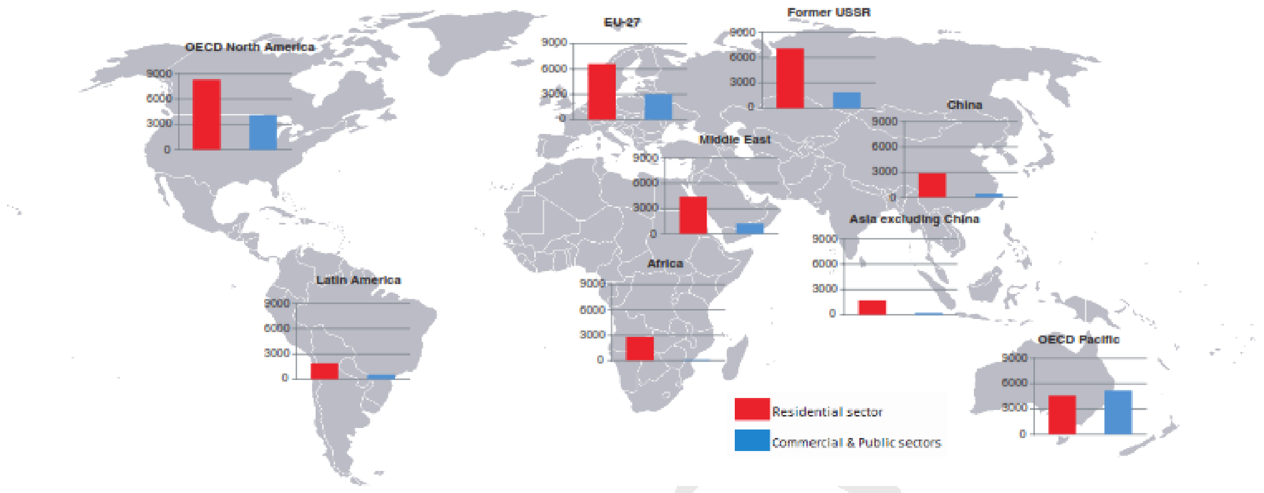

Figure 10.4 | Total annual final energy use in the residential and commercial/public sectors, building energy use per capita by region and building type in 2007 (kWh/capita/yr). Source: data from IEA Online Statistics, 2007.

Figure 9.2 Final energy use in the building sub-sectors by region, year 2007 [AUTHORS: WILL BE UPDATED WIT IEA DATA]. Figure originally from (Ürge-Vorsatz, 2012a; GEA, 2012)

According to IEA data and estimates, energy consumption in the buildings sector has steadily increased, particularly in the residential sector of developing countries, and such trends are likely to continue, as shows (Figure 9.3), driven by growth in population, and increasing demand for building services and comfort levels .

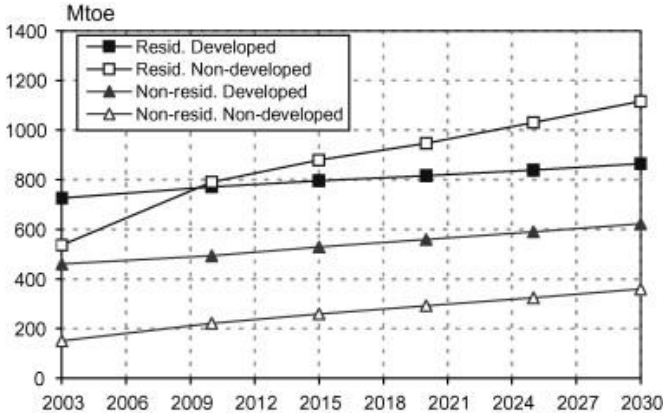

Figure 9.3 World trends in total final energy consumption in the buildings sector, from IEA data (Pérez-Lombard et al., 2008).

9.2.2 Building energy use trends by end-use and building types

Total energy use in buildings is determined by two major factors: the total scale of buildings and the intensity of energy use within them.

9.2.2.1 The total scale of buildings

The usual metrics of scale are the number of residential units and the floor area of non-residential buildings (commercial buildings and public buildings) (Scrase, 2000; Adnot, 2002; Chan, 2004; US EERE, 2011). For the first, (Table 9.2) shows the differences amongst countries related to number of households and their growth rate in the first half of the last decade.

Table 9.2: Households trends in selected countries. .(HSS, 2001; UNHSP, 2005)

Countries	Number of Households (million)		Growth Rate (%/yr)
	2000	2005	
China	360	405	2.4
India	185	209	2.5
US	107	119	2.1
Japan	48	51	1.2
Brazil	45	51	2.5
Germany	35	36	0.6
France	24	25	0.8
South Africa	12	17	7.2
Canadá	9	13	7.6
Colombia	8,7	10	2.8
Kenya	7,2	8,7	3.9
Australia	7	8	2.7
Sudan	3,3	3,8	2.9
Switzerland	3	3,3	1.9
Zimbabwe	2,9	3,5	3.8
Israel	1,6	1,8	2.4
Bolivia	1,6	1,7	1.2

As populations grow, keeping same or having better living standards imply increasing demand for energy services in buildings. Figure 9.4 shows the variation between countries in floor area per capita.

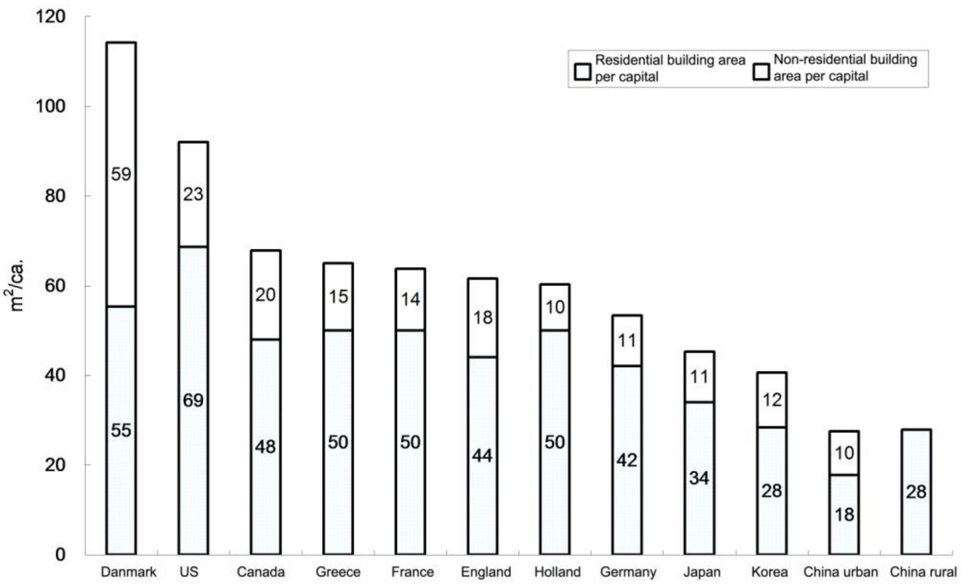

Figure 9.4. Building area per capita (ECEEE, 2011)

Household's average occupancy has overall declined between years 2000 and 2005 (Figure **9.5**). Average OECD occupancy in the residential sector dropped from 2.9 in 2006 to 2.6 in 2009 (IEA, 2012) . Increasing the space and hours of air conditioning is an important driver of energy consumption in several regions, as reported by (Zhang, Jiang, et al., 2010)and N. Zhou et al. (2008).The projected increase in building's energy use for 2050 is driven by a 67% rise in the number of households and a near tripling of the service sector building area (WEO, 2011).

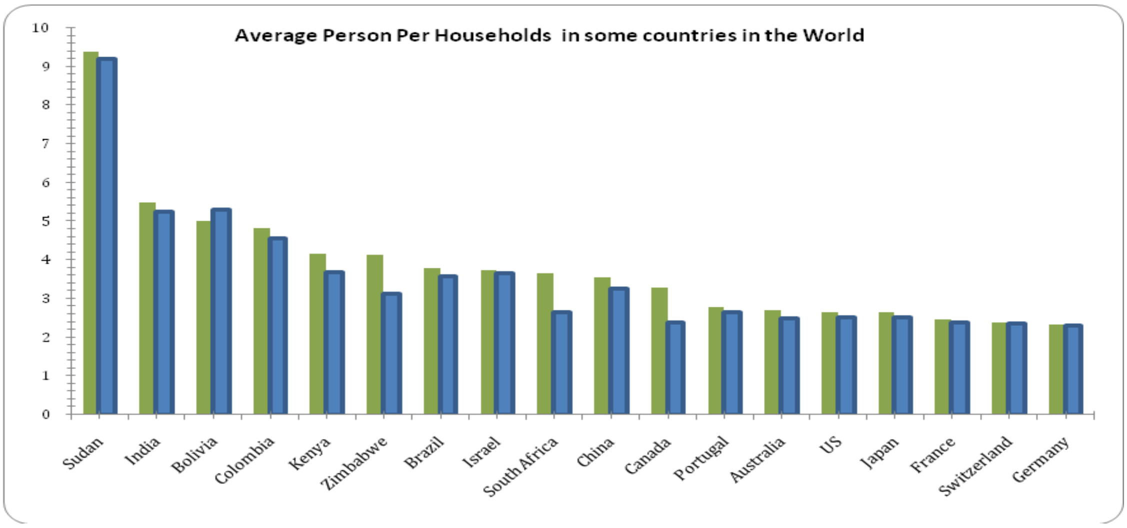

Figure 9.5 Average number of persons for each residential unit. (UNHSP, 2009)

Around one third of the urban population in developing countries in 2010 did not have access to adequate housing, living in slums (UNHSP, 2010). Although the proportion of the urban population living in slums in the developing world has been declining in the last decade (39% in 2000 to 32% in 2010), in absolute terms the numbers of slum dwellers have grown (6 million per annum) and will probably continue to rise in the near future (UN-Habitat, 2011), Providing affordable and efficient housing in developing countries imposes an urgent challenge, which can be addressed by improving affordable sustainable housing technologies (Wallbaum et al., 2012).

9.2.2.2 The intensity of energy used by buildings

The level of development is a major influence on energy consumption in buildings. (WBCSD, 2009) . Energy intensity for residential buildings (per capita) for selected countries shows a wide variation between regions, as shown in Figure 9.6. Similarly, a variation is also found in Figure 9.7, for residential and commercial buildings in terms of specific consumption (energy per floor area).

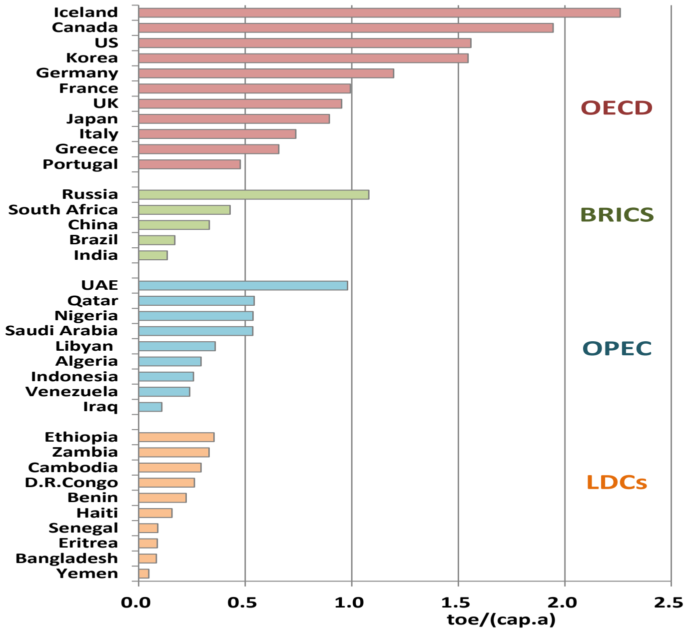

Figure 9.6 Building energy consumption per capita in 2008 (IEAS, 2011)

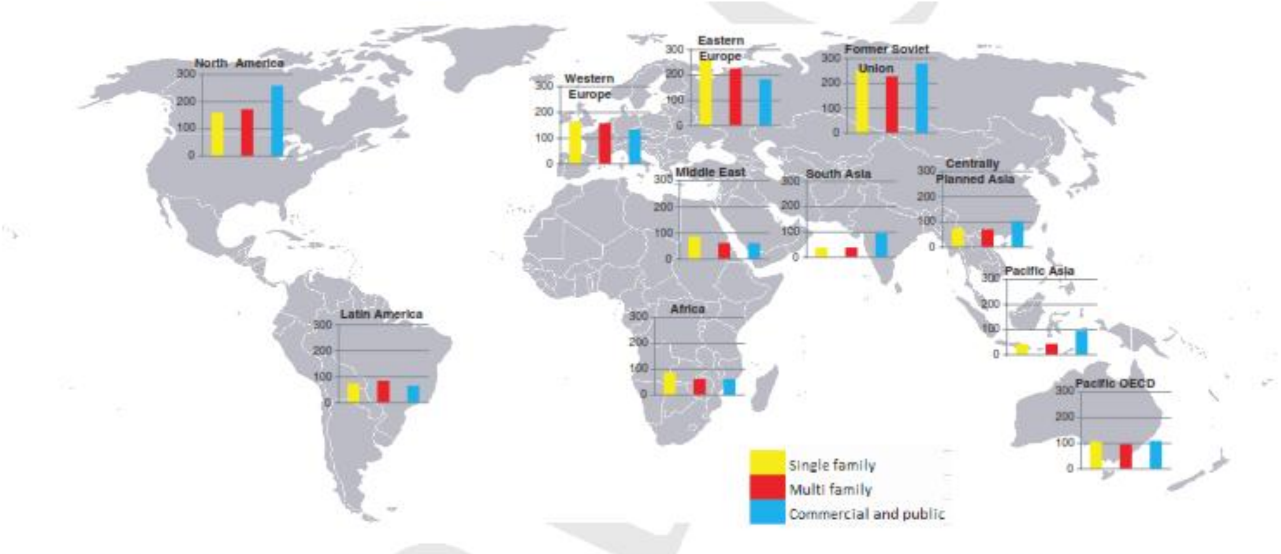

Figure 10.5 | Final heating and cooling specific energy consumption by region and building type in 2005 (kWh/m²/yr). Source: Model estimations (see Section 10.7).

Figure 9.7. Title, same as from source (Ürge-Vorsatz, 2012a; GEA, 2012)

An expected increase in buildings energy use is also driven by higher ownership rates for existing energy-consuming devices and increasing demand for new types of energy services. With the improvement of building energy performance, the ratio of energy consumption for building system and appliances to total energy consumption of the building is increasing. Although their lifetime is shorter than the building, building system and appliances also have lock-in effect in certain amount, being thus important to choose best practice technologies (IEA 2010b) .

9.2.3 Drivers of building-originated emissions

Increasing the space and hours of end-use energy demand (Section 9.3.8) are important drivers of energy consumption (Zhou et al., 2008; Zhang, Jiang, et al., 2010) and, therefore, of building originated emissions. By 2050, emissions from the building sector, including those associated with electricity use, willcould nearly double from 8.1 Gt to 15.2 Gt CO_2according IEA Energy Technology Perspective reference scenario (IEA, 2010). The increase in emissions will mostly come from the developing world, especially from Asia, Middle East/North Africa and Latin America (Levine et al., 2007).

9.2.3.1 Urbanization and economic activity

Rapid economic development, accompanied by urbanization, is propelling huge building activity in developing countries (WBCSD, 2007), which will concentrate most of the expected urban population growth in the coming decades. China and India together projected to account for a third of the increase in the urban population (WBCSD, 2009). Buildings in urban areas account for 70% of the total final building energy consumption, despite the fact that the rural population is still larger with as high values as 82% for the US (Ürge-Vorsatz et al. 2012). With increasing urbanization this trend continues: 85% of growth in building energy use until 2050 may come from urban areas, 70% of it from developing country cities. As a result, new building is dominated by developing countries, which 5% growth rate compares with 1% in developed countries. In some developing countries the growth rate is even higher. For example in India floor area doubled between 2000 and 2005 (WBCSD, 2007). More than half of the world's new construction since 2007 was taking place in Asia and almost half in China alone (ABC, 2008) , which was adding 2 billion square meters a year (Li and Colombier, 2009), compared to a stock of 40 billion square meters. This is equivalent to twice the existing office building stock in the USA or equivalent to adding the complete Japan building area every 3 to 4 years (WBCSD, 2009). Most of the new floor area is in large commercial office buildings and mixed use development. This presents both a huge opportunity and an equally large challenge in terms of emissions. The impact of urbanization on emissions is positive for all the income groups, but it is more pronounced in the middle-income group than in the other income groups (WBCSD, 2007)

9.2.3.2 Access to energy and fuel type

Figure 9.8 shows the global buildings energy system. Such totals do not show, however, huge inequalities. The sources of energy used in buildings vary greatly between regions. Worldwide, biomass, electricity and natural gas are the main energy sources (Jennings et al., 2011; IEA, 2012) (Figure 9.9). Addressing access to clean, reliable and affordable modern energy services in the context of a fast growing building activity in emerging and developing countries, imposes an urgent challenge to substantially improve energy efficiency and reduce emissions in new buildings. Development and urbanization are associated with increased electricity use, which will significantly increase primary energy demand in emerging countries (US EERE 2011), (WBCSD 2006), and therefore emissions where electricity is carbon intensive. Providing energy to the more than 1 billion people without access to electricity (Pachauri 2012), as well as to the 2.7 billion people, nearly 40% of humanity (Hailu 2012), who do not have clean cooking facilities is one of the world's most critical development challenges. The ways these energy services are provided will significantly determine building-related emissions, since energy sources and technologies vary greatly between regions (WBCSD 2006).

Figure 9.8. Energy consumption in the building sector worldwide, year 2009 (IEAS, 2011)

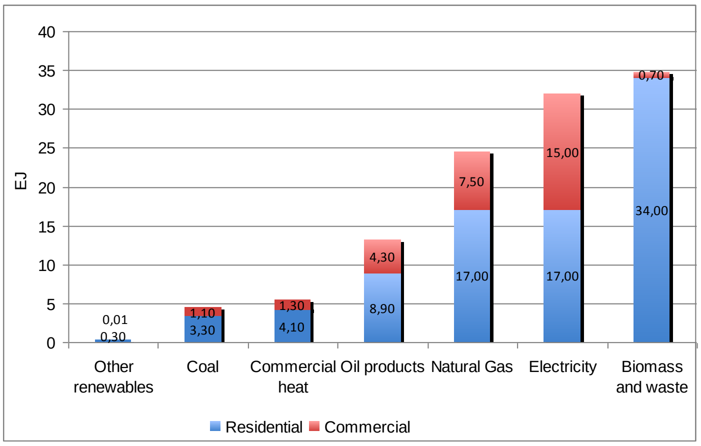

Figure 9.9. Final energy use by fuel in buildings sector, 2009 (IEA ETP 2012 data)

9.2.4 Different Challenges

The structure of the building sectors are markedly different in the developed and developing countries, with the OECD countries faced with tackling emissions from existing buildings whilst rapidly expanding economies such as China and India must deal with increasing numbers and areas of buildings(Jennings et al., 2011). In OECD countries, the rate of new construction is low. Annual new building constitutes about 1% of housing stock. In Europe, residential buildings built since 1996 only account 0.6% - 16% of the total (Eurostat, 2011)and the energy performance of existing buildings is poor in most cases. Retrofit of existing buildings is an important strategy for developed stocks. In contrast, in fast growing developing countries (such as China, India and Brazil) most buildings have been built since the 1990s. In China, for example, more than 90% of buildings have been built since 1996. Energy standards and energy use in new buildings is therefore critical in these countries. Regarding end-services, an important case to mention is *tourism*, both in the context of buildings (e.g. impacts in the local environment) and accommodation (in many cases with wasteful water and energy usage, plus construction materials with different life cycles)[1].

9.3 Mitigation technology options and practices, behavioural aspects

9.3.1 Key points from AR4

AR4 (Levine et al., 2007) contains an extensive discussion of the wide range of technical and design measures that can be taken to reduce the energy use of new buildings. AR4 emphasized that the

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[1] For Tourism, see also Chapters 5 and 12

energy use of buildings depends to a significant extent on how the various energy-using devices (pumps, motors, fans, heaters, chillers, and so on) are put together as systems, rather than depending primarily on the efficiencies of the individual devices. The savings opportunities at the system level are generally many times what can be achieved at the device level, and these system-level savings can often be achieved at a net investment-cost savings (see also (Harvey, 2008). A 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. However, the conventional process of designing a building is a largely linear process, in which the architect makes a number of design decisions with little or no consideration of their energy implications, and then passes on the design to the engineers, who are supposed to make the building habitable through mechanical systems. The design of mechanical systems is also largely a linear process with, in some cases, system components specified without yet having all of the information needed in order to design an efficient system (Lewis, 2004). This is not to say that there is no integration or teamwork in the traditional design process, but rather, that the integration is not normally directed toward minimizing total energy use through an iterative modification of a number of alternative initial designs and concepts so as to optimize the design as a whole. (Montanya et al., 2009) provide a particularly enlightening example of the iterative process that is needed with regard to one particular low-energy feature - underfloor air distribution.) As discussed in AR4, the essential steps in the design of low-energy buildings are: (i) to consider building orientation, form, thermal mass; (ii) to specify a high-performance building envelope; (iii) to maximize passive heating, cooling, ventilation, and day-lighting; (iv) to install efficient systems to meet remaining loads; (v) to ensure that individual energy-using devices are as efficient as possible, and properly sized; and (vi) to ensure the systems and devices are properly commissioned. By focusing on building form and a high-performance envelope, heating and cooling loads are minimized, daylighting opportunities are maximized, and mechanical systems can be greatly downsized. This generates cost savings that can offset the additional cost of a high-performance envelope and the additional cost of installing premium (high-efficiency) equipment throughout the building. 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%. AR4 also briefly reviewed the technical potential for energy savings through comprehensive retrofits of existing buildings. The various case studies and analyses reviewed in AR4 indicate that retrofits should be able to routinely achieve savings in total energy use of 25-70%.

9.3.2 Significant technological developments since AR4

There have been no major technological developments since AR4, although there have been incremental improvements in the performance and reductions in the cost of several technologies, and further significant improvements are foreseen (as reviewed by (Dubois and Blomsterberg, 2011) for lighting; (Bansal et al., 2011) for household appliances (Baetens et al., 2011; Korjenic et al., 2011; Jelle, 2011) for insulation materials; and (Chua et al., 2010) for heat pumps). Rather, the main developments have been related to the increasing application of existing knowledge and technologies, both in new buildings and in the retrofitting of existing buildings. This has been driven in part by targeted demonstration programs in a number of countries, and has been accompanied by an impressive strengthening of the energy provisions of the building codes in many countries and plans for significant further tightening of building codes in the near future (see Section 9.11.2). In the following sections we review the literature published largely since AR4 concerning the energy intensity and cost of low-energy new buildings and of deep retrofits of existing buildings. The interested reader can refer to AR4 and recent textbooks (i.e., (Harvey, 2006)**)** for an in-depth discussion of how, in technical terms, deep reductions in building energy use are achieved.

9.3.3 Exemplary New Buildings

A brief overview of studies published since AR4 was finalized is presented here, while a more detailed review and analysis can be found in (Harvey, 2013).

9.3.3.1 Energy intensity of high-performance buildings

Case studies based on measured energy use

There is a growing catalogue of buildings of all types and from diverse regions and climates where measured energy intensities are several times lower than those of recently completed local buildings. Examples from Germany, the UK and the US are provided in Table 9.3. Achieved savings range from 25-85% compared to recent new construction.

Table 9.3: Examples of energy savings achieved in new high-performance buildings compared to recent practice for new buildings. Energy use is measured energy use unless indicated otherwise.

Case	**Total on-site energy intensity**	**Savings**	**Baseline**	**Source**
11 non-residential buildings in the German *Research for Energy Optimized Construction* (EnOB) program	30-65 kWh/m^2/yr	75-85%	Average of new construction and retrofits	(Kalz et al., 2009)
9 passively cooled buildings in Germany	25-55 kWh/m^2/yr	Factor of 3-5	Conventional (175 kWh/m^2/yr)	(Voss et al., 2007)
21 passively cooled buildings in Germany	55-110 kWh/m^2/yr	Factor of 2-3		
6 US high-performance buildings	~ 100 kWh/m^2/yr	25-62%	Simulated minimally code-compliant version of each building	(Torcellini et al., 2006)
As above + improved electrical lighting, daylighting, overhang shading, orientation	92 kWh/m^2/yr (simulated)	(65% savings)		
UK, good practice mechanically-ventilated	175-186 kWh/m^2/yr	40-45%	Conventional new office buildings (300-300 kWh/m^2/yr)	(Walker et al., 2007)
UK, naturally ventilated	127-145 kWh/m^2/yr	55-65%		

The Passivhaus standard (a heating requirement of less than 15 kWh/m^2/yr, compared to 60-100 kWh/m^2/yr for new residential buildings in Germany) was originally developed for residential buildings, and over 20,000 buildings in central Europe have meet this standard. The Passive House standard had captured 7% of the market share for new houses in Upper Austria by 2006, while low-energy houses (having a heating requirement of ≤ 30 kWh/m^2/yr) captured another 79% (Laustsen, in print). It has also been achieved by many different kinds of commercial, institutional and educational buildings in Europe (as reviewed in (Harvey, 2013). With insulation levels that meet the Passive House standard for heat demand in southwestern Europe (Portugal, Spain, southern France, Italy), comfortable summer conditions can be maintained through a combination of daytime ventilation with heat recovery, night ventilation with cool air that bypasses the heat exchanger, exterior shading, and cooling and dehumidification of the supply air as needed. The result is a reduction in heating loads by a factor of 6-12 (100-200 kWh/m^2/yr to 10-15 kWh/m^2/yr) and in cooling loads be factor of 10 (from < 30 kWh/m^2/yr to < 3 kWh/m^2/yr) (Schneiders et al., 2009).

9.3.3.2 Simulation studies

Complementing the case studies of measured performance in real buildings are simulation studies in which the energy uses of a base case or reference building are simulated with a detailed computer model, then the effect of various alterations to the design is estimated. In the US, the National Renewable Energy Laboratory (NREL) extracted the key energy-related parameters from a sample of

5375 buildings in the 1999 *Commercial Buildings Energy Consumption Survey*, and then used energy models to simulate their energy performance (Torcellini and Crawley, 2006). The results of this exercise are: (i) average total energy use as built is 266 kWh/m^2/yr; (ii) average energy use if complying with the ASHRAE 90.1-2004 standard is 157 kWh/m^2/yr, a savings of 41%; (iii) average energy use would be 92 kWh/m^2/yr with improved electrical lighting, daylight, overhangs for shading and elongation of the buildings along an east-west axis (applicable only to new buildings) (a savings of 65%). (Huovila and UNEP, 2009) simulated the energy use for reference residential and commercial buildings, and for buildings with modest improvements in the thermal envelope and in the heating and cooling systems in New York, New Delhi, Beijing and Madrid. Heating savings range from 85-100%, cooling energy savings range from 50-60% and the lighting savings is 75%. Other simulations of office buildings in Malaysia (Kumar et al., 2005), Beijing (Zhen et al., 2005), London (Jenkins et al., 2009) and Atlanta (Wasserman, 2008), and of a school in Tel Aviv (Perez and Capeluto, 2009) indicate the potential for savings in total energy use of 60-70% through relatively simple measures. (Garde et al., 2011) present building simulation results indicating that a total energy use of no more than 50 kWh/m^2/yr can be easily achieved for most 2- or 3-story buildings on the French tropical island of La Reunion.

9.3.3.3 Importance of post-occupancy evaluation to energy savings

Advanced building control systems are a key to obtaining very low energy intensities in commercial buildings. It routinely takes over one year (one complete heating and cooling season) to adjust the control systems so that they deliver the expected savings, and it sometimes takes two years (Jacobson et al., 2009). This is only possible through detailed monitoring of energy use once the building is occupied.

9.3.3.4 Zero energy/carbon and energy plus buildings

Net zero energy buildings (NEBs) refer to buildings with on-site renewable energy systems (either PV or wind turbines) that, over the year, generate as much energy (in the form of electricity) as consumed by the building in all forms. NZEBs can be defined in terms of a net balance of on-site energy, or in terms of a net balance of primary energy associated with fuels used by the building and avoided through the net export of electricity to the power grid (Marszal et al., 2011). (Musall et al., 2010) identify almost 300 net zero or almost net zero energy buildings, both commercial and residential. There have also been some NZE retrofits of existing buildings. Some jurisdictions have adopted legislation requiring some portion of, or all, new buildings to be NZEBs by specific times in the future (Kapsalaki and Leal, 2011). An extension of the NZEB concept is the Positive-Energy Building Concept (having net energy production) and their role in a two-way interaction with the electricity grid (Stylianou, 2011; Kolokotsa et al., 2011). Issues related to NZEBs include (i) the feasibility of NZEBs, (ii) minimizing the cost of attaining an NZEB, where feasible, (iii) the cost of a least-cost NZEB in comparison with the cost of supplying a building's residual energy needs (after implementing energy efficiency measures) from off-site renewable energy sources, (iv) the sustainability of NZEBs, and (v) life-cycle energy use. Creation of a NZEB at minimal cost requires implementing energy saving measures in the building in order of increasing cost up to the point where the next energy savings measure would cost more than the cost of on-site renewable energy systems. In approximately one third of NZEBs worldwide, the reduction in energy use compared to local conventional buildings is about 60% (Musall et al., 2010). Attaining net zero energy use is easiest in buildings with a large roof area (to host PV arrays) in relation to the building's energy demand, so a requirement that buildings be NZE will place a limit on the allowed height and therefore on urban density. In Abu Dhabi, NZE is possible in buildings of up to 5 stories if internal heat gains and lighting and HVAC loads are aggressively reduced (Duncan Phillips et al., 2009). Space heating and service hot water has been supplied in NZEBs either through heat pumps (supplemented with electric resistance heating on rare occasions), biomass boilers, or fossil fuel-powered boilers, furnaces, or cogeneration. An NZEB in which on-site fossil fuel use is offset through PV electricity that displaces central power-plant fossil fuel use is not truly sustainable, given limitations on fossil fuel supplies, and would not result in zero net greenhouse gas emissions once the electricity grid is decarbonized. If space heating is to be supplied through electric heat pumps, than reductions in heating loads not only reduce the required size of the heat pump by reducing the peak heating loads, but also allow the heat pump to operate more efficiently (with coefficients of performance (COP) - of up to 5 for ground source heat pumps in Germany (DEE, 2011), thereby reducing the size of the PV array needed to supply sufficient electricity to offset the heat pump electricity use. (Torcellini and Crawley, 2006) report that adding PV to 50% of the roof area in the sample of 5375 buildings from CBECS (Section 9.3.3.1) reduces the net energy demand (after implementation of the energy efficiency measures discussed in Section 9.3.3.1) from 92 kWh/m^2/yr to 49 kWh/m^2/yr. However, with further technical improvements in building efficiency, the commercial building stock in the US as a whole could become a net source of energy. In this scenario, almost all single story buildings could be a NZEB, but only about 50% of 2-story and 10% of 3-story buildings would be NZEBs.

9.3.4 Retrofits of existing buildings

9.3.4.1 Residential building retrofit case studies

Various studies in Europe and North America, summarized in Table 9.4, indicate that comprehensive retrofits of residential buildings can reduce on-site heating energy requirements by 25-90%[2]. Almost half of the more than 120 projects in the database are expected (based on computer simulations) to reduce measured total pre-retrofit primary energy use by a factor of 2-4 and almost half are expected to reduce total primary energy use by a factor of 4-10 (see summary in (Harvey, 2013) (measurement of actual post-retrofit energy use is currently underway).

Table 9.4: Estimates of the potential reduction in energy use of existing residential buildings through retrofits

Building type and location	Change in energy use or savings	Economics	Reference
Belgium	55-60%, heating energy		(Verbeeck and Hens, 2005)
1960s multi-story, Denmark	90%, heating energy	30-year payback	(Tommerup and Svendsen, 2006)
1960s single-family detached, Denmark	75%, heating energy	30-year payback	
Single-family detached, Denmark	Heating energy intensity from 140 kWh//m^2/yr to 40 kWh//m^2/yr	30-year payback for one case studied in detail	(Dyrbøl et al., 2005)
Block of flats, Denmark	Heating energy intensity from 140 kWh//m^2/yr to 20 kWh//m^2/yr	Or here?	
Pre-1948, Switzerland	Total [TSU: To be confirmed in SOD whether this is the total] energy intensity from 700 kWh//m^2/yr to 320 kWh//m^2/yr	Profitable if heating fuel \$0.80/litre (1 SF/litre)	(Amstalden et al., 2007)
1948-1975, Switzerland	50%, total?	Profitable if heating fuel \$0.80/litre	

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[2] A database of buildings that have been retrofitted in the UK is being assembled at www.retrofitforthefuture.org.

Building type and location	Change in energy use or savings	Economics	Reference
		(1 SF/litre)	
1950s apartments, German	Heating energy intensity from 380 kWh//m^2/yr to 26 kWh//m^2/yr	This is the upgrade that is calculated to be economically optimal	(Bastian, 2009)
1970s apartments, Toronto	Heating energy intensity from 203 kWh//m^2/yr to 9.4 kWh//m^2/yr	17-year simple payback time	(Kesik and Saleff, 2009) [check final version]

The German EnOB program, mentioned earlier with regard to high-performance new buildings, has also carried out many demonstrations of deep energy savings in retrofits of existing buildings. Figure 9.10 compares the measured or calculated heating, plus DHW (domestic hot water) energy intensity before and after renovations of 12 different buildings (representing 12 different building types)[3].

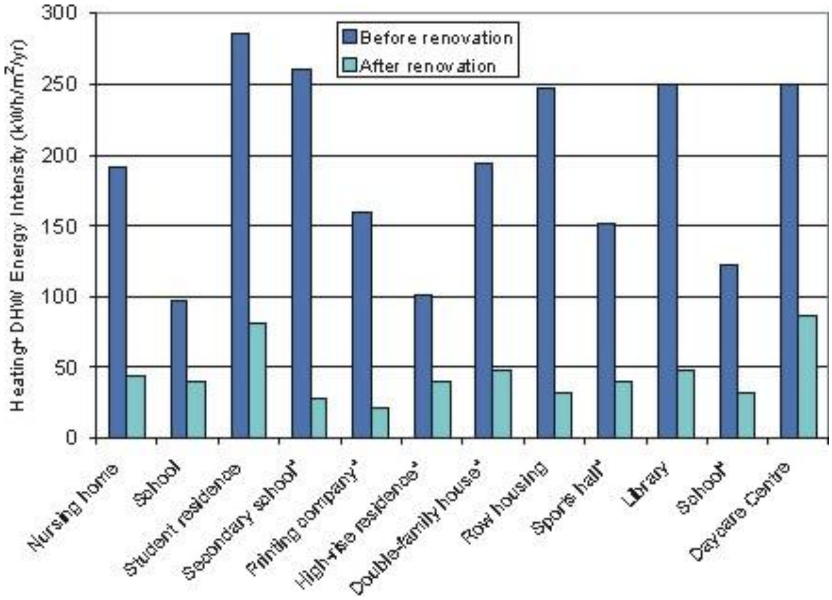

Figure 9.10. Comparison of measured heating plus DHW energy use before and after retrofits as part of the German EnOB program, except for buildings marked with (*), where the energy use is calculated rather than measured and is heating energy only. Source: EnOB website, www.enob.info/en

9.3.4.2 Commercial building retrofit case studies

There are now many examples worldwide of retrofits of commercial buildings that have achieved 50-80% reductions in energy use. A few such examples, and additional examples of savings based on computer simulations, are:

- Average realized savings of 68% in natural gas use after conversion of 10 US schools from non-condensing boilers producing low pressure steam to condensing boilers producing low temperature hot water, and an average savings of 49% after conversion of 10 other US schools from high- to low-temperature hot water and from non-condensing to condensing boilers (Durkin, 2006);

- Projected savings of 36-77% through retrofits of a variety of office types in a variety of European climates (Dascalaki and Santamouris, 2002; Hestnes and Kofoed, 2002) ;

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[3] Further information can be found on the EnOB website (www.enob.info/en)

- Projected savings of 48% from a typical 1980s office building in Turkey through simple upgrades to mechanical systems and replacing existing windows with low-emittance (low-e) windows having shading devices, with an overall payback economic payback of about 6 years (Çakmanus, 2007); and
- Projected savings of 30-60% in cooling loads in an existing Los Angeles office building simply by operating the existing HVAC system in a manner so as to make maximum use of night cooling opportunities (Armstrong et al., 2006a).
- A retrofit planned for the Sears Tower in Chicago (built during the 1970s) that is expected to reduce electricity use by 80% (Anonymous, 2009).
- The renovation of the 18-story General Services Administration Byron Rogers building in Denver, which is expected to reduce the energy intensity from 375 kWh/m^2/yr to 81 kWh/m^2/yr (RMI, 2011) – a reduction of 78%.

A significant potential area for reduced energy use in existing buildings is through replacement of existing curtainwalls, or upgrades of existing insulation and windows. Recently, the curtainwalls were replaced on the 24-story 1952 Unilever building (Lever House) in Manhattan[4] so there seems to be no major technical problems in undertaking complete curtainwall replacements on high-rise office buildings. The BRITA in PuBs (Bringing Retrofit Innovation to Application in Public Buildings[5]) project involves an exemplary retrofit of 8 demonstration public buildings in 4 different regions of Europe (Thomsen et al., 2009). Reductions in total energy use of 60% have been achieved. (Hart et al., 2011) report on the results of a survey of over 300 rooftop HVAC units in the US. They estimate, through hourly simulations, that a comprehensive set of control-system retrofits would produce HVAC savings of 30-48% (i.e., without changing the equipment itself). For large retail facilities in the US southwest, (Bourne et al., 2008) used a calibrated simulation model of a real store with packaged roof-top HVAC units (RTUs) to investigate the impact of various feasible retrofits for existing buildings and system changes (such as the incorporation of radiant cooling) in new buildings.

9.3.4.3 Assessments of national and regional potential savings from retrofits

Studies for the European Mineral Wool Manufacturers Association (EURIMA) by The Dutch consulting firm Ecofys indicate that it is cost-effective over a 30-year time horizon to reduce the heating energy consumption in old buildings in western Europe (EU-15) by more than 50%, and by 60-80% in new countries of the EU-27 (Petersdorff et al., 2005a, 2005) (using rather conservative assumptions concerning the future cost of energy). Further analyses by (Boermans and Petersdorff, 2007) show that the insulation measures consistent with achieving an 85% reduction in heating energy use are similar to the set of measures that minimizes total costs over a 30-year period. (Waide et al., 2006) estimated a savings potential of 70-80% and simple cost payback times of 3-16 years for various countries in Europe.

9.3.5 Affordable low-energy housing

The previous case studies of high-performance buildings assume that mechanical heating, cooling, and ventilation systems are provided as needed in order to maintain building temperatures and humidities within acceptable ranges, although allowance is made for adaptive thermal comfort standards and the installed systems have been greatly downsized through the attention to passive building design features and provision of a high-performance thermal envelope. However, in many parts of the world, such systems – especially for housing – are not affordable. The goal then is to use principles of low-energy design to provide comfortable conditions as much of the time, thereby reducing the pressure to later install energy-intensive cooling equipment such as air conditioners. These principles are embedded in vernacular designs throughout the world, which evolved over

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[4] see http://www.som.com/content.cfm/lever_house_curtain_wall_replacement

[5] http://www.brita-in-pubs.eu

centuries in the absence of mechanical heating and cooling systems. For example, vernacular housing in Vietnam tested by (Nguyen et al., 2011) experienced conditions warmer than 31°C only 6% of the time. In the hot-humid regions of Brazil, an airflow > 0.8 m/s is sufficient for a temperature of 31°C to be deemed acceptable by 90% of respondents (Cândido et al., 2011). The natural and passive control system of traditional housing in Kerala (India) maintains bedroom temperatures of 23-29°C as outdoor temperatures vary from 17-36°C on a diurnal time scale (Dili et al., 2010). However, to promote vernacular architecture, it is necessary to consider the cultural and convenience factors and perceptions concerning “modern” approaches, as well as the environmental performance, that influence the decision to adopt or abandon vernacular approaches(Foruzanmehr and Vellinga, 2011). It may also be the case that modern knowledge and techniques can be used to improve vernacular designs.

9.3.6 Energy Management Systems and Control

Both new and existing buildings can be made more energy-efficient using a combination of best design and technical solutions. Implementing integrated controls, in new and existing buildings, can cut energy use by more than half (NEEA, 2011). Energy Management and Control Systems (EMCS) in a building integrates the operation of various local controls through a computerized supervisory monitoring and control system and a control network. EMCS also allows real-time monitoring and analysis of various systems for a more intelligent and efficient operation of the building. Advances in control and communications have resulted in large-scale implementation of digital-control-based technologies in both commercial and residential buildings. However, many of these technologies are not utilized to their fullest potentials. For example, while EMCS in commercial buildings are utilized to control the operation of the systems (e.g., lighting and HVAC), their applications are primarily used for scheduling of the operation of the zones and systems. Also, most cooling and heating of the zones are controlled by individual direct control systems through thermostat settings. Predictive and adaptive control algorithms for a building and the optimal operation of its systems (HVAC, lighting, DHW and others) are not yet widely applied. Furthermore, advances in daylighting and its effect on cooling and heating energy uses require an integrated control through building automation. In addition, the energy use and historical trend information from EMCSs are not used for more ‘optimal’ operation of buildings. Many researchers have investigated the use of existing EMCS for collecting data optimal operation of buildings. In several case studies, researchers have investigated the capabilities of in-place EMCSs for remote monitoring of building energy performance; for utility-sponsored real-time electricity pricing programs; and for building retrofit performance monitoring (Heinemeier and Akbari, 1992a, 1992c, 1992b, 1987, 1990). Based on this research, (Heinemeier and Akbari, 1992c) proposed guidelines for using EMCSs for performance monitoring. These studies continued to investigate technologies and interface requirements for various utility-sponsored programs such as demand response program (Piette et al., 2005a, 2005b, 2006; Motegi et al., 2006; Bushby and Holmberg, 2009). Researchers have also documented the potential of integrated control algorithms for optimal and operation of buildings, modellings and eventual problems associated with controls and direct digital control systems(Braun and Lee; Armstrong et al., 2006a, 2006b; Ardehali et al., 2003; Henze and Liu, 2004; Zhou et al., 2005; Olesen et al., 2006; Xu and Haves, 2006; Braun, 2007; Lawrence and Braun, 2007; Miyajima et al., 2007).

Further research is needed to build on the existing literature and advance the field by examining the actual performance of a few test building; analyze the results to provide feedback to the building operations; develop integrated control algorithms that can be installed in building EMCS; and evaluate techniques for an integrated building-utility systems operation through a utility-initiated demand response program. The research should also focus on development of adaptive controls for optimal operation of systems. Adaptive controls are very useful for setting control loops and setpoints based on historical performance of the building and its systems.

9.3.7 Building materials lifecycle

Research published since AR4 confirms that the total life-cycle energy use of low-energy buildings is less than that of conventional buildings, in spite of greater embodied energy in the materials and energy efficiency features. Building lifecycle includes their GHG footprint, including non- CO_2 gases such as methane and nitrous oxide from combustion processes, fluorinated gases from cooling and refrigeration, fire extinguishing systems and insulation expansion agents.(Energy Star, 2011, Ireland EPA, 2010) A wide review on Life Cycle Assessment (LCA), life cycle energy analysis (LCEA) and Material Flow Analysis (MFA) in buildings (conventional and traditional) can be found in (Cabeza et al., 2013) , a study that found different classifications, both for buildings and the construction industry. In Switzerland, (Citherlet and Defaux, 2007) find that the life cycle energy of a low-energy use with PV and solar hot water is about half that of a house meeting the Swiss Minergie standard, which in turn is about two-thirds that of a conventional house. In Sweden, Karlsson and Moshfegh (2007) find that a low-energy house, while having 40% greater embodied energy, requires 40% less total energy over a 50-year period than a conventional Swedish house. Sartori and Hestnes (2007) find that a house built to the Passive House standard uses significantly less energy on a life-cycle basis than any alternative. (Ramesh et al., 2010)show, based on 73 case studies across 13 countries, that lower operating energy use is consistently associated with lower life cycle energy use. Recent research also confirms that wood-based wall systems entail 10-20% less embodied energy than concrete systems (Upton et al., 2008; Sathre and Gustavsson, 2009) and that concrete-framed buildings entail less embodied energy than steel-framed buildings(Xing et al., 2008). Pre-fabrication of wood frame modules can reduce wood waste by 20-40%, with a corresponding reduction in embodied energy (Monahan and Powell, 2011). Insulation materials entail a wide range of embodied energy per unit volume, and the time required to pay back the energy cost of successive increments insulation through heating energy savings increases as more insulation is added. However, this marginal payback time is less than the expected lifespan of insulation (50 years) even as the insulation level is increased to that required to meet the Passive House standard (Harvey, 2007). The use of phase-change materials is also beneficial on a life-cycle basis (de Gracia et al., 2010; Castell et al., 2012). The embodied energy of biomass-based insulation products is not lower than that of many non-biomass insulation products when the energy value of the biomass feedstock is accounted for, but is less if an energy credit can be given for incineration with cogeneration of electricity and heat, assuming the insulation is extracted during demolition of the building at the end of its life(Ardente et al., 2008).

9.3.8 Behavioural aspects: changing consumption patterns and lifestyles

Chapter 2 discusses behavioural aspects, in a broader sense. In buildings, lifestyle has a major effect on energy use (and thus emissions) beyond technologies and architecture. Changing lifestyles due to increased income tend to result in higher energy use as people aspire to higher levels of comfort and different lifestyles (WBCSD 2006). In India, China, South East Asia, Subsaharan Africa and Brazil, cooking is currently the main end-use function, but others such as space heating, cooling and appliances are becoming more important (Daioglou et al., 2012). These trends towards greater use effects currently overwhelm technical improvements. Buildings with state-of-the -art systems may have higher energy use than normal buildings, as the lifestyle they allow and promote increases energy use. Figure 9.11 shows that emerging economies like China have different consumption level benchmarks from developed nations.

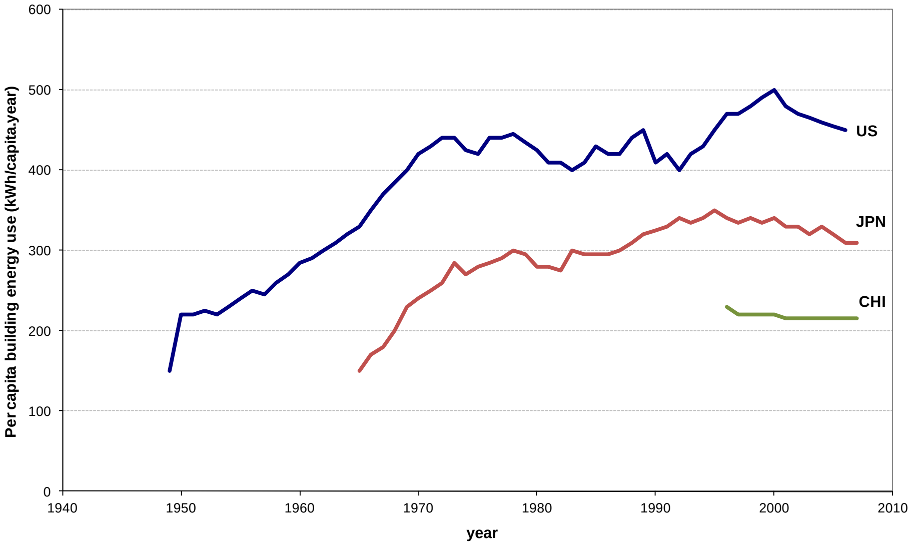

Figure 9.11. Per capita building final energy use in the US, Japan and China urban average (Ürge-Vorsatz, 2012a; GEA, 2012)

9.4 Infrastructure and systemic perspectives

9.4.1 Urban Form and human settlement

Land use planning influences greenhouse gas emissions in several ways (see Chapter 12), including through the energy consumption of buildings. More compact urban form tends to reduce consumption due to lower per capita floor areas, reduced building surface to volume ratio, increased shading, better passive cooling and more opportunities for district heating and cooling systems (Ürge-Vorsatz, 2012b).

9.4.2 Energy infrastructure

Energy using activities in buildings and their energy supply networks co-evolve. Whilst the structure of the building itself is key to the amount of energy consumed, the energy supply networks largely determine the energy vector used, and therefore the carbon intensity of supply. This section therefore focuses on the interaction of buildings with the wider energy infrastructure, and its implications for use of lower carbon fuels.

9.4.3 Heating and Cooling infrastructure

Heating and cooling networks facilitate mitigation where they allow the use of higher efficiency systems (notably cogeneration and trigeneration) or the use of waste heat or lower carbon fuels (e.g. solar heat and wastes) than can be used cost effectively at the scale of the individual building. High efficiency distributed energy systems, such as gas engine cogeneration and solid oxide fuel cells generate electricity more efficiently then centralized power plant. Distributed energy resources of this type may become increasingly important in new smart energy systems, as there is more use of intermittent supplies and new loads, such as electric heating and electric vehicles (see 9.4.2.2). District energy systems differ between climate zones. The large-scale district heating systems traditionally adopted in cold-climate cities, such as in northern Europe and the north of China, predominantly provide for space heating in winter and domestic hot water throughout the year. There are also some recent examples that utilize non-fossil heat sources, notably waste incineration (Holmgren, 2006). In regions with cold winters and hot summers, district energy systems can deliver both heating and cooling, usually at city block scale, and primarily to commercial buildings. Energy savings of 30% can be achieved through systems utilizing trigeneration, load levelling, thermal storage, highly-efficient refrigeration, and advanced management (Nagota et al., 2008). Larger benefits are possible by using waste heat from incineration plants (Shimoda et al., 1998) and from heat pumps that use seawater (Song et al., 2007), river water and wastewater. In addition to energy saving, district energy systems can give other benefits, including mitigating heat island effects, less air pollution, improved urban energy security, and better aesthetics in the urban landscape (Kuzuki et al., 2010). Despite their energy saving benefits, fossil fuel-fired district heating systems cannot alone deliver very low carbon buildings. In very-low energy buildings, heating loads are predominantly hot water, and the high capital and maintenance costs of district heating infrastructure may be uneconomic (Thyholt and Hestnes, 2008; Persson and Werner, 2011). The literature is therefore presently divided on the usefulness of district heating in very low energy building infrastructures.

9.4.3.1 *Electricity infrastructure*

Electricity grid infrastructure is ubiquitous in the developed world. Universal access to electricity remains a key development goal in developing countries. Its implications for energy demand and greenhouse gas emissions will depend on the generation fuels, generation efficiency (including cogeneration and trigeneration) and efficiency of use. Electricity is the dominant fuel for cooling and appliances, but heating energy use for heating is dominated by direct use of fossil fuels in most countries. Electrification of heating can therefore be a mitigation measure, depending on the levels of electricity decarbonisation and end use efficiency. Heat pumps may be important as a technology to facilitate this benefit as they allow electrification to be a mitigation technology at much lower levels of electricity decarbonisation (Lowe, 2007), and therefore earlier in the decarbonisation process. Ground source heat pumps already have a high market share in some countries with low cost electricity and, by current standards, efficient buildings, e.g. Sweden, Switzerland and Austria (IEA HPG, 2010). There is a growing market for low-cost air source heat pumps in mid-latitude countries, notably Italy and France (Singh, Muetze, et al., 2010)., New Zealand(Howden-Chapman et al., 2009), some regions of China (Cai et al., 2009) and Japan. In many cases the attraction is that there are not pre-existing whole house heating systems and that air source heat pumps can provide both heating and cooling. Underground thermal energy storage (UTES) plays a big role in improving energy efficiency of ground source heat pumps, allowing seasonal storage (Sanner et al., 2003). A review of a number of scenario studies indicates heating electrification may have a key role in energy system decarbonisation (Sugiyama, 2012) with heat pumps usually assumed to be the preferred electric heating technology (IEA, 2010). However, this implies a major technology shift from direct combustion of fossil fuels in the heating systems of buildings. Use of electricity, even at high efficiency, for heating will increase winter peak demand(Cockroft and Kelly, 2006) with implications for generation and distribution capacity that have not been fully assessed. There are challenges in retrofitting to buildings not designed for heating with low temperature systems (Fawcett, 2011). Both these factors imply that demand reduction may be required to make large scale electrification of heat feasible (Eyre, 2011). However, the viability of a high cost heating system in a low energy building is problematic. The literature therefore remains unclear on the scale of electrification of heating as a mitigation option. Electricity infrastructure will increasingly use information technology. Smart meters provide better information and therefore can facilitate demand reduction, but they also facilitate smart grids via demand response. This can lead to mitigation directly through the use of lower carbon off peak electricity. It may be critical for the effective operation of electricity systems with high levels of intermittent supply (Sims et al., 2011). Thermal energy storage technologies could become important as means of storing energy in regions with electricity systems using high levels of intermittent renewable energy, as well as for taking advantage of annual and diurnal temperature variations to reduce heating/cooling loads. The use of storage in a building can smooth temperature fluctuation. Thermal energy storage in buildings can be implemented by sensible heat (increasing and decreasing the temperature of the building envelopes, for example), or by latent heat (with the inclusion of phase change materials – PCM – to increase thermal inertia). Latent storage can be used for heating and for cooling of buildings, and it can be incorporated as a passive system or also in active systems (Cabeza et al., 2011) . More recently, thermochemical energy storage is being studied as a good tool to achieve seasonal solar energy storage (Freire Gonzalez, 2010).Storage can therefore play a major role in improving load factors, and therefore for reducing heating and cooling system size, which will be particularly important if heating is electrified. Changing fuels and energy supply infrastructure to buildings will be needed even with the major demand reductions outlined in 9.3.Some studies show that considerable electrification of heating will be needed, but this raises some challenges that need to be considered in design and refurbishment. Significant energy demand reduction remains critical, both directly as a mitigation option and to facilitate moving to lower carbon supplies.

9.4.3.2 Gas infrastructure

Gas supply infrastructure is, at present, critical to building energy systems for heating and cooking in many countries. Reduction of heat demand (see section 9.3) and increased use of heat networks and/or electrification (see section 9.4.2.2) are likely to reduce gas demand and the need for gas infrastructure. In principle, the gas grid can be decarbonised using either hydrogen (Anderson and Leach, 2004) or biogas (Lantz et al., 2007). However, there is little analysis of the feasibility or detailed implications of these possible changes.

9.4.4 Infrastructure costs

The costs of energy infrastructure systems represent a relatively high fraction of the costs of energy services in buildings. Much lower energy buildings offer the potential for some reduction in infrastructure cost. However, this potential will not automatically be realized as infrastructure is frequently over-sized. Improved design and commissioning procedures may be required to ensure infrastructure is sized to meet the needs of efficient buildings. Changing infrastructure within the existing built environment has higher costs than installation in new buildings – hence the economic barriers identified above to moving to low carbon vectors in low energy buildings.

9.4.5 Path Dependencies and lock-in

Buildings and their energy supply infrastructure are some of the longest lived components of the economy, and therefore lock-in is a key issue for both. Building lifetimes vary from a few decades to centuries; the major retrofit cycle of buildings is typically 20 to 50 years; and the lifetime of electricity, gas and heat infrastructure is similar. This means that buildings constructed and retrofitted in the next few years/decades will dominate the emissions of the building sector for many decades, without major opportunities for change, and that it will take decades to capture the large potentials indicated in this chapter. Therefore it is crucial that when a major retrofit or new construction takes place it applies the state-of-the-art performance levels discussed in section 9.3, and that building codes adopt these ambitious levels as soon as possible. Without aiming at these achievable high performance levels, even the fully implemented most ambitious policy trends in the building sector today will leave the world on a significantly increasing building energy use path instead it going down(Ürge-Vorsatz, 2012c). Literature acknowledges that the building sector is particularly prone to lock-in, with the relevant industries favoring incremental change over radical technological advances (Bergman et al., 2008), traditionally low levels of innovation, mass production from large suppliers, separation of design from construction (Rohracher, 2001) and generally high inertia (Brown and Vergragt, 2008). Therefore, the transformational change that is needed for a major reduction in building energy use will not take place without strong policy efforts. Sunk costs of district heating, in particular, can be a disincentive to investments in very-low energy buildings, therefore major investments in new, or retrofitting of existing, district heating systems need to be carefully weighed against the alternatives of high-performance building retrofit investments. There are few quantitative estimates of the size of the lock-in effect. The Global Energy Assessment and updated research (Ürge-Vorsatz, 2012a; c) find that by 2050 the size of the lock-in risk is equal to almost 80% of 2005 global building heating and cooling final energy use (see Figure 9.12). This represents the gap between a scenario in which today's best cost-effective practices in new construction and retrofits (such as building codes) become standard after a transitional period, and a scenario in which energy-efficient new construction and retrofits are encouraged by policies, but to levels of building energy performance that are only consistent with today's policy ambitions rather than demonstrated and feasible best practice. The size of the lock-in risk varies significantly by region: for instance, in South-East Asia (including India) the lock-in risk is over 200% of 2005 final heating and cooling energy use; although even the ambitious scenario projects a major increase in thermal energy use.

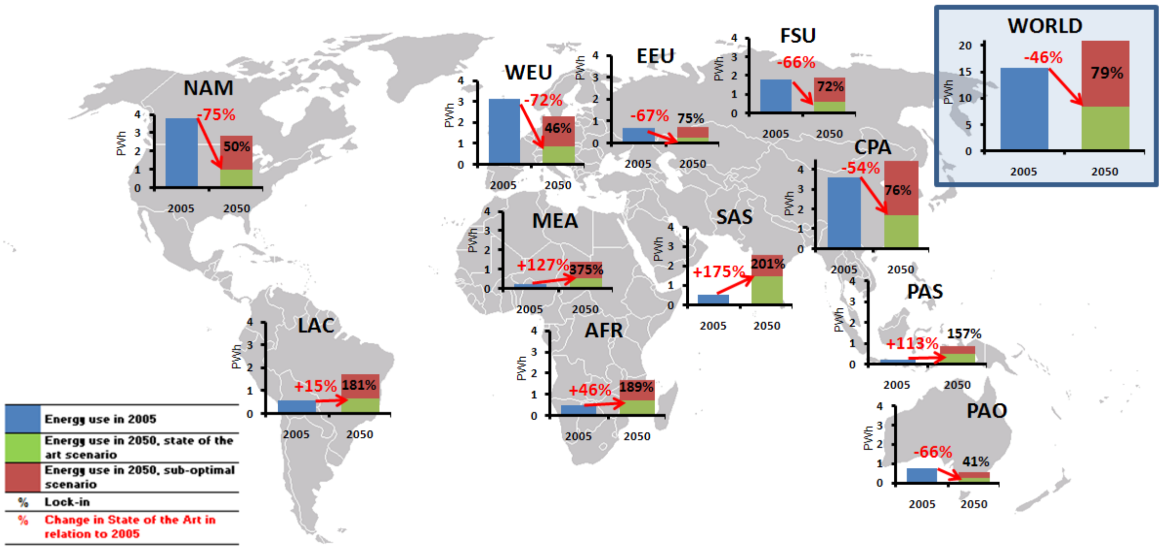

Figure 9.12. Final building heating and cooling energy use scenarios to 2050 in the Global Energy Assessment by IEA region (Ürge-Vorsatz, 2012a).

Notes: Green bars, indicated by red arrows and numbers; represent the opportunities through the GEA state-of-the-art scenario, while the red bars with black numbers show the size of the lock-in risk (difference from the sub-optimal scenario). Percent figures are relative to 2005 values.

9.5 Climate change feedback and interaction with adaptation

Buildings have a wide-range of sensitivities to changing climatic conditions. They also offer many opportunities to prepare for future conditions by modifying design goals and engineering specifications. These actions can increase resilience to climate change, while meeting goals for the design, construction, and operation of low-carbon buildings (Pyke et al., 2012). The adaptation and mitigation effects may be different in developed (where there is minimal change in urban development) and developing countries (where there are rapid changes in building and construction settings in urban areas). While there is no consensus on definitions of climate adaptive buildings, a review of the numerous definitions of concepts relating to the adaptive capacity of buildings, whether climate focussed or not, reinforce the aim of providing building occupants with a range of options for modifying their environments to maintain comfort. Enabling such choice requires minimising energy consumption for building operation. This is not only fundamental for mitigating GHG gas emissions, but also for providing adaptive capacity and resilience to the building stock. Minimizing energy consumption also reduces costs for maintaining thermal comfort and reduces the vulnerability of building occupants to extreme heat or cold. Low energy consuming buildings thus reduce the risk of experiencing fuel poverty, the risk of disruption to energy supply during extreme weather events. Bio-climatically designed buildings have been shown to best provide this adaptive capacity (Roaf et al., 2009). Low energy consuming buildings also improve the cost effectiveness of providing on-site and off-site renewable energy generation. In turn, lower-energy consuming building stock can improve the viability of distributed renewable energy supply, and thus resilience of energy supply to potential social and environmental climate change impacts (Atkinson et al., 2009). Reference 9.3.3 ZEB's. Strategies for lowering building total life-cycle energy (direct energy consumption) also contribute to mitigation and adaptation. Buildings that are designed for functional adaptability can be easier to renovate thus reducing initial and recurring embodied GHG emissions from building material manufacturing, construction and demolition (Graham, 2005). This also provides a significant co-benefit by offering the potential to reduce solid-waste generated from construction and demolition. Yet contemporary strategies for adapting buildings to climate change still often emphasize increasing the physical resilience of building structure and fabric to extreme weather and climatic events such as severe storms, floods or bush-fires. This can lead to decreased functional adaptability and increased embodied energy and associated GHG emissions. Increased extremes in local weather-patterns can lead to sub-optimal performance of buildings that were designed to provide thermal comfort 'passively' using principles of bioclimatic design. In such circumstances increased uncertainty over future weather patterns may encourage demand for mechanical space heating and/or cooling regardless of the climate-zone.

9.5.1 The impact of CC and CC mitigation on building energy use

The buildings sector is sensitive to climate change as the variation of climatic conditions influences both the total energy demand in buildings and its profile. As the climate warms, cooling demand increases and heating demand decreases(Day et al., 2009; Isaac and Van Vuuren, 2009b; Hunt and Watkiss, 2011), while passive cooling approaches become less effective (Artmann et al., 2008; Chow and Levermore, 2010). (Isaac and Van Vuuren, 2009b) assessed future global residential energy demand for heating and cooling under a +3.7 oC scenario by 2100. They found that on a worldwide basis the reduction in heating energy demand due to climate change will reach 34% in 2100, while cooling demand will increase by more than 70% in the same time horizon. The net result is relatively small and point to a net decrease in energy demand by approximately 6% in 2050, while an increase of approximately 5% is projected by 2100. On a regional basis there are significant differences: the absolute reductions in heating energy demand are much larger in temperate regions (e.g. more than 20% in Canada and Russia); demand for cooling increases by at least half in the warmer regions, while in cold regions the percentage increases are even higher. These patterns will lead to a shifting of energy consumption in buildings from fossil fuels to electricity affecting peak loads (Isaac and Van Vuuren, 2009b; Hunt and Watkiss, 2011), which is most important in warmer regions (Aebischer et al., 2007). The climate implications of this shift are related to the nature of the fuels and technologies used for electricity generation in each country/region. For example in the reference scenario presented by Isaac and Van Vuuren (2009b), climate change results in an increase of global CO_2 emissions from the residential sector by more than 0.3 Gt C in 2100, which is about half of the total CO_2 emissions from the residential sector in 2000, due to this shift to electricity and its emission factor, which is significantly above that of fuels. The projected changes in heating and cooling energy demands associated with the future climate (i.e. less heating in winter and more cooling in summer) can be mitigated and even offset occasionally (e.g. in some office buildings) by using more efficient equipment, which results in restricting heat losses (Jenkins et al., 2008).

9.5.2 Radiation management (geo-engineering) through buildings and pavements

Roofs and pavements constitute over 60% of most urban surfaces. Many studies have demonstrated building cooling-energy savings in excess of 20% upon raising roof reflectivity from an existing 10-20% to about 60% (Akbari et al., 2001). Cool roofs are most effective in hot climates. In temperate climates, a fraction of summertime cooling energy savings may be lost by incremental heating penalties during the winter (Akbari and Konopacki, 2005; Ihara et al., 2008). Increasing the albedo of urban surfaces (roofs and pavements) reduces the summertime urban temperature and improve the urban air quality (Ihara et al., 2008; Taha, 2008). The energy and air quality savings resulting from increasing urban surface albedos in the U.S. alone can exceed $2B per year(Akbari et al., 2001). Using a global climate model coupled with an urban canyon model, (Oleson et al., 2010) estimate, averaged over all urban areas, a decrease in urban daily maximum temperature by 0.6 K and daily minimum temperature by 0.3 K. (Millstein and Menon, 2011) have simulated the effect of a large-scale cool roof program in USA and concluded that the summertime afternoon temperature in urban areas decreased by 0.1-0.5 K. Also, analyzing the ambient temperature in large white-washed greenhouse areas in Almeria region of Spain, (Campra et al., 2008) have documented a reduction of about 0.7K (from 1983 to 2006) in the ambient temperature over the area. An added benefit of enhanced reflection of incoming solar radiation is to counteract the effects of global warming (Akbari et al., 2008). Based on existing data, it is possible to increase the albedo of roofs and pavements by at least 0.25 and 0.15, respectively (Akbari et al., 2003). The proposed increase in roof and pavement albedo will result in an increase of 0.1 in the albedo urban areas, resulting in an increase of 3x10-4 in the Earth's albedo. Changing albedo of urban surfaces and changing atmospheric CO2 concentrations both result in a change in radiative forcing (RF). (Akbari et al., 2008), using the available published data on RF (Hansen et al., 1997a,b; Hansen at al., 2005; Myhre et al., 1998) to calculate the CO2-equivalent offset by increasing albedo to urban surfaces. They calculate that changing the reflectance of a roof by 0.40 (changing an existing dark roof of solar reflectance of 0.15 to an aged white roof of solar reflectance of 0.55) can offset 100 kg CO2 per m2 of roof area (i.e., 10 m2 of cool roof area to offset 1 tonne of emitted CO2). For cool-colored roofs with a proposed albedo change of 0.25, and for cool pavements with a proposed albedo change of 0.15, the estimate of the global emitted annual? CO2 offset potentials is calculated to be ~ 24 Gt of CO2 and 20 Gt of CO2, respectively. A follow up study using NASA (GEOS-5) General Circulation Model has estimated the global emitted CO2 offset potentials for cool roofs and cool pavements of 78Gt of CO2 (Menon et al 2010). More recently, (Akbari et al., 2012) have calculated the long-term effect of surface albedo modification on global temperature and its CO2 equivalent emission offset, estimating that increasing the albedo of a m2 area of a surface by 0.01 results in a global temperature reduction of 3x10-15 K and offsets emission of 7 kg of CO2. These figures can be used to estimate the effect of other surface albedo geo-engineering techniques.

9.5.3 Soot emissions from cooking

Black Carbon (BC) or soot is highly absorptive of solar radiation and can be transported by clouds over long-distances (Ramanathan and Carmichael, 2008) leading to an increase in the radiative forceRF (RF) of the Earth. BC is a pollutant emissions resulting from incomplete combustion of coal, oil products and, particularly to the buildings sector, of bio fuelsfuelwood and other types of traditional biomass utilized (e.g., cooking on wood burning fire in developing countries. Domestic cooking and heating, plus small industries) with resource intensive technologies utilize inefficiently (10-20% conversion) this widely available source of energy. With a global consumption estimated between 37-43 EJ in 2008, around 2.7 billion people depended on traditional biomass in 2008, a number projected to increase to 2.8 billion by 2030 (Edenhofer et al., 2011) (Edenhofer et al., 2011) It is also highly polluting, emitting besides BC other types of particulate matter, sulphur dioxides, nitrogen oxides, carbon monoxide and other toxic substances. Premature deaths from biomass smoke in households accounted for 1.5 million people in 2008, a number - above those from tuberculosis and malaria - that may change little until 2030 according to projections following the present trends. Changing to cleaner fuels and using more efficient technologies result in lower fuel consumptuion, improves indoor and local air quality and lowers the atmospheric RF (Edenhofer et al., 2011), (Edenhofer et al., 2011).

9.6 Costs and potentials

9.6.1 Technical potentials for mitigation measures

Table 9.5: Summary of literature whole-building findings categorized by method

Reg	Description of mitigation measures/package (year)	End-uses	Type	Sector	Base-end yrs	% change to baseline	% change to base yr	Ref
CARBON EFFICIENCY								
ES	An optimal implementation of the Spanish Technical Building Code and usage of 17% of the available roof surface area	W	T-E	BS	2009	-68.4%		[1]
TECHNICAL EFFICIENCY								
WO	Significant efforts to fully exploit the potential for EE, all cost-effective RES for heat and electricity generation, production of bio fuels, EE equipment	ALL	T	BS	2007-50	-29%		[2]
US	The principal technologies or efficiency improvement assumptions used for each end-use. The technologies are widely available in the marketplace as of 2008	ALL	T-E	RS	2010-30	app. -29%		[3]
		ALL	T-E	CS	2010-30	app. -35%		
NO	Wide diffusion of heat pumps and other energy conservation measures, e.g. replacement of windows, additional insulation, heat recovery etc.	ALL	T	BS	2005-35	-9.50%	-21%	[4]
TH	Building energy code and building energy labeling are widely implemented, the requirements towards NZEBs are gradually strengthened by 2030	ALL	T	CS	by 2030	-43% (LPG) -47% (electr.) -57% (oil)		[5]
N. Eu	Improvements in lamp, ballast, luminaire technology, use of task/ambient lighting, reduction of illuminance levels, switch-on time, manual dimming, switch-off occupancy sensors, daylighting	L	T	CS	2011	-50%		[6]
Cat, ES	Implementation of Technical Code of Buildings for Spain, using insulation and construction solutions that ensure the desired thermal coefficients	H/C	T	BS	2005-15		-29%	[7]
BH	Implementation of the envelope codes requiring that the building envelope is well-insulated and efficient glazing is used	C	T	CS	1 year		-25%	[8]
UK	Fabric improvements, HVAC changes (incl. ventilation heat recovery), lighting and appliance improvements and renewable energy generation	ALL	T	CS	2005-30		-50% (CO_2)	[9]
CHN	Best Practice Scenario (BPS) examined the potential of an achievement of international best-practice efficiency in broad energy use today	APPL	T	RS, CS	2009-30	-35%		[10]
SYSTEMIC EFFICIENCY								
WO	Today's cost-effective best practice integrated design & retrofit becomes a standard	H/C	T-E	BS	2005-50	-70%	-30%	[11]
WO	The goal of halving global energy-related CO_2 emissions by 2050 (compared to 2005 levels); the deployment of existing and new low-carbon technologies	ALL	T-E	BS	2007-50	-34%		[12]
WO	High-performance thermal envelope, maximized the use of passive solar energy for	ALL	T	BS	2005-50	-48%		[13]

Reg	Description of mitigation measures/package (year)	End-uses	Type	Sector	Base-end yrs	% change to baseline	% change to base yr	Ref
	heating, ventilation and daylighting, EE equipment and systems							
US	Advanced technologies, infrastructural improvements and some displacement of existing stock, configurations of the built environment that reduce energy requirements for mobility, but not yet commercially available	ALL	T-E	BS	2010-50	-54%	-39%	[14]
EU27	Accelerated renovation rates up to 4%; 100 % refurbishment at high standards; in 2010 20 % of the new built buildings are at high EE standard; 100% - by 2025	ALL	T	RS	2004-30	-66%	-71%	[15]
	A full technology diffusion of best energy saving technologies to the technical limits. This is a hypothetical maximum that will never be reached in practice	H/C/W	T	CS	2004-30	-56%	-67%	
	A full technology diffusion of best energy saving technologies to the technical limits. This is a hypothetical maximum that will never be reached in practice	APPL	T	CS	2004-30	-23%	10%	
DK	Energy consumption for H in new RS will be reduced by 30% in 2005, 10, 15, 20; renovated RS are upgraded to the energy requirements applicable for new ones	H	T-E	RS	2005-50		-80%	[16]
HK	Implementation of performance-based Building Energy Code	ALL	T	CS	1 year	-20.5%		[17]
CH	Compliance with the standard comparable to the MINERGIE-P5, the Passive House and the standard A of the 2000 Watt society with low-carbon systems for H and W	H/W	T	RS	2000-50	-60%	-68%	[18]
	Buildings comply with zero energy standard (no heating demand)	H/W	T	RS	2000-50	-65%	-72%	
DE	The proportion of very high-energy performance dwellings increases by up to 30% of the total stock in 2020; the share of nearly zero and ZEBs makes up 6%	H/W	T	BS	2010-20		-25%(pr.en) -50% (CO_2)	[19]
DEMAND EFFICIENCY								
FR	EE retrofits, information acceleration, learning-by-doing and the increase in energy price. Some barriers to EE, sufficiency in H consumption are overcome	H	T	BS	2008-50	-58%	-47%	[20]
LT	Change in life style towards saving energy and reducing waste	ALL	T	RS	1 year	-44%		[21]

Notes: 1) The Table presents the potential of final energy use reduction (if another is not specified) compared to the baseline and/or base year for the end-uses given in the column 3 and for the sectors indicated in the column 5. 2) H – space heating; C – space cooling; W – hot water; L – lighting; APPL – appliances; ALL – all end-uses; BS – the whole building sector; RS – residential sector; CS – commercial sector; T – technical; T-E – techno-economical; EE – energy efficiency; RES – renewable energy sources; HVAC – heating, ventilation and air-conditioning; ZEB – zero-energy building; pr.en. – primary energy; electr. – electricity; red. – reduction; app. – approximately.3) Reg. – region; ES – Spain, WO – world, US – United States of America, TH – Thailand, N.Eu – Northern Europe, Cat – Catalonia, BH – Bahrain, CHN- China, EU27 – European Union, DK – Denmark, HK – Hong Kong, CH – Switzerland, DE – Germany, FR – France, LT – Lithuania4) [1] -(Izquierdo et al., 2011), *[2]* - (GPI, 2010), *[3]* - (Brown et al., 2008), *[4]* - (Sartori et al., 2009), *[5]* -(Pantong et al., 2011), *[6]* - (Dubois and Blomsterberg, 2011), *[7]* - (Garrido-Soriano et al., 2012), *[8]* - (Radhi, 2009), *[9]* -(Taylor et al., 2010), *[10] - N. Zhou et al. 2011, [11]* - (Ürge-Vorsatz, Petrichenko, et al., 2012), *[12]* -(IEA, 2010), *[13]* -(Harvey, 2010) *[14]* (Laitner et al., 2012)- *, [15]* -(Eichhammer et al., 2009) –*[16]* (Tommerup and Svendsen, 2006), *[17]* -(Chan and Yeung, 2005), *[18]* - (Siller et al., 2007), *[19]* -(Schimschar et al., 2011), *[20]* - (Giraudet et al., 2012) *[21]* - (Streimikiene and Volochovic, 2011)

9.6.2 Cost assessment of mitigation measures

Earlier sections have shown the importance of whole building design and engineering for both new construction and retrofits. The cost effectiveness of whole building design and engineering on mitigation costs typically hinges on the relationship between incremental costs for design, incremental costs for high-performance measures and processes, and the lifecycle benefits of resulting performance improvements. Table 9.5 presents a summary of literature whole-building findings categorized by method. The following sections present important considerations for whole building new construction and retrofit.

9.6.2.1 New Construction

There are multiple lines of evidence that can be applied to understand the cost effectiveness of whole building new construction and retrofit, including project-based incremental cost accounting, population studies, and comparative modelling. In a *project-based cost-benefit framework*, project teams typically create two cost-benefit estimates: one for a notional "baseline" building and another for the designed high performance building. The team characterizes the costs and operational benefits of both designs and computes the net present value of savings across the life cycle. For example, the (USGSA, 2004) analysed the marginal cost of different high-performance green building design standards for prototypical office buildings and courthouses. They found whole building cost premiums of -0.4% to +8.1% for courthouses and +1.4% to +7.8% for office buildings. These types of buildings are designed to reduce energy by 15% to more than 45% relative to advanced energy codes while also including a variety of greenhouse gas mitigating features associated with transportation, water, solid waste, and materials. (Kats, 2009)also used a project-based approach to analyse a sample of 146 LEED-certified projects in North America. He found cost premiums associated with higher levels of green building certification ranging from 3% to over 8%. Kats found no correlation between self-reported project cost premiums and energy performance design goals. Similarly, a number of project teams [TSU: number and reference will be added in SOD] associated with a sample of residential buildings meeting the Passive House standard and reported incremental costs of 4-15% relative to conventional (up to 90% savings) or less stringent low-energy standard building. For commercial buildings, there are instances where the there has been no additional cost in meeting standards as high as the Passive House standard, or where the cost of low-energy buildings has been less than that of buildings meeting local energy codes (see OISD). Similarly, a growing literature describes low cost strategies to achieve 30-40% energy relative to standard construction practices (e.g., (McIlvaine and Beal, 2010)). (Parker, 2009) reports that very low energy homes (similar to Passive House Standards) can be achieved for the equivalent cost of $0.10/kWh invested. Project-focused cost-benefit analysis have the advantage of specificity, however, the approach contributes the notion of a separability of measures and processes between conventional and high-performance design. This becomes increasingly difficult to manage with expanding use of the integrated design concept. Comparative studies of population of convention vs. high-performance green building offer a complementary approach. Surveys of delivered full building construction costs in the United States and Australia have compared conventional and green buildings in variety of circumstances. The goal is to characterize the average delivered cost of convention vs. high-performance building. These studies have been consistently unable to detect a significant difference in delivered price between these two categories. Rather, they find a wide range of variation costs irrespectively of performance features. In other words, there are relatively expensive low-performance buildings and relatively cheap high-performance, green buildings(Langdon, 2007aa; Urban Green Council and Langdon, 2010). Collectively these studies indicate significant improvements in design and operational performance can be achieved today under the right circumstances at relatively low or potentially no increases in total cost. Conversely, it is clear that in some circumstances higher performance has been associated with significant additional costs, particularly in inexperienced markets. Costs of performance gains consistently escalate as buildings approach limits of technology. This is particularly well documented for buildings attempting to achieve very low or “zero net” energy operations. The cost and feasibility of achieving various ZNEB definitions have shown that such goals are rarely cost-effective by conventional standards; however, specific circumstances, operational goals, and incentives can make them feasible(Boehland, 2008; Meacham, 2009). Table 9.6 summarizes published estimates of the incremental cost of net zero-energy buildings; even for these buildings, there are cases where there appears to have been little additional cost (e.g., NREL Laboratory).The costs of new ZNE buildings are heavily dependent on supporting policies, such as net metering and feed-in-tariffs, discount rates, and anticipated holding times.

9.6.2.2 Retrofits

The retrofit of existing buildings also offers numerous opportunities to reduce energy demand, improve energy efficiency, and mitigate greenhouse gas emissions (Zhai et al., 2011) . Studies have repeatedly indicated the important distinction between conventional “shallow” retrofits, often reducing energy use by 10-30%, and aggressive “deep” retrofits (i.e., 50% or more relative to baseline conditions. (Korytarova and Ürge-Vorsatz, 2012) evaluated a range of existing building types to characterize different levels of potential energy savings under different circumstances. They describe the potential risk for shallow retrofits to result to lower levels of energy efficiency and higher medium-term mitigation costs when compared to performance-based policies promoting deep retrofits. Mata et al., (2010) studied 23 retrofit measures for buildings in Sweden. They report a simple technical potential for energy savings in the residential sector of 66 TWh/yr or 68% of annual energy use. They estimated cost per kWh saved between -0.07 Euro/kWh/yr(appliance upgrades) and +0.34 Euro/kWh/yr (façade retrofit).Polly et al., (2011) present a method for determining optimal residential energy efficiency retrofit packages. They report on methods to evaluate and select retrofit measures based on a 30-year period of annual cash flows assuming a 3% discount rate and a 3% annual fuel escalation rate. They identify near cost neutral packages of measures providing between 29% and 48% energy savings across 8 US locations. (Mills, 2011) evaluated the benefits of commissioning and retro-commissioning for a sample of 643 buildings in California. The study reports a 16% median whole building energy savings in existing buildings and 13% in new construction with payback time of 1.1 years and 4.2 years.

Table 9.6: Summary of estimates of the extra investment cost of buildings with low energy use.

Case	Extra investment cost	Reference
Residential buildings *Project-specific cost-tracking*		
Passive House Projects in central Europe	5-8% (100-160€/m^2)	(Schnieders and Hermelink, 2006) Bretzke (200?) [TSU: This reference needs to be confirmed] (Bretzke, 2005)
Comparison-based		
Average of 5 passive houses (62 kWh/m^2/yr total) compared to average of 3 conventional houses (224 kWh/m^2/yr total) in Belgium	16% (187€/m^2) (of which about 60% is due to envelope improvements and 40% due to installation of a MVHR system)	(Audenaert et al., 2008)
Passive House apartment block in Vienna (8-15 kWh/m^2/yr heating energy use) compared to low-energy apartment block (33-46 kWh/m^2/yr heating energy use)	5% (52€/m^2) 8-18 years simple payback time	(Mahdavi and Doppelbauer, 2010)
Model-based		
12 very low or net zero-energy houses in the US	7-12 cents/kWh cost of saved energy (includes efficiency measures and solar PV and DHW)	(Parker, 2009)
Cost of meeting the ‘Advanced’ thermal envelope standard (44% energy savings) of the UK *Code for*	7.1-9.1% (68-79£/m^2)	Langdon 2007a

Case	Extra investment cost	Reference
Sustainable Housing, above that for meeting the 2006 mandatory regulations.		
Cost of meeting Code Level 5 (net zero CO_2 emission) of the UK *Code for Sustainable Housing* relative to the 2006 mandatory regulations	17-20% for the least cost option ('Good' envelope + biomass boiled + PV)	Langdon 2007a
Commercial buildings *Project-specific cost-tracking*		
10 buildings in the German SolarBau programme (5 with < 100 kWh/m^2/yr primary energy demand compared to 300-600 kWh/m^2/yr for conventional building)	Comparable to the difference in cost between alternative standards for interior finishes	(Wagner et al., 2004)
High performance commercial buildings in Vancouver (100 kWh/m^2/yr total) compared to conventional (180 kWh/m^2/yr total)	10% lower cost	(McDonell, 2003)
Offices and laboratory, Concordia University, Montreal	2.3%	(Lemire and Charneux, 2005)
University building, constructed in 2006, 60% less energy use than if built relative to ASHRAE 90.1-1999	2.4% lower cost	(Interface Engineering, 2005)
Sample of LEED for New Construction Buildings with design energy performance x-y above ASHRAE 90.1 or Title 24 energy codes	0.66-15%	(Kats, 2010)K
Comparison-based		
Kindergartens built to Passive House standard and conventional standards	Lower cost for Passive House standard	(Jordan, 2009)
Welsh Information and Technology adult learning centre (CaolfanHyddgen) built to Passive House standard compared to BREEAM 'Excellent' standard	No extra cost	(Pearson, 2011)
Sample of LEED buildings	No significant difference	D(Langdon, 2007b)
Cost of green in New York City for new construction and commercial interiors	No significant difference	(Langdon, 2007b)
Cost of green in Australia	No significant difference	(Langdon, 2007b)
Comparison of LEED and non-LEED banks	<2%	Mapp, Nobbe, and Dunbar 2011 JOSE
Model-based		
Hypothetical 6,000 m^2 office building in Las Vegas with different degrees of design integration	Incremental costs of \$12,700, \$69,630 and \$114350 for energy savings of 42%, 34% and 37% respectively (simple payback times of 0.5, 3.3, and 4.8 years, respectively)	(Vaidya et al., 2009)
Proposed 10-story, 7,000 m^2 residential building in Denmark, with 14 kWh/m^2/yr heating energy demand instead of 45 kWh/m^2/yr	3.4% (86€/m^2)	(Marszal and Heiselberg, 2009)

Table 9.7: Extra costs of NZEBs.

Building	Cost premium	Basis of calculation	Comments
Leslie Shao-Ming Sun Field Station, Stanford University, California	4-10% more based on hard construction costs, 6.6% less to 10% more when soft costs are included	Comparison with nearby similar buildings built during roughly the same time period	Envelope and orientation measures permitted almost complete elimination of air conditioning
Hudson Valley Clean Energy Headquarters, NY	Extra investment cost entails an extra \$680/month in mortgage payments but saves \$841/month in energy costs		
Richardson Elementary School, Bowling Green, KY	Unknown.		The NZEB school was built within the state's budget for new school construction
IAMU Office, Ankeny, IA	Zero	Same cost as that of comparable conventional buildings	Largest cost item was the ground-source heat pump
EcoFlats Building, Portland,	Zero monetary cost		Some amenities were cut in order

Building	Cost premium	Basis of calculation	Comments
OR			to offset the cost of zero-energy features
Proposed 10-story, 7,000 m^2 residential building in Denmark	24% (418€/m^2)		(Marszal and Heiselberg, 2009)

Source: NBI (2012), except where indicated otherwise

Table 9.8: Estimated cost of retrofits for existing buildings and resulting savings in energy use. The cost of conserved energy has been computed based on an assumed 50-year lifespan for thermal envelope measures and financing at a real interest rate of 3%/yr.

Case	Energy Savings		Investment Cost	Cost of Conserved Energy (CCE)	Reference
	(kWh/m^2/yr)	%			
Toronto towers	194	95	\$257/m^2	\$0.052/kWh	(Kesik and Saleff, 2009)
European multi-family housing	62-150	52-86	37-87 €/m^2	0.01-0.016 €/kWh	(Petersdorff et al., 2005a, 2005)
European terrace housing	97-266	59-84	63-145 €/m^2	0.09-0.016 €/kWh	(Petersdorff et al., 2005a, 2005)
European high-rise housing		70-81	1.8-4.1 €/m^2/yr	0.013-0.020 €/kWh	(Waide et al., 2006)
German 1950s MFH	82-247	30-90	36-314 €/m^2	0.017-0.049 €/kWh	(Galvin, 2010)
UK Victorian flat[6]	192-234	48-59	192-480 £/m^2	0.043-0.088 £/kWh	(United House, 2009)
Danish 1925 SFH, insulation and window package	120	?	166 €/m^2	0.054 €/kWh	(Kragh and Rose, 2011)
German 1929 MFH	140-200	58-82	125-255 €/m^2	0.045-0.066 €/kWh (based on 30yr lifespan)	(Hermelink, 2009)

9.6.3 Economic potential for mitigation measures

As Section 9.6.1 has already pointed out, the recent literature often does not clearly distinguish between the economic and technical potentials. This is for several reasons. First, as partially outlined in the previous section, due to the diversity of building stock and service demands and the complexity of and many alternative approaches to high-performance building solutions, determining cost-effective performance levels precisely is very difficult. For instance, “cost-optimality” is a central theme in the European Performance of Buildings Directive (EPBD), and it took very extensive studies and expert consultations to establish methodologies for establishing cost-optimal levels. Second, the economic potential depends largely on carbon prices that are expected to change in the next few decades.

Therefore, Section 9.6.1. reviewed the potential literature from a quantitative perspective, while this section includes a discussion on the factors that are influential and that are important to consider for determining the economic potentials.

9.6.3.1 Methodological challenges to determining cost-effectiveness

The previous section has demonstrated that there are significant opportunities to cost-effectively reduce building energy use through high performance construction and retrofits. The challenge is to understand the economic feasibility of these cost-saving, emissions reducing measures in the context of a myriad of boundary conditions (e.g., cost estimation methodology, opportunity cost, financing costs, risk tolerance, uncertainty, time, technology, and many related factors). The first

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[6] Uses expensive aerogel insulation. There is a big jump in cost when mechanical ventilation with heat recovery is assumed to be installed.

step to interpreting these conditions lies in dissecting the choice of cost estimation and return-on-investment methodology. Cost estimation techniques vary widely (Akintoye and Fitzgerald, 2000), and the selection of estimation and comparison approaches has significant impacts on results and conclusions(Gwang et al., 2004). Studies vary with respect to: (1) *system scale*, e.g., measures, sub-system or system, whole building, neighbourhood, community, industry segment, building stock, (2) *time*, e.g., months, years, decades, and (3) *baseline*, e.g., notional, regulatory, statistical benchmark, or population. Studies also differ in their approaches to addressing essential assumptions such as ownership structures, discount rates and opportunity costs. Variation in these factors often makes it difficult to interpret and compare results between studies. For example, governments create new buildings with the intention of operating them for long periods of time with access to relatively low-cost capital. Under these circumstances, many energy conservation measures have net negative lifecycle costs returning savings to the owner. In contrast, commercial real estate developers often create buildings with the intention of holding them for only a brief period of time while facing relatively high, risk-adjusted costs of capital. Under these circumstances, many measures will not yield a payback within the hold time of the developer and this means that a smaller fraction of available measures may be seen as cost effective. This illustrates that there is no single answer to the cost effectiveness of a project or approach. Rather cost effectiveness reflects the combination of performance characteristics and social and economic factors (Muldavin, 2010).

The integrated design of whole buildings clearly has the potential to save energy and reduce emissions (Smeds and Wall, 2007). However, understanding and communicating the incremental costs of achieving whole building benefits is a persistent challenge. The situation is more complex than for single measures where the baseline is typically the presence or absence of a technology. In the case of whole buildings, only one building is created and it reflects a complex mixture of design and engineering decisions needed to achieve higher performance (Larsson and Clark, 2000). In practice, there are three general approaches to cost estimation, including project-specific cost-tracking, comparison-based, and modelling-based approaches (Harvey, 2013). With project-specific cost tracking, a notional baseline building is established and higher-performance features added while incremental costs are tracked. In comparison-based approaches, cost data are collected across populations of buildings and used to detect differences between conventional and high-performance projects. Finally, in modelling-based studies, whole building designs are adapted to increasingly stringent energy performance goals and subjected to iterative whole-building cost estimation. These complementary approaches offer practical tools for different circumstances and the potential for multiple lines of evidence when used together.

9.6.3.2 The economic benefits of integrated and community-based approaches

Achieving very high-performance buildings requires more than the incremental adoption of energy conservation measures. It requires understanding and leveraging whole-system design to minimize energy demand and maximize efficiency. Such concepts may be more common in the industrial ecology literature than traditional design and construction research (Jelinski et al., 1992). Ultimately, the goal is to uncover synergies that allow greater benefits to be achieved at lower costs. Traditional cost studies presume positive relationships between cost and performance, i.e., marginal gains in performance are associated with additional costs for construction or retrofit(Campell et al., 2010). Some researchers have hypothesized circumstances with important discontinuities in the cost of incremental improvements in building performance. For example, (Lovins, 2010)describes the concept of “tunneling through cost”, hypothesizing that first costs increase up to a point where technological and process breakthroughs reveal opportunities for systematic changes that dramatically improve performance while reducing cost. Some exceptionally high performance projects have begun to demonstrate some of the features of this hypothesis (e.g., (Pless et al., 2011).

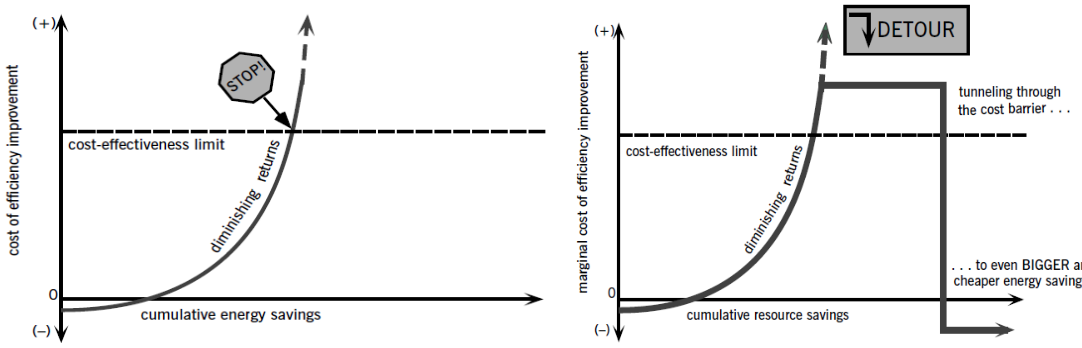

Figure 9.13. Illustration of potential non-linear relationships between costs and energy savings. Source: (Hawken et al., 2008)

Figure 9.14 shows the development of best-practice costs for multifamily building retrofits as a function of retrofit depth. The figure demonstrates that cost-effectiveness of retrofits does not necessarily depend on the depth: similar specific costs can be achieved both through very deep retrofits as through shallow ones - as demonstrated by the lower envelope of the data space.

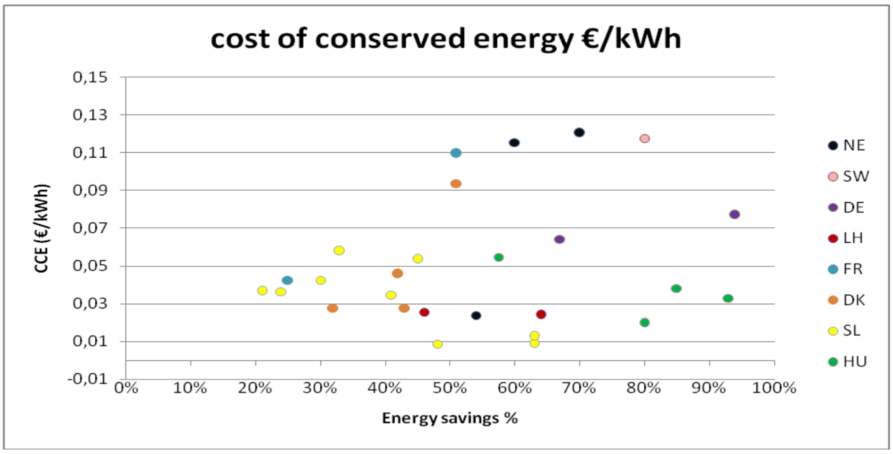

Figure 9.14. Cost of conserved energy as a function of depth of retrofit, for multifamily buildings in Europe, selected documented best practices. Based on meta-analysis of data reported by the literature.

9.7 Co-benefits, risks and spill-overs

9.7.1 Overview

It has long been recognised that the implementation of GHG mitigation policies and measures in the buildings sector yields a wide spectrum of benefits beyond energy conservation and the associated reduction of GHG emissions. (Ürge-Vorsatz et al., 2009; GEA, 2012), synthesizing several previous research efforts, recognizes five major categories of co-benefits, namely; (i) health effects (e.g. reduced mortality and morbidity from the improved indoor and outdoor air quality), (ii) ecological effects (e.g. reduced impacts on ecosystems due to the improved outdoor environment), (iii) economic effects (e.g. decreased energy bill payments, employment creation, improved energy security, improved productivity etc.), (iv) service provision benefits (e.g. elimination of energy losses during energy transmission and distribution), and (v) social effects (e.g. fuel poverty alleviation, increased comfort due to better control of indoor conditions and the reduction of outdoor noise, increased safety, etc.). The IPCC AR4 (Levine et al., 2007) as well as other major studies completed recently (UNEP, 2011; GEA, 2012) provides a detailed and comprehensive presentation and analysis of these effects, highlighting the further need for their quantification and incorporation as positive welfare effects in decision analysis.. Therefore, the following paragraphs review recent advances reported in the literature focusing on selected co-benefits, with a view to provide methods, quantitative information and examples that can be exploited in the decision-making process.

9.7.2 Socio-economic effects

9.7.2.1 Impacts on employment

An opportunity lies in the pursuit of so-called "green jobs" - employment that contributes to protecting the environment and reducing humanity's carbon foot-print. Specifically, an increasing number of studies are finding that greater use of renewables and energy efficiency in the buildings sector result in positive economic effects through job creation, economic growth, increase of income and reduced needs for capital stock in the energy sector (see for example (Scott et al., 2008; Pollin et al., 2009; Kuckshinrichs et al., 2010); these conclusions, however, have been criticized on grounds that include, among others, the accounting methods used and the efficacy of using public funds for energy projects instead for other investments (Carley et al., 2011). These effects can be classified as: (i) direct (i.e. the jobs created, particularly in the construction industry, for retrofitting homes etc.); (ii) indirect, created on the sectors of the economy that supply material and services for the implementation of the mitigation measures; and (iii) induced, as a result of the additional income that will be available to workers and/or households, which will be spent to other activities (Jeeninga et al., 1999; Scott et al., 2008). Focusing on labour market, several approaches (Scott et al., 2008; Ürge-Vorsatz and others, 2010) can be implemented for quantifying the impact of interventions to address climate change: (i) indices and multipliers from specific case studies; (ii) input-output analysis; (iii) computable general equilibrium analysis; and (iv) transfer of results from previous studies. In the context of this assessment, a review of the literature on quantification of the employment effects of energy efficiency and GHG mitigation measures in the buildings sector was conducted and the main results are presented in Figure 9.15. The bulk of the studies reviewed, point out that the implementation of GHG mitigation interventions in buildings generates between 0.7 and 35.5 job-years per $2010 1 million spent. Two studies (Scott et al., 2008; Gold et al., 2011) focus on cost savings from unspent energy budgets that can be redirected to economy, estimating that the resulting employment effects range between 6.0 and 10.2 job-years per $2010 1 million spent. Several studies (Pollin et al., 2009; Ürge-Vorsatz, 2010; Wei et al., 2010; Carley et al., 2011) agree that building retrofits and investments in clean energy technologies are more labour-intensive compared to conventional approaches (i.e. energy production from fossil fuels, other construction activities etc.). However, to what extent spending a given amount of money on clean energy investments creates more employment compared to conventional activities depends also on the structure of the economy in question and the level of activities undertaken domestically. To this end, the estimation of net employment benefits instead of gross effects is of particular importance for an integrated analysis of energy efficiency implications on the economy. It is also worth mentioning that investing in clean technologies would create new job activities (e.g. in solar industry, in the sector of new building materials etc.), but the vast majority of jobs will be in the same areas of employment that people already work today(Pollin et al., 2009). Monetization of employment effects through techniques based on the total fiscal cost per unemployed worker, the public expenditures for creating one extra year of employment, the opportunity cost of labour etc.(Markandya, 2000; Tourkolias et al., 2009; Kuckshinrichs et al., 2010), can accelerate their incorporation in decision-making process.

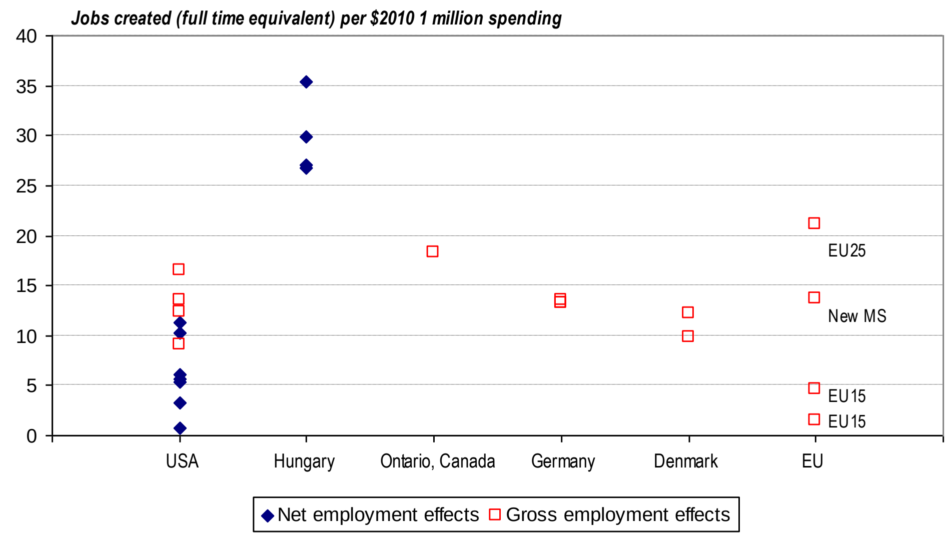

Figure 9.15. Employment effects attributed to GHG mitigation initiatives in the building sector.

Notes: For developing this Figure the following sources have been used: USA:(Scott et al., 2008; Bezdek, 2009; Hendricks et al., 2009; Pollin et al., 2009; Garrett-Peltier, 2011; Gold et al., 2011). *All the studies include the direct, indirect and induced effects of energy conservation initiatives considered. In* (Gold et al., 2011) *and* (Scott et al., 2008) *the induced effects from energy savings are also taken into account. Hungary:* (Ürge-Vorsatz and others, 2010). *The direct, indirect and induced effects including those associated with energy savings are taken into account. Ontario, Canada:* (Pollin and Garrett-Peltier, 2009). *The direct, indirect and induced effects are taken into account. Germany:* (Kuckshinrichs et al., 2010). *It is not specified what type of employment effects are included in the analysis. Denmark:* (Ege et al., 2009). *The direct and indirect effects are taken into account. EU:* (ETUC, 2008). *Only the direct effects are taken into account.*

9.7.2.2 Energy security

Implementation of GHG mitigation measures in the buildings sector can play an important role in increasing the energy security by: (i) strengthening the power grid reliability, through the enhancement of properly managed on-site generation and the reduction of the overall demand, which result in reduced power transmission and distribution losses and constraints (Kahn, 2008; Passey et al., 2011); (ii) reducing cooling-related peak power demand and shifting demand to off-peak periods; however, this reduction in peak demand may be significantly lower compared to electricity savings (Borg and Kelly, 2011; Steinfeld et al., 2011); (iii) increasing the diversification of energy sources as well as the share of domestic energy sources used in a specific energy system (see for example (Dixon et al., 2010); and (iv) reducing the stress on the whole energy supply chain due to the reduced demand. There is a relative dearth of studies and tools aiming at quantifying these benefits. An International Energy Agency study (IEA, 2007) explored the interactions between climate policies and energy security through two quantitative energy security indices, addressing: (i) to what extent energy prices are allowed to adjust in response to changes in demand and supply; and (ii) the physical unavailability of energy. This approach was implemented in 5 European OECD countries and demonstrated that promotion of energy efficiency in electricity uses has positive impacts of similar magnitude on energy security. Specifically a 5% reduction in countries’ emissions from baseline by 2030 through improved end-use efficiency was shown to result in commensurate improvements of both energy security indices (by 2.5% to 4.3% of the price indicator and by 2.3% to 37% of the index addressing the physical unavailability of energy). (Bigano et al., 2010) implemented an econometric approach (panel analysis) in the EU15 countries and Norway to explore whether policies and measures that affect indicators of energy efficiency performance influence also security of supply indicators. They found that energy efficiency policies, with the exception of residential loans, aimed at the residential and tertiary sectors have little effectiveness in improving energy security. Instead, broadly defined cross cutting policies, in particular market-based instruments, that naturally encompass different sectors and energy uses are those having the strongest influence on energy security. Monetization of the welfare impacts of energy insecurity (usually expressed with the index Value of Lost Load – VOLL) or alternatively the assessment of willingness to pay (WTP) to improve security of supply are also powerful tools for incorporating energy security issues in decision making process. To this end, the methodologies used worldwide can be grouped into three main categories (Leahy and Tol, 2011): (i) stated preferences, based on customer surveys (see for example (Damigos et al., 2009; Chou et al., 2010); (ii) proxy methods, such as the production function approach (see for example (De Nooij et al., 2007; Leahy and Tol, 2011); and (iii) case studies, based on collection of data immediately after the occurrence of large-scale power supply interruptions.

9.7.2.3 Social implications: poverty alleviation, equity, distributional impacts, gender

While recognizing the financing challenges for the housing, the UN Habitat has indicated concern for low cost housing needed for the poor in many countries, such as Zimbabwe (Mutekede and Sigauke, 2009), Indonesia (UNHSP, 2008a) and Bolivia (UNHSP, 2008b), which have mixed types of dwellings comprising from traditional to modern materials. Changes in urbanization and income affect these profiles. Improvements such as sewerage (mostly in urban areas) and electricity (also in rural) are taking place, changing the patterns of consumption. Upliftment and up gradation would be a potential source of growth in energy, building materials and CO_2 emissions in the future decades. Fuel (or energy) poverty is a condition in which a household is unable to guarantee a certain level of consumption of domestic energy services (especially heating) or suffers disproportionate expenditure burdens to meet these needs (Boardman, 1991; BERR, 2001; Healy and Clinch, 2002; Buzar, 2007; Ürge-Vorsatz and Tirado Herrero, 2012). As such it has a range of negative effects on the health and welfare of fuel poor households. For instance, insufficient indoor temperatures affect vulnerable population groups like children, adolescent or elders (Liddell and Morris, 2010; Marmot Review Team, 2011) and increase excess winter mortality rates (The Eurowinter Group, 1997; Wilkinson et al., 2001; Healy, 2004). In fact, it is estimated that between 10% to over 40% of excess winter deaths in temperate countries is related to inadequate indoor temperatures (Clinch and Healy, 2001; Marmot Review Team, 2011; Hills, 2012) which in larger countries such as Poland, Germany or Spain equals to several thousand – up to 10,000 – excess annual winter deaths. These figures suggest that in developed nations fuel poverty may be causing a number of premature deaths per year similar to or higher than that of road traffic accidents (Bonnefoy and Sadeckas, 2006; Ürge-Vorsatz, Wójcik-Gront, et al., 2012; Tirado Herrero et al., 2012). Improving the thermal performance of buildings to very high (such as Passive house) levels can largely alleviate fuel poverty. However, this, along with most social benefits are non-market ones and therefore are rarely taken into consideration in financial assessments of mitigation or energy efficiency programmes. When incorporated in a social cost-benefit analysis framework along with other co-benefits such as improved air quality of populated areas, they have demonstrated that large net positive welfare effects can be expected from buildings energy efficiency investments. Such studies have shown that fuel poverty-related welfare gains make up over 30% of the total benefits of energy efficiency investments and are more important than those arising from avoided emissions of greenhouses gases and other harmful pollutants like SO_2, NO_x and PM_{10} (Tirado Herrero and Ürge-Vorsatz, forthcoming; Clinch and Healy, 2001).

9.7.3 Environmental and health effects

9.7.3.1 Health co-benefits due to improved indoor conditions

The implementation of energy efficiency interventions in buildings improves the indoor conditions (e.g. air quality, control of indoor temperature etc.), thus resulting in significant co-benefits for public health and productivity(Chau et al., 2007; Wilkinson et al., 2009; Bone et al., 2010; Singh, Syal, et al., 2010). For the United States, the estimated potential annual savings and productivity gains are $2010 21 to $2010 60 billion from reduced respiratory disease, allergies, asthma and sick building syndrome symptoms, and \$2010 25 to \$2010 201 billion from direct improvements in worker performance that are unrelated to health(Fisk, 2000). The cookstove program in India showed substantial benefits for acute lower respiratory infection in children, chronic obstructive pulmonary disease, and ischemic heart disease. Calculated on a similar basis to the UK case study, the avoided burden of these outcomes was estimated to be 12500 fewer DALYs and a saving of 0.1-0.2 mega tones CO_2-equivalent per million people in 1 year, mostly in short-lived greenhouse pollutants (Wilkinson et al., 2009). Improved residential insulation is expected to reduce illnesses associated with room temperature thus providing non-energy benefits, such as reduced medical expenses and prevention against loss of income due to unpaid sick leave from work. The quantification of these co-benefits is of particular importance and improves the economic performance of GHG mitigation measures. A health survey and a study were conducted (Ikaga et al., 2011) on 10,000 residents who lived in poorly insulated houses, but who then moved into houses with better insulation. According to the results, for a new- construction investment of 1 million yen (i.e. \$2010 11,390) for a house with advanced thermal-insulation, if only reduced air-conditioning costs are considered as the benefit (\$2010 399 per annum), the return period is 29 years. However, the return period can be shortened to 16 years if the non-energy benefits that are related to health are also included (\$2010 308 per annum). By further including the reduction in health insurance, this would result in 11 years. The lifecycle-impact assessment method of endpoint modeling (LIME) has been developed to simultaneously evaluate the trade-off relationship between direct health- damage due to indoor air pollution caused by building materials, adhesives, paints and open-type heaters or cooking burners, and the indirect health damage due to reduced ventilation in houses, which is intended to decrease CO_2 emissions (Natsumi et al., 2005; Itubo and Inaba, 2010).

9.7.3.2 Benefits related to workplace productivity

For offices, adjusting air-conditioning settings and reducing the frequency of opening widows to allow fresh air in can contribute to a reduction in air-conditioning costs and CO_2 emissions. However, energy conservation management, which relies solely on the patience of the office users significantly, lowers productivity in the workplace (Wargocki et al., 2006; Tawada et al., 2010). Investment in low-carbon technologies related to air conditioning and walls during construction or renovation can be effectively returned in the trade-off between the promotion of low-carbon societies and improved workplace productivity.

9.7.3.3 Health co-benefits due to the reduced outdoor air pollution

The implementation of GHG mitigation measures in the buildings sector reduces the consumption of fossil fuels, thus improving the outdoor air quality and resulting in reduced mortality and morbidity, particularly in developing countries and big cities (Harlan and Ruddell, 2011). A great number of studies, primarily in North America and Europe and more recently in some developing countries, provide quantitative concentration-response functions that link changes in outdoor PM, ozone and other pollutant concentrations to changes in rates of mortality and various morbidity effects, often for different age groups, allowing for a quantification of the relative co-benefits associated with energy efficiency measures (Jack and Kinney, 2010). However, only a few of them focus on health effects due to chronic exposure to air pollution (see for example (Pope et al., 2002)). Based on these concentration-response functions from these and similar works, many studies (see for example (Bickel and Friedrich, 2005; Mirasgedis et al., 2008; Tollefsen et al., 2009; Fahlen and Ahlgren, 2010; Pietrapertosa et al., 2010; Zhang, Aunan, et al., 2010; Carnevale et al., 2011; Sakulniyomporn et al., 2011) have monetised the human mortality and morbidity effects attributed to outdoor air pollution.

9.7.3.4 Environmental benefits: water savings, air quality

As already mentioned the reduced consumption of fuels and electricity due to the implementation of energy efficiency measures in buildings results in lower outdoor air pollutants concentrations (i.e.

SO_x, NO_x, PM, etc.), thus implying less stresses to natural and anthropogenic ecosystems. Valuation of these benefits is possible (see for example (Welsch, 2006; Muller and Mendelsohn, 2007; Kuosmanen et al., 2009; Busch et al., 2011) providing a sound basis for describing in a quantitative manner how enhancement of energy efficiency is associated with upgrading of ecosystem services. In addition, using energy efficient appliances such as washing machines and dishwashers in homes, results in considerable water savings (Bansal et al., 2011). More generally, a number of studies show that green design in buildings is associated with lower demand for water. For example, (Kats et al., 2005) evaluated 30 green schools in Massachusetts and found an average water use reduction of 32% compared to conventional schools.

9.7.4 Technological risks and public perception

Improvements in energy efficiency in buildings, as in other economic activities, can be offset by increases in demand for energy services due to the “rebound effect” (sometimes known as “takeback”). This has been extensively studied, including two major reviews (Greening et al., 2000; Sorrell, 2007). The effect has two components: direct rebound effects caused by the reduced cost of the energy service for which the energy efficiency has been improved, and indirect rebound effects caused by the additional spending in the wider economy resulting from the economic resources produced by the improvement. Direct rebound effects have been studied empirically and tend to be in the range 0-30% for major energy services in buildings such as heating and cooling (Sorrell et al., 2009; Ürge-Vorsatz et al., 2011). For energy services where energy is a smaller fraction of total costs, e.g. from electrical appliances, there is less evidence, but lower values are expected. The rebound effect declines with saturation of demand for a particular energy service. It is therefore dependent on income, with somewhat higher rebound levels found for lower income groups (Hens, Parijs, and Deurinck 2010; Roy 2000), implying that rebound contributes positively to energy affordability and development. However there is limited evidence about rebound effects outside OECD countries (Roy, 2000; Ouyang et al., 2010) and further research is required here. *Indirect effects* are more controversial. Empirical evidence is difficult to obtain, and therefore analyses tend to focus on economic modelling, e.g.(Barker et al., 2007; Turner and Hanley, 2011), with diverging and uncertain predictions, depending critically on assumptions about the role of energy efficiency in economic growth. Some claims have been made that indirect rebound effects may be very large (Brookes, 2000; Saunders, 2000), even exceeding 100% so that energy efficiency improvement would increase energy use. These claims may have some validity for critical ‘general purpose technologies’ such as steam engines during intensive periods of industrialisation (Sorrell, 2007). With some macroeconomic assumptions, negative rebound effects are conceptually possible (Turner, 2009). However, there is no empirical evidence to support large or negative rebound effects for energy efficiency in buildings. Modestly declining energy intensities in developed countries with strong policies for energy efficiency in buildings are indicative of the opposite conclusion. Many analyses of rebound effect assume energy prices are set in markets with no effective public policy for climate mitigation. Further research on rebound in different policy environments is required. However, effective energy efficiency policies can reduce rebound (Binswanger, 2001), and therefore some existing analysis may be invalid in real policy environments. Rebound effects should be taken into account in energy efficiency policies and programmes, but are unlikely to alter conclusions about their importance and cost effectiveness in climate mitigation (Sorrell, 2007). More on technological change can be found in Section 3.9.

9.7.5 Public perception: integrating co-benefits into decision-making frameworks

Voluntary programs such as the LEED (Leadership in Energy and Environmental Design) Rating System, the Architecture 2030 Challenge, the American College and University Presidents' Climate Commitment and the Clinton Climate Initiative focus almost exclusively on reducing energy consumption and increasing renewable energy generation. Mandatory regulations such as the International Energy Conservation Code, the International Green Building Code and CalGreen also emphasize GHG emission reduction targets. In 2010, the not-for-profit organization ICLEI: Local

Governments for Sustainability launched a climate change adaptation program to complement their existing mitigation program, which supports municipalities who have signed the U.S. Conference of Mayors' Climate Protection Agreement. Tools introduced to measure community vulnerability to the impacts of climate change include Health Impact Assessments (HIAs) as an approach to designing climate change resilience into specific building projects, to prioritize design/retrofit interventions that will result in the largest co-benefits to owners, the surrounding community and the environment. By contributing to the resilience, HIAs enhance the longevity of a building project's useful life, protect its property value of the surrounding community and result in design decisions that prioritize strategies that maximize both short-term efficiencies and long- term environmental, economic, and social value (Houghton, 2011). According to (Li and Colombier, 2011), an institutional reorganization could upgrade the current Chinese BEE standard to best practices in the world coupled with the state-of-the-art energy supply system would imply an abatement cost at 16US$/tCO$_2$, compatible with the international carbon market price.

9.8 Barriers and opportunities

Barriers and opportunities are referred as conditions that hinder or facilitate the implementation of the analyzed mitigation measures. This section covers some of the main topics related to the deployment of less carbon intensive buildings, framed into three main aspect areas, as shown in Table 9.9.

Table 9.9: Main areas of barriers and opportunities related to the deployment of climate change strategies in the buildings sector

	Barriers	Opportunities
Technological	lack of skills and technologies lack of awareness of materials lack of monitoring and assessing weak coordination among renovation concepts	implementation of innovative technologies hybrid strategies to tackle resistance against passive technologies extensive monitoring campaigns sustainable construction assessment systems
Financial	full costs and their perception lack of awareness of materials and land savings lack of awareness of land savings performance uncertainty limited direct financial costs and benefits ('efficiency gaps') and market barriers in limiting the rate of technology adoption	powerful packages of flanking measures energy simulation in key building typologies (offices, healthcare, education and housing) over a multi-year time period and post-occupancy evaluation to avoid costly monitoring financial penalties or incentives driving changes to business activity
institutional, cultural and legal	perceiving climate change as a current matter for attention rather than a distant concern for beyond 2020 lack of education in professional programmes little consideration to the integration of existing communities in need of regeneration lack of legislation threats of litigation, perception that the work of the design and building team is finished at the point of handover perceived barriers (e.g. risk of air-borne cross-infection in healthcare buildings) poor communication among actors	policy interventions changes in national standards and guidelines routine feedback in policy development and design office practice improved climate change regulations and voluntary programs for Mit-Ad measures corporate reputation and on the importance of individuals' values in shaping corporate behaviour (see also Chapters 10 and 12) coherence between policies at different levels, developing over time and international requirements (e.g. city networks)

Source: according to (Collins, 2007; Short, 2007, 2009; Greden, 2007; Lomas, 2007, 2009; Power, 2008; Monni, 2008; Stevenson, 2009; Amundsen, 2010; Hegner, 2010; Kwok, 2010; Mlecnik, 2010; Pellegrini-Masini and Leishman, 2011; Houghton, 2011).

9.9 Sectoral implication of transformation pathways and sustainable development

9.9.1 Overview of building sector energy projections in the pathways literature

The transformation pathways assessed in Chapter 6 include projections of the buildings sector's energy demand and related emissions as part of integrated projections including all energy supply and demand sectors and other GHG emission sectors outside of the energy system. Figure 9.16 shows how final energy use in the buildings sector develops in the transformation pathways dependent on the climate stabilization category (see 6.2.2 for details). In baseline or non-intervention scenarios final energy use tends to increase in the majority of the pathways by 2030 and further to 2050, largely driven by economic development in emerging economies and developing countries. The demand for energy services related to buildings tends to increase even stronger than suggested by the final energy use suggests, because the increasing service demand is typically accompanied by a transition from traditional fuel use (mostly biomass, but also coal) to modern energy carriers (oil products, electricity) with substantially higher conversion efficiencies that partly compensated the service demand increase (Krey et al., 2012) (). The picture is substantially different in industrialized countries where the analysis even under baseline assumptions shows stagnating or decreasing final energy use in the buildings sector while the increase in emerging economies and developing countries is significantly stronger than suggested by the global picture in Figure 9.16. In the most stringent stabilization scenarios final energy use stays at a significantly lower level than in the baselines with in many stagnating, but often even decreasing energy use compared to 2010 levels of about 120 EJ/yr (ref). However, a few transformation pathways achieve stabilization from rather high final energy demand levels in the buildings sector, thereby focusing on energy supply side measures for reducing emissions. In per capita terms, these scenarios have about twice as high final energy demand in buildings by 2050 compared to the lowest stabilization scenarios.

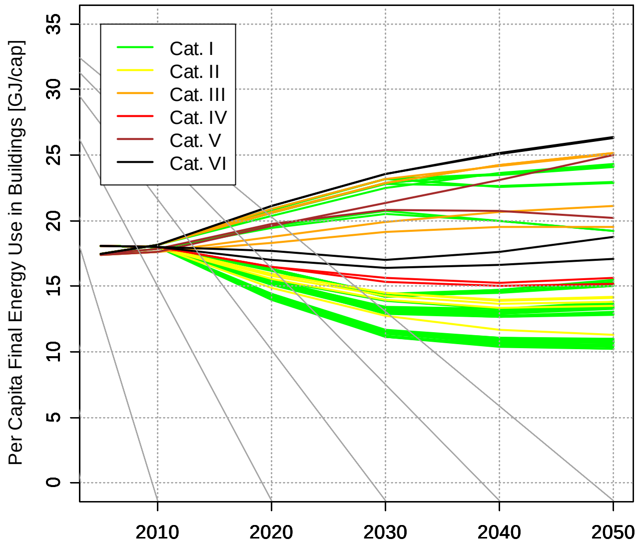

Figure 9.16. Development of the buildings sector's per-capita final energy use in the transformation pathways assessed in Chapter 6 grouped by different climate stabilization categories (see 6.2.2 for details).

9.9.2 Analysis of selected bottom-up and top-down building sector scenarios

[AUTHORS: This section is in the making – it is going to compare a few selected bottom-up and top-down building sector scenarios. The figures included here will be updated with more models included]. One of the main hypotheses is tested here that bottom-up models are more optimistic about the sector's performance in mitigation than top-down optimisation ones.So far confirmed by the one detailed study included.]

Figure 9.17 summarizes and contrasts the findings of a selection of recent studies projecting building energy use. We review energy findings and not GHG ones, since assumptions on supply side decarbonisation significantly influence the CO_2e numbers, and thus emission changes may say more about the supply side than the actions in the building sector per se. While the actual numbers in the figure are not all directly comparable since different end-uses are covered, some general observations can be made. A robust finding is that despite all assumed increases in GDP, floorspace and service levels, global building energy use can at least be held constant, or decrease, as a result of measures. Studies that cover space heating and cooling only report a larger reduction potential as compared to base year energy use (see Figure 9.18), confirming the more theoretical discussions in this chapter, i.e. that these end-uses are where deeper reductions can be expected; while appliance energy use will be more difficult to reduce or even limit its growth. For instance, (Laustsen, in print) reports that as large a final energy use reduction is possible in 2005 heating/cooling/hot water final energy use by 2050 as 64%; while (Ürge-Vorsatz, Wójcik-Gront, et al., 2012) show a 46% reduction in heating and cooling; both of these fully accounting for business-as-usual increase in wealth and amenities. Another general finding is that studies show larger reduction potentials by 2050 than by 2030, pointing to the fact that this sector needs a medium-term, strategic policy planning, since it takes a long time while the building infrastructure can be fully modernized from a climate change mitigation perspective. In fact, 2020 figures in most of these studies and scenarios show energy growth, with the decline starting later, suggesting that "patience" and thus policy permanence is vital for this sector in order to be able to exploit its large mitigation potentials.

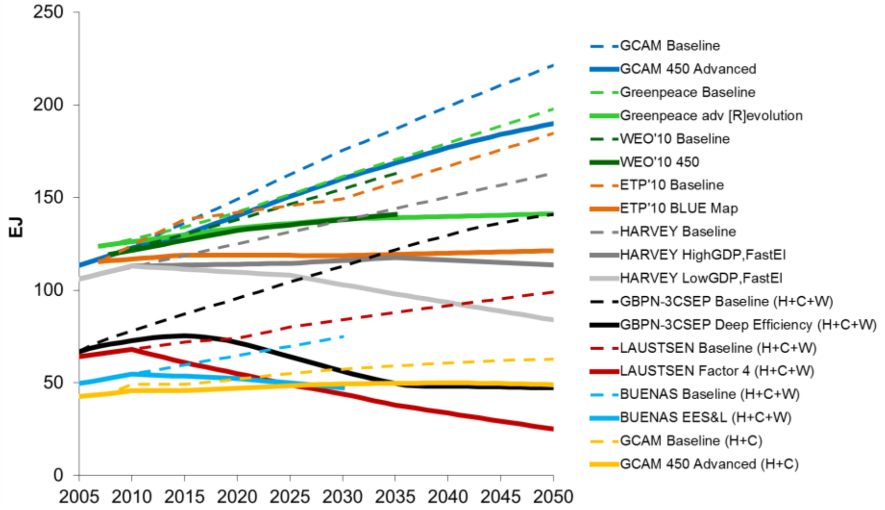

Figure 9.17. Global final building sector energy use projections by different key studies: advanced and reference (baseline) scenarios.

Notes: H=heating, C=cooling, W= hot water.Harvey, GEA -3CSEP and GBPN-3CSEP report heating and cooling energy use only, while Laustsen heating/cooling/hot water. All other studies cover all end-uses. Based on data from(Laustsen, in print; LBNL, 2008; IEA, 2010; WEO, 2011; Ürge-Vorsatz, Wójcik-Gront, et al., 2012; Harvey, 2013) (Laustsen, in print; Ürge-Vorsatz, Wójcik-Gront, et al., 2012)[7]

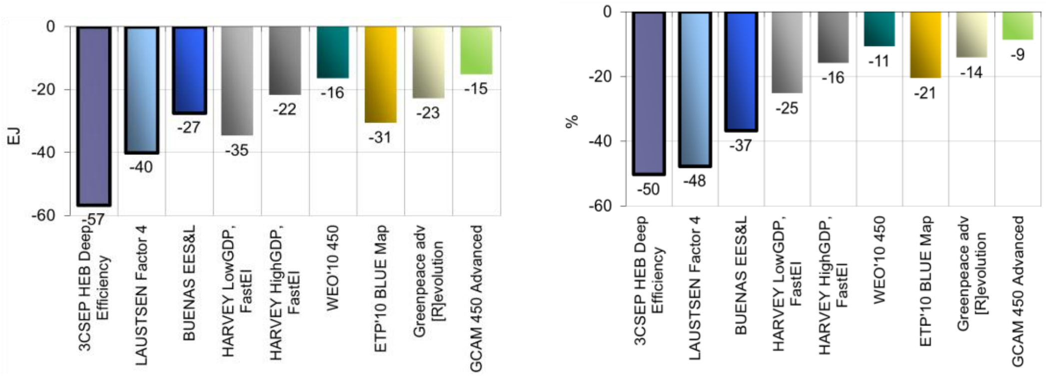

Figure 9.18. Projected reduction potential in global final building energy use in 2030 by different studies, in EJ (first figure) and % (second figure).

Notes: Difference between baseline and advanced scenarios. Studies covered by solid bars are for all end-uses; horizontal stripes are heating+cooling+hot water, while angled stripes heating and cooling only. For the studies and their sources please see Figure 9.10.

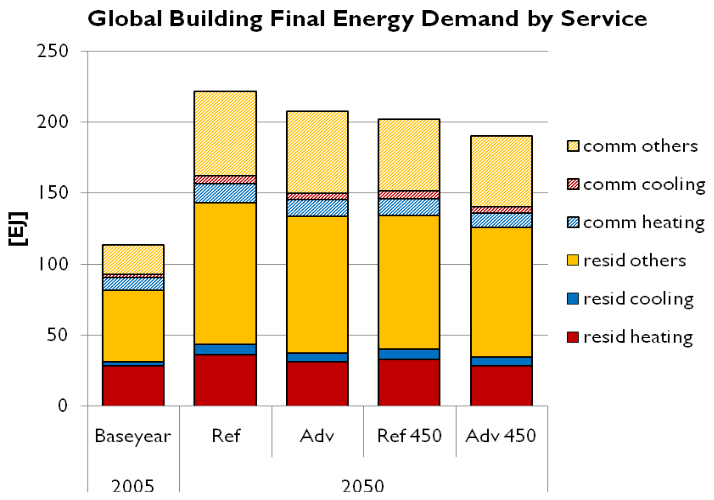

Figure 9.19. Global building final energy demand by source (GCAM [TSU: year of and full reference will be determined for SOD])

9.10 Sectoral policies

9.10.1 Policies for Energy Efficiency in Buildings (highlighting new developments)

The previous sections demonstrated that many strong barriers prevent the full uptake of energy saving measures. Market forces alone will not achieve the necessary transformation towards low carbon buildings without external policy intervention. However, in order to achieve this, policy intervention needs to be complemented by new business and financial models that overcome the first-cost hurdles, one of the key barriers to energy efficiency. There is a broad portfolio of effective policy instruments available to remove the barriers, with many of them implemented in developed countries, but more recently also in developing countries, showing reductions of emissions at large negative costs. When policies are dynamically developed and implemented in a long term coordinated manner, including RD&D, incentives and financing, they could be effective to reverse the growing energy consumption (as example UK residential gas consumption declined for the last 5 years – source Digest of UK Energy Statistics 2010, as results of more efficient boilers and increased building insulation). Beside the technological improvements (improvement in energy efficiency) which has been so far the main focus of most polices, recently the policy makers attention has been drawn to the need of changing consumer behavior and lifestyle. It is estimated that in developed countries existing building stock gets renewed at the rate of 1-2% annually and more than 60% of this building will still be standing in 2050 (Lewis , 2010). Therefore policies to reduce emissions in buildings also need to target the existing stock, through accelerates rates of refurbishments and at the same time avoiding locked-in savings with suboptimal retrofits. This is also becoming true for some developed caountrie ss example, energy efficiency retrofits for existing residential buildings (EERERB) in northern China have been observed as having the great potential to provide significant social and environmental benefits (Dongyan, 2009). Policies require periodic revision to follow technical developments and market transformation, in particular they need regular strengthening, for example for equipment minimum efficiency standards or building codes. Recently a lot of attention has been placed on proper enforcement and implementation if countries would achieve the full potential of the implemented or planned policies. The most common policies for the building sector are summarised in the **Table 9.10**, which includes some examples of the results achieved. Research for the UNEP Sustainable Buildings and Construction Initiative (SBCI) identified policies that were both cost-effective and successful in reducing emissions (Anonymous, 2009). The research concluded that:

- Mandatory measures such as building codes and appliance standards are one of the most effective and cost-effective instruments in the analysed sample of policies, if properly enforced. This is also confirmed by other reports (NEW REFENCE: IEA The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action)
- Market based instruments such as white certificates have ben recently introduced, but have so far proven to be very cost-effective.
- Fiscal and financial instruments, such as low interest loans, grants and tax dedecuation can induce large savings (e.g. tax deductions in Italy).Incentives are very effective to enlarge the market for new efficient products and buildings deep retrofits.
- The effectiveness of voluntary instruments (labelling and agreements) depends on the local context and on accompanying policy measures (rather successful in the Netherlands) .
- Information instruments are relatively effective on their own depending on their design, but they can support other instruments, in particular in combination with standards.
- In this report the highest GHG emission reductions were achieved by equipment standards, building codes, suppliers' obligations, and tax exemptions. Among the most cost-effective instruments were appliance standards, suppliers' obligations, public benefit charges and labelling. Most of these are regulatory and control instruments.

In developing countries, it is essential that the co-benefits of energy-efficiency policies, such as energy security, poverty alleviation or improved social welfare, reduced mortality and morbidity or improved health, job creation and improved industrial productivity are well-mapped, quantified and well understood by the policy- makers (Ürge-Vorsatz and Koeppel, 2007). Policy integration with other policy domains is particularly effective to leverage these co-benefits in developing countries, and energy-efficiency goals can often be pursued more effectively through other policy goals that have much higher ranks on political agendas and thus may enjoy much more resources and a stronger political momentum.

9.10.2 Emerging policy instruments in buildings

Since recent reports have reviewed building-related policy instruments comprehensively (see(IPCC, 2007; GEA, 2012), this chapter provides insights only into recent developments in emerging or important instruments.

Policy instruments to encourage sufficiency

While technical efficiency improvements are still needed and important to reduce energy demand, due to rebound effect, the need for energy services (especially in developing countries) and increased usage of energy due to increased built space per capita and additional equipment, policies need to influence consumer behaviour and lifestyle(Herring, 2006; Sanquist et al., 2012). To this end the concept of sufficiency has recently been introduced in the energy efficiency policy debate (Darby, 2007). Policies to target sufficiency aims at capping or discouraging constant increase in energy use due to increased floor space, comfort levels (e.g. over cooling buildings in summer), and additional equipment. Policy instruments are already available: example includes personal carbon allowance (to include also reduction in transport needs); property taxation. Policies can introduce absolute maximum consumption limits rather than efficiency requirements for equipment and buildings (e.g. kWh/person year rather than kWh/m^2 year). In order to reduce energy demand policies may address meeting needs for space in an effective manner, including promoting density, high space utilization, and efficient occupant behaviour, as increased floor space entails more energy use. A recent example are incentives based on reduction of energy consumption (or energy savings), the so-called energy saving feed-in tariff (Bertoldi, 2010).

New developments in building codes (ordinance, regulation or by-laws)

The EU has introduced in 2010 a new law (Directive) requiring its Member States to introduce building codes set at the cost optimal point using a life cycle calculation methods both for new and refurbished buildings. As result of the same Directive in the EU by the end of 2020 all new buildings must be near zero energy by law. Many Member States (Denmark, Germany, etc.) have announced progressive building codes to gradually reduce the energy consumption of buildings toward net zero energy. The city of Brussels has mandated that all new social and public buildings must meet Passivehouse levels from 2013, while all new buildings have to meet these norms from 2015.

Energy efficiency ‘white’ certificates

White certificates as incentive schemes have been applied European Union (Bertoldi et al., 2009) and Australia (Crossley, 2008), although there are more recent uses in Brazil and India. White certificates evolved from non-tradable obligations on monopoly energy utilities, largely but not only in the USA. Market liberalisation initially led to a reduction in such activity (Ürge-Vorsatz et al., 2011), driven by a belief that such approaches were not needed in or incompatible with competitive markets, although this is not correct (Vine et al., 2003). Their main use has been in regulated markets driven by obligations on energy companies to save energy(Bertoldi and Rezessy, 2008) The use of tradable obligations began in the UK in 2000, and these obligations are now significant in a number of EU countries, notably UK, France and Italy (Eyre et al., 2009). White certificates form a key part of future proposed EU policy for energy efficiency, with new EU legislation requiring all EU Member States to introduce this policy instrument. Precise objectives, traded quantity and rules differ across countries in which white certificates are used. Cost effectiveness is typically very good (Bertoldi et al., 2009). However, white certificates tend to have incentivised low cost, mass market measures rather than deep retrofits, and therefore there are concerns that this policy approach may not be best suited to the future energy efficiency policy objectives (Eyre et al., 2009).

A holistic approach

A holistic approach implies considering the whole lifespan of the building, and includes master planning, life cycle analysis, and integrated building design to obtain the broadest impact possible in the building industry. Energy efficiency in buildings needs to begin at the neighbourhood or city level. In the holistic approach, integrated and regionally adequate codes, design, operation, maintenance must be coordinated in order to reduce emissions. Continuous monitoring of buildings real performances and dynamic codes allows closing the gap with the efficiency potential and achieve the co-benefits. The use of modern technologies to provide feedback on consumption in real time, allowing adjustment of energy performance also in function of external energy supply is important. Dynamic information can also be used for energy certificates and database to disclose the building energy performances (for example this is required for public buildings in Denmark). Delivering low carbon buildings requires solving major challenges for education, capacity building and training of specialised workforce.

9.10.2.2 Single instruments

Table 9.10 attests that there is a broad portfolio of effective policy instruments available to remove these barriers, with many of them being implemented widely also in developing countries saving emissions at large negative costs.

9.10.2.3 Policy packages

There is agreement among experts and it is widely reported in literature (Harmelink et al., 2008) that no single policy would be enough to achieve the potential energy savings and that a number of coordinated and complementary policies would be very effective (and cost-effective). As example in the EU the Energy Service Directive requires Member States to describe the co-ordinated packages of policies in the National Energy Efficiency Action Plans (NEEAPs), which have to be prepared every 3 years since 2008. Example of effective packages of polices adopted by countries are energy labelling, Among the most common energy efficiency packages adopted by several developed countries are equipment MEPS, energy label and financial incentives all based on a common technical analysis (e.g. phasing out in time the lowest classes of the energy label, and giving incentives for the highest efficiency class; this was very successful for the market transformation of domestic appliances in the EU), supported by an effective communication campaign for end-users. Other packages of measures for the retrofitting of existing buildings are mandatory audits and financial incentives linked to the implementation of the audit findings (the financial incentives could be also proportional to the achieved efficiency level indicated in the building certificates). In other jurisdictions the financial incentives are provided by suppliers' obligation or white certificates. Other policy packages include voluntary programmes coupled with tax exemption and other financial incentives (Murphy et al., 2012).

9.10.3 Financing opportunities

9.10.3.1 New financing schemes for energy efficiency (for deep retrofits)

Energy efficiency (EE) is not a single market: it covers measures in a diverse range of end-user sectors, end-use equipment and technologies and consists of very large numbers of small, dispersed projects with a dispersed range of decision makers. As the chapter has demonstrated, many EE technologies in the building sector are proven and economic: if properly financed, the investment costs are paid back over short periods from energy cost savings. However, many potentially attractive energy investments do not meet the short-term financial return criteria of businesses, investors and individuals. While significant savings are possible with relatively modest investment premiums, a first-cost sensitive buyer or lacking financing will never adopt transformative solutions. Major causes for this gap are the lack of EE finance and delivery mechanisms that suit the specifics of EE projects and the lack – in some markets – of pipelines of bankable energy efficiency projects. One solution is that energy utilities, businesses and financial institutions develop creative business models that overcome the first-cost hurdle, such as energy services companies (ESCOs). One innovative example are energy-efficiency investment funds capitalizing on the lower risk of mortgage lending on low-energy housing; the funds to provide such investment could be attractive to socially responsible investment funds. In Germany through the KfW development bank energy efficiency loans low interested rate are offered making it attractive to end-users, the scheme as triggered many building refurbishments (Harmelink et al., 2008).

Table 9.10: Policies and measures for energy efficiency in buildings, their impact and cost-effectiveness

Title and brief definition	Comments	Effectiveness (selected best practices of energy or CO$_2$ emission reduction, MtCO$_2$/yr)	Cost of CO$_2$ emission reduction (selected best practices, \$2010/tCO$_2$ per yr)	References
Building Codes are sets of standards for (most commonly new-built) buildings or building systems determining minimum requirements of energy performance.	Lately also adopted for existing buildings, when refurbished (European Union). Traditionally typical low enforcement has resulted in lower than projected savings. Building codes need to be regularly strengthened to create market transformation.	EU: 35-45 MtCO$_2$ (2010-2011) LV: 0.002 MtCO$_2$/yr in 2016 (estimated in 2008) ES: 0.35 MtCO$_2$/yr in 2012 SL: 0.086 MtCO$_2$/yr in 2016 UK : 0.02 MtCO$_2$/yr by 2020 (estimated in 2011)	EU region: <36.5 \$/tCO$_2$ ES: 0.17\$/tCO$_2$ LV: -206 \$/tCO$_2$	D. Ürge-Vorsatz and Koeppel 2007; EU 2002; Gov't of Latvia 2011; Government of Slovakia 2011b; DECC 2011
Minimum Efficiency Performance Requirements (MEPS) for equipment are rules or guidelines for a particular product class that set a benchmark, and usually prohibit the sale of underperforming products.	Voluntary agreements with equipment manufacturers are acknowledged as an alternative in some jurisdictions. E.g, in Japan the Top Runners Schemes have proven as a successful alternative to MEPS. Proper enforcement of MEPS has been acknowledged as an issue as well as the need for international harmonization (in particular in developing countries, which may receive products banned from other markets or inefficient, second hand products).	JP: 0.1 MtCO$_2$/yr in 2025 (Top Runner Scheme, 2007) US: 158 MtCO$_2$ cummulative in 2030 (2010), updating the standard – 18 MtCO$_2$/yr in 2040 (2010) KE: 0.3 MtCO$_2$/yr (for lighting only) BF: 0.01 MtCO$_2$/yr (lighting only)	JP: 51 \$/tCO$_2$ (Top Runner) Mor: 13 \$/tCO$_2$ AU: -52 \$/tCO$_2$ US: -82 \$/tCO$_2$ EU: -245 \$/tCO$_2$	(ACEEE, 2010; Enlighten, 2010; US EERE, 2011)(Kazuari, 2007)
Equipment Energy Labelling is the mandatory (or voluntary) provision of information about the energy/other resource use of products to end-users at the point of sale.	Implemented either through voluntary endorsment labelling (such as the Energy Star) or through mandatory energy labelling (for example the EU energy label). Technical specifications for the label must be regularly updated to ensure that the label targets the best products on the market. MEPS and labels are usually co-ordinated policy measures with common technical analysis.	EU: 237 MtCO$_2$ (1995-2020) OECD N-Am: 792 MtCO$_2$ (1990-2010) OECD Eu: 211 MtCO$_2$ (1990-2010) NL: 0.11 MtCO$_2$/yr (1995-2004) DK: 0.03 MtCO$_2$/yr (2004)	AU: -38 \$/tCO$_2$	(IEA, 2003; Wiel and McMahon, 2005; Luttmer, 2006)
Building labels and certificates rate and/or compare buildings related to their energy performance and provide credible information about it to users/buyers.	Building labels could be mandatory (for example in the EU) or voluntary (such as BREEAM, CASBEE, Effinergie, LEED, European GreenBuilding label, Minergie and PassivHaus). Labels are beginning to influence market prices.	SK: 0.05 MtCO$_2$ (during 2008-2010) for mandatory certification SK: 0.001 MtCO$_2$ (during 2008-2010) for promoting voluntary certification and audits	EU: 27 \$/tCO$_2$ (2008-2010) for mandatory certification DK: almost 0 \$/tCO$_2$	(Gov't of Slovakia, 2011b)
Mandatory energy audits measure the energy performance of existing buildings and identify cost-effective improvement potentials, ensuring that professionally informed energy investment decisions are made.	Audits should be mandatory and (for developing countries) subsidized to ensure an effective method for already existing buildings, especially if there are incentives or regulations to implement the cost-effective measures.	SK: 0.001 MtCO$_2$ (during 2008-2010) for promoting voluntary certification and audits FI: 0.036 MtCO$_2$ (2010)	FI: 27.7 \$/tCO$_2$ (2010) mandatory audit programme	(Gov't of Slovakia, 2011b; Government of Finland, 2011a; Ürge-Vorsatz and Koeppel, 2007)
Sustainable public procurement is the organized purchase by public bodies following pre-set procurement regulations incorporating energy performance /sustainability requirements.	By setting a high level of efficiency requirement of all the products that the public sector purchases as well as requiring energy efficient buildings when renting or constructing them can achieve a significant market transformation because the public sector is responsible for a large share of these purchases and investments.	SK: 0.01 MtCO$_2$ (introduction of principle of sustainable procurement in administration) (2011-2013) CN: 3.7 MtCO$_2$ (1993-2003) MX: 0.002 MtCO$_2$ (2004-2005) UK: 0.34 MtCO$_2$ (2011) AT: 0.02 MtCO$_2$ (2010)	SK: 0.03 \$/tCO$_2$ CN: -10\$/tCO$_2$	(Gov't of Slovakia, 2011b; FI, 2005; Van Wie McGrory et al., 2006; LDA, 2011)

Promotion of energy services (ESCOs) is aimed at increasing the market and quality of energy service offers, whereas savings are guaranteed and investment needs are covered from cost savings.	Energy performance contracting (EPC) schemes enabling ESCOs or other players to offer innovative contracts guaranteeing the level of services and the energy savings to the customer. Many countries have recently adopted policies for the promotion of EPC deliverd via ESCOs.	EU:40-55MtCO$_2$ by 2010 AT: 0.016 MtCO$_2$/yr in 2008-2010 US: 3.2 MtCO$_2$/yr Cn: 34 MtCO$_2$	EU: mostly at no cost AT: no cost HU: <1 \$/tCO$_2$ US: Public sector: B/C ratio 1.6, Private sector: 2.1	(Ürge-Vorsatz and Koeppel, 2007; AEA, 2011)
White Certificates record and prove that a certain amount of energy has been saved. In some schemes they are also a tradable commodity with rights to these savings.	Suppliers' obligations and white certificates introduced in Italy, France, Poland the UK, Denmark and the Flemish Region of Belgium and in Austrlia. In all the White Certificates schemes the targets imposed by governments have been so far exceeded (Bertoldi, Rezessy 2010).	FR: 6.6 MtCO$_2$/yr (2006-2009) IT: 21.5 MtCO$_2$ (2005-2008) UK: 24.2 MtCO$_2$/yr (2002-2008) DK: 0.5 MtCO$_2$/yr (2006-2008) Flanders (BE): 0.15 MtCO$_2$ (2008-2016))	FR: 36 \$/tCO$_2$ IT: 12 \$/tCO$_2$ UK: 24 \$/tCO$_2$ DK: 66 \$/tCO$_2$ Flanders (BE): 201 \$/tCO$_2$	(Pavan, 2008; Bertoldi and Rezessy, 2009; Togeby et al., 2009; Bertoldi et al., 2010; Lee, 2011; Giraudet et al., 2012)
Carbon market project mechanisms establish a virtual carbon market, and limit the total amount of allowed emissions on a per-country basis. Carbon emission allowances are then distributed to commercial entities on a market where trade of emissions is allowed.	Carbon cap and trade for the building sector: this policy instrument is emerging is some regions and countries, e.g. the Tokyo Metropolitan Government (TMG) initiated the "Tokyo CO2 Emission Reduction Program, by imposing a cap on electricity and energy emissions for large commercial buildings).	CDM projects: 1267 MtCO$_2$ (average cumulative saving per project for 32 registered CDM projects on residential building efficiency, 2004-2012) JI projects: 699 MtCO$_2$ (cummulative) from the single JI project on residential building enegy efficiency (2006-2012) JP: 1.4 MtCO$_2$/yr (which is 13% av. reduction, Tokyo cap-and-trade programme, 2010)	CDM end-use energy efficiency projects, In: -113 to 96\$/tCO$_2$ JI projects (buildings): between 122 and 238 USD/tCO$_2$	(BETMG, 2012; UNEP Risoe, 2012)
Energy and carbon tax is a fiscal tool levied on fossil fuels and related products, whereas charging depends on their carbon contents.	They are very powerful, but need to be quite substantial to have an effect on behaviour and energy efficiency investments, due to inelasticity of demand.	SE: 1.15 MtCO$_2$/yr (2006) DE: 24 MtCO$_2$cummulative (1999-2010) DK: 2.3 MtCO$_2$ (2005) NL: 3.7 -4.85 MtCO$_2$/yr (1996-2020)	SE: 8.5 \$/tCO$_2$ DE: 96 \$/tCO$_2$ DK: 32.5 \$/tCO$_2$ NL: -421 to -552 \$/tCO$_2$ (2000-2020)	(Knigge and Görlach, 2005; EPC, 2008; Price et al., 2011)
Use of Taxation, such as tax reduction are a type of subsidy, representing a transfer of wealth from the society at large to investors in energy efficiency.	Examples include reduced VAT, accelerated depreciation, tax deductions, feebates etc; could be a very effective financial incetives; feebates investigated in California for new homes	TH: 2.04 MtCO$_2$ (2006-2009) IT: 0.65 MtCO$_2$ (2006-2010) FR: 1 MtCO$_2$ (2002) US: 88 MtCO$_2$ (2006)	TH: 26.5 \$/tCO$_2$	(GMCF, 2009; APERC, 2010; BPIE, 2011)
Grants and subsidies are economic incentives, in the form of funds transfer.	Incentives (e.g. grants and subsidies) and financing (e.g. low interest loans,) for investments in energy efficiency, as in the UK Green Deal pay as you save scheme.	DK: 170 MtCO$_2$ cummulative (1993-2003) UK: 1.41 MtCO$_2$ (2008-2009) CZ: 0.05 MtCO$_2$ (2007) AU: 0.7 MtCO$_2$ (2009-2011) FR: 0.4 MtCO$_2$ (2002-2006)	DK: 0.5 \$/tCO$_2$ UK: 84.8 \$/tCO$_2$ FR: 17.9 \$/tCO$_2$	(DPMT, 2009; GMCF, 2009; Missaoui and Mourtada, 2010; BPIE, 2011; Hayes et al., 2011)
Soft loans (including preferential mortgages) are given for carbon-reduction measures with low interest rates. Typically the government provides a fiscal incentive to the bank, which in turn offers a preferential interest rate to its customers.	Incentives (e.g. grants and subsidies) and financing (e.g. low interest loans,) for investments in energy efficiency, as in the UK Green Deal pay as you save scheme.	TH: 0.3 MtCO$_2$ (208-2009) LT: 0.33 MtCO$_2$/yr (2009-2020) PL: 0.98 MtCO$_2$ (2007-2010)	TH: 108 \$/ tCO$_2$ (total cost of loan)	(BPIE, 2011)

Voluntary and negotiated agreements are tailored contracts between an authority and another entity, aimed at meeting a predefined level of energy savings by prescribing either the targets or the sets of measures to be implemented.	Voluntary programmes: also applied in the built environment as in the Netherlands and Finland, where housing association and public property owners agree on energy efficiency targets with the government;	FI: 9.2 MtCO$_2$ NL: 2.5 MtCO$_2$ (2008-2020) DK: 0.09 MtCO$_2$/yr (1996)	FI: 0.15 $/ tCO$_2$ NL: 14 $/ tCO$_2$ DK: 39 $/ tCO$_2$	(Government of Finland, 2011a; Ürge-Vorsatz and Koeppel, 2007; MIKR, 2011)
Awareness raising and information campaigns, are programs transmitting general messages to the whole population. *Individual feedback* is characterized by the provision of tailored information.	Information campaigns to stimulate both behavioural changes (e.g. to turn down the thermostat by 1 C during the heating season) as well as investments in energy efficiency technologies; new developments in the area of smart metering will also impact on consumer behaviour	BR: 6-12 MtCO$_2$/yr (2005) UK: 0.01 MtCO$_2$/yr (2005) EU: 0.0004 MtCO$_2$ (2009) FI: 0.001 MtCO$_2$/yr (2010) SK: 0.003 MtCO$_2$ (information campaigns), 0.001 MtCO$_2$ (training) UK: 0.25% household energy saving/yr, that is 0.5 MtCO$_2$/yr (cumulated 2011-2020) (billing and metering)	BR: -69 $/ tCO$_2$ UK: 8.4 $/ tCO$_2$ EU: 40.2 $/ tCO$_2$ US: 20-98 $/ tCO$_2$	(Gov't of Slovakia, 2011b; Ürge-Vorsatz and Koeppel, 2007; Uitdenbogerd et al., 2009; UK DE, 2011; CB, 2012) Wilhite and Ling 1995 in (CPI, 2011)
Public Leadership Programmes are public practices going beyond the minimum requirements in order to lead by example and demonstrate what behavior and investment changes are possible.		IE: 0.033 MtCO$_2$ (2006-2010) BR: 6.5-12.2 MtCO$_2$/yr	ZA: 25 $/ tCO$_2$ BR: - 125 $/ tCO$_2$	(Ürge-Vorsatz and Koeppel, 2007; Government of Ireland, 2011)

Notes: country codes (ISO 3166): AT-Austria; AU-Australia; BE- Belgium; BF- Burkina Faso; BR- Brazil; CN- China; CZ-Czeck Republic; DE- Germany; DK- Denmark; ES- Spain; EU- European Union; FI- Finland; FR-France; HU- Hungary; IE- Ireland; IT-Italy; JP- Japan; KE- Kenya; LT- Lithuania; LV- Latvia; Mor – Morocco; MX- Mexico; NL-The Netherlands; OECD EU- OECD countries in Europe; OECD N-Am: OECD countries in North-America; PL- Poland; SE-Sweden; SK- Slovak Republic; SL- Slovenia; TH- Thailand; UK- United Kingdom; US- United States; ZA- South Africa

UK Green Deal and the PACE financing

The new 'Green Deal' is a new initiative by the UK government designed to facilitate the retrofitting of energy saving measures to residential buildings across the UK. The scheme enables private firms to offer consumers energy efficiency improvements to their building, and to recoup payments through a charge in instalments on the electricity bill. The finance will be tied to the energy meter rather than the building owner, meaning that credit ratings will not be an issue when it comes to qualifying. The UK government plan to subsidise the loan interest rate charged to homeowners, as the current commercial rates would not be attractive to end-user. In areas of the US with PACE (Property Assessed Clean Energy) legislation in place municipality governments offer a specific bond to investors and then turn around and loan the money to consumers and businesses to put towards an energy retrofit. The loans are repaid over the assigned term (typically 15 or 20 years) via an annual assessment on their property tax bill.

ESCOs

ESCOs projects provide comprehensive solutions for improving energy efficiency in building by guaranteeing that energy savings are able to repy the efficiency investment, thus overcome financial constraints to energy efficiency investments. The ESCO model has been found to be effective in developed countries such as Germany and the USA, and rather less in developing countries (UNEP SBCI, 2007). However, in the last decade ESCOs have been created in number of developing countries (e.g. China, Brazil, and South Korea) supported by international financial institutions and their respective governments (UNEP SBCI, 2007; Da-li, 2009). Since the introduction of international cooperation project in the field of energy conservation by Chinese government and World Bank in 1998, the market-based EPC mechanism and ESCO industry were developed in China (Da-li, 2009). Chinese government has supported and aggressively pushed this industry since its establishment. Financing environment for ESCOs needs to be improved to ensure they operate optimally and sources of financing such as debt and equity need to be located. Possible financing sources such as: commercial banks, venture capital firms, equity funds, leasing companies and equipment manufacturers shall be investigated (Da-li, 2009). In social housing in Europe funding could be provided through the Energy Performance Contracts (EPC), in which an ESCO invests in a comprehensive refurbishment (building insulation and renovation of the heating systems), and repays itself through the generated savings. In the FRESH project, social housing operators and ESCO from France, United Kingdom, Italy and Bulgaria have established the legal, financial and technical framework for EPC's in social housing. Interesting results using the ESCO models in multifamily buildings were also achieved in Hungary (Milin and Bullier, 2011).

Taxation

Taxes such as energy and carbon (CO_2) taxes have increasingly been implemented to accelerate energy efficiency (UNEP SBCI, 2007). They have an advantage of complementing and reinforcing the effectiveness of other policy instruments such as standards. Energy taxes imposed on building sector can reduce GHG emissions in three ways: increase the end user energy price to foster reduced energy demand, shorten pay back period for investment in energy efficiency and on the other hand governments can reinvest tax revenues into energy efficiency interventions (UNEP SBCI, 2007). Tax exemptions and reductions if appropriately structured can provide more effective mechanism than taxes (UNEP SBCI, 2007). In Italy a tax deduction of 55% for building retrofits (windows, boilers, insulation), is in force since January 2007; this represents one of the most generous system of incentives ever established by the governments to promote energy efficiency. The results have been successful; since 2007, over 600,000 requests for deduction have been submitted, during the first three years about 8 billion Euro where invested by taxpayers, over 4,400 GWh of energy saved per year, roughly one million tons of CO_2 emissions avoided.

Another option is value-added tax (VAT) exemption, hence stimulate uptake of energy efficiency technologies in new homes and commercial buildings. Tax policies are used to incentivize the implementation of EERERB in China in a form of tax relief as VAT, property tax and land use tax in cities and towns (Dongyan, 2009).Certified Carbon Emissions generated from CDM projects are exempted from normal (company) tax in South Africa (RSA, 2009).

9.10.3.2 Opportunities in financing for green buildings

Global trends for eco-friendly real estate

The existing global green building market is valued at approximately $550 billion and is expected to grow through to 2015, with Asia anticipated to be the fastest growing region (Lewis, 2010). According to results of the survey carried out by the United Nations Environment Programme Finance Initiative Property Working Group (UNEP FI PWG) on responsible property investing (RPI), covering key markets around the world, it is possible to achieve a competitive advantage and greater return on property investment by effectively tackling environmental and social issues when investing in real estate (UNEP FI and PRI signatories, 2008). In Japan, new rental-apartment buildings equipped with solar power systems and other energy-saving devices had significantly higher occupancy rates (occupancy rate is about 100%) than rates as average 81.3% of other properties in the neighbourhood, and investment return rates were also higher (MLIT, 2010a; b)(. According to results of a survey comparing rent and vacancy rates of buildings certified by the U.S. Building Council LEED and those not certified (Watson, 2010), rent for LEED certified buildings were consistently higher than that for uncertified buildings, although vacancy rates varied according to market conditions. In many municipalities in Japan, assessment by the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and a notification of assessment results are required at the time of construction for buildings. Several financial products are available that provide a maximum discount of more than 1% on housing loans, depending on the grade received by the CASBEE assessment. This has been contributing to the diffusion of green buildings through financial schemes (IBEC, 2009). In addition, a housing eco-point system was implemented in fiscal 2009 in Japan. The eco-point system was broadly divided between a home appliances eco-point system and a housing eco-point system; in the housing eco-point system, housing which satisfies the Top Runner-level standards are targeted. The housing eco-point system targets newly constructed as well as existing buildings. There were 160,000 applications for subsidies for newly constructed buildings, accounting for approximately 20% of newly constructed buildings in 2010. This program has contributed to the promotion of green buildings in the market. Regarding existing buildings, the number of window replacements has increased, and has attracted much attention (MLIT, 2012).

9.10.3.3 Financing opportunities in developing countries

Economic instruments and incentives are recognised as very important means to encourage stakeholders and investors in building sector to adopt more energy efficient approaches at the stages of design, construction and operation of buildings (Huovila, 2007). This section provides an overview of financial instruments commonly applied in the developing world to promote emissions reduction in building sector.

Carbon markets

The Clean Development Mechanism (CDM), has a great potential to promote energy efficiency and lower emissions in building sector. The CDM is regarded as one of the important international market mechanisms to finance emissions reduction projects in developing countries, and with its strong financial and technology transfer incentives it puts building sector on the good position to be a target for project developers (Huovila and UNEP, 2009). Carbon finance can provide additional revenue stream that can facilitate a project financial closure (UNEP FI, 2009). There are barriers for financing energy efficiency projects with flexible mechanisms under Kyoto Protocol due to the size of the projects and the M&V criteria (Huovila and UNEP, 2009). Carbon markets are divided into two categories of compliance market (such as CDM), which is influenced by policies and regulations, and voluntary market based on ‘willing’ market (Chaurey and Kandpal, 2009). In the voluntary market, Verified Emissions Reductions (VER) are traded instead of Certified Emissions Reductions (CER), which are carbon assets generated by CDM project. An example of emerging voluntary markets such as retail carbon market that sells emissions reductions to individuals and companies willing to reduce their carbon footprints can also be a potential source of financing for household interventions such as solar home systems(SHS) (Chaurey and Kandpal, 2009). World Bank has established a Community Development Carbon Fund (CDCF) that supports projects having twin objectives of community development and emissions reduction while improving the quality of life of the poor and their local environment (Chaurey and Kandpal, 2009). CDCF is also one of the funds that can provide carbon financing to SHS type of projects.

Public benefits charges and demand side management (DSM)

Public benefits charges are incentive mechanisms meant to raise funds for energy efficiency measures and to accelerate market transformation in both developed and developing countries (UNEP SBCI, 2007). In a developing country like Brazil, all energy distribution utilities are required to spend a minimum of 1% of their revenue on energy efficiency interventions while at least a quarter of this fund is expected to be spent on end-user efficiency projects (UNEP SBCI, 2007). Utility DSM may be the most viable option to implement and finance energy efficiency programs in smaller developing countries (Sarkar and Singh, 2010). In developing country context, it is common practice to house DSM programmes within the local utilities due to their healthy financial means, strongest technical and implementation capacities, for example, in Argentina, South Africa, Brazil, India, Thailand, Uruguay and Vietnam (Winkler and Van Es, 2007; Sarkar and Singh, 2010).. Eskom, South African electricity utility uses its DSM funds mainly to finance load management and energy efficiency improvement including millions of free issued compact fluorescent lamps(CFLs) that have been installed in the households of South Africa (Winkler and Van Es, 2007).

Subsidies, loans and grants

Capital subsidies, grants and subsidized loans are among the most frequently used instruments for the implementation of increased energy efficiency projects in buildings. These are common in residential sector to overcome financial barrier of initial capital costs (UNEP SBCI, 2007). Financial subsidy is used as the primary supporting fund in the implementation of EERERB in China (Dongyan, 2009). In recent years, the World Bank Group (WBG) has steadily increased energy efficiency lending. This includes the highest lending ever in fiscal year (FY) of 2009 to reach US$3,3 billion and US$1,7 billion committed investments in the same year alone (Sarkar and Singh, 2010). The examples include: funded energy efficient lighting programmes in Mali, energy efficiency project in buildings in Belarus, carbon finance blended innovative financing to replace old chillers (air conditioning) with energy efficient and CFC-free chillers in commercial buildings in India (Sarkar and Singh, 2010). Government of Nepal has been providing subsidies in the past few years to promote the use of solar home systems (SHS) in rural households (Dhakal and Raut, 2010). The certified emission reductions (CERs) accumulated from this project was expected to be traded in order to supplement the financing of the lighting program. The Global Environmental Facility (GEF) has directed significant share of its financial resources to SHS and World Bank similarly has provided a number of loans for SHS projects in Asia (Wamukonya, 2007). GEF has provided a grant to a value of $210 million in financing 23 off-grid SHS projects in 20 countries (Wamukonya, 2007).

9.10.4 Implementation and enforcement challenges

Implementation and enforcement of policies is a key component of the policy design. It is the only way to ensure that the expected results of the policy are achieved. Developed countries are right now raising the importance of proper implementation and enforcement, to survey equipment efficiency when MEPS are in place and to check compliance with building codes (there is still evidence in some EU Member States the compliance of new building with building code is quite low, as it is based on the building design and it is not checked when the buildings is declared fit for occupancy; recommendation includes mandatory check of building performace when the building is operared and use of sanctions). Public money invested in implementation and enforcement will be highly cost effective, as it contributes to the overall cost-effectiveness of energy efficiency policies. Implementation and enforcement is still a major challenge for developing countries which are without much capacity (e.g. test labs for checking equipment efficiency) and knowledge to implement policies such as standards and labels and building codes. In addition to enforcement also proper ex-post evaluation of the policies is needed to assess the real imoact of the policy and eventually review the policy design, stringency or to complement it with other policy instruments. Another challenge is the need to develop the needed skills and training for delivering low carbon buildings. To implement the large number of energy saving projects (building retrofits or new construction) will need a large, skilled workforce to carry out high-quality work at relatively low cost. This could also be a great employment creation.

9.11 Gaps in knowledge and data

Lack of adequate bottom-up data is a major gap, leading to a dominance of top down and supply-focused decisions about energy systems. Misinformation and simplified techniques are risks to the understanding of integrated and regionally adequate building systems, leading to fragmented actions and poorer results. Poor information about opportunities and costs affects optimal decisions and appropriate allocation of financial resources. Energy indicators should also include those related to sufficiency and not only efficiency. Improved and more comprehensive databases on real, measured building energy use, capturing behaviour and lifestyles, are needed to develop exemplary practices from niches to standard. Continuous monitoring and dynamic modification of performance and dynamic of codes allows catching up with efficiency improvements and co-benefits. It also provides better feedbacks to the policymaking process, as well as education, capacity building and training. Positive and negative externalities over the building life cycle are not seldom quantified and monetized, thus not well integrated into the decision-making processes.

9.12 Frequently asked questions

FAQ 9.1. How much could the building sector contribute to ambitious climate change mitigation goals, and what would be the costs of such efforts?

According to the GEA “efficiency” pathway, by 2050 global heating and cooling energy use could decrease by as much as 46% as compared to 2005, if today’s best practices in construction and retrofit know-how are broadly deployed (Ürge-Vorsatz, Petrichenko, et al., 2012). This is despite the over 150% increase in floor area during the same period, as well as significant increase in thermal comfort, as well as the eradication of fuel poverty (Ürge-Vorsatz, Petrichenko, et al., 2012). The costs of such scenarios are also significant, but according to most models, the savings in energy costs typically more than exceed the investment costs. For instance, (Ürge-Vorsatz, Petrichenko, et al., 2012) projects an approximately EUR 18 billion in cumulative additional investment needs for realizing these advanced scenarios, but estimates an over 50 billion cumulative energy cost savings until 2050.

FAQ 9.2. What are the recent advances in building sector technologies and know-how since the AR4 that are important from a mitigation perspective?

The main advances since AR4 do not lay in major technological developments, but rather in the extended their application as well as in incremental improvements in the performance and reductions in the cost of several technologies. For instance, the Passive house standard accounts for cca 7% of of the market share for new houses in Upper Austria by 2006, while low-energy houses (having a heating requirement of ≤ 30 kWh/m^2/yr) captured another 79% (Laustsen, 2008). There are over 20,000 buildings meeting Passive house standard in central Europe (mainly in Germany and Austria). This standard, and even higher energy performance building levels are being successfully applied to new and existing buildings, including non-residential buildings. The costs have been gradually declining, for residential buildings at the level of Passive house standard accounting for 5-8% of conventional building costs (Schnieders and Hermelink, 2006).

FAQ 9.3. How significant are co-benefits associated with energy-efficiency and building-integrated renewable energy policies that provide attractive opportunities for policy integration?

Since the AR4, there has been significant advances in quantifying the co-benefits related to GHG mitigation through energy efficiency in buildings. Some examples include between 0.7 and 35.5 job-years created per $2010 1 million spent in different countries (see Figure 9.14, Section 9.8.3.1); $2010 21 to $2010 60 billion saved in productivity gains as a result of healthier indoor environments in US commercial buildings (Fisk, 2000) and $2010 25 to $2010 201 billion from direct improvements in worker performance that are unrelated to health, cost premiums associated with higher levels of green building certification ranging from 3% to over 8% (Kats, 2009).FAQ 4. Which policy instrument(s) have been particularly effective and/or cost-effective in reducing building-sector GHG emission (or their growth, in developing countries)? Policy instruments in the building sector have proliferated since the AR4, with new instruments such as white certificates, preferential loans, grants, progressive building codes based on principles of cost-optimum minimum requirements of energy performance and life cycle energy use calculation, energy saving feed-in tariffs as well as suppliers'obligations and other measures introduced in several countries (UNEP SBCI, 2007). Among these, regulation-based instruments seem the most environmentally effective, due to the strong barriers that prevail in the building sector. Among them, appliance standards are often the most cost- and environmentally effective, and building codes can result in large emission reductions but can be less cost-effective and needs strong enforcement and regular strengthening.

FAQ 9.4. How decisions in the buildings sector contribute to GHG emissions, direct and indirectly?

Decisions in the building sector affect GHG emissions for decades, as they last for 50-100 years, requiring carbon-intensive infrastructure for power and heat supply, transportation and most urban systems An inefficient lock-in energy use can be exemplified by architectural options favoring the intensive installation of air conditioning and the need of parking spaces for cars. Such option brings up consequences such as consolidated cities where mass transport has little space to be developed and high demand for power supply. On the other hand, the pursuit of higher building performance can lower energy costs and significantly address climate change mitigation needs. Efficiency (including use of ICT, on-site renewable energy generation and cogeneration, integration through smart grids) improves energy security (thus reducing dependence of imports) and entails socio-environmental ancillary life cycle benefits (water reuse, dematerialization, substitution of high-GWP gases, substitution of indoor traditional solid fuel burning, job creation, increased education and induced innovation). It is crucial to influence such decisions, taking into consideration both the urgency to deal with climate change and the pace necessary to supply the booming demand for new buildings, especially in emerging economies.

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