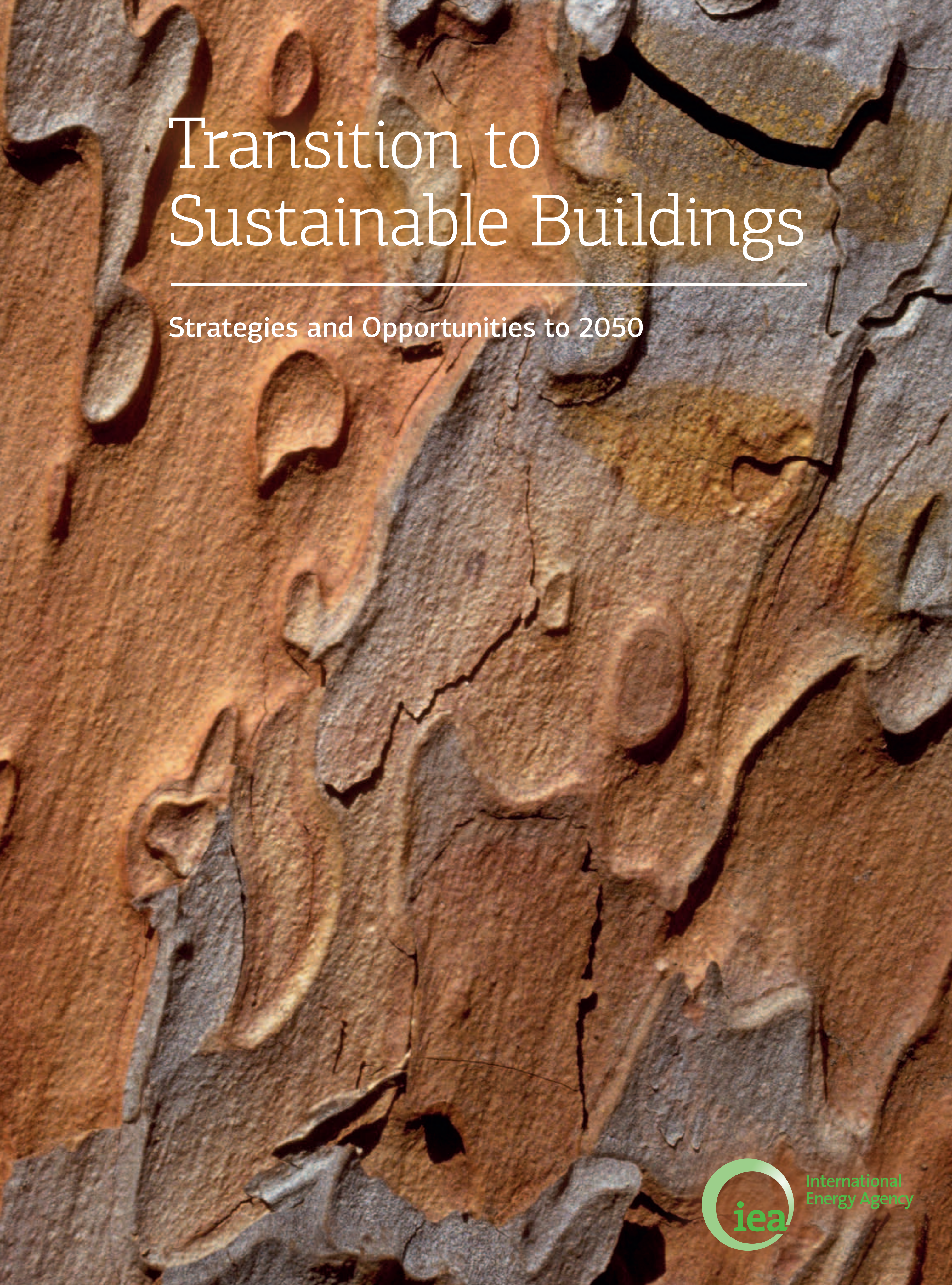

Transition to Sustainable Buildings

Strategies and Opportunities to 2050

International
Energy Agency

Transition to Sustainable Buildings

Strategies and Opportunities to 2050

Buildings are the largest energy consuming sector in the world, and account for over one-third of total final energy consumption and an equally important source of carbon dioxide (CO_2) emissions. Achieving significant energy and emissions reduction in the buildings sector is a challenging but achievable policy goal.

Transition to Sustainable Buildings presents detailed scenarios and strategies to 2050, and demonstrates how to reach deep energy and emissions reduction through a combination of best available technologies and intelligent public policy. This IEA study is an indispensible guide for decision makers, providing informative insights on:

- cost-effective options, key technologies and opportunities in the buildings sector;
- solutions for reducing electricity demand growth and flattening peak demand;
- effective energy efficiency policies and lessons learned from different countries;
- future trends and priorities for ASEAN, Brazil, China, the European Union, India, Mexico, Russia, South Africa and the United States;
- implementing a systems approach using innovative products in a cost effective manner;
- pursuing whole-building (*e.g.* zero energy buildings) and advanced-component policies to initiate a fundamental shift in the way energy is consumed.

This publication is part of the *Energy Technology Perspectives* series and one of three end-use studies, together with industry and transport, which looks at the role of technologies and policies in transforming the way energy is used.

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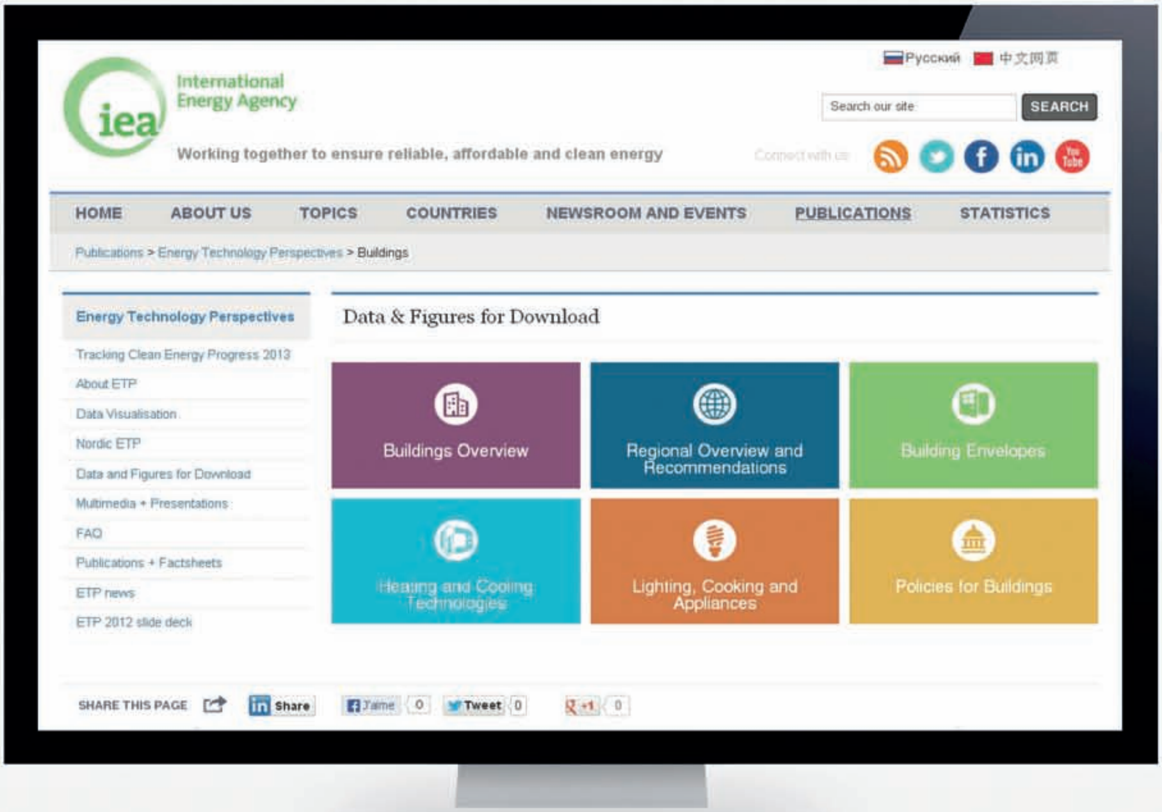

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International Energy Agency

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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International Energy Agency
9 rue de la Fédération
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Foreword

Buildings represent the largest energy-consuming sector in the economy, with over one-third of all final energy and half of global electricity consumed there. As a result, they are also responsible for approximately one-third of global carbon emissions. With an expected population increase of 2.5 billion people by 2050, and given improvements in economic development and living standards, energy use in the buildings sector is set to rise sharply, placing additional pressure on the energy system.

However, technologies and measures already exist that allow the buildings sector to be more energy efficient and sustainable, and thus to play its part in transforming the energy sector. Unlocking the potential of energy efficiency, particularly in the buildings sector should be a priority for all countries. The *World Energy Outlook 2012* showed that in the absence of a concerted policy push, two-thirds of the economically viable potential to improve energy efficiency will remain unrealised through to 2035.

This publication is part of the *Energy Technology Perspectives* series and completes a suite of technology focused analysis for the three end-use sectors of buildings, industry and transport. It builds on other IEA energy efficiency analysis and highlights actions that can be pursued today and lessons learned in different countries on implementing energy efficiency policies for the building sector. The publication also provides a detailed overview of the key technologies that are needed to curtail growth in buildings energy demand.

Many cost-effective options are already available in the buildings sector that can significantly reduce both energy consumption and emissions. In the immediate term, the priority should be to work collectively to support investment in advanced, clean and energy efficient technologies in rapidly developing countries where the building stock is growing strongly. It is essential that new buildings be constructed to the highest possible standards, especially as buildings in some countries can last over 100 years. The construction methods of today can lock-in unnecessary emissions for a long time to come.

But lock-in need not be permanent. Within the existing built environment, deep renovations with best available technology and comprehensive building policies can significantly reduce energy demand. A systems approach with innovative products can be implemented in a cost effective manner which will support energy efficiency goals, while also helping to stimulate the economy, ensure greater energy security, and improve environmental sustainability.

Since barriers to efficiency measures are often due to market failures, mandatory buildings policies including standards and labelling programmes need to be expanded to more products and to all countries around the globe. Existing examples bear out the point. Successful market saturation of energy efficient technology in some countries and the banning of inefficient technology in others demonstrate the potential to dramatically curb energy demand and carbon emissions in buildings.

This publication highlights a path forward for the buildings sector to be much less energy and carbon intensive, while investing in high-performance buildings and highly efficient products. The result alleviates the need for additional and new sources of energy, with benefits for the environment and for energy security.

This publication is produced under my authority as Executive Director of the IEA.

Maria van der Hoeven,
Executive Director,
International Energy Agency

Executive Summary

Overview

The rationale for changing our current energy and climate path is compelling. Energy efficient and low-carbon technologies will play a crucial role in the energy revolution needed to make this change happen. The buildings sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally and an equally important source of carbon dioxide (CO_2) emissions. In certain regions highly dependent on traditional biomass, energy use in buildings represents as much as 80% of total final energy use.

The buildings sector, including the residential and services sub-sectors, uses a wide array of technologies. They are used in the building envelope and its insulation, in space heating and cooling systems, in water heating, in lighting, in appliances and consumer products, and in business equipment. The long lifetime of buildings and related equipment presents both challenges and opportunities for the sector.

Some of the technologies needed to transform the buildings sector are already commercially available and cost effective, with payback periods of less than five years. Others are more costly and will require government intervention if they are to achieve wide market uptake. Unlike many of the technologies needed in the transport and industry sectors, only a small proportion require major research and development (R&D) breakthroughs. Many could, however, benefit from a combination of additional R&D and economies of scale to reduce costs, enhance performance and improve their affordability.

Market barriers in the buildings sector are complex and can be difficult to overcome, so successful implementation of public policy will be essential to achieving high levels of market diffusion. There is a need for integrated and comprehensive policies to help overcome a range of barriers, such as higher initial costs, lack of consumer awareness of technologies and their potential, split incentives and the fact that the true costs of CO_2 emissions are not reflected in market prices.

The transformation of the buildings sector will have positive benefits for other sectors, most notably the power sector, as over half of all electricity consumed today is used in buildings. Electricity savings in buildings will have far-reaching benefits for the power sector and will translate into avoided electrical capacity additions, as well as reduced distribution and transmission network expansion, with potentially huge savings for utilities.

Achieving significant energy and CO_2 emissions reduction is a challenging policy goal, but this publication demonstrates that it is possible with a combination of best available technology and intelligent public policy. Ensuring that all available options are tapped will require unprecedented effort and co-ordination among a diverse set of stakeholders, including policy makers, builders, technology developers, manufacturers, equipment installers, financial institutions, businesses and household consumers.

How to get on track for saving energy in the buildings sector

The International Energy Agency (IEA) annual report to the Clean Energy Ministerial categorised buildings as being in serious trouble for meeting energy savings and carbon emissions reduction (IEA, 2013). While there has been significant technological progress, implementation has been delayed. Examples of best available building technologies combined with renewable energy sources in advanced buildings, such as zero-energy buildings, only represent a small niche market today.

In most cases, this trend can be changed with assertive policy action. However, it still may not be easy from a political perspective. With the world economy struggling, policy makers need to realise that promoting building energy efficiency can increase jobs, support economic development and lead to reduced energy consumption. For example, when a high performance value-added building material or equipment is installed instead of a typical product, that results in an immediate investment today, rather than continued purchasing of often imported fossil fuel for years to come.

This publication makes specific recommendations for policy actions, and is supported with the pertinent technological background to initiate the immediate implementation process. A whole-building approach is critical to get the buildings sector on track. A key action to curtail the energy consumption of fast-growing developing markets is the adoption of enforceable building codes. This publication and the forthcoming *Policy Pathway on Building Energy Codes* and *Technology Roadmap on Energy Efficient Building Envelopes* will significantly improve the knowledge base on how to do this. The IEA is calling on major economies in collaboration with leading product manufacturers to have greater focus on implementing building codes globally.

Constructing a sustainable buildings sector

If no action is taken to improve energy efficiency in the buildings sector, energy demand is expected to rise by 50% by 2050. This increase is driven by rapid growth in the number of households, residential and services floor area, higher ownership rates for existing electricity-consuming devices and increasing demand for new products. However this growth could be limited to just over 10% without changing comfort levels or requiring households to reduce their purchases of appliances and other electronic equipment.

An estimated 40 exajoules (EJ), equivalent to current energy use in Russia and India combined, could be saved in the buildings sector in 2050 through the wide deployment of best available technologies. Examples include high-performance windows, optimal levels of insulation, reflective surfaces, sealants, heat pumps, solar thermal heating, co-generation, energy efficient appliances and equipment, efficient cook stoves and solid-state lighting (SSL), among others.

Achieving the goal of limiting global temperature rise to 2°C (*Energy Technology Perspectives 2012* [*ETP 2012*] 2°C Scenario [2DS]) would require an estimated 77% reduction in total CO_2 emissions in the buildings sector by 2050 compared to today's level. Energy demand reduction, increased use of renewables and, most importantly, a decarbonised power sector will be the main drivers of this decarbonisation in buildings (Figure ES.1).

A combination of efficiency standards, greater use of heat pumps, solar thermal and co-generation with waste heat and renewables could reduce growth in electricity demand by 2 000 terawatt-hours (TWh) in 2050. This is equivalent to half the final electricity consumption of the United States in 2010, or the final electricity consumption of South America, Africa and the Middle East combined in 2010. These savings would represent avoided capacity expansion of roughly 330 gigawatts (GW) of coal-fired capacity or 460 GW of gas-fired capacity and savings of between USD[1] 70 billion and USD 150 billion in new generation capacity.[2] In

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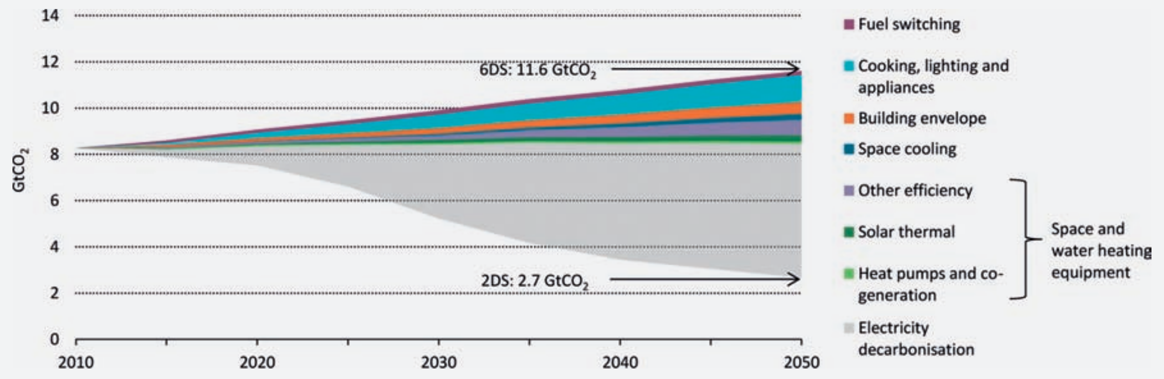
[1] Unless otherwise noted, all costs and prices are in real 2010 USD. Other currencies have been converted into USD using purchasing power parity exchange rates.

[2] This is based on an assumed load factor of 70% for coal-fired capacity and 50% for gas-fired capacity.

Figure ES.1 Contribution of CO_2 emissions reduction in the buildings sector



Key point *Enhanced energy efficiency options in all end-uses combined with a decarbonised power sector can reduce CO_2 emissions in the building sector to just one-quarter of current levels.*

addition, there would also be savings from reduced investments in expanding distribution and transmission networks.[3]

Regional priorities and recommendations

Energy trends in the buildings sector can vary significantly from country to country depending on a number of factors ranging from climate, population, income, economic development and household sizes. Immediate priorities and future goals will need to reflect a country's energy supply and consumer profile. Most of the technology options and policy recommendations discussed in this book could be applicable to all countries either immediately or in the future. However, given constraints on resources there is a need to prioritise those actions that have the largest impact in each country. Nine countries or regions have been examined in detail in this publication and recommendations for policy and technology priorities are summarised below (Table ES.1).

End-use contributions

More efficient building envelopes to keep energy use down

The building envelope determines the amount of energy needed to heat and cool a building, and hence needs to be optimised to keep heating and cooling loads to a minimum. A high-performance building envelope in a cold climate requires just 20% to 30% of the energy required to heat the current average building in the Organisation of Economic Co-operation and Development (OECD). In hot climates, the energy savings potential from reduced energy needs for cooling are estimated at between 10% and 40%.

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[3] Savings from the distribution and transmission network are regionally specific and have not been calculated for this present study.

Table ES.1 Regional priorities in the buildings sector

Technology	ASEAN[4]	Brazil	China	European Union	India	Mexico	Russia	South Africa	United States
Advanced envelope – cold climate (highly insulating windows, air sealing and insulation)			🔴	🟡			🔴		🔴
Reduced cooling loads – hot climates (reflective technologies and advanced cooling equipment)	🟡	🟡				🟡			
Heat pumps (water heating and/or space heating and/or space cooling)			🟡	🔴			🟡		🟡
Solar thermal (water heating and/or space heating)		🔴			🟡	🔴		🔴	
More efficient use of biomass (more efficient cooking and water heating, and leading to modern biogas)	🔴				🔴			🟡	
Policy									
Building codes with supporting infrastructure (education, product ratings, and implementation to pursue holistic approach with advanced envelopes)	🟡	🟡	🟡		🔴	🟡	🟡	🟡	
Appliance and equipment standard (promoting advanced appliances, lighting, heat pumps, heat pump water heater, gas condensing boilers, miscellaneous electrical loads, efficient cooling)	🔴	🔴	🔴		🟡	🔴		🔴	
Deep renovation of existing buildings (systems approach with advanced envelopes and high-performance equipment)				🔴			🔴		🔴
Zero-energy new buildings (advanced holistic building design with integrated renewable energy)				🟡					🟡

Notes: red indicates immediate priority, while gold indicates second priority. This is not intended to be an exhaustive list, but intentionally shows the immediate priority for technology and policy, along with a second goal, to help highlight which technologies and policies will have the largest impact in the country or region. Most of the technology and policy categories could be applicable to all countries.

Primary strategies and technologies needed for efficient building include high-performance envelopes optimised to harvest passive solar energy and daylight, combined with advanced windows, optimal insulation and proper sealing, along with reflective surfaces in hot climates.

An important first step in improving the global building stock is to establish and enforce stringent building codes that include minimum energy performance for new and refurbished buildings. With buildings in some countries lasting well over 100 years and expensive to retrofit, urgent action is needed to ensure that high-performance building envelopes rapidly gain market share and quickly become the standard for all new construction globally. Priority should also be given to refurbishing existing buildings, particularly in the European Union,

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[4] Association of Southeast Asian Nations.

Russia and the United States, where approximately 60% of current building stocks will still be in use in 2050.

More than 40% of the savings expected in heating and cooling energy demand under a low-carbon scenario can be directly attributable to improvements in the building envelope. This represents energy savings of about 6 EJ in 2050, equivalent to the current energy consumption of the United Kingdom. Lower heating and cooling requirements will also allow downsizing of the equipment needed to reach a desired indoor temperature.

Building comfort through efficient heating and cooling systems

Currently, space heating and cooling together with water heating are estimated to account for nearly 60% of global energy consumption in buildings. They therefore represent the largest opportunity to reduce buildings energy consumption, improve energy security and reduce CO_2 emissions, particularly due to the fact that space and water heating provision in some countries is dominated by fossil fuels. Meanwhile, cooling demand is growing rapidly in countries with highly carbon-intensive electricity systems such as ASEAN, China and the United States.

A systems approach, where equipment upgrades are co-ordinated in particular with improved building envelopes, will be key to achieving higher energy efficiencies and a low-carbon heating and cooling supply. The use of electric resistance heaters as the primary source of heating and for water heating in existing buildings needs to be avoided and should eventually be prevented for new installations and equipment replacements.

Instead, heat pumps, solar thermal and co-generation for space heating and cooling as well as hot water should be prioritised. The inefficient use of biomass for space and water heating is unsustainable. A major initiative is needed to promote modern biomass equipment that can reduce air pollution and improve human health, while allowing more of this scarce resource to be used in central systems.

With the demand for space cooling expected to triple between 2010 and 2050, the priority for countries with hot climates should be highly reflective external surfaces, to reduce the need for cooling, and the development and wide adoption of high-performance cost-effective air conditioners. The implementation of minimum efficiency standards will help to improve energy efficiency and control the growth in electricity demand from this end-use. This will be particularly beneficial in reducing peak loads, which often coincide with demand for space cooling.

Lighting more with less

Lighting has significant potential for energy efficiency improvements through the application of more efficient technologies, better matching of lighting intensity to need, and continued emphasis on technical and behavioural solutions that turn off or reduce lighting levels when no longer needed. Improved building design can also offer significant potential to reduce the demand for lighting in buildings, through building orientation and advanced fenestration technologies such as dynamic windows. With better use of natural lighting and adoption of highly efficient lamp technologies, buildings energy consumption for lighting could be reduced by 40% in 2050 compared to current levels.

In the 2DS, incandescent lighting in all regions of the world is progressively replaced with more efficient lighting technologies, including best available fluorescent lighting and SSL. Variable controls and sensors should be added to existing lighting systems via retrofit programmes. In the future, new solutions will be needed for problematic fixture types where current solutions are unacceptable to consumers or which are cost prohibitive to replace. In new buildings, lighting power intensity requirements should be added to all buildings codes and deep retrofit programmes globally.

Moving from traditional biomass towards modern fuels for cooking

Cooking is currently one of the largest end-uses in the residential sub-sector, accounting for nearly one-quarter of global residential energy consumption and about 20% of total buildings energy use. In some regions, such as India, ASEAN countries and Africa, cooking can represent over half of residential energy use. The promotion of low-cost, efficient cook stoves is critical to reducing the use of traditional biomass in developing countries, with a co-benefit of reducing harmful emissions.

As economies mature, the move away from traditional biomass to modern fuels will help to improve household productivity and quality of life, reducing the social, environmental and economic impacts of traditional biomass cooking techniques. The transition away from traditional biomass to modern fuels could save 3.5 EJ of energy, equivalent to the current energy consumption of Australia or ASEAN countries. More efficient use of biomass in buildings will free up this resource for use in power, industry and transport.

Appliances and other electronics which save us time and electricity

In many countries, appliances and other electrical equipment represent the fastest-growing end-use for energy in buildings. This trend is expected to continue in the future, as household wealth rises in major economies such as China, India and South Africa, where current penetration of appliances and other equipment is well below that of OECD countries. This will place additional pressure on power systems that are already facing security of supply concerns.

Urgent action is needed to ensure that electricity demand from the buildings sector does not put undue pressure on the power sector. The deployment of best available technology and continued improvements in appliance and equipment efficiency will help to limit electricity demand growth from buildings and reduce peak demand for electricity. Growth in electricity demand could be reduced to 40% of current levels in a low-carbon scenario compared to a near doubling under a business-as-usual scenario.

Additional R&D is needed to develop smart electronics which can help curtail growing electricity loads. Some improvements have been realised, but additional effort is required to address on-idle power consumption and standby energy use. Innovative, low-cost sensors and controls for appliances and electronic equipment could reduce peak loads on average by about 15%.

Recommendations

Governments will need to work together and with key stakeholders to ensure that markets around the world send consistent signals to consumers and manufacturers, both to maximise efficiency and to limit the cost of future changes. Common medium- and long-term targets for implementing building codes and minimum energy performance standards for lighting, appliances, heating and cooling equipment would enable key market players to plan ahead. For those producing efficient products, knowing that a wide range of markets will be eager for their products will help them plan production and cut costs as their market expands.

In addition to setting and reaching efficiency targets, national governments need to collaborate with each other and with key stakeholders to develop and deploy energy efficient and low-carbon building technologies. New technology development strategies need to be supported by a carefully chosen selection of policies that will drive technology from concept to full market saturation. Successful advanced building programmes striving for zero-energy buildings need to continue; their standards should eventually become mandated.

It is recommended that integrated policies be implemented that can address technologies relative not just to individual components, but also the performance of whole buildings. These policies are equally applicable to the large array of highly effective yet under-utilised energy efficient building technologies and the introduction of existing technologies to new markets.

Rigorous building codes will need to be implemented in all countries. New buildings in cold climates should be subject to progressively tighter regulatory standards, to between 15 kilowatt-hours per square metre per year (kWh/m^2/year) and 30 kWh/m^2/year for heating purposes. In hot climates, the cooling energy demand intensity should be reduced by around one-third compared with current levels.

In OECD countries and non-OECD Europe and Eurasia, large-scale refurbishment of residential buildings should be the priority. Approximately three-quarters of all buildings in these countries will still be standing in 2050 and hence will need to be upgraded to a low-energy standard. In fast-growing economies with rapid new-build rates, the implementation of effective building codes should be the priority. Improved building envelopes in all regions will allow for the downsizing of heating and cooling equipment, and for a significant reduction in energy use.

Tougher regulation will be needed to reduce electricity demand for lighting, appliances and cooling. Support for R&D to reduce the cost of more efficient technologies should be provided, with tighter minimum energy performance standards implemented worldwide. Current best performing appliances should provide the minimum standard for efficiency by 2030 in most countries.

Efficient district heating systems can benefit from thermal energy storage coupled with waste heat and renewables, offering increased systems efficiency and flexibility. However, cross-sectoral policies will be needed among the industrial, power and building sectors to bring them to fruition. Accordingly, older inefficient district heating systems need to be upgraded. Opportunities to integrate building end-use equipment into smart grids and smart metering should be promoted, to help reduce peak load and bring other economic benefits.

Roadmaps that show what is needed to take technologies from their current status through to full commercialisation are a useful tool to help governments and the private sector take the right actions. The IEA is developing energy technology roadmaps with broad international participation and in consultation with industry. These roadmaps detail the technical, policy, legal, financial, market and organisational requirements necessary for an earlier uptake of more efficient low-carbon technologies.[5] In combination, this publication and the forthcoming roadmaps will give the public and private sectors the tools to change the course of the building sector, onto a low-carbon path.

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[5] The IEA has developed a roadmap on efficient heating and cooling technology, and will soon release a roadmap on energy efficient building envelopes.

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Nilesh Y Jadhav, Nanyang Technical University, Singapore

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Richard Karney, Department of Energy, United States

Hallie Kennan, Energy Innovation, Policy and Technology, LLC, United States

Nicola King, Intertek, United Kingdom

Torsten Kleiss, Siemens

Shpresa Kotaji, Huntsman, Belgium

Wilhelm Kuckshinrichs, Forschungszentrum Juelich GmbH, Germany

Hartwig Kuenzel, Fraunhofer Institute of Building Physics, Germany

Roberto Lamberts, Universidade Federal de Santa Catarina, Brazil

Jens Laustsen, Global Building Performance Network

Simon Leach, Intertek, United Kingdom

Jane Lee, Intertek, United Kingdom

Ulrike Lehr, Gesellschaft für Wirtschaftliche Strukturforschung mbH, Germany

Ronnen Levinson, Lawrence Berkeley National Laboratory, United States

J. Owen Lewis, Energy in Buildings and Communities IEA Implementing Agreement

Sabine List, Abteilung für Energie- und Umwelttechnologien – Bundesministerium für Verkehr, Innovation und Technologie

Yantao Liu, Natural Resources Canada

Oliver Loebel, PU Europe

Carlos Lopez, Institute for Energy Saving and Diversification, Spain

Catriona McAlister, Sea Green Tree S.L., Spain

Michael McNeil, Lawrence Berkeley National Laboratory, United States

Ricardo Enriquez Miranda, CIEMAT, Spain

Luis Munuera, Imperial College (London), United Kingdom

Pam Murphy, Solar Heating and Cooling IEA Implementing Agreement

Marco Antonio Nieto, CONUEE Comision Nacional para el Uso Eficiente de la, Mexico

Roger Nordman, SP Technical Research Institute of Sweden

Michelle Orfei, American Chemical Council

Chen Peng, Tsinghua University, China

Jeffrey Rissman, Energy Innovation, Policy and Technology, LLC, United States

Conny Rolén, The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning

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Takao Sawachi, Building Research Institute, Japan

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Ming Shiao, Lawrence Berkeley National Laboratory, United States

Sophie Shnapp, Global Building Performance Network

Bill Sisson, United Technologies Corporation, United States

Jörgen Sjödin, Swedish Energy Agency

Aart Snijders, IFTech International B.V., The Netherlands

Dan Staniaszek, Buildings Performance Institute Europe

Tanya Strevens, World Business Council for Sustainable Development

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Jeremy Tait, Tait Consulting Limited, United Kingdom

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Comments and questions are welcome and should be addressed to:

Buildings Analysts
Directorate of Sustainable Policy and Technology
International Energy Agency
9, rue de la Fédération
75739 Paris Cedex 15
France
Email: buildingsinfo@iea.org

Part 1

Scenarios for the Buildings Sector

Part 1 sets out the scene for the development of an energy efficient and low-carbon buildings sector. It provides analysis of the scenarios for the buildings sector with the aim of identifying the technology and policy pathway required to reach a global goal of halving CO_2 emissions by 2050.

Chapter 1 provides the context and the global overview of the buildings analysis. It contains a quantitative analysis of the buildings sector to 2050 and investigates the key technologies to achieve the reductions.

Chapter 2 provides more in-depth analysis in the context of nine world regions, offering assessments of current technological and policy challenges, and identifying the greatest opportunities to reach deep energy and emissions reduction.

Chapter 1 **Buildings Overview** **25**

The buildings sector is expected to play a significant role in achieving substantial energy and emissions reduction in the future. This will need to be reconciled with the sector's rapidly growing energy consumption and related emissions, which result from the expansion of both the built environment and ownership of energy-consuming equipment.

Chapter 2 **Regional Overview and Recommendations** **49**

Different regions and countries face very different challenges for reducing energy consumption and CO_2 emissions in the buildings sector. Each country will have a different energy and consumer profile that will need to be considered when designing the most appropriate building policies and measures to support an energy efficient and low-carbon buildings sector.

Chapter 1

Buildings Overview

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Key findings

- The buildings sector consumes nearly one-third of global final energy consumption,[1] making it responsible for about one-third of total direct and indirect[2] energy-related carbon dioxide (CO_2) emissions. It therefore has a key role to play in reaching global energy and environmental targets.
- Energy demand in buildings rises by almost 50% between 2010 and 2050 in a business-as-usual scenario. Following an energy efficient and low-carbon pathway can lead to a 25% reduction in total energy use compared to business-as-usual. This represents energy savings of more than 40 exajoules (EJ), equivalent to current energy use in India and Russia combined.
- Energy consumption and emissions reduction in the buildings sector are vital to any long-term strategy to curb carbon intensity. With more than half the current global building stock expected to still be standing in 2050, and considering that buildings can last for over 100 years, actions cannot be limited to tighter controls on new constructions.
- Additional investment needed to transform the energy and emissions profile of buildings is estimated at USD 12 trillion in the period to 2050. The fuel cost savings resulting from these investments would more than offset the additional investment costs.

Near-term recommendations

- Aggressive measures and policies to encourage renovation and energy efficiency improvements need to be implemented to dramatically improve the energy efficiency of existing buildings. This will require significant upfront investment, and their economics will depend heavily on energy prices.
- Moving to a secure and sustainable energy system will require the widespread deployment of existing, fully commercial technologies and the further development of a range of new technologies, which are currently at different stages of maturity.
- Achieving significant energy and CO_2 emissions reduction is technically possible, but a challenging policy goal. Ensuring that all available options are tapped will require unprecedented effort and co-ordination among a diverse set of stakeholders, including policy makers, technology developers and household consumers, with often conflicting goals.

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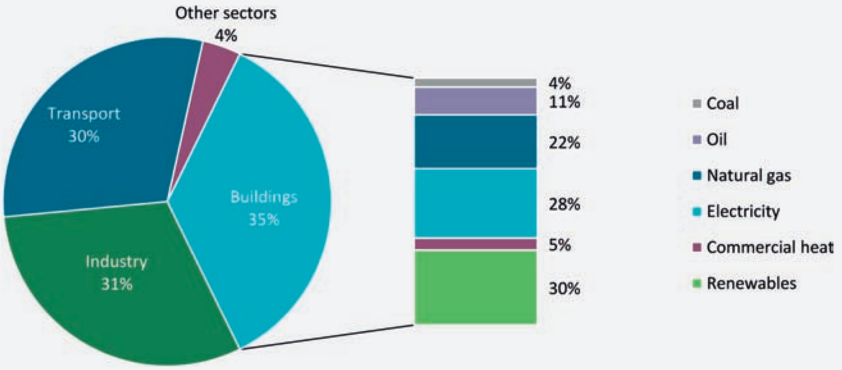
[1] Final energy consumption is the sum of consumption by the different end-use (buildings, industry, transport and agriculture).

[2] Indirect CO_2 emissions refer to upstream emissions from the generation of heat and electricity only.

This publication is part of the IEA *Energy Technology Perspectives (ETP)* series and focuses on the key building technologies and systems that need to be promoted and deployed, along with recommendations on research and development (R&D) to achieve major reductions in energy consumption and CO_2 emissions in the buildings sector through to 2050. It is intended for multiple audiences including policy makers, industry, researchers, efficiency advocates, investors and practitioners with limited or extensive backgrounds in the buildings sector. It is also intended to serve as a reference document that addresses major technologies that need to be pursued in both developed and developing countries, along with supporting policies.

The buildings sector, comprising both the residential and services sub-sectors (Box 1.1), consumes 35% of global final energy use (Figure 1.1). It is responsible for about 17% of total direct energy-related CO_2 emissions from final energy consumers. If indirect upstream emissions attributable to electricity and heat consumption are taken into account, the sector contributes about one-third of global CO_2 emissions.

Figure 1.1 Final energy consumption by sector and buildings energy mix, 2010



Notes: final energy consumption excludes non-energy use. Other sectors include agriculture, forestry, fishing and other non-specified.
Source: unless otherwise noted, all tables and figure in this chapter are derived from IEA data and analysis.

Key point *Buildings are a major end-use in global energy markets and need to be a strong component of any country's plan to save energy.*

The buildings sector uses a wide array of technologies. They are used in the building envelope and its components, in space heating and cooling systems, in water heating, in lighting, in appliances and consumer products, and in office and service equipment. There are numerous measures that are already cost effective and should be pursued immediately. Others can become cost effective with modest government support and incentives. There are also many areas that, along with synergies and an integrated systems approach, will result in least-cost options and the greatest energy-saving potential. These should certainly be pursued.

Due to the long lifetime of buildings and related equipment, combined with prevailing financial barriers in the sector, many buildings do not apply existing efficient technologies to the degree that life-cycle cost minimisation warrants. Among the barriers that exist to improving energy efficiency and decarbonising energy use are higher initial costs, lack of consumer awareness of technologies and their potential, split incentives and the fact that the true costs of CO_2 emissions are not reflected in market prices. Overcoming these barriers will need a comprehensive, sequenced policy package, to target specific barriers with effective policy responses and enforcement measures.

Box 1.1 **Buildings definition and boundaries used in this publication**

The residential and services sub-sectors are collectively referred to as "the buildings sector" in this publication.

The residential sub-sector includes those activities related to private dwellings. It covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances. It does not include energy use for personal transport which is covered in the transport sector, and energy use to generate electricity and heat, which is covered in the transformation sector.

The services sub-sector includes activities related to trade, finance, real estate, public administration, health, food and lodging, education and commercial services (International Standard Industrial Codes revision 4.0 [ISIC rev. 4.0] 33 to 99). This is also referred to as the commercial and public service sector. It covers energy used for space heating, cooling and ventilation, water heating, lighting and in a number of other miscellaneous energy-using equipment such as commercial appliances and cooking devices, x-ray machines, office equipment and generators. Energy use for transportation, or for commercial transport fleet, and energy use for electricity and heat generation are excluded from the services sub-sector.

The large array of opportunities outlined in this publication are not a "take it or leave it" set of policies. The set of policies and measures that are required to achieve large reductions in energy and emissions in a particular country depends on that country's energy situation, characteristics and consumers' habits and behaviour. They should be selected as such, and can be incrementally or jointly implemented.

This publication explores the complexities of the technology transition as they apply to buildings in both the residential and services sub-sectors. Its goal is to provide a deeper understanding of buildings sector technologies, exploring both the better use of existing technologies and the development of new ones. It also addresses needs and opportunities for scaling-up knowledge and expertise in buildings, and assesses the finance and R&D needed to achieve widespread uptake of energy efficient building technologies.

The buildings sector, a key part of the energy system

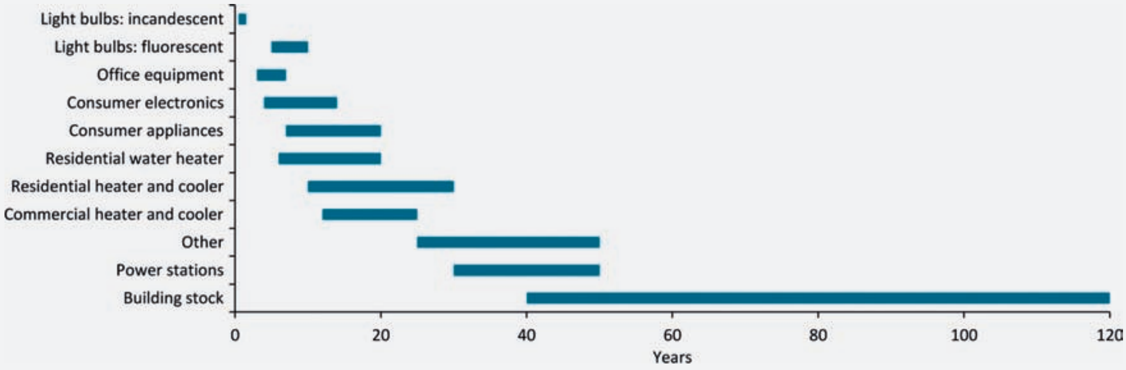
In 2012, the IEA published the latest version of *ETP 2012* (IEA, 2012a). It is intended to be a reference point for policy makers and others interested in identifying how existing and emerging energy technologies and policies can bring about substantial reductions in global CO_2 emissions while also improving energy security. Using a techno-economic approach, the report identified the main technical and policy barriers to the implementation of change as well as the measures that will be needed to overcome them.

There is widespread agreement that reliable, environmentally sustainable and affordable energy sources are fundamental to economic stability and development. It is also widely accepted that achieving them will require a truly global and integrated energy technology revolution. The world therefore faces critical questions about both the most appropriate mix of technologies for energy supply and demand in the future, and the policies that can most effectively and efficiently promote their development and deployment.

Most buildings last for decades. Some last for centuries (Figure 1.2). More than half of the current global building stock will still be standing in 2050. In OECD countries this figure will be closer to three-quarters, especially as buildings in OECD countries are more frequently refurbished than replaced. This has significant implications for policy makers: the very low retirement rate of the residential building stock in OECD countries is a significant constraint, particularly on reducing heating and cooling demand in the more ambitious CO_2 emissions reduction scenarios.

Appliances and lighting with short economic lives can be replaced relatively quickly with each generation of more energy efficient versions at lower overall costs. For most appliances, initial or early shifts to best available technology (BAT) can be an expensive abatement option until market-scale deployment (and competition) reduces costs. Additionally, there are some appliances, notably washing machines and clothes dryers, whose energy savings potential is modest compared to the likely rate of growth in ownership.

Figure 1.2 Economic life spans of energy-consuming equipment and infrastructure



Key point *As the building stock is very long-lived, action on appliances, equipment and systems is the key to achieving early low-cost CO_2 emissions reduction.*

Integrated energy system

To achieve the technology revolution required to reach the energy and emissions reduction goals set out in *ETP 2012*, systems should be integrated to maximise their respective contribution to the overall vision. The IEA envisages a future where the transport and buildings sectors are integrated with electrical vehicle charging. Co-generation and greater industrial sector integration are pursued with significant adoption of renewable energy resources. These examples and other areas of development contribute to an integrated and intelligent energy network of the future (Figure 1.3).

While it is recognised that energy system integration is an important component of a low-carbon future, it is not within the scope of this publication. Similarly, the importance urban planning can play in maximising the benefits of system integration and optimising the synergies between the different sectors is excluded from the present analysis.

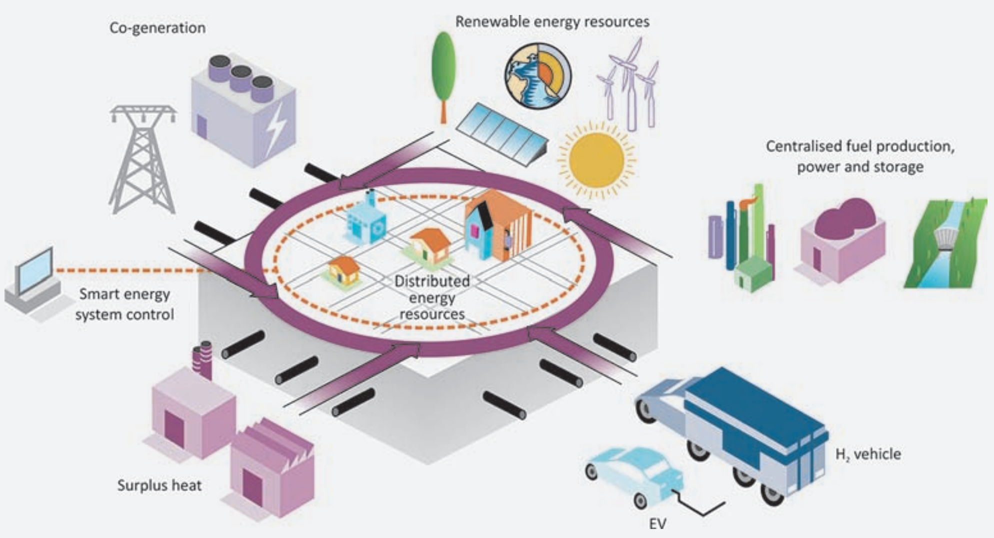
This publication presents technology options that are related directly to the buildings sector. Further analysis on how buildings can influence the energy system (*e.g.* buildings becoming an electricity provider) or how other sectors can supply the energy needs of buildings (*e.g.* provision of surplus industrial heat) may be part of future analysis.

Synergies between the buildings and power sectors

The goal of this publication is to provide an analysis of the options available to the buildings sector to reduce its energy consumption and related CO_2 emissions. As a result, the analysis considers final energy consumption only, and excludes the reduction in primary energy used in the transformation sector. However, it is recognised that the buildings sector will have an important role to play in the decarbonisation of the power sector.

In 1971, buildings accounted for 37% of total final electricity consumption. In 2010, this share reached about 50% (Figure 1.4), confirming its importance to the power generation sector, and the impact it can and must play in its decarbonisation.

Figure 1.3 Integrated and intelligent energy network of the future



Notes: EV = electric vehicle, H_2 = hydrogen.

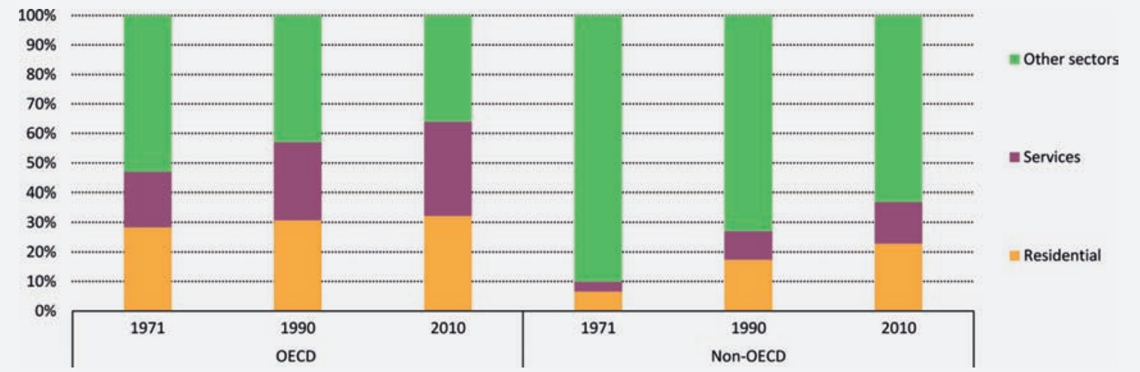
Key point *The energy system of the future will integrate the sources of and requirements for energy from all parts of the energy system.*

Improvement in energy efficiency of electrical equipment will not only save energy in the buildings sector, it will reduce the energy required to produce this electricity (Figure 1.5). As a result, every unit of electricity saved in the buildings sector will translate into even more fossil fuel saved, or will help avoid capacity expansion in the power sector. For example, an average of 14 400 terawatt-hours (TWh) of global electricity generation are based on fossil fuels (67% of total global generation) and account for 142 EJ of fossil energy in 2010.

Regional variations and factors influencing buildings energy consumption

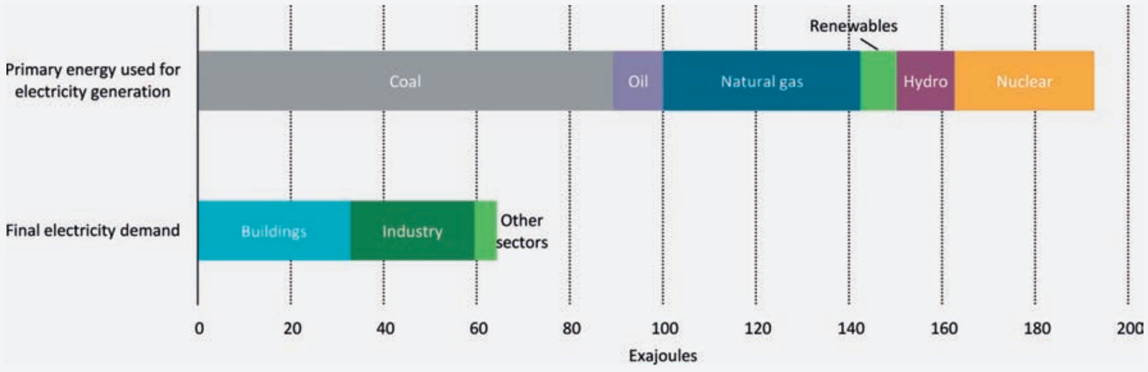
From an energy perspective, buildings are complex systems in which the interaction of technologies almost always has an influence on energy demand. Occupancy profiles, consumer preferences and the local climate all affect overall energy demand in a building. Architectural trends, product design and consumer behaviour also have an important impact on the energy intensity of buildings.

Figure 1.4 Buildings electricity use as a share of total electricity consumption



Key point *Buildings accounted for about 50% of global final electricity consumption in 2010.*

Figure 1.5 Energy use for power generation and total final electricity demand, 2010

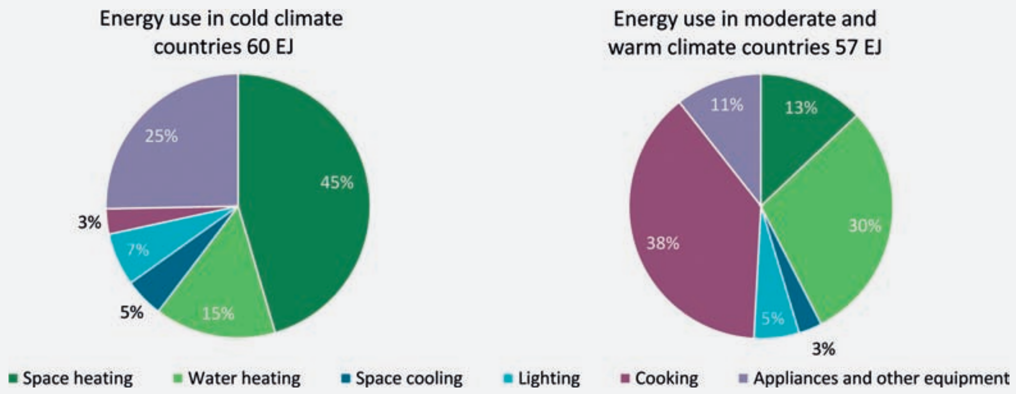


Key point *Electricity savings in the buildings sector will translate into even greater savings in primary energy use in the power sector.*

There is wide disparity of energy consumption patterns in the buildings sector across major countries and regions. Differing characteristics include housing unit size, occupancy density, wealth, climate, differences in preferences and behaviour, and varying availability and use of a wide array of appliances and electronics.

As an example, the climate of a country has a strong impact on its energy consumption pattern (Figure 1.6). In countries with cold climates, a high proportion of buildings energy consumption is used for heating buildings. As such, policies and measures should, in most cases, first target improved building envelopes, then heating equipment, to reduce the overall energy consumption of the buildings sector. On the other hand, such policies would not be relevant or a priority in countries with low heating and cooling loads and where a large share of the energy is used for cooking. More in-depth results at the country and regional level are presented in Chapter 2 of the publication.

Figure 1.6 Buildings end-use energy consumption, 2010



Notes: EJ = exajoule. Cold climate countries comprise OECD countries excluding Australia, Mexico, New Zealand and Israel, and non-OECD Europe and Eurasia. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Key point *About 70% of buildings energy consumption is for space heating and appliances in cold climates, and for water heating and cooking in moderate and warm climates.*

This publication does not provide an exhaustive analysis of the need for behavioural change. However, it is recognised that to be successful, policies will need to take into consideration consumer interest and ensure non-financial barriers, such as lack of information, lack of consumer awareness or public acceptance, are addressed. Although it does not explicitly quantify the role of consumer behaviour, it is implicitly taken into consideration in the development of the buildings model assumptions. For example, it is assumed that the number of households currently relying on traditional biomass will decrease dramatically. While some households currently use traditional biomass by choice, the analysis assumes that consumer preference will lead to a move away from this form of energy for cooking.

Current status of energy and emissions in the buildings sector

Energy consumption trends in the residential sub-sector are closely related to a wide range of factors, including changes in population, number of households, building characteristics, building age profile, house size, income growth, consumer preferences and behaviour, climatic conditions, appliance ownership levels, and overall energy efficiency improvements. Between 1990 and 2010, the world's population grew by 30% to reach 7.0 billion. Most of this growth occurred in non-OECD countries (Table 1.1).

In the services sub-sector, energy consumption trends are more closely related to the sector's level of economic activity and the related growth in floor area, building types (relative to sector activity), age of buildings, climatic conditions and energy efficiency improvements. Gross domestic product (GDP) has increased rapidly, almost doubling between 1990 and 2010. The increase in the sector's value-added[3] was even faster, globally increasing by 3.3% per year.

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[3] Value-added can be measured either gross or net, that is, before or after deducting consumption of fixed capital: a) gross value-added is the value of output less the value of intermediate consumption; and b) net value-added is the value of output less the values of both intermediate consumption and consumption of fixed capital.

The level of GDP per capita and services value-added are reflected in buildings energy use per capita. OECD countries, where per-capita income is 5.8 times the non-OECD level, use almost four times more energy per capita than non-OECD countries. Space heating requirements also explain, in part, the higher intensity in OECD countries.

Table 1.1 Recent trends in buildings sector drivers

	OECD countries				Non-OECD countries			
	1990	2000	2010	AAGR 1990-2010	1990	2000	2010	AAGR 1990-2010
Population (million)	1 062	1 146	1 230	0.7%	4 319	5 072	5 776	1.5%
GDP (in billion 2010 USD, at PPP)	26 595	33 591	40 985	2.2%	12 959	22 398	33 336	4.8%
Services value-added (in billion 2010 USD, at PPP)	18 222	24 619	29 768	2.5%	6 160	8 831	16 713	5.1%
GDP per capita (USD/person)	25 042	29 323	33 312	1.4%	3 001	4 416	5 771	3.3%
Buildings energy consumption (PJ)	39 855	47 400	51 286	1.3%	43 472	52 111	65 698	2.1%
Residential energy consumption (PJ)	25 079	29 145	30 730	1.0%	39 110	46 845	56 033	1.8%
Services energy consumption (PJ)	14 776	18 255	20 556	1.7%	4 363	5 266	9 665	4.1%
Buildings energy use per capita (GJ/person)	37.5	41.4	41.7	0.5%	10.1	10.3	11.4	0.6%

Notes: AAGR = average annual growth rate, GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, PJ = petajoule, GJ = gigajoule.

Trends in buildings energy use and CO_2 emissions

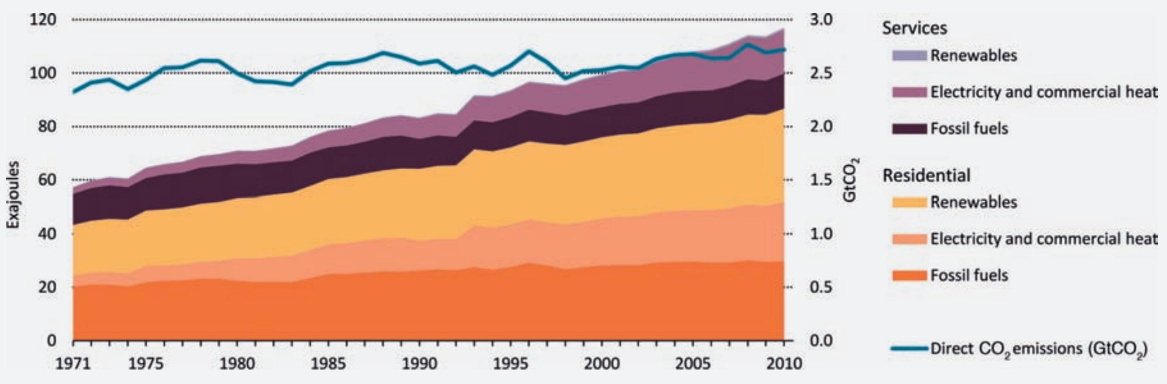
Between 1971 and 2010, total energy consumption in the buildings sector grew by 1.8% per year. The residential sub-sector requires the largest share of energy (around three-quarters of total energy consumption in buildings), although the services sub-sector has increased its share of total buildings energy use since 1990, from 23% to 26% (Figure 1.7).

Energy consumption in the buildings sector is no longer dominated by OECD countries, whose share of total energy consumption fell from 57% in 1971 to 44% in 2010. However, OECD countries still account for the largest share of modern commercial fuels, with much of the energy consumption in non-OECD countries still derived from traditional biomass. When combustible renewables (*e.g.* biomass) and waste are excluded, OECD regions accounted for around 60% of total energy consumption in buildings in 2010.

While the global consumption of fossil fuels in buildings increased by 36% between 1971 and 2010 (from 32 EJ to 43 EJ), its share decreased substantially over the same period. In 1971, 55% of buildings energy needs were met by fossil fuels. By 2010, the share was down to 37%. This change in the composition of the energy mix in buildings is explained by an increased penetration of electrical appliances and equipment, a shift away from oil and coal boilers for heating purposes in OECD countries, and the increased numbers of non-OECD households using biomass as a main fuel for cooking.

Electricity and natural gas are the main fuels used in OECD countries and in non-OECD Europe and Eurasia (Figure 1.8). Natural gas, mostly used for space heating purposes, accounted for 35% of buildings energy requirements in these regions in 2010. Electricity use increased by

Figure 1.7 Global buildings energy consumption by energy source and direct CO_2 emissions



Note: $GtCO_2$ = gigatonne of CO_2.

Key point *The residential sub-sector consumes about three-quarters of the total energy used in the buildings sector.*

66% between 1990 and 2010, largely as a result of higher numbers of people in these regions buying and using more small electric appliances and electronic devices. Other renewables, including solar, wind and geothermal sources, were the fastest-growing energy source in the residential sub-sector, although they only reached 0.6% of total energy consumption in 2010. In non-OECD Europe and Eurasia, district heating remains important in the residential sub-sector with consumption of commercial heat reaching 3.6 EJ in 2010, or 34% of total buildings energy consumption.[4]

In non-OECD countries, excluding non-OECD Europe and Eurasia, biomass and waste (particularly traditional biomass, including wood, charcoal and dung) remain the largest source of energy used in the buildings sector, with consumption at 32 EJ in 2010 (or about 60% of buildings final energy).[5] As in OECD countries, electricity is one of the fastest-growing energy commodity, where its use increased by 320% between 1990 and 2010 to reach 17% of total final energy consumption. This increase was driven by the increased ownership of appliances and a greater electrification of households. At the same time, the declining use of inefficient traditional biomass in favour of electricity and commercial fuels is one of the main reasons that net growth in energy use in non-OECD countries has not been more significant. However, this shift away from biomass had an upward impact on the total CO_2 emissions of the sector.

The *ETP* 2°C Scenario for the buildings sector

The *ETP 2012* 2°C Scenario (2DS) (Box 1.2) showed that the buildings sector has a key role to play in halving global energy-related CO_2 emissions by 2050. Direct CO_2 from the buildings sector will need to be brought well below today's levels by 2050, with further reductions in

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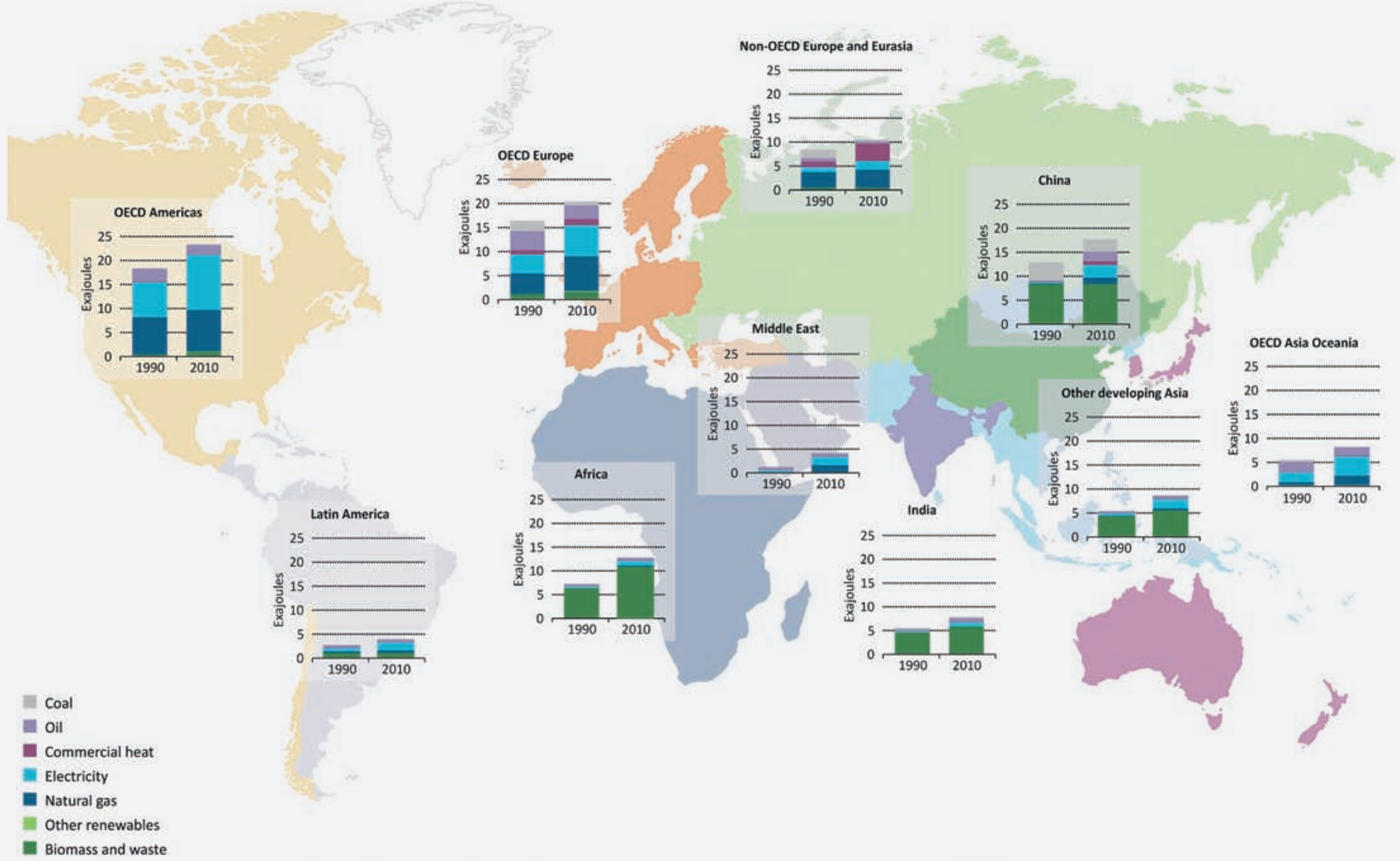
[4] In IEA statistics for the residential and services sub-sectors, "heat" refers only to purchased heat. It is not the total energy consumed for heating purposes or the heat generated on-site.

[5] The efficiency of traditional biomass use is typically very low (around 8% to 15% for traditional cook stoves is common). Its use has a wide range of negative impacts, such as degraded indoor air quality and deforestation. Switching to modern biomass or commercial fuels would consume a fraction of current energy, as these energy sources are much more efficient and have other significant benefits.

Figure 1.8 Energy consumption by region and energy source in the buildings sector, 1990 and 2010



This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Key point *While energy consumption in the buildings sector increased by 1.3% in OECD countries between 1990 and 2010, it increased by 2.1% per year in non-OECD countries.*

indirect emissions from electricity production achieved through a reduction in electricity demand from the buildings sector and a substantial decarbonisation of the power sector.

Under the 2DS, 13% of the global CO_2 reductions come from the buildings sector (direct emissions reduction and indirect emissions reduction from the decrease in buildings electricity demand). *ETP 2012* concludes that there are many existing cost-effective energy efficiency options already available in the buildings sector that can reduce energy consumption and CO_2 emissions from heating and cooling, lighting and appliances.

Modelling framework for the buildings sector

The buildings sector is modelled using a global simulation stock accounting model, split into residential and services sub-sectors and applied across 31 regions. For both sub-sectors, the model uses income, population and urbanisation data, as well as services value-added to project floor area per capita and activity levels such as cooking and appliance ownership. Based on this set of drivers, demand for individual energy services and the share of each energy technology needed to meet this demand are modelled to 2050. Modelling (from the bottom-up) all energy uses traditionally associated with buildings, the *ETP* buildings model is suited to analysing global scenarios for energy efficiency in buildings and the transition to advanced end-use technologies.

More details on the modelling framework and data assumptions for the buildings sector are provided in Annex A.

Box 1.2 *ETP 2012* Scenarios

ETP 2012 uses extensive modelling to examine possible scenarios of global energy demand in the future, beginning with a simple extension of current trajectories and then identifying technology, policy and pricing options needed to reach specific targets at the lowest cost.

The 6°C Scenario (6DS), which serves as the baseline scenario for the buildings analysis presented in this publication, is largely an extension of current trends, with no effort on the part of government, industry or the general public to curb emissions. By 2050, global energy use in the 6DS almost doubles (compared with 2010) and total emissions rise even more. In the absence of efforts to stabilise atmospheric concentrations of greenhouse gas, average global temperature rise is projected to be at least 6°C in the long term. While autonomous energy efficiency is observed, this scenario expects no major shifts in technology or in the energy consumption mix for the buildings sector. As a result, global direct CO_2 emissions from all buildings are about 25% higher in 2050 than in 2010, and reach 3.5 gigatonnes of CO_2 ($GtCO_2$).

By contrast, the 2DS is target driven: it starts with the aim of limiting the increase in global average temperature to 2°C and examines how to achieve the deep emissions cuts (including CO_2 and other greenhouse gases, such as methane and nitrous oxides) required to at least halve global emissions by 2050. This does not mean that the buildings sector needs to reduce its emissions by over 50%; rather, reaching this objective in the most cost-effective way requires each economic sector in each country to contribute, based on its costs of abatement. Under this scenario, annual global buildings direct emissions would be 1.9 $GtCO_2$ in 2050, about 35% less than current levels.

These scenarios are not predictions. They are internally consistent analyses of pathways that may be available to meet energy policy objectives, given a certain set of technology assumptions.

Scenario results

In the 6DS, total energy demand in the buildings sector increases from 117 EJ in 2010 to 173 EJ in 2050. The services sub-sector grows more rapidly, at 1.5% a year between 2010 and 2050, while the residential sub-sector grows by 0.8% per year.

In the 2DS, energy consumption in the buildings sector reaches 130 EJ by 2050, 25% lower than in the 6DS and only 11% higher than in 2010, despite a 68% increase in the number of households, 74% increase in residential floor area and greater services sub-sector floor area (66% increase) over the same time period. Achieving such reductions will not only require a technology revolution, it will also depend on the implementation of strong policies to ensure the full potential of energy efficiency is tapped.

Box 1.3

Building an efficient world: a blueprint for savings

Achieving deep energy and emissions reduction require concrete, forceful and complementary policy measures. As the nature of the barriers to energy efficiency is manifold and divergent, depending on the circumstances of the specifics of the sector or economy considered, a portfolio of measures is needed. While much can be achieved by individual countries or regions, full realisation of the benefits is likely to depend on a formal global commitment, to raise energy efficiency and report results regularly, using mutually agreed verification mechanism. The Efficient World Scenario of the *World Energy Outlook 2012* highlighted the following guiding principles:

- The energy performance of each energy end-use and services needs to be made visible to the market.
- The profile and importance of energy efficiency needs to be raise.
- Create and support business models, financing vehicles and incentives to ensure investors in energy efficiency reap an appropriate share of the rewards.
- Energy efficiency needs to be normalised if it is to endure.
- Monitoring, verification and enforcement activities are needed to verify claimed energy efficiency.
- Achieving the supply and widespread adoption of energy efficient goods and services depends on an adequate body of skilled practitioners in government and industry.

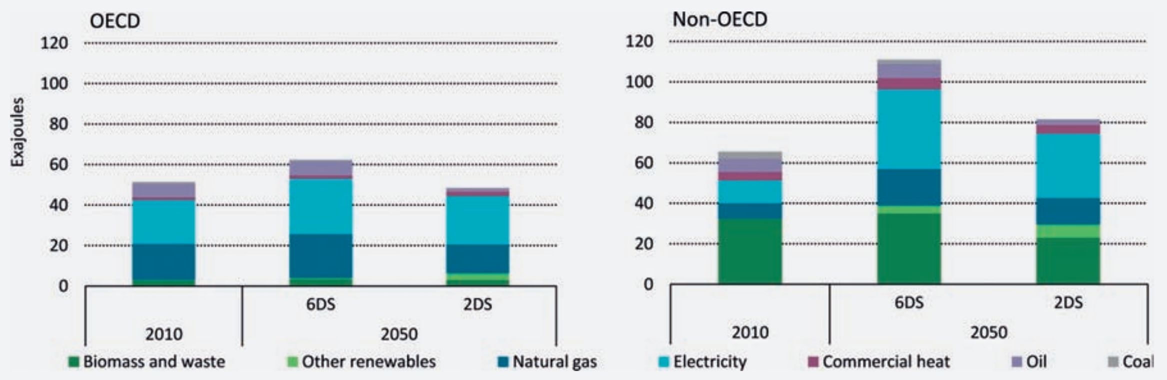
Source: IEA, 2012b.

Energy sources and growth-demand patterns in OECD and non-OECD countries are dramatically different in both the 6DS and 2DS (Figure 1.9). While electricity and natural gas remain the main energy sources for OECD countries in both scenarios, non-OECD countries will continue to rely on biomass in the 6DS, but are expected to progressively switch to high-efficiency cook stoves using modern types of biomass or other fuels, such as liquefied petroleum gas (LPG), natural gas and electricity.

While overall energy consumption decreases in the 2DS by 2050 compared to the 6DS, the consumption of solar and geothermal energy is higher in 2050 in the 2DS than in the 6DS. In particular, the contribution of solar thermal in the buildings sector rapidly grows in the 2DS to become 27 times greater in 2050 than in 2010 and twice that in the 6DS. Fossil-fuel consumption in 2050 in the 2DS will be 56% that of the 6DS. This reduction results from fuel switching and energy efficiency improvements. Biomass consumption in 2050 will be 32% lower in the 2DS than in the 6DS due to greater use of cleaner, more efficient modern biomass (biogas, biofuels, etc.).

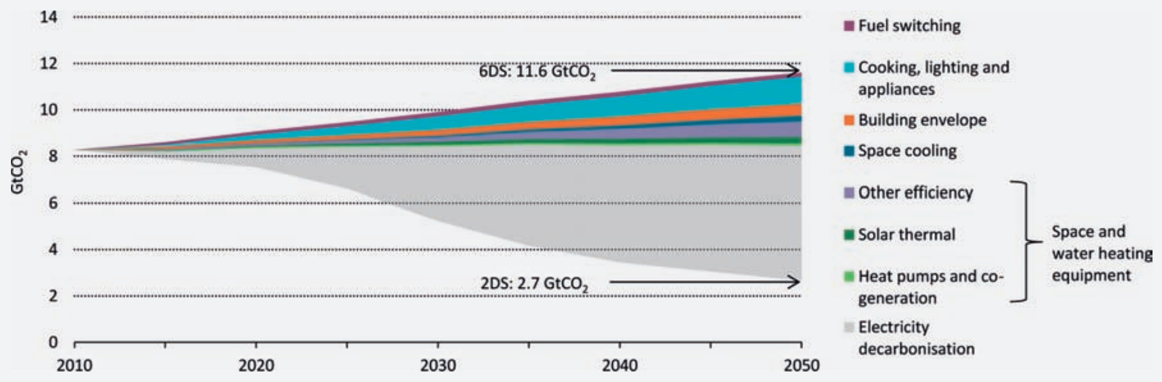
In the 6DS, buildings sector direct and indirect CO_2 emissions are expected to increase by 40% to 12 $GtCO_2$ in 2050. In the 2DS, total CO_2 emissions will decrease to 2.7 $GtCO_2$ in 2050, over 75% lower than they would be in the 6DS (Figure 1.10). More than 60% of these reductions will be attributable to decarbonisation of the power and heat generation sectors. Energy demand reduction will also play an important part in reducing buildings CO_2 emissions.

Figure 1.9 Buildings sector energy consumption by energy source



Key point *Despite the growing importance of electricity, biomass and waste remain key energy sources for non-OECD countries.*

Figure 1.10 Contribution of CO_2 emissions reduction options between the 6DS and 2DS



Key point *Improvements in the building envelope and energy savings in cooking, lighting and appliances dominate total CO_2 reductions.*

Improvements in the thermal envelopes of buildings account for 17% of the 3.2 $GtCO_2$ savings directly attributable to buildings in 2050 (Figure 1.10) and enable the downsizing of heating and cooling equipment.

Increased deployment of efficient technologies for cooking, lighting and appliances contributes more than 35% of the 2DS savings. The use of heat pumps for space and water heating; as well as the deployment of more efficient air conditioners for cooling and solar thermal systems for space and water heating contribute about 40%. Co-generation plays a small but important role in reducing CO_2 emissions and helps to balance the renewables-dominated electricity system in the 2DS.

All of these measures are needed to achieve the 2DS goals for reducing CO_2 emissions.

Box 1.4 The impact of rebound effect in the buildings sector

The 2DS features increased adoption of energy efficient technologies that provide the same level of service using less energy, making services cheaper. If consumers find heating their homes is cheaper as a result of renovations that improve the building envelope, they might opt to increase the indoor temperature of the house. The amount by which actual energy savings differ from those predicted by a technology-only estimate is termed the rebound effect. Its impact varies greatly by technology, region and sector, and can offset part of energy savings.

The evidence base for the possible magnitude of the rebound effect is sparse, largely focused on direct effects for a few services, sometimes contradictory and almost exclusively based on OECD countries (Table 1.2). As a result the scope for estimating its impact is limited.

In the long time frames contemplated in the scenario analysis, the rebound effect is likely to be dwarfed by income growth, and dampened by the saturation of many energy service demands. Simply put, there is a maximum level of, say, thermal comfort or washing machine cycles. This suggests that rebound effects will decline across the developing world as incomes rise; in every non-OECD region, incomes are projected to rise at a faster pace than fuel prices up to 2050.

There are also other, indirect effects that could prevent the full potential for energy efficiency presented in the 2DS from being realised. Consumers can use cost savings from such improvements to acquire goods or services in other sectors of the economy that in turn require energy. In addition, energy services have secondary attributes that are difficult to quantify but can greatly determine the response to greater energy efficiency; for example, tighter building envelopes can reduce airflow and increase moisture levels that may encourage behavioural responses.

Table 1.2 Possible magnitude of the rebound effect

	Rebound effect Low	High	Detail	Source
Space heating	-20%	-40%	Lower energy costs lead to higher temperature demands, more frequent heating, and could curb the future potential for low-temperature technologies.	Schwarz and Taylor, 1995; Guertin *et al.*, 2003; Haas and Biermayer, 2000.
Space cooling	-1%	-26%	Lower energy costs lead to higher cooling demands, larger equipment, shift from room to central air conditioning.	Dubin *et al.*, 1986.
Indirect effects	Limited evidence base	Limited evidence base	Savings can lead consumers to purchase other more energy-intensive services (*e.g.* overseas holiday), or increase the demand for lower-priced industrial goods and energy services that derive from them.	Binswanger, 2001; Grubb and Schipper, 2000.

Note: a rebound effect of 100% means that the expected energy savings are entirely offset, leading to zero net savings.

The residential sub-sector

OECD countries had an estimated 474 million households in 2010. While data on the number of households for non-OECD countries are not always available, they have been estimated at 1 412 million. These estimates are used as a basis for the projection of future energy consumption.[6]

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[6] More information on the analytical approach applied in the IEA buildings model can be found in Annex A of this publication.

The number of households globally is projected to grow by 68% by 2050, almost twice the rate of population increase. OECD countries are expected to reach 608 million households by 2050, while in non-OECD countries household numbers are estimated to reach 2 551 million by 2050 (Table 1.3). China and India dominate total household numbers today and are expected to see significant growth in households by 2050. OECD countries, with low population growth rates and generally fewer people per household already, will contribute to 11% of the total new households added by 2050.

Table 1.3 Key drivers for residential energy and emissions trends

Drivers / Region	Population (million)		Per-capita income (USD/capita)		Number of households (million)		Average house size (m^2)	
	2010	2050	2010	2050	2010	2050	2010	2050
World	7 006	9 448	10 608	28 262	1 886	3 159	89	93
OECD	1 230	1 399	33 312	64 974	474	608	124	134
Non-OECD Europe and Eurasia	332	313	11 746	41 635	121	148	70	92
Asia	3 741	4 589	5 186	26 791	906	1 520	83	87
Latin America	477	607	9 460	24 251	124	249	72	76
Africa	1 022	2 192	2 966	6 149	184	489	73	76
Middle East	204	348	12 215	34 255	76	145	48	68

Notes: m^2 = square metre, USD = United States dollar. Per-capita income is based on 2010 USD at purchasing power parity. Number of households and average house size for most non-OECD countries are estimated based on available information on income per capita, people per house, new constructions as well as information on building stock from national statistical agencies.

The expected increase in per-capita income in non-OECD countries will have a noticeable impact on the occupancy rate in housing units. In 2010, there was an average of 4.1 persons per household in non-OECD countries, compared to 2.6 in OECD countries. By 2050, the average occupancy rate is expected to reach 3.2 in non-OECD countries and 2.3 in OECD countries. Furthermore, increased wealth in non-OECD countries, combined with a strong increase in construction of new residential units, will also increase average house size.

While the number of persons per household and average house size are expected to continue to converge between the OECD and non-OECD regions up to 2050, there will still be an important difference in energy consumption per household, even in the 2DS (Figure 1.11). This difference is due in part to different climate, income levels, lifestyles and preferences. Higher energy intensity in OECD countries (particularly OECD Americas and OECD Europe) and non-OECD Europe and Eurasia is explained largely by the high share of space heating requirement in these cold regions.

At the global level, space heating will continue to dominate residential energy use in both the 6DS and 2DS, while energy devoted to cooking will still represent a larger share in non-OECD countries.[7] Space cooling is projected to more than double to 6.5 EJ by 2050 in the 6DS. This growth is driven by increasing incomes in developing countries and the fact that much of the population in developing countries lives in climates that require significantly more space cooling than space heating.

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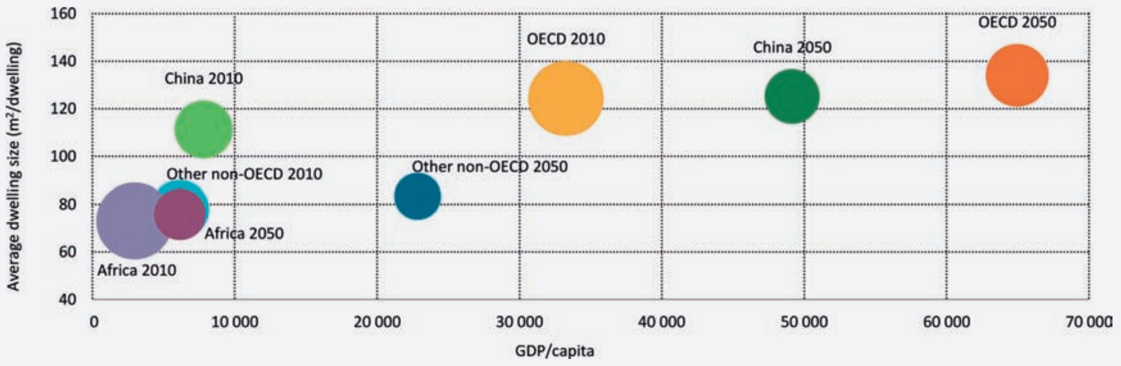
[7] There is no reliable estimate on how the consumption of combustible renewables and waste (predominantly biomass) can be apportioned between cooking, water heating and space heating in developing countries as a whole. Therefore care should be taken in interpreting the split between end uses at the global level. What is clear is that the total is related to the provision of heat for one kind of use or another.

Figure 1.11 Average house size in relation to GDP per capita in the 2DS

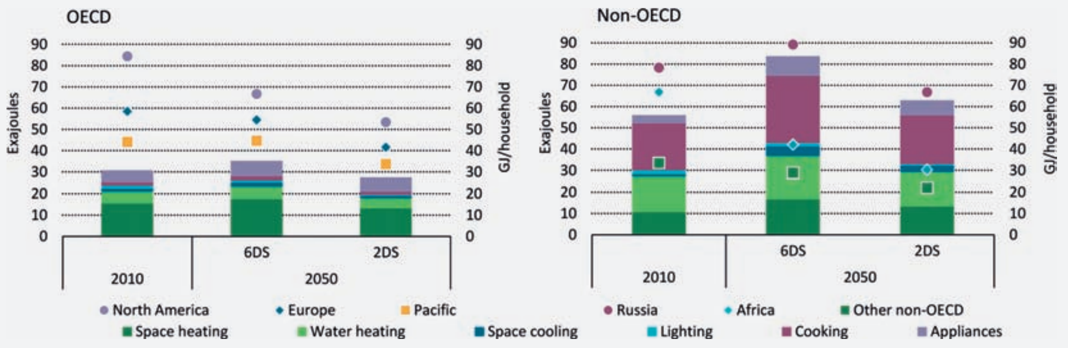


Note: bubble size represents the energy consumption per dwelling.

Key point *Despite the increase in house size, residential energy intensity will be lower in 2050 in the 2DS than it currently is.*

Energy intensity varies widely between countries. However, by 2050 in the 2DS, there is a convergence in intensity of different countries (Figure 1.12). The greater reduction in OECD is partly explained by the current potential for improvement in building envelope efficiency and adoption of BAT when replacing old equipment. For non-OECD countries, most of the stock is yet to be built and penetration rate of equipment is currently relatively low. As such, most improvements in intensity would be from the selection of efficient materials and equipment, with more moderate improvement from the replacement of existing units. In the case of Africa, the relatively high intensity is due to the large share of traditional biomass used for cooking and water heating. The move away from traditional biomass will have a noticeable impact on energy intensity in both the 6DS and 2DS. In Russia, the higher intensity in the 6DS is entirely due to increased house size; the intensity in GJ/m^2 improved by about 25%.

Figure 1.12 Residential sub-sector energy consumption by end-use and intensity for selected countries

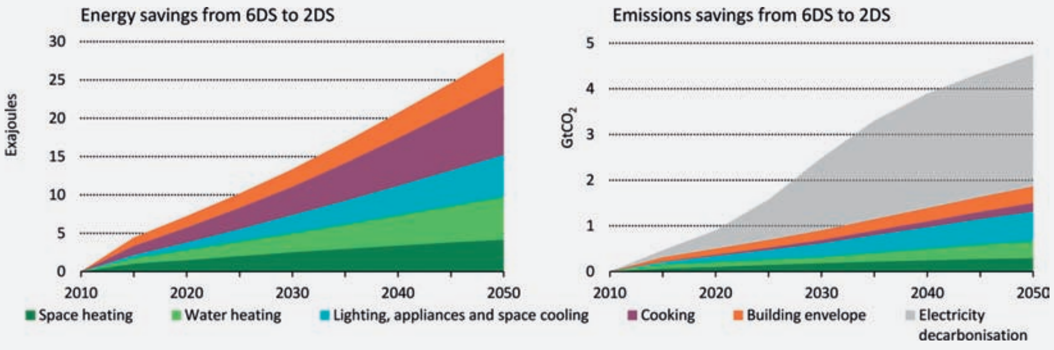


Notes: GJ = gigajoule. Symbols for the different regions represent energy intensity in GJ/household.

Key point *Most reductions in energy consumption are from space heating in OECD countries and cooking in non-OECD countries.*

Total energy demand in the 2DS is 29 EJ below 6DS in 2050 (Figure 1.13). Globally, energy consumption for space heating is reduced by 7.5 EJ, including the savings from more efficient envelope, and energy savings from cooking account for over 30% of 2DS savings. Given the increased penetration of electrical appliances and end-uses such as space cooling in both the 6DS and 2DS, decarbonisation of the power sector will play a key role in reducing total CO_2 emissions from the residential sub-sector in the 2DS. To this extent, efficiency improvements in the 2DS become all the more important in reducing emissions from the sector. This will require improvements in building envelopes, the penetration of highly efficient appliances and the adoption of efficient technologies, such as heat pumps and solar thermal technologies.

Figure 1.13 Energy and CO_2 emissions savings from 6DS to 2DS in the residential sub-sector



Key point *All options need to be tapped to achieve the reductions envisaged in the 2DS.*

The services sub-sector

The floor area of the services sub-sector is expected to increase by 66% between 2010 and 2050. In OECD countries, floor area will continue the steady trend since 1990 of continued growth (Table 1.4). In non-OECD regions, convergence with the lower end of today's current OECD floor area per unit of value-added is assumed, meaning that growth in floor area in many non-OECD regions will continue to be rapid.

Table 1.4 Growth in services sub-sector floor area by region

Region	Services floor area (million m^2)				
	2010	2020	2030	2040	2050
World	37 633	43 908	52 124	57 449	62 514
OECD	20 910	23 497	26 448	28 552	30 560
Non-OECD Europe and Eurasia	1 011	1 172	1 327	1 419	1 538
Asia	13 309	16 302	20 646	23 087	25 262
Latin America	741	821	875	945	1 025
Africa	674	857	1 120	1 352	1 687
Middle East	989	1 260	1 708	2 094	2 441

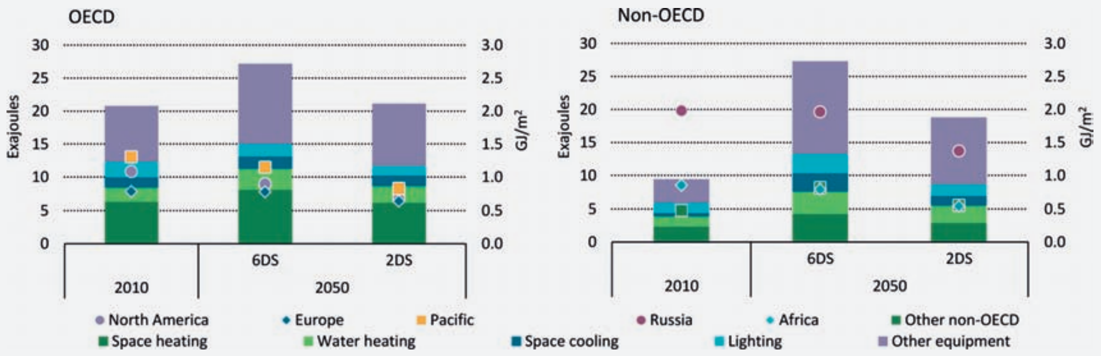
Note: m^2 = square metre.

Since 1990, energy consumption has grown by 39% in OECD countries and 122% in non-OECD countries. Despite the slower increase in OECD countries, and the more marked impact of the economic recession on those countries, OECD regions still accounted for 68% of global energy consumption in this sub-sector.

In the 2DS, electricity consumption represents 57% of total energy consumption in the services sub-sector in 2050, up from 49% in 2010. This trend reflects the much greater consumption of electrical end-uses, notably space cooling, lighting, office equipment and other electrical equipment (everything from refrigerated display cabinets to electric motors to information technology networks to x-ray machines). Space heating accounts for 23% and water heating 13% of services energy consumption, considerably lower than in the residential sub-sector (Figure 1.14).

Drawing conclusions about the efficiency of the services sub-sector based solely on overall energy intensity of the sector can be misleading. Energy intensity is highly dependent on the structure of the services sub-sector. Different building types have different energy needs (*e.g.* health-care facilities require more energy than warehouses), and the relative importance of the building types within the services sub-sector will have a direct impact on the sector's energy intensity and CO_2 emissions. Intensity is also influenced by the energy mix used in the sector; the higher intensity in OECD Pacific is due, in part, to relatively higher share of oil in the services sub-sector.

Figure 1.14 Services sub-sector energy consumption by end-use and intensity for selected countries



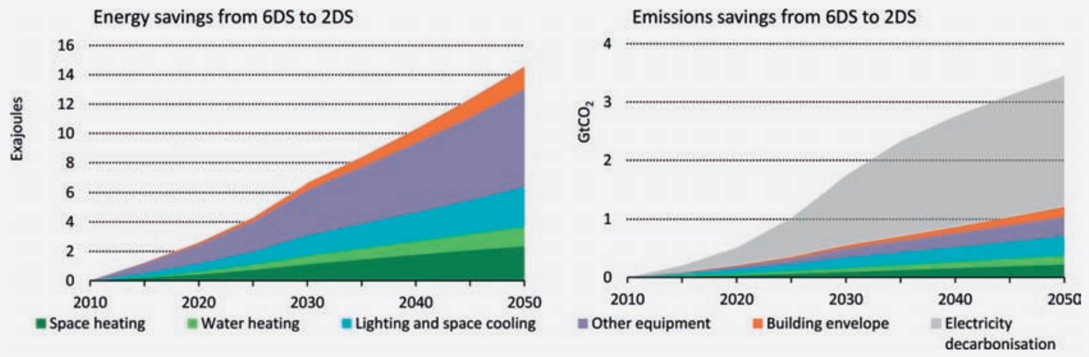
Notes: GJ = gigajoule, m^2 = square metre. Symbols for the different regions represent energy intensity in GJ/m^2.

Key point *The strong increase in floor area in non-OECD countries will drive the doubling in energy consumption between 2010 and 2050 in the 2DS.*

Improving building envelopes to reduce cooling loads is a first key step to reach the CO_2 emissions reduction goals set out in the 2DS, and replacing less-efficient air conditioners with newer technology in developing countries is an important opportunity. In OECD countries, performance standards for air conditioners have generally tightened over time, but the average efficiency of the stock is still significantly below today's best units on the market. If further progress can be made in improving BAT, and if performance standards are regularly updated accordingly, the savings from cooling systems could be even greater by 2050.

The CO_2 emissions reduction due to improvement in lighting efficiency is greater than average for the buildings sector, despite a large increase in the global level of lighting services between 2010 and 2050 (Figure 1.15). This scenario may become even more efficient as projected performance improvements and cost-reduction scenarios for solid-state lighting (SSL) become commonplace.

Figure 1.15 Energy and CO_2 emissions savings from 6DS to 2DS in the services sub-sector



Key point: *Most of the savings in the services sub-sector will be from the energy efficiency improvements in other equipment used.*

Investment needs and benefits of a low-carbon buildings sector

The transition to more sustainable energy use in the buildings sector will require the wide deployment of more energy efficient building envelopes, space heating and cooling systems, lighting and appliances. Over the next four decades, an estimated USD 31 trillion will be required to purchase these technologies in the 2DS (Figure 1.16): this breaks down into USD 19 trillion for the residential sub-sector and USD 12 trillion for services sub-sector.[8] This represents additional investment of USD 12 trillion, or about 70% more than under the 6DS.

Comparing the additional investment needs and energy savings in the 2DS over time shows several interesting trends. Investments in more efficient cooking and water heating yield the highest returns with low additional investment requirements and high energy savings. Building envelope investments are needed throughout, but are particularly high over the next two decades. Space cooling improvements represent a growing share of additional investments as demand in emerging and developing countries grows, but the energy savings they yield appear to be the lowest amongst the end-use categories.

In OECD countries, the level of investment is higher in the earlier time period than in the later, because existing building stock requires significant retrofitting. This is particularly the case in the European Union, where the residential sub-sector requires about twice the additional investment needed by the services sub-sector. China's rapid economic growth over the next two decades is expected to lead to substantial expansion of its services sub-sector. By contrast, additional investment needs of other non-OECD countries are in the residential sub-sector, some two to six times higher than in the services sub-sector. As these economies are less mature, the relative size of the services sub-sector compared to the residential sub-sector is significantly less than in developed economies. This difference declines as the economies mature and the services sub-sector grow.

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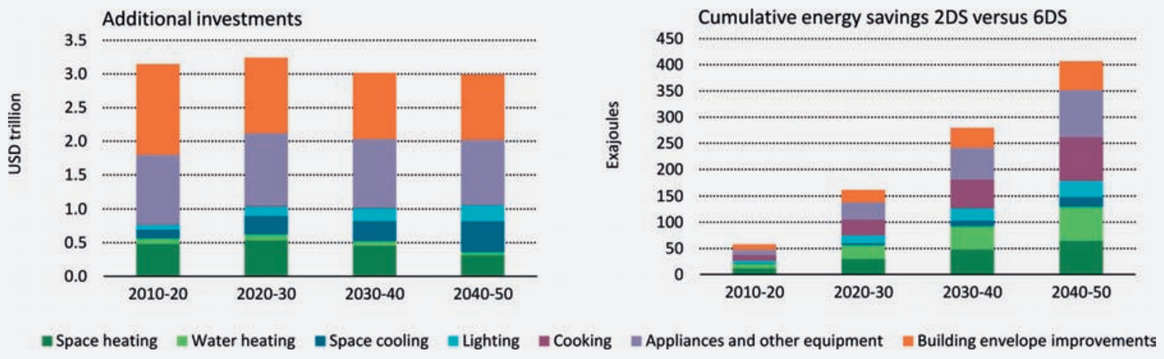
[8] For buildings, investment includes heating and cooling, other end-use technologies and energy-efficient building envelope (insulation, windows, roofs and seals).

Figure 1.16 Additional investment needs and cumulative energy savings by end-use



Key point *Investments in cooking and water heating yield the quickest payback, while those for building envelope improvements and appliances require longer payback times.*

Although significant additional investment will be needed in more energy efficient building technologies, these costs will in most cases be more than offset by fuel savings resulting from investment in a low-carbon buildings sector. OECD countries, where the largest share of early investments are made, see high returns as the fuel savings are reflected over a longer period. With a larger share of investment occurring in later decades, non-OECD countries show much lower fuel savings compared to additional investment as fuel savings are accrued for a much shorter period (Table 1.5).

Table 1.5 Cumulative investment and fuel savings in the buildings sector in the 6DS and 2DS

USD billion	Total investments in 6DS 2010-50	Total investments in 2DS 2010-50	Additional investments 2010-50	Fuel savings in 2DS 2010-50
United States	2 673	4 462	1 789	1 044
European Union (27)	2 602	4 773	2 171	4 547
Other OECD countries	2 275	3 822	1 546	2 896
China	3 513	5 069	1 556	1 678
India	910	1 633	723	408
Latin America	897	1 717	820	920
Other developing Asia	1 714	3 286	1 572	820
Middle East and Africa	1 530	2 668	1 138	3 001
Other non-OECD	2 541	3 626	1 085	1 182
Total	**18 655**	**31 056**	**12 401**	**16 523**

When evaluating the cost-benefit of these investments, other co-benefits also need to be considered, such as improved health, job creation and higher comfort levels. The move away from traditional biomass and waste to modern fuels and more efficient cook stoves used in the least developed and emerging economies will not only save lives and reduce negative health impacts from use of inefficient cook stoves, it will also free up time spent collecting traditional biomass and waste for other more productive activities.

An estimated 905 EJ will be saved over the 2010 to 2050 period in the 2DS compared to the 6DS and the amount spent on fuel and electricity drops sharply as energy use in the buildings sector becomes more efficient. The energy savings in 2050 (43 EJ) are equal to the current energy consumption of India and Russia combined.

Total fuel cost reductions reach USD 17 trillion between 2010 and 2050. This calculation includes the impact of lower fuel prices and higher electricity costs resulting from lower demand for fossil fuels and decarbonising the power sector. Improved efficiency will lead to large declines in the purchase of oil and gas. For countries that import oil and gas, this represents a significant improvement in current account balances and frees up foreign reserves for other uses. However, higher costs for biomass will be seen as many OECD countries and other major economies switch from fossil fuels to biomass.

Additional investment needs compared with fuel savings in the 2DS show a net benefit of USD 4.1 trillion (undiscounted) from 2010 to 2050 and USD 0.9 trillion (with a 3% discount rate). However, when applying a 10% discount rate to both the additional investments and fuel savings, the net benefit becomes a net cost of USD 1.3 trillion as considerable payback time is needed to offset the high upfront costs. However, the fuel savings, which reflect only reduced costs for electricity and direct fuels, exclude the benefits of reduced capital expenditure and fuel purchases in the power sector as the result of lower energy consumption.

Some of the technologies needed to transform the buildings sector are already commercially available and cost effective with payback periods of less than five years. Others are more costly with significantly longer payback periods and would require government intervention if they are to achieve wide market uptake. According to a study by the World Business Council for Sustainable Development (WBCSD), an investment of USD 150 billion per year would lead to energy savings in buildings in the six regions evaluated by 40%, with discounted paybacks of five years or less (WBCSD, 2009). An additional investment of USD 150 billion more per year would cover options with discounted payback of five to ten years and would increase total energy savings to just over 50%.

A major challenge for the sector will be to incentivise a large number of users in the residential and services sub-sectors to change investment patterns to favour higher capital-intensive technologies with lower fuels inputs. Chapter 6 provides a more detailed discussion on policies that can help to overcome these challenges.

Recommended actions to deliver a sustainable buildings sector

Achieving the vision of the 2DS for the buildings sector is technically possible, but a challenging goal. Ensuring that all best available options are tapped will require unprecedented effort and co-ordination between a diverse set of stakeholders with often conflicting goals, including: policy makers, builders, investors, technology developers, manufacturers, equipment installers, energy management companies, businesses and household consumers.

Table 1.6 Required actions to achieve the 2DS

	Policy and technology priorities	
Improvement area	**Immediate recommendations**	**Future requirements**
Building codes are widely implemented in all countries for all new buildings	Regulatory standards for new buildings in cold climates are tightened progressively. In hot climates, cooling loads are reduced by around one-third.	Loads reduced to between 15 kilowatt-hours per square metre per year (kWh/m^2/year) and 30 kWh/m^2/year for heating purposes, with little or no increase in cooling load.
Large-scale refurbishment of residential buildings in OECD countries and non-OECD Europe and Eurasia	R&D on market viablility of deep renovation technologies and services.	Around 90% of today's residential dwellings in OECD countries that will still be standing in 2050 will need to be refurbished to a low-energy standard (approximately 50 kWh/m^2/year), which also enables the downsizing of heating equipment. This represents the refurbishment of around 400 million residential dwellings, facilitated by co-ordinated policy packages.
Increased R&D and deployment of highly efficient heating, cooling and ventilation systems	Higher-efficiency standards for heating and cooling equipment.	Heating systems need to be both efficient and cost effective. Heat pumps with coefficients of performance (COPs) over 3.0 are used in cold climates along with small-scale gas absorption heat pumps with COPs greater than 1.2. Solar thermal has a significant share of water heating and is used for some space conditioning.
Improved lighting efficiency R&D and standards	Regulations to improve efficiency of lighting continue to be implemented.	SSL is widely available as a result of integrated policies.
Improved equipment efficiency is promoted and regulated	Appliance and heating and cooling equipment standards are assumed to shift rapidly to least-cost levels on a life-cycle basis.	Current BAT levels become minimum efficiencies by 2030 in most countries.
Widespread deployment of low- or zero-carbon technologies	Case studies and R&D for more cost-effective applications.	Micro- and mini-co-generation for space and water heating become viable but still are not widely deployed. Co-generation in large buildings becomes more prevalent and represents a modest share of building heat and power with annual system efficiencies greater than 75%.
Cross-sectoral policies and technologies	Modern district heating systems that can benefit from thermal energy storage coupled with waste heat and renewables offer increased system efficiency and flexibility.	Building equipment becomes increasingly integrated into smart grids and smart metering to provide peak-load and economic benefits.

Chapter 2

Regional Overview and Recommendations

Different regions and countries face very different challenges for reducing energy consumption and carbon dioxide (CO_2) emissions in the buildings sector. Each country will have a different energy and consumer profile that will need to be considered when designing the most appropriate building policies and measures to support an energy efficient and low-carbon buildings sector.

Key findings

- In OECD member countries and in non-OECD Europe and Eurasia, where significant heating load exists, refurbishment or renovation of existing building stocks offer the largest abatement potential. Priorities should focus on reducing heating and cooling loads in existing buildings.
- In developing countries, buildings tend to have shorter life spans, and the building stock growth rate is expected to be very rapid. Priorities should focus on improving the energy performance of new buildings, especially with respect to cooling loads and lighting.
- Standards for appliances and other equipment are already widely deployed in many countries, with the toughest minimum energy performance standards (MEPS) found in the United States. Wider use of MEPS will be needed across all countries to improve energy efficiency in buildings.
- Over two-thirds of all energy used globally in buildings is consumed in the nine countries/regions covered in this chapter. Action in these major energy-consuming countries will be needed if we are to transition to a low-carbon buildings sector.

Near-term recommendations

- Policy support for improved building envelopes and deep renovation is needed in the European Union (EU), Russia and the United States. MEPS requirements for heating equipment and appliances should also be strengthen in these countries.
- Stringent building codes are needed for all new buildings, particularly in fast-growing developing and emerging economies in the Association of Southeast Asia Nations (ASEAN), Brazil, China, India and South Africa, where rapid buildings growth is expected. Deployment of reflective envelope technology to reduce growing cooling loads is also needed.
- The inefficient use of traditional biomass in ASEAN, India, Mexico and South Africa needs to be replaced with modern fuels and efficient cooking and water heating technologies such as low-cost efficient biomass cook stoves and solar thermal technologies for water heating.

Trends in energy consumption in the residential sub-sector are influenced by a number of factors including: changes in population, number of households, buildings characteristics, building age and profile, energy prices and availability, house size, income, consumer preferences and behaviour, climatic conditions and ownership rate of appliances and equipment.

In the services sub-sector, energy consumption tends to be more closely related to the sector's level of economic activity, growth in floor area, population profile, building types, age of buildings and climatic conditions.

Each of the factors impacting the trends in buildings energy consumption will evolve differently by region and country. While general conclusions can be drawn for a region, each country has a different energy supply and consumer profile which will have a direct impact on the policies and measures which will be needed to maximise energy efficiency and emissions reduction.

This chapter presents the specificities of nine different countries/regions of the world: the ASEAN, Brazil, China, the EU, India, Mexico, Russia, South Africa and the United States.

Together, these regions/countries accounted for 68% of global buildings final energy consumption in 2010. Each regional sub-chapter discusses in more detail the current policy and energy situation and is divided into six main sections:

- **Introduction** discusses the current energy and policy situation as well as the distinctive characteristics of the buildings sector.
- **Recent trends** presents the evolution of energy consumption since 1990 and the end-use mix of the region/country.
- **Scenarios for buildings** outlines the main drivers, from 2010 to 2050, of energy consumption in the sec*tor*.
- **Future trends in energy consumption** discusses the expected evolution of energy consumption in buildings under the 6°C Scenario (6DS) and 2°C Scenario (2DS), as set out in the IEA *Energy Technology Perspectives (ETP)* 2012, in relation to the region/country's drivers and specificities.
- **Future trends in CO_2 emissions** provide an overview of the key factors contributing to the reductions in CO_2 emissions between the 6DS and 2DS.
- Each sub-chapter concludes by providing **Recommended actions** specific to the region/country analysed.

1. ASEAN[1]

ASEAN is one of the fastest-growing regions in the world and it has a rapidly rising energy demand, driven by economic and demographic growth. ASEAN is comprised of the ten member states of Brunei, Cambodia, Indonesia, Laos PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. Since 2000, it has averaged 4.1% per year in gross domestic product (GDP) growth, and population grew by around 70 million people. This has driven growth in demand for households and services, especially as large numbers of people have moved to cities in the past decades.

ASEAN constitutes diverse climate and energy needs, although most countries have tropical-hot and humid conditions with plentiful rainfall during monsoon season. As a result, space heating is not common in many regions, and demand for space cooling is rapidly growing. Energy in ASEAN countries is often used in inefficient and unhealthy processes, and there is significant potential for more sustainable uses of biomass and renewable energy, which is seriously underdeveloped, due to a lack of technology and investment.

Inefficient and unhealthy burning of biomass for cooking and water heating continues to be a major concern in most ASEAN countries. Biomass comprises the largest fuel share for buildings end-uses, where open fires and inefficient cooking and water heating technologies are common. The opportunity to use biomass more efficiently and to improve the lives and health of millions of people therefore is great. Low-cost solar thermal to mitigate hot water energy consumption also has great potential.

Many ASEAN countries have worked on achieving high-performance buildings under special voluntary programmes. For instance, the Building and Construction Authority (BCA) in Singapore developed a green building master plan, which aims to bring 80% of buildings in Singapore up to the Green Mark[2] certification standard by 2030. However, the vast majority of ASEAN buildings being constructed are still not built using best available technology (BAT), and few mandatory building policies exist. Asia-Pacific Economic Cooperation (APEC) studies on advanced windows and cool roofs also show that there still is a large educational and institutional gap to deploy advanced technologies (APEC, 2011a and b).

Strong private leadership and national support are important drivers for achieving green buildings and energy efficiency in ASEAN countries. Financial support, such as the scheme for Building Retrofit Energy Efficiency Financing (BREEF) in Singapore, are also needed to provide loans to building owners and encourage energy services companies to enable energy efficiency improvements in buildings (APERC, 2012).

Recent trends

Since 1990, ASEAN GDP grew by an average of 5.0% per year, while population grew by around 150 million people, reaching close to 600 million people in 2010. Energy demand in buildings increased at a rate of 2.3% per year from 1990 to 2010 (Figure 2.1.1), whereas

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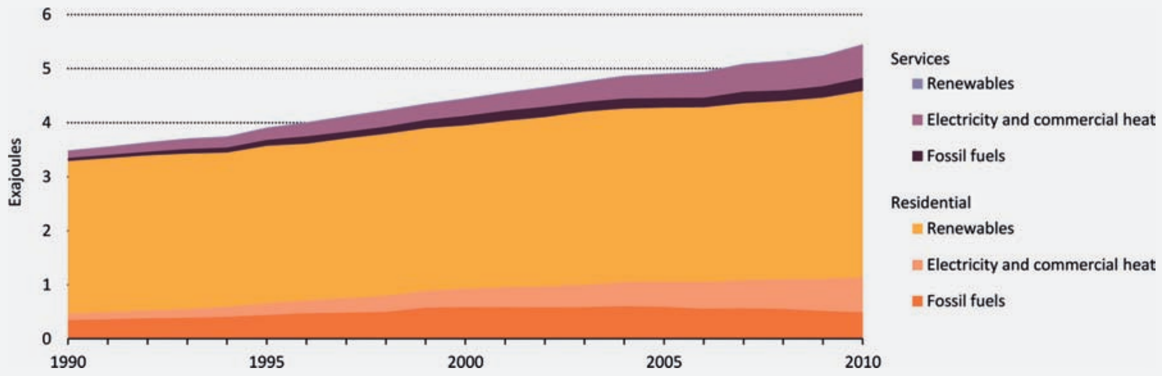
[1] The IEA will release a special report on energy trends in Southeast Asia as part of its *World Energy Outlook* series in September 2013.

[2] The Green Mark standard provides a differentiation of buildings using a benchmarking scheme that incorporates internationally recognised best practices in building design and performance.

electricity consumption grew at 8.6% per year. This growth decreased slightly in the past decade, where total energy and electricity consumption grew by a smaller 2.0% and 6.9% per year, respectively. The residential sub-sector dominates overall energy consumption, where biomass, mostly used for cooking and water heating, accounts for three-quarters of residential energy use.

Figure 2.1.1 Historical energy consumption in ASEAN buildings by energy source



Note: renewables include biomass, waste, wind, solar and geothermal.
Source: unless otherwise noted, all tables and figures in this chapter are derived from IEA data and analysis.

Key point *Biomass use dominates the region and needs to be better utilised.*

Cooking accounted for nearly 80% of residential energy consumption and about two-thirds of final energy consumed by buildings in 2010 (Figure 2.1.2). Water heating and appliances accounted for another 16% of residential energy use. Lighting and space cooling each accounted for roughly 2% of final residential energy use in 2010. Space cooling and appliances are fast-growing end-uses in households, driven largely by urbanisation and increased wealth. Space heating demand accounted for less than 1% of final energy consumption in 2010.

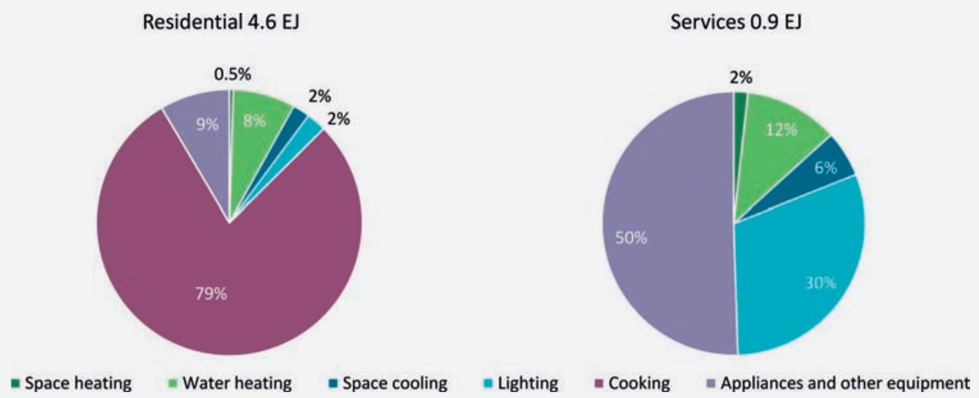
In the services sub-sector, service equipment accounted for half of final energy consumption in 2010. Space cooling represents a small share of services energy consumption, although it is rapidly growing. Lighting accounted for nearly one-third of total services energy use by 2010. Much of these shares are driven by Thailand, Indonesia and Malaysia, who accounted for roughly 70% of ASEAN services energy consumption in 2010.

Scenarios for buildings in ASEAN

ASEAN GDP is expected to continue to grow, but at a slower rate than historically, averaging 4.1% per year through 2050. Population is also expected to continue to grow at a slower rate through 2050 although at a slower rate, while still adding over 160 million people to the region (Table 2.1.1). Urbanisation is also expected to continue, with roughly two-thirds of ASEAN population in cities by 2050. This results in the addition of around 237 million people to urban areas in ASEAN countries, or almost doubling today's levels (UN DESA, 2012). These increases in wealth, population and urbanisation will create a large demand for new housing and service buildings, while expected increases in per-capita wealth are likely to result in lower occupancy rates (persons per household) and larger houses.

Figure 2.1.2

Residential and services sub-sectors energy consumption by end-use for ASEAN, 2010



Note: EJ = exajoule.

Key point *Cooking accounts for roughly two-thirds of energy consumption by buildings and represents a significant opportunity to improve energy efficiencies through better use of biomass.*

A near-quadrupling in per-capita income, paired with ASEAN's generally hot climate, is also expected to contribute to greater demand for comfort. The share of cooled houses is expected to grow from roughly 10% in 2010 to 60% by 2050. Electronics and appliances ownership are likewise anticipated to increase considerably. This will have significant impact on overall electricity demand in the residential sub-sector, while a quadrupling of floor areas in the services sub-sector similarly will have a significant impact on cooling and electricity demand.

Table 2.1.1

Indicators for energy demand in ASEAN buildings sector

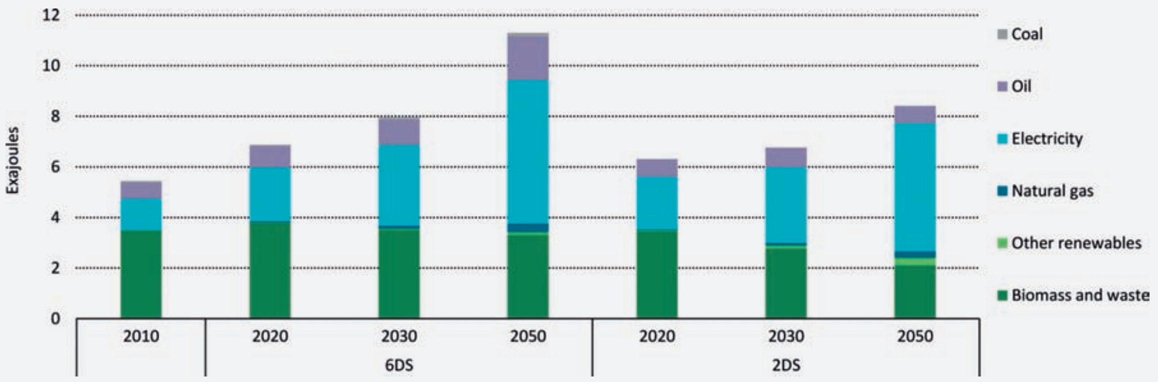
Indicator	2010	2020	2030	2040	2050
Population (million)	593	656	706	741	759
Share of population living in urban area (%)	44%	50%	56%	61%	66%
GDP (billion 2010 USD at PPP)	3 078	5 072	7 129	10 238	15 160
Per-capita income (USD GDP/capita)	5 187	7 732	10 097	13 818	19 968
Services floor area (million m^2)	1 253	1 944	2 687	3 661	5 233
Residential floor area (million m^2)	8 558	11 747	14 345	16 819	18 612
Number of households (million)	154	207	248	285	309
Occupancy rate (people per household)	3.9	3.2	2.8	2.6	2.5
Average house size (m^2/house)	55.6	56.7	57.8	59.0	60.2
Refrigerator penetration rate (refrigerator/household)	65%	84%	90%	98%	108%
Clothes washer penetration rate (clothes washer/household)	20%	29%	33%	39%	48%
Share of residential cooled floor area (as a% of total floor area)	10%	23%	35%	48%	60%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; UN DESA (2012) for urbanisation rate; IEA (2012) for GDP; other data from IEA analysis.

Future trends in energy consumption in ASEAN

Biomass use in the 6DS decreases slightly due to continued urbanisation and increased demand for modern cooking and appliances. Between 2010 and 2050, biomass declines by 0.1% per year, although it still represents nearly one-third of final energy consumption in 2050 (Figure 2.1.3). In the 2DS, biomass use decreases by 1.2% per year, accounting for roughly one-quarter of final energy use by 2050. Electricity demand in the 6DS and 2DS continues to grow dramatically, but it is lower by 11% in 2DS compared to 6DS in 2050 due to efficiency improvements in residential and services end-uses. Oil is also dramatically reduced in the 2DS compared to the 6DS, with only a net increase of less than 5% to 2050, compared to about 165% increase in the 6DS.

Figure 2.1.3 Energy consumption in ASEAN buildings by energy source in the 6DS and 2DS



Note: other renewables includes wind, solar and geothermal.

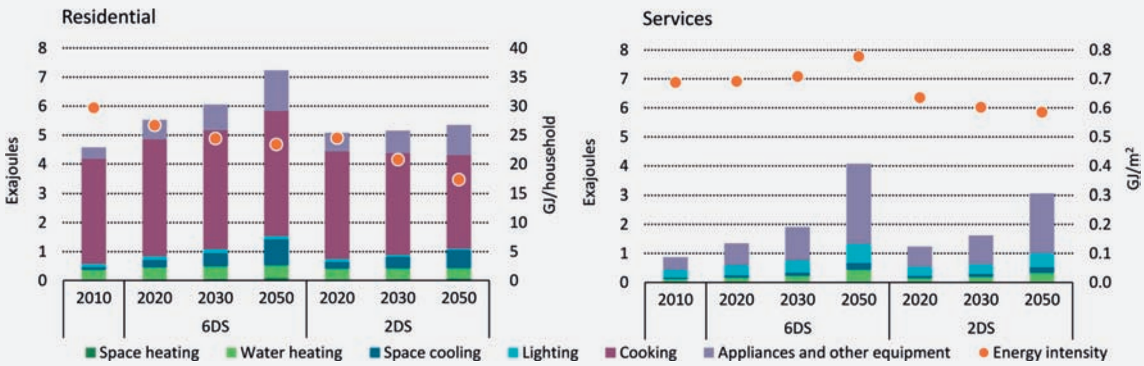
Key point *Biomass and electricity dominate 2050 fuel shares.*

High use of biomass for cooking continues to dominate the residential sub-sector in 2050 under both the 6DS and 2DS. By 2050, cooking energy consumption is expected to grow by about 20% in the 6DS, accounting for nearly 60% of residential energy use. By contrast, cooking energy use falls by more than 10% over 2010 and 25% over 6DS levels in the 2DS. Reductions in biomass use and efficiency improvements in the residential sub-sector contribute to the 26% decline in average residential energy intensity (expressed in gigajoules [GJ] per household) in the 2DS compared to the 6DS in 2050. This equates to a 42% reduction in residential energy intensity compared to average residential intensity in 2010.

In the services sub-sector, service equipment is expected to increase more than sixfold by 2050 in the 6DS. In the 2DS, this growth is limited to a 4.7-fold increase, which is 25% lower than in the 6DS. This contributes to the overall reduction in energy intensity per unit of floor area, which is 25% lower in the 2DS in 2050, or 15% lower than in 2010 (Figure 2.1.4).

Fuel switching, better building envelopes and energy efficiency improvements contribute to nearly 1 900 petajoules (PJ) in potential annual energy savings in the 2DS compared to the 6DS by 2050 in the residential sub-sector and an additional 1 000 PJ in the services sub-sector (Figure 2.1.5). Cooking reductions represent nearly 60% of potential residential energy

Figure 2.1.4 ASEAN residential and services sub-sectors energy consumption and intensities

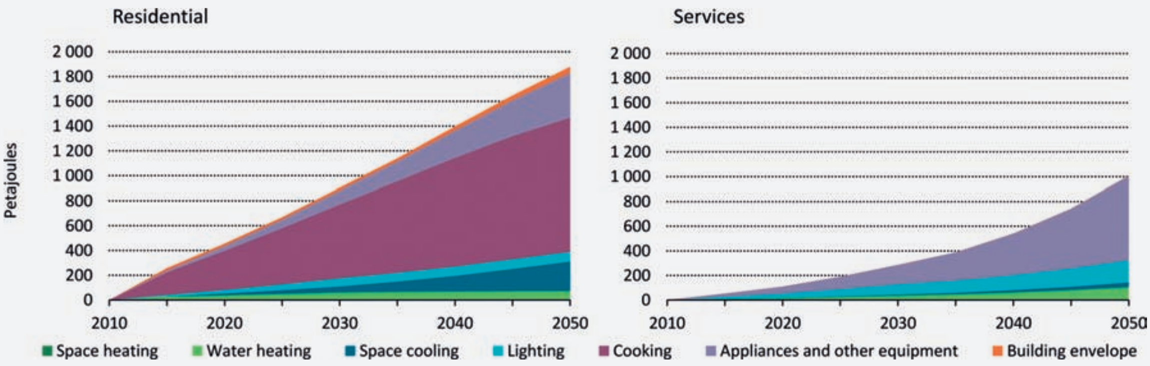


Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Cooking in the residential sub-sector continues to dominate energy use, although reduced use of biomass and overall energy efficiency improvements lead to significant intensity reductions in buildings.*

reductions and nearly 40% of total buildings energy savings. Appliances represent another 20% in the residential sub-sector and service equipment more than two-thirds of savings in services buildings, while space cooling efficiency improvements account for roughly 15% and 5% of residential and services savings in 2050, respectively. In the services sub-sector, the largest savings are for service equipment, and lighting accounts for an additional 18% of potential energy reductions.

Figure 2.1.5 Energy savings from 6DS to 2DS in ASEAN in the residential and services sub-sectors



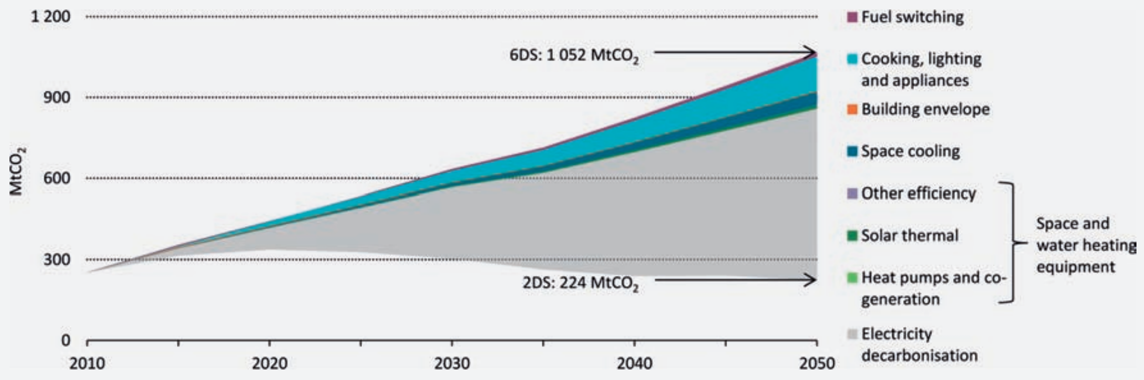
Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *The largest overall savings are from cooking in the residential sub-sector, while efficiency improvements in appliances and service equipment also considerably reduce energy use in buildings.*

Future trends in CO_2 emissions in ASEAN

While improvements in cooking and reductions in inefficient use of biomass significantly reduce energy consumption, shifts to more efficient, modern cooking technologies mean the impact on CO_2 emissions reduction is modest. CO_2 savings in the 2DS are predominantly achieved through decarbonisation of electricity, which accounts for three-quarters of total potential emissions reduction. Nearly 75% of the remaining reductions are from cooking, lighting and appliances demand reduction (Figure 2.1.6). Efficiency in space cooling equipment represent about 25% of buildings emissions savings, or roughly 5% of total direct and indirect emissions savings.

Figure 2.1.6 Contribution of CO_2 emissions reduction options in ASEAN between the 6DS and 2DS



Key point *CO_2 reductions in ASEAN are less significant because energy improvements are largely from reduced and improved biomass use.*

Recommended actions for ASEAN

ASEAN has abundant biomass resources but the majority is inefficiently used. The current use of biomass in the buildings sector wastes a renewable resource that can be better utilised through the transition to modern forms of energy, including biogas for use in co-generation plants that generate electricity and utilise waste heat streams for industrial or hot water applications (IEA, 2012). Shifts to modern gas and electric cooking technologies will also significantly improve quality of life for ASEAN households while reducing adverse health effects of traditional biomass use.

Lighting, space cooling, appliances and miscellaneous plug loads need to be addressed to diminish overall growth in electricity demand. Labelling and standards programmes are critical to support energy efficiency improvements, and while initial programmes are encouraging, these need to be expanded to all energy-consuming devices in all ASEAN countries. Efficiency initiatives also need to move beyond voluntary implementation to mandatory standards that take into account realistic time tables for local and regional market conditions. APEC has conducted several efforts to promote energy efficiency in buildings, including the Cooperative Energy Efficiency Design for Sustainability (CEEDS) project on labelling, standards and buildings codes. Several workshops have also been hosted by ASEAN countries in support of these objectives. However, increased efforts are needed, and harmonisation of standards in the region can reduce barriers to implementation and trade.

In order to curtail increasing space cooling loads, low-cost technologies, such as cool roof coatings and low-emissivity (low-e) windows, should be promoted for existing buildings. Enforceable building codes that require better building envelopes should be pursued, especially for the expected large growth in new buildings. Research and development (R&D) efforts like the APEC building material test centre should also be extended to support increased availability and penetration of BAT throughout the ASEAN region. Additionally, collaborative research should be pursued to develop low-cost solar cooling solutions. Advancements in solar collectors and thermal heat pumps will pave the way for cooling solutions. However, systems suitable for the ASEAN region need to be developed to address large latent loads due to high humidity, since less heat will be gained with improved building envelopes.

2. Brazil[3]

Brazil is the world's fifth-largest country, both by geographical area and by population. Brazil has the world's seventh-largest GDP in terms of purchasing power parity (PPP). In terms of energy consumption, it is the world's eighth largest energy consumer and the largest consumer in Latin America.

The buildings sector accounted for 16% of total final energy consumption in Brazil in 2010. As a result, it has not been a priority for the government, and few policies or measures are in place to reduce building energy consumption and emissions. A labelling programme for household goods is in place, and some city and state programmes have been developed and implemented, including the Solar Thermal Law of Sao Paulo and the State-run programme for efficient public lighting.

The National Program of Electric Energy Conservation (Procel) created in 1985 was transformed into a governmental programme in 1991. Its objective is to decrease the waste of electric energy through more efficient and rational use. In 2011, the project amounted to 6 696 terawatt-hours (TWh) saved, equivalent to the demand of approximately 3.6 million homes (Eletrobras, 2009 and 2011).

Two of the programmes under the umbrella of Procel are targeting directly the buildings sector:

- Procel Edifica (buildings), developing activities to promote and encourage the adoption of energy efficiency concepts in buildings and contributing to the expansion of efficient buildings. The programme rates energy performance, evaluating the envelope, lighting and heating, ventilation and air-conditioning (HVAC) system of new and existing buildings.
- Procel EPP (energy efficiency in public buildings), providing support to agents involved in the administration of public buildings, including the development of six technical energy efficiency manuals.

Brazil is going through a period of transition in which its future energy provision structure and consequent technological pathways are being defined. Although Brazil represents one of the cleanest energy matrices in the world, with CO_2 emissions per kilowatt-hour (kWh) and electricity consumption per capita still being well below levels in OECD countries, its projected economic growth is expected to put pressure on electricity demand, potentially resulting in an increased share of fossil fuel required for power generation. While buildings only account for a small portion of total energy consumption in Brazil, they are a major electricity user. About 55% of total energy consumption in buildings is from electricity, and almost 50% of Brazil's total electricity is used by buildings. The buildings sector will therefore play a key role in limiting the pressure on the electricity system.

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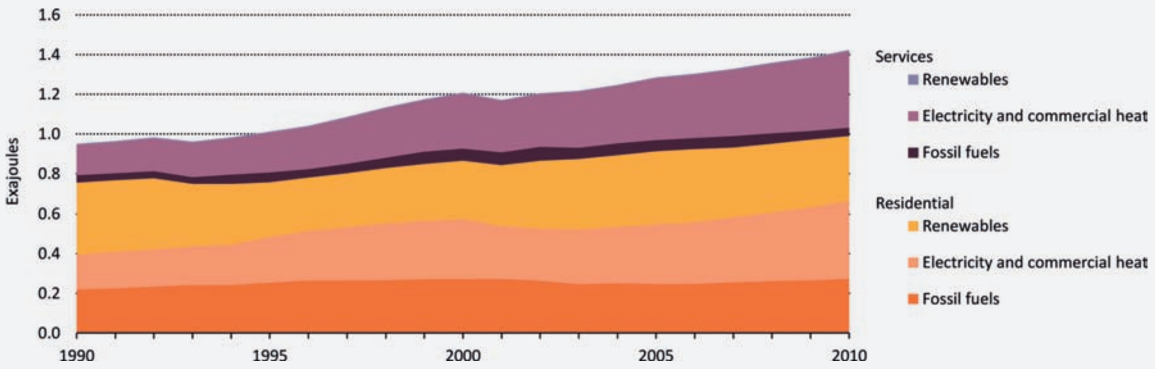
[3] The forthcoming *World Energy Outlook 2013* will feature a Brazil Energy Outlook.

Recent trends

There have been major changes in the economy and demography of Brazil since 1990. While population increased by 30% between 1990 and 2010, the number of people living in rural areas decreased by 22% and accounted for only 16% of total population by 2010 (UN DESA, 2012). GDP also increased dramatically over the same period, by almost 80%.

Rapid urbanisation and economic development, paired with population growth, had a strong impact on energy consumption in the residential and services sub-sectors, which increased by 31% and 122% respectively between 1990 and 2010 (Figure 2.2.1). Biomass, mostly used for water heating and cooking, was the principal source of energy in 1990, accounting for about 40% of total energy consumption in buildings. By 2010, biomass only accounted for 23% of building energy use, while electricity became the main energy source, accounting for 54% of total building energy use. Growth in large and small appliances and the higher share of buildings with air conditioning were the main drivers for this change in the energy mix.

Figure 2.2.1 Historical energy consumption in Brazilian buildings by energy source



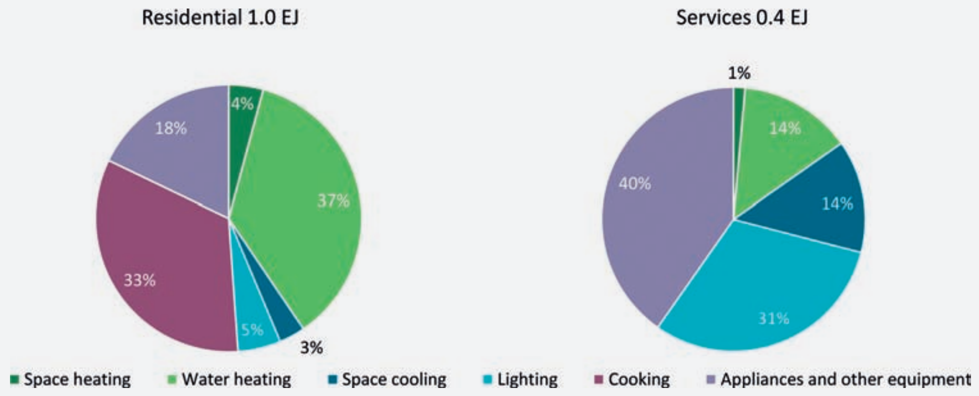
Note: renewables include biomass, waste, wind, solar and geothermal.

Key point *Energy use in buildings increased by 2.0% per year between 1990 and 2010, with most of the growth coming from the services sub-sector.*

Biomass in Brazil is mostly used for cooking and water heating in the residential sub-sector. While biomass use decreased in the last decades, it still accounted for one-third of residential energy consumption in 2010. This high share can be explained by the low efficiencies of conventional biomass uses, which can be as low as 8% to 15% for traditional cook stove. Given the inefficient use of biomass in traditional cook stoves and water heaters, cooking and water heating accounted for 70% of total residential energy consumption in 2010 (Figure 2.2.2). Appliances are another major energy user, accounting for 18% of consumption.

Energy consumption by end-use is quite different in the services sub-sector. Lighting and service equipment, which includes information technologies, office equipment, medical technologies, appliances and small plug loads, accounted for over 70% of total services energy consumption. Nearly 85% of energy consumed by service equipment is from electricity.

Figure 2.2.2 Residential and services sub-sectors energy consumption by end-use for Brazil, 2010



Note: EJ = exajoule.

Key point *While residential is dominated by cooking and water heating, services is dominated by lighting and service equipment.*

Scenarios for buildings in Brazil

While population is expected to rise by only 0.3% per year between 2010 and 2050 (compared to 1.3% between 1990 and 2010), the number of households in Brazil is expected to increase by 1.4% per year to 2050 (UN DESA, 2011). The higher increase in the number of households is explained by a continuous trend towards fewer people per household (Table 2.2.1). At the same time, the average size of houses increase, from 67 square metres (m^2) to 73 m^2, adding energy demand for lighting, space cooling and, to a lesser extent, space heating.

GDP is expected to increase at a rate of 3.4% per year between 2010 and 2050. This drives the increase in floor area in the services sub-sector as well as household appliances ownership levels. Urbanisation is also expected to continue, where only 9% of the population is expected to live in rural areas by 2050 compared to 16% in 2010.

Future trends in energy consumption in Brazil

Electrification, greater urbanisation and increased wealth are the main factors impacting energy consumption in Brazil to 2050. In the 6DS, energy consumption increases by 65% between 2010 and 2050. Most of this increase comes from growth in electricity demand, driven notably by increases in appliances and space cooling. By 2050, electricity's share of energy consumption under the 6DS is expected to reach about 60% of total energy consumption in buildings (Figure 2.2.3). In the 2DS, electricity's share in building energy consumption increases to 65% by 2050, where shifts away from fossil-fuel use for space and water heating towards electricity offset some of the energy reductions from improved energy efficiencies.

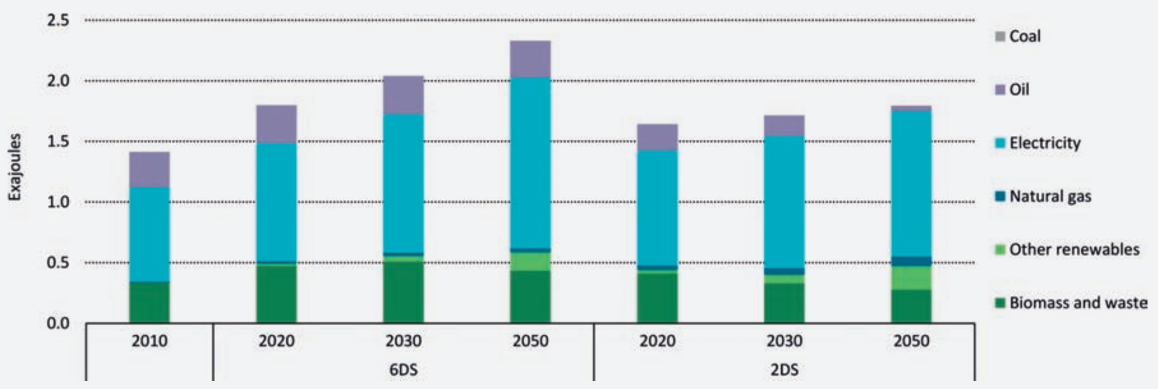
While energy consumption in buildings is 23% lower in the 2DS than in the 6DS in 2050, it is still 27% higher than it is today. The move away from traditional biomass and increased efficiencies in lighting, cooling and appliances is not enough to offset pressures from

Table 2.2.1 Indicators for energy demand in Brazilian buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	195	210	220	224	223
Share of population living in urban area (%)	16%	13%	12%	10%	9%
GDP (billion 2010 USD at PPP)	2 129	3 205	4 418	6 005	8 019
Per-capita income (USD GDP/capita)	10 919	15 229	20 036	26 755	35 986
Services floor area (million m^2)	389	433	475	525	581
Residential floor area (million m^2)	3 514	4 980	5 978	6 553	6 749
Number of households (million)	52	72	85	92	93
Occupancy rate (people per household)	3.7	2.9	2.6	2.4	2.4
Average house size (m^2/house)	67.3	68.7	70.1	71.5	72.9
Refrigerator penetration rate (refrigerator/household)	82%	90%	96%	104%	112%
Clothes washer penetration rate (clothes washer/household)	56%	62%	66%	72%	77%
Share of residential cooled floor area (as a% of total floor area)	44%	47%	50%	63%	75%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; UN DESA (2012) for urbanisation rate; IEA (2012) for GDP; other data from IEA analysis.

Figure 2.2.3 Energy consumption in Brazilian buildings by energy source in the 6DS and 2DS



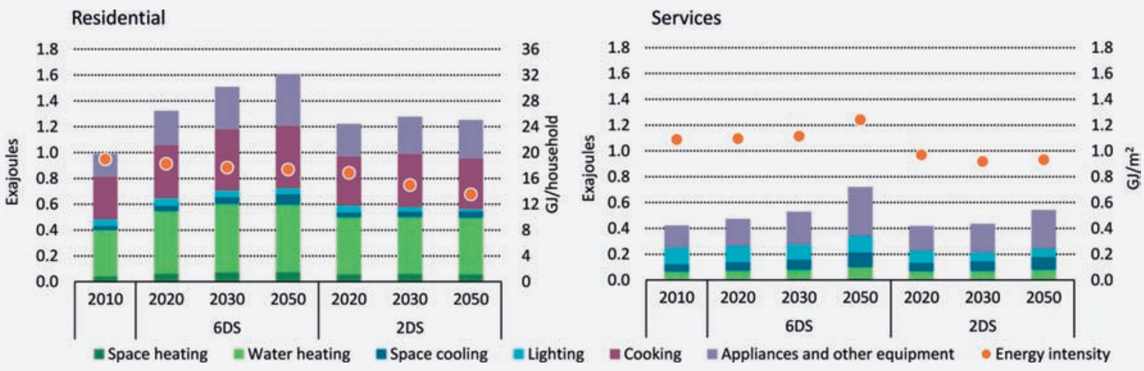
Note: other renewables includes wind, solar and geothermal.

Key point *Electricity will continue to be the most important energy source in both scenarios.*

increased number of household and services energy demand. At the same time, increases in more efficient electric cooking and water heating equipment help to offset overall demand for electricity.

In the residential sub-sector, shifts away from traditional biomass for cooking and water heating have a noticeable impact on energy consumption and contribute to a decrease in overall energy consumption per household (Figure 2.2.4). Cooking energy use per household under the 6DS decreases by 17% over 2010 levels by 2050. In the 2DS, cooking intensities decrease by about one-third. The penetration of more efficient lighting, space cooling and appliances also contributes to lower residential energy intensities, which decrease by nearly 30% in 2050 compared to 2010 levels.

Figure 2.2.4 **Brazil residential and services sub-sectors energy consumption and intensities**



Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *While energy consumption will increase between 2010 and 2050 in both scenarios, energy intensities will improve in the 2DS.*

In the services sub-sector, energy consumption increases by 1.3% per year in the 6DS between 2010 and 2050. This rate of growth is less than half in the 2DS, mostly as a result of more efficient lighting and electronic equipment. Average energy intensity increases from 1.09 GJ/m^2 in 2010 to 1.24 GJ/m^2 in 2050 in the 6DS as a result of a higher share of buildings that are cooled and heated and more service equipment. Under the 2DS, services energy intensity decreases to 0.93 GJ/m^2 as a result of energy efficiency improvements.

About 50% of energy savings in buildings between the 6DS and 2DS are from electricity-using end-uses, including lighting, appliances, service equipment and space cooling (Figure 2.2.5). Cooking and water heating are also important to reduce electricity and overall energy consumption, accounting for roughly one-third of total savings in the 2DS.

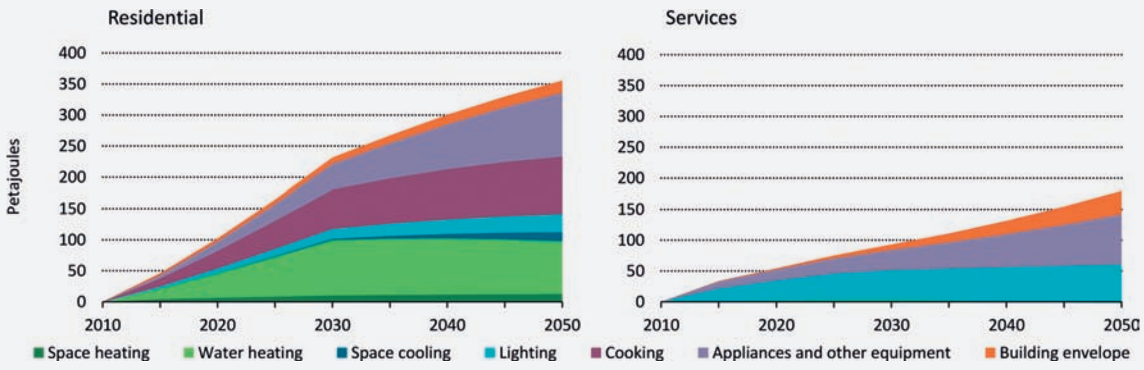
Future trends in CO_2 emissions in Brazil

In the 6DS, the CO_2 intensity of the power sector is expected to increase from 56 grammes of CO_2 (gCO_2) per kWh in 2010 to 134 gCO_2/kWh in 2050 as an increase share of fossil fuel is required to meet the growing electricity demand. Improved energy efficiency and electricity demand reduction contribute to a virtual decarbonisation of the power sector in the 2DS or just 7 gCO_2/kWh by 2050.

Electricity is a major energy commodity for the buildings sector, and its importance is set to grow in the future. As a result, decarbonising the power sector, from its expected level in the 6DS, will have a major impact on reducing indirect emissions from the buildings sector. About 60% of total direct and indirect emissions reduction between the 6DS and 2DS in buildings comes from the decarbonisation of the power sector (Figure 2.2.6).

In the 2DS, total direct and indirect emissions in the Brazilian buildings sector are limited to 11 megatonnes of CO_2 ($MtCO_2$) in 2050, which is about one-third of 2010 levels. Reduction in

Figure 2.2.5 Energy savings from 6DS to 2DS in Brazil in the residential and services sub-sectors

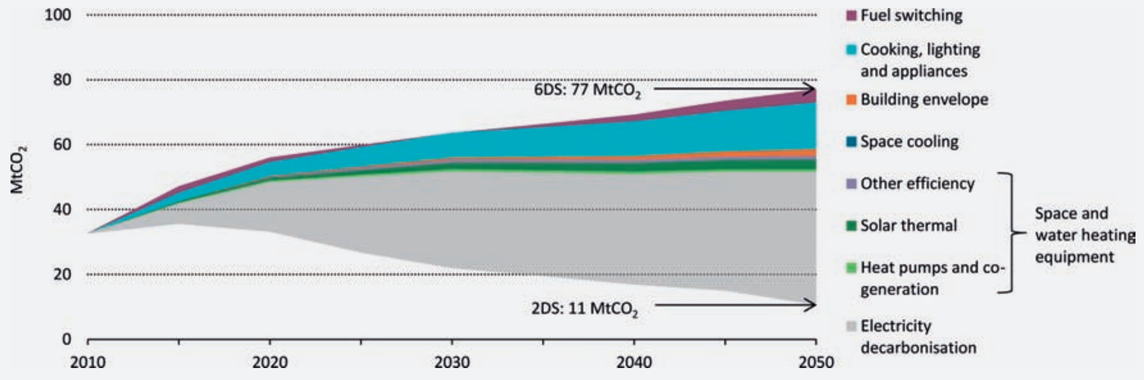


Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Most energy savings will come from electricity-using equipment and end-uses.*

electricity demand from lighting, appliances and cooking plays a key role in limiting total CO_2 emissions from buildings and accounts for over 55% of emissions reduction in the 2DS (excluding savings from electricity decarbonisation). Shifts away from biomass offset part of the expected savings, as biomass is considered CO_2-neutral in this analysis.

Figure 2.2.6 Contribution of CO_2 emissions reduction options in Brazil between the 6DS and 2DS



Key point *Over 60% of total CO_2 emissions reduction between the 6DS and the 2DS will come from the decarbonisation of the electricity sector.*

Recommended actions for Brazil

Attention to opportunities for further development of clean energy projects in Brazil will be important in the next decade, particularly at a time when Brazil's focus is on major infrastructure investments to prepare for the 2014 World Cup and 2016 Summer Olympics.

Voluntary labelling of residential and services buildings as well as voluntary performance rating of buildings are already in place in Brazil. This is a first step toward the implementation of mandatory labelling throughout the country, and the implementation of region-specific building codes aimed at reducing cooling loads in hot parts of the country and heating loads in colder climates. Mandatory labelling would encourage increased adoption of energy efficiency improvements in new and existing buildings. Training and support to ensure the workforce and materials are available to develop and enforce mandatory building codes is also required.

Given the increased importance of appliances and cooling on electricity demand, mandatory labelling should be developed for all appliances while MEPS should be extended to more appliances and equipment. Performance standards should also be updated and strengthened to take into account technology improvements. Continued support for the development of the solar market, most noticeably for water heating, is another priority area that can contribute to energy and emissions reduction in buildings. Such policies and support will help to reduce peak demand in the power sector and will allow Brazil to maintain strong shares of renewables in its total energy mix. Power generation from hydropower and wind offer considerable potential, and Brazil is expected to increase deployment of both technologies.

3. China

China is the most populous country in the world, with 1.34 billion people in 2010, 19% of the global population. The Chinese economy in terms of GDP was the second largest in the world in 2010 after the United States. China's GDP per capita is still low at around USD 7 800 per capita in 2010, or roughly one-quarter of the OECD average (measured in terms of PPP).

China's role as an energy consumer is increasingly important. By 2010, China was the largest energy-consuming country in the world and it outpaced the United States in terms of total primary energy supply (TPES). By 2010, China accounted for 19% of global TPES, while the United States accounted for roughly 17%.

China covers a number of diverse climate regions. As a result, energy consumption levels and patterns vary widely across the country. Buildings in the Northeast have significant heating loads, while those in the centre have cold winters and warm summers and buildings in the Southeast have very modest heating requirements.

The Chinese government's *12th Five-Year Energy Industry Development Plan*, covering the 2011-15 period, has an emphasis on easing energy consumption growth by 2015. The 12th five-year plan set a goal to cap annual energy consumption at 4 billion tonnes of coal equivalent (Btce) per year by 2015 (Interfax, 2013). Under the 12th five-year plan, annual power consumption will also be limited to 6 150 TWh by 2015. Energy consumption per unit GDP should be reduced by 16% from 2010 levels, and carbon intensity should fall by 17% by 2015.

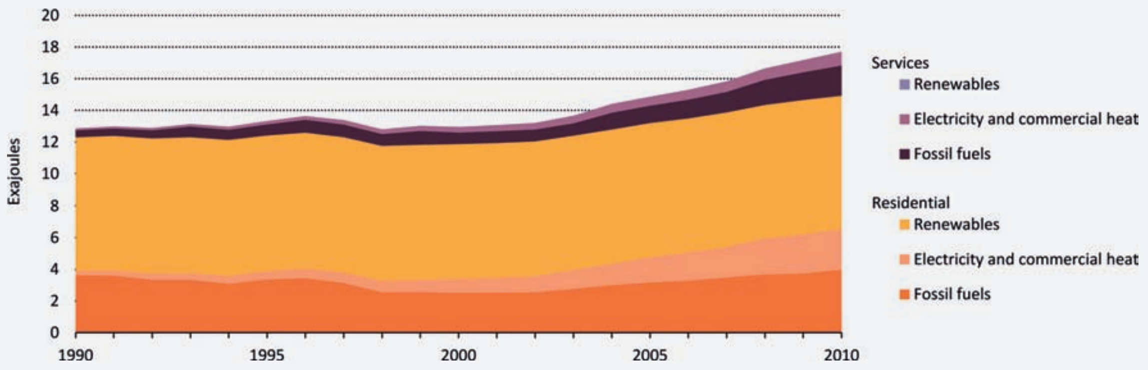
Low-carbon technologies and energy efficiency policies in China have been promoted in the buildings sector. Active solar thermal systems have been installed at a rapid pace in recent years; in 2008, China installed 87 500 megawatt thermal (MW_{th}), which was around 40% more installed capacity than the rest of the world combined (Weiss, *et al.*, 2010). China has also developed building energy codes for residential and non-residential buildings to improve building envelopes and HVAC system efficiencies.

Recent trends

Energy consumption in China's buildings sector increased steadily since 2000 and accounted for 18 exajoules (EJ) in 2010 (Figure 2.3.1). In the residential sub-sector, energy consumption reached 15 EJ in 2010, although energy consumption per household in China is still well below that in OECD countries. At just 39 GJ/household in 2010, the average Chinese household consumes about one-third that of households in the United States.

Biomass dominates in the residential sub-sector, although its share decreased from 68% of total final energy use in households in 1990 to 56% in 2010. The share of coal also declined, from 28% in 1990 to 14% in 2010. On the other hand, electricity and commercial heat use sharply increased between 1990 and 2010. In the services sub-sector, electricity and commercial heat rose more than sevenfold during this period.

Figure 2.3.1 Historical energy consumption in Chinese buildings by energy source

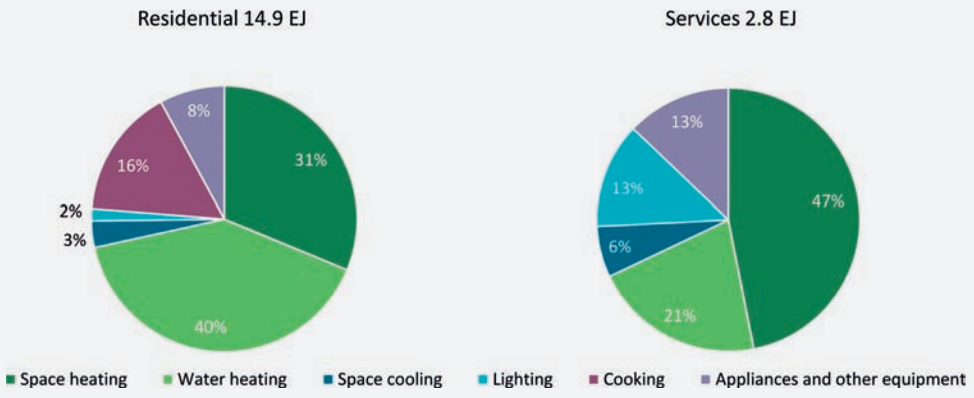


Note: renewables includes biomass, waste, solar, wind and geothermal.

Key point *Energy consumption in buildings is dominated by the residential sub-sector, which accounted for 84% of total energy consumption in 2010.*

Water and space heating accounted for over 70% of total final energy demand in the residential sub-sector in 2010 (Figure 2.3.2). The share of cooking was 16%, which is higher than that in most OECD countries because traditional biomass is still commonly used for cooking in rural and less developed areas. In the services sub-sector, space heating accounted for about half of total energy consumption in 2010. Lighting and service equipment, including office equipment and other services appliances, accounted for another 26% of energy use in the services sub-sector.

Figure 2.3.2 Residential and services sub-sectors energy consumption by end-use for China, 2010



Note: EJ = exajoule.

Key point *Space and water heating dominate energy use in the residential and services sub-sectors.*

Scenarios for buildings in China

China's population is expected to reach about 1.4 billion people by 2030 (UN DESA, 2011). By 2050, it is projected to decline to slightly less than 1.3 billion (Table 2.3.1). At the same time, the number of households is expected to increase steadily as the trend towards fewer people per household accelerates. China is expected to become the world's largest economy in the coming decade, with GDP per capita increasing rapidly to around USD 50 000 by 2050. While this is still lower than in OECD regions, growth in household wealth will drive demand for appliance ownership and overall energy consumption. In the services sub-sector, GDP growth drives services floor area, which is expected to increase by an average of 1.0% per year to 2050.

Table 2.3.1 Indicators for energy demand in Chinese buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	1 341	1 388	1 393	1 361	1 296
GDP (billion 2010 USD at PPP)	10 520	22 293	34 233	49 398	63 697
Per-capita income (USD GDP/capita)	7 843	16 063	24 574	36 298	49 164
Services floor area (million m^2)	10 241	12 692	15 752	16 515	16 367
Residential floor area (million m^2)	42 867	51 207	54 197	58 432	59 604
Number of households (million)	385	460	477	484	476
Occupancy rate (people per household)	3.5	3.0	2.9	2.8	2.7
Average house size (m^2/house)	111.3	111.4	113.6	120.7	125.1
Refrigerator penetration rate (refrigerator/household)	72%	76%	82%	88%	94%
Share of residential heated floor area (as a% of total floor area)	22%	29%	38%	43%	50%
Share of residential cooled floor area (as a% of total floor area)	45%	50%	55%	70%	85%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

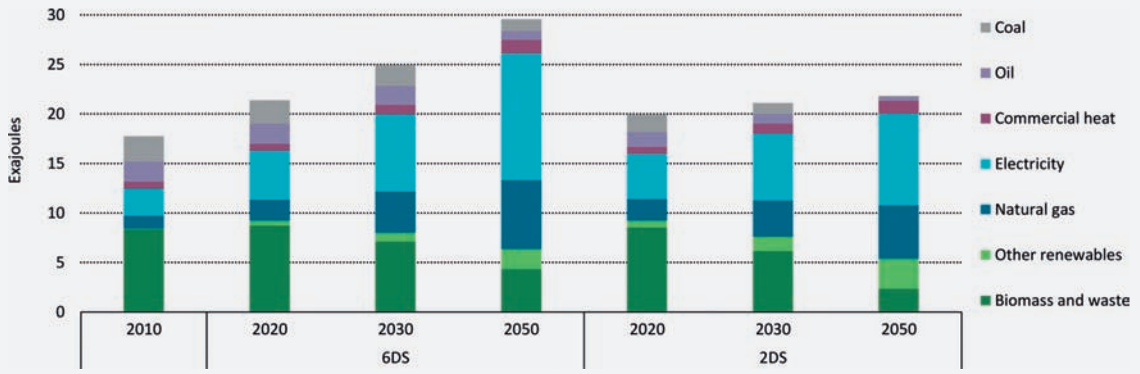
Future trends in energy consumption in China

Total energy consumption in the Chinese buildings sector reaches 30 EJ in 2050 in the 6DS and 22 EJ in the 2DS (Figure 2.3.3). In the 6DS, electricity is the largest energy source in 2050, accounting for over 40% of total energy used in buildings and growing at 4.0% annually between 2010 and 2050. Natural gas also represents an increasing share in buildings energy use, rising 5.4-fold to 2050. Biomass and waste, used mainly for heating and cooking, decrease to 4.3 EJ in 2050, or about half of current levels. Oil and coal decline by more than half.

In the 2DS, energy consumption is 23% higher in 2050 than that in 2010, despite energy efficiency measures and fuel switching over the 6DS. At the same time, electricity demand is roughly 30% lower than the 6DS in 2050. Solar use increases significantly and reaches 2.9 EJ in 2050, which is more than 50% higher than in the 6DS.

In the residential sub-sector, space and water heating continues to dominate in both the 6DS and 2DS in 2050, accounting for about three-quarters of household energy use (Figure 2.3.4). Energy consumption for space cooling increases considerably as incomes rise, while average household energy intensity, in terms of GJ per household, increases gradually in the 6DS. In the

Figure 2.3.3 Energy consumption in Chinese buildings by energy source in the 6DS and 2DS



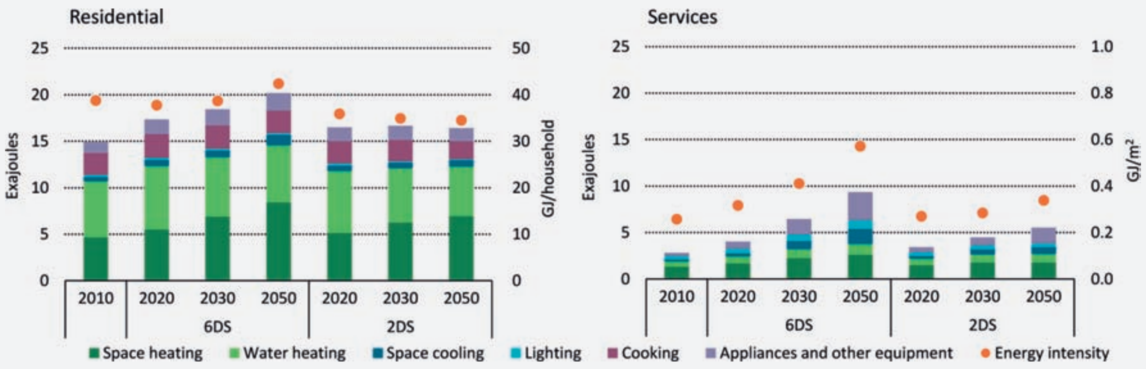
Note: other renewables includes wind, solar and geothermal.

Key point *Electricity and natural gas demand increases dramatically in both the 6DS and 2DS.*

2DS, residential energy intensity decreases by 11% over 2010 levels as a result of energy efficiency improvements and fuel switching.

Energy consumption in the services sub-sector increases more than threefold between 2010 and 2050 in the 6DS, from 2.8 EJ to 9.4 EJ. Energy consumption by all end-uses increases with continued strong growth in the Chinese economy. Services energy intensity increases from 0.26 GJ/m^2 in 2010 to 0.57 GJ/m^2 in 2050. In the 2DS, energy consumption is reduced by roughly 40% in 2050 compared with the 6DS. Lighting, space cooling, service equipment in particular have large potential for energy savings through efficiency improvements.

Figure 2.3.4 China residential and services sub-sectors energy consumption and intensities



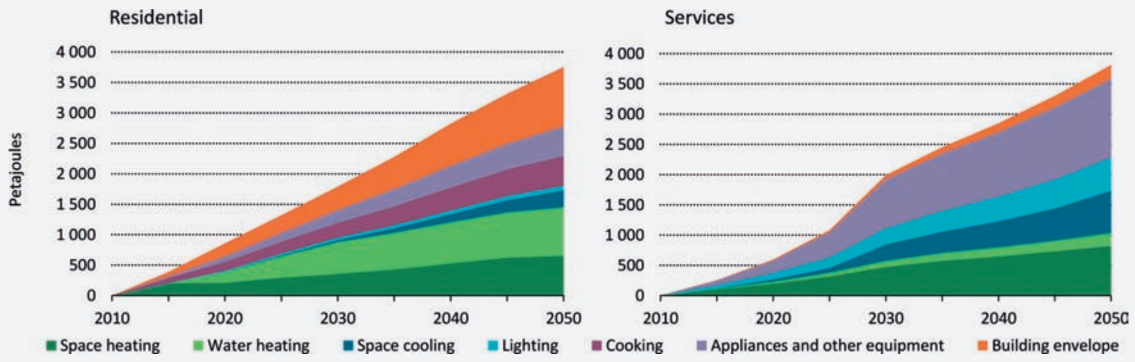
Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Residential energy intensity declines in the 2DS, while both total energy consumption and energy intensity in the services sub-sector increase in the 6DS and 2DS.*

Fuel switching from traditional biomass, used for cooking and heating, to modern fuels offers significant energy savings potential in the residential sub-sector. Improvements in the thermal envelope of residential buildings and other envelope enhancements account for about 22% of energy reduction in 2030 over the 6DS and 26% in 2050 (Figure 2.3.5). Improvement to the building envelope is a necessary first step in improving building efficiency as it will not only reduce energy needs (heating and cooling loads) but also allow downsizing of heating and cooling equipment.

In the services sub-sector, efficiency improvements in space heating and service equipment offers significant potential to reduce growth in energy demand to 2050. Service equipment accounts for nearly 35% of energy reductions to 2050 over the 6DS, while space cooling reductions account for 18% of potential savings and lighting an additional 14% of energy reduction over the 6DS. Space heating accounts for more than 20% of energy savings, where efficiency improvements in space heating equipment can considerably improve heating intensities in services buildings.

Figure 2.3.5 **Energy savings from 6DS to 2DS in China in the residential and services sub-sectors**



Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

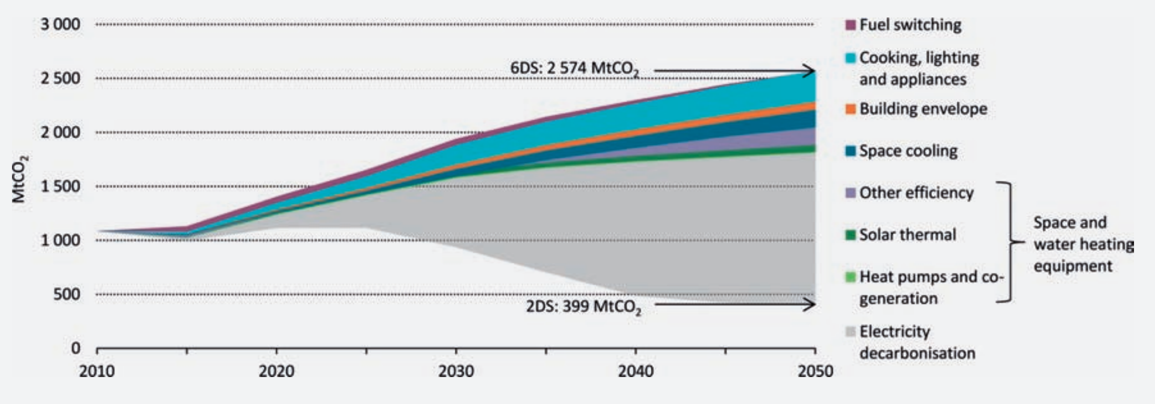
Key point *Building envelope improvements can play an important role in reducing energy consumption in the residential sub-sector.*

Future trends in CO_2 emissions in China

Direct CO_2 emissions from the Chinese buildings sector accounted for about 5% of total Chinese CO_2 emissions in 2010. This relatively low share is partly due to the size of the industrial sector in China as well as the widespread use of biomass in the residential sub-sector, which is considered CO_2-neutral in this analysis. The relatively low penetration of appliances and cooling equipment also contributes to the low share of total Chinese emissions.

In the 6DS, direct and indirect CO_2 emissions increase by 1.5 gigatonnes of CO_2 ($GtCO_2$) between 2010 and 2050. Total CO_2 emissions in the 2DS fall by more than half to just 0.4 $GtCO_2$ in 2050 (Figure 2.3.6). About two-thirds of CO_2 emissions reduction in the 2DS comes from the decarbonisation of the power and commercial heat sectors in China, whose CO_2 intensity in 2050 is 538 g/kWh in the 6DS and 31 g/kWh in the 2DS. Electricity-consuming end-uses, especially appliances, lighting and cooling, also have a large potential to reduce CO_2 emissions in buildings, accounting for more than 20% of total emissions reduction.

Figure 2.3.6 Contribution of CO_2 emissions reduction options in China between the 6DS and 2DS



Key point *Decarbonisation of the power and commercial heat sectors and energy efficiency in cooking, lighting and appliances play a significant role in meeting the 2DS target.*

Recommended actions for China

Vast differences in China's climatic zones have a strong influence on technology options available for energy efficiency improvements and CO_2 abatement. Policies in the buildings sector should take into consideration buildings energy demand in the various climate regions. Space conditioning (heating and cooling) holds the largest potential for energy reduction across all end-uses. In northern areas, the potential lies in improving the energy efficiency of the heating supply, which at present is largely centralised and antiquated. In the future, higher incomes and the drive for private ownership of individual heating equipment will require more efficient solutions, including solar thermal and heat pump technologies. Biomass boilers and micro co-generation units also have the potential to reduce heating energy consumption in buildings.

In the central climatic regions, there is significant potential for bi-modal (heating and cooling) heat pumps. In the southern regions where cooling dominates, a variety of technologies, including highly efficient solar roof top units (RTUs) in commercial areas and high-efficiency heat pumps in residential areas, will play a key role in reducing cooling demand.

A necessary first step in improving energy efficiency in the buildings sector is to develop and enforce stringent building codes that include MEPS for new and refurbished buildings. Improved building envelopes have the additional benefit of allowing space heating and cooling equipment to be downsized. China has developed three building energy codes for new residential buildings and one for existing residential buildings located in severe cold and cold climates zones when they are renovated. Achieving the 2DS will require the codes to be extended to other climatic regions.

Policies are required to promote the research, development, demonstration and deployment (RDD&D) of new technologies for buildings in China. This includes efficiency improvements in appliances and service equipment as well as increased integration of electrical end-uses through smart energy networks. Using low-carbon technologies, including district heating and cooling (DHC), co-generation, heat pumps and energy storage can be good options for smart energy networks in China because the country has many dense mega-cities. In addition, government policies need to target non-technical barriers, such as public acceptance, shortages of skilled workers and market risks of new technologies that significantly weaken penetration of new, more efficient technologies.

4. European Union (27)

In 2010, the European Union (EU)[4] was the world's largest regional energy market and the largest energy importer. Energy is one of the greatest challenges for the EU, where increasing dependence on gas and oil imports jeopardises energy security and economic competitiveness. Buildings in the EU represent the largest share of energy consumption and accounted for nearly 40% of final energy use in 2010.

With a combined population of about 500 million people, the EU represents the world's largest single economic market in terms of combined GDP, with significant variance in per-capita GDP across the 27 member states. The EU also represents a significant variation in climates – from the colder Nordic states and the mild maritime coasts in the west to the warmer Mediterranean climate in the south and the drier, continental climates in the east. These differences in climate result in significantly different energy needs in buildings, where Nordic and Eastern European member states tend to have higher numbers of heating degree days, and warmer Mediterranean regions increasingly have growing demands for space cooling.

Building types also vary significantly in the EU. Roughly two-thirds of services sub-sector floor area in 2010 was situated in countries in Northern Europe, where there tend to be long heating seasons and relatively low cooling demand. Residential buildings differ by country, where in countries like the United Kingdom, almost 90% of households live in single-family homes. In contrast, nearly 65% of the Spanish population live in apartments, which are also common in many Eastern European states and throughout urban areas in the EU (IEA, 2012).

Despite differences in building energy needs and types, age is a common feature of the European building stock. Nearly 40% of all residential buildings in the EU were built before 1960 and almost 84% are at least 20 years old (IEA, 2012). As energy use is strongly linked to building age, there is enormous energy and CO_2 savings potential in upgrading building envelopes and heating and cooling systems to modern standards.

Recognising the importance of energy efficiency improvements in the buildings sector, the EU introduced the Energy Performance of Buildings Directive (EPBD) in 2002. The EPBD required all member states to improve building regulations by establishing minimum energy performance requirements, an energy performance calculation method and energy certification and inspection schemes for boilers and air-conditioning systems in buildings. In 2010, the EPBD was revised with tougher requirements for buildings, including the requirement for member states to ensure that all new buildings will be nearly zero-energy buildings (ZEBs) by the end of 2018 for buildings owned by public authorities and by the end of 2020 for all other new buildings.

Recent trends

Between 1990 and 2010, energy consumption in buildings in the EU increased by 0.9% per year (Figure 2.4.1). Coal and oil use decreased considerably since 1990, although coal use for space heating in the residential sub-sector increased slightly between 2000 and 2010. At the same time, natural gas use increased by nearly 65% between 1990 and 2010, while electricity use increased by 62%. Renewable energy use increased by 81% during the same period, where renewables in the services sub-sector in particular more than tripled since 1990. By 2010, renewables accounted for nearly 10% of total final energy consumption in buildings.

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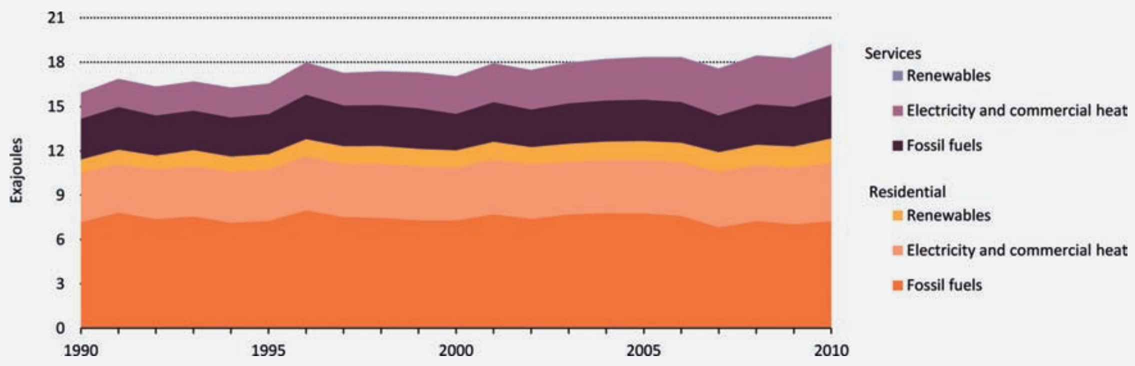
[4] Croatia is an acceding country and will become the 28th member of the EU on 1 July 2013.

Figure 2.4.1 Historical energy consumption in EU (27) buildings by energy source

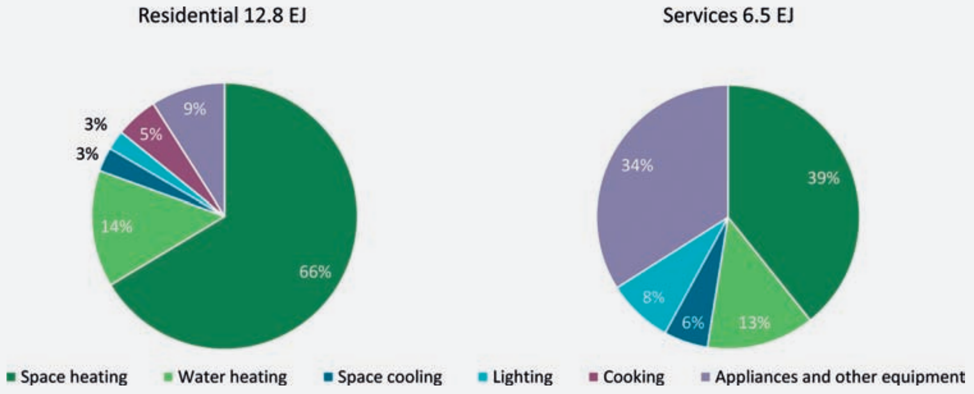


Note: renewables include biomass, waste, wind, solar and geothermal.

Key point *Overall energy use in EU buildings increased at 0.9% per year since 1990, where renewable energies grew the fastest, at more than 3.0% per year.*

Space heating in the EU is the largest end-use in terms of final energy consumption, accounting for two-thirds of residential energy use and about 40% of services energy consumption (Figure 2.4.2). Space heating demand varies considerably by region, where in colder Nordic countries and some Eastern European member states, space heating accounts for as much as 65% of total final energy demand in buildings. In warmer climates, including many Mediterranean country members, space heating demand is often less than half of building energy consumption.

Figure 2.4.2 Residential and services sub-sectors energy consumption by end-use for EU (27), 2010



Note: EJ = exajoule.

Key point *Space and water heating account for about 70% of buildings final energy consumption in the EU, where space heating energy use is driven principally by residential demand.*

Water heating is another major end-use accounting for nearly 15% of final energy consumption in buildings in 2010. In contrast with space heating, water heating demand in the EU tends to be equally intense in most countries, ranging from 10% to 15% of building energy use.

Lighting, cooking, household appliances and service equipment accounted for one-quarter of total final energy use in buildings in 2010, while space cooling was less than 5% of final energy demand. Space cooling is the fastest-growing end-use in both the residential and services sub-sectors, with an estimated increase of 69% and 63% between 2000 and 2010, respectively.

Scenarios for buildings in the EU (27)

The population of the EU is expected to increase marginally in the next decades and then to decrease slightly to roughly 508 million people in 2050 (UN DESA, 2011). Despite this marginal growth in population, growth in services value-added and residential income will have an upward impact on floor area in the residential and services sub-sectors (Table 2.4.1). Total services floor area is expected to increase by over 35% by 2050, while the number of households is expected to increase by more than 15%. The higher increase in the number of households compared to population is explained by a continuous trend towards fewer people per household. At the same time, the average occupancy rate of households is expected to decrease by 12% by 2050, while average household size (in m^2) is expected to increase by nearly 10%.

Table 2.4.1 Indicators for energy demand in EU (27) buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	497	508	512	512	508
GDP (billion 2010 USD at PPP)	18 637	23 660	29 335	36 027	42 948
Per-capita income (USD GDP/capita)	37 494	46 615	57 240	70 353	84 472
Services floor area (million m^2)	8 096	9 039	10 107	10 571	11 007
Residential floor area (million m^2)	20 063	21 714	23 173	24 264	25 087
Number of households (million)	210	224	235	240	242
Occupancy rate (people per household)	2.4	2.3	2.2	2.1	2.1
Average house size (m^2/house)	95.7	97.0	98.8	101.0	103.5

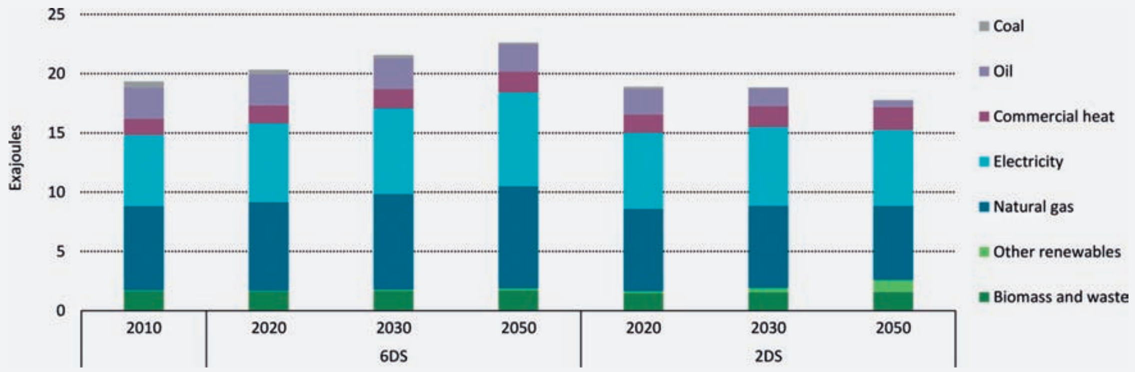
Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

Future trends in energy consumption in EU (27)

The EU is already on track to continue reductions in oil and coal use in buildings under present commitments. Under the 6DS, oil and coal use in the EU is expected to decrease more than 20% by 2050, where in particular coal use is expected to decrease by two-thirds from 2010 levels (Figure 2.4.3). In contrast, electricity and commercial heat use in buildings are expected to increase by nearly one-third to 2050. Natural gas use grows by 22% under the 6DS, while renewables, excluding biomass and waste, more than double.

In the 2DS, oil and coal use decreases by more than 85%, while natural gas use gradually decreases to near-2000 levels by 2050. Electricity use increases only marginally in the 2DS, while renewables (excluding biomass and waste) and commercial heat show significant growth.

Figure 2.4.3 Energy consumption in EU (27) buildings by energy source in the 6DS and 2DS



Note: other renewables includes wind, solar and geothermal.

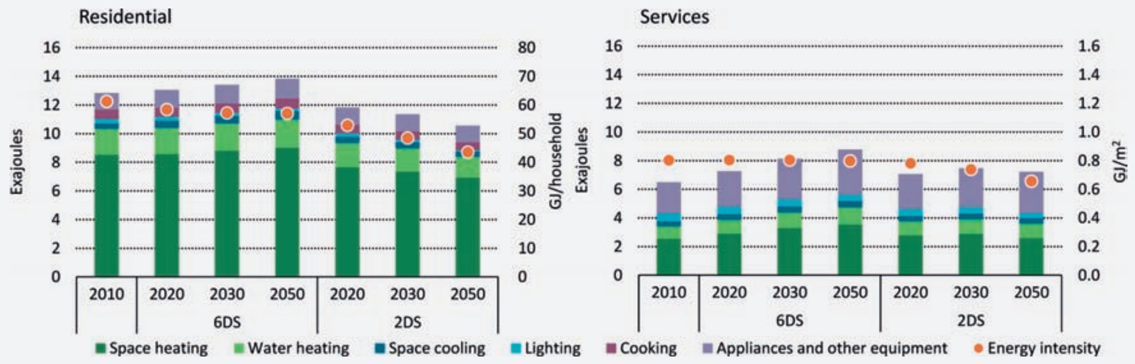
Key point *Coal and oil use decrease significantly, while renewables are ramped up considerably in order to meet energy and emissions targets by 2050.*

Shifts away from coal and oil use in buildings, especially in the residential sub-sector, have a noticeable impact on energy consumption. Under the 2DS, overall building intensities are expected to decrease almost 30% in the residential sub-sector and nearly 20% in the services sub-sector by 2050 (Figure 2.4.4). Lighting intensities in particular, expressed in GJ/household, decrease by about 80% by 2050 in the residential sub-sector and by 55% in services buildings as more efficient lighting technologies, such as solid-state lighting (SSL), penetrate the market. The penetration of improved heating technologies, such as heat pumps and solar thermal technologies, also helps to reduce the energy intensity of the residential and services sub-sectors.

Building envelope improvements, including better wall insulation and highly insulated windows, offer significant potential energy savings in the 2DS and contribute to the reductions from space heating and cooling. Space heating is expected to provide the largest energy reductions in the 2DS (Figure 2.4.5), while water heating improvements, including solar thermal technologies, and efficiency improvements in lighting, appliances, service equipment and space cooling account for an additional 29% of savings.

Overall energy savings from both residential and services buildings in the 2DS account for roughly 4.8 EJ of reduced annual energy consumption by 2050 compared to the 6DS. Nearly 45% of total energy reductions in residential buildings are expected to come from improved space heating equipment and reduced space heating loads in the residential sub-sector. Total improvements in the services sub-sector account for roughly one-third of overall buildings energy savings to 2050.

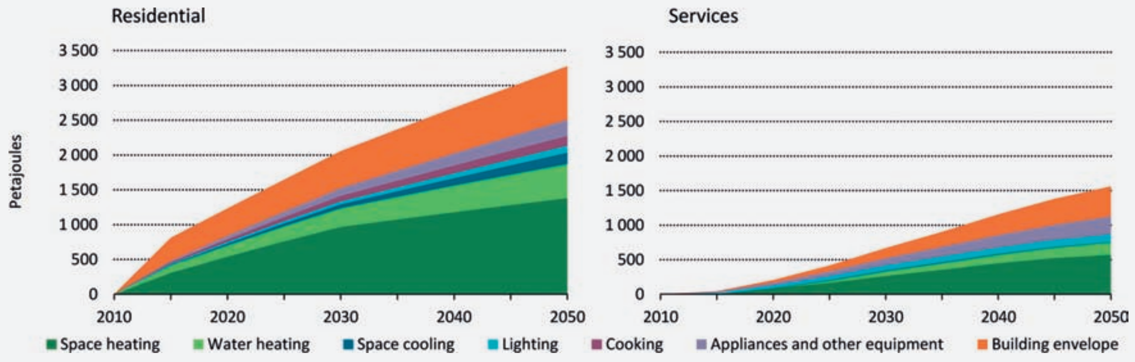
Figure 2.4.4 EU (27) residential and services sub-sectors energy consumption and intensities



Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Average household energy intensity decreases by 29% over 2010 levels by 2050 under the 2DS, while energy intensity in services buildings decreases by 18% by 2050.*

Figure 2.4.5 Energy savings from 6DS to 2DS in EU (27) in the residential and services sub-sectors



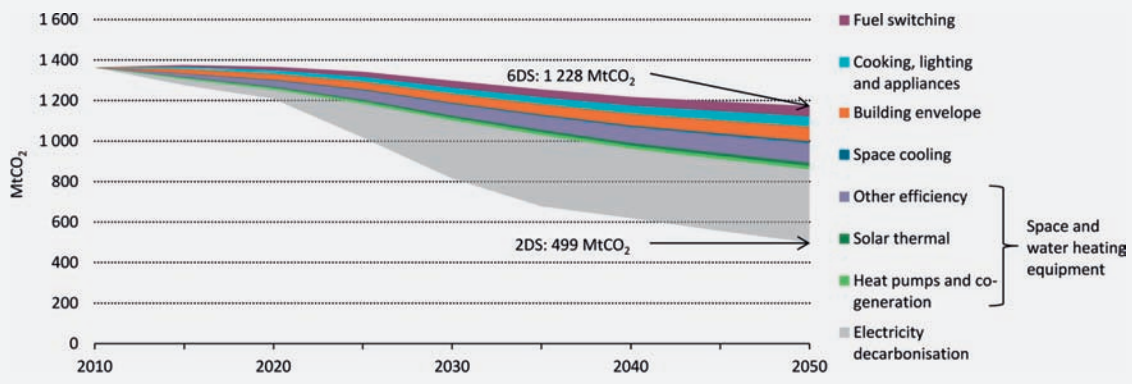
Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Space heating improvements can significantly reduce building energy intensities, where space heating accounts for about half of total buildings energy savings to 2050 in the 2DS.*

Future trends in CO_2 emissions in EU (27)

In order to meet energy and climate change objectives, the EU will need to improve overall energy intensities of buildings beyond current policy measures and expected efficiency gains. Without further action, annual emissions by buildings are only likely to decrease by 10% over 2010 levels by 2050, to 1 228 $MtCO_2$ in 2050 (Figure 2.4.6).

Figure 2.4.6 Contribution of CO_2 emissions reduction options in EU (27) between the 6DS and 2DS



Key point *Efficiency improvements in building envelopes and space and water heating equipment account for about one-third of total emissions reduction in buildings to 2050 in the 2DS.*

In the 2DS, annual emissions in the buildings sector are expected to decrease to less than 500 $MtCO_2$ by 2050, or nearly 60% less than 6DS levels in 2050. More than half of these savings comes from decarbonisation of the power sector and one-third from building envelopes, space heating and water heating. More efficient cooking, lighting and appliances are the other major contributors to emissions reduction, accounting for another 7% of total emissions savings in the 2DS. Fuel switching and cooling opportunities represent the remaining savings.

Recommended actions for EU (27)

The buildings sector in the EU is characterised by a high share of old, inefficient buildings located in regions where there is significant need for space heating. As a result, most of energy consumption by buildings in the EU is used for heating, and the largest potential for energy savings is through improvements in building envelopes and heating equipment.

In order to tap into the important potential for energy and emissions reduction in European buildings, a first step is to improve building envelopes through deep renovations in the existing building stock. The new Energy Efficiency Directive, adopted in October 2012, addresses a mandatory establishment of a long-term strategy for mobilising investments in the renovation of residential and services buildings, including a mandatory 3% refurbishment rate per floor area and year of public buildings. However, policies still do not address the large share of older private buildings unless they undergo major renovations, in which case only buildings larger than 250 m^2 are required to meet efficiency improvement standards. Mandatory measures and building codes should therefore be extended to all existing buildings in order to achieve significant improvements by 2050. Moreover, efficiency measures should be required for all buildings outside the scope of major renovations in order to avoid a lock-in effect[5] of low-efficiency buildings and higher cost of implementation in the future.

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[5] Lock-in effect refers to building investments (*e.g.* replacement of heating equipment) that do not achieve significant efficiency improvements, thereby "locking in" sub-optimal savings in comparison to savings that could have been gained through deep renovations.

Policy action is also needed to require minimum efficiency standards in building heating equipment. Belgium, Denmark, France, Italy and the United Kingdom have established innovative energy efficiency schemes that encourage more efficient equipment, including condensing boilers. These types of national policies should be introduced in all European countries to encourage greater uptake of energy efficient heating technologies. Mandatory measures should also be applied to ensure that high-efficiency condensing boilers are at least the minimum requirement for heating equipment, while policy action is needed to progressively replace conventional electric resistance heaters with heat pumps as the primary means of space and water heating.

Standards for appliances and equipment should be updated to take into consideration recent improvements in appliance energy efficiencies. Given the increased importance of appliances and other end-uses using electricity, especially in the residential sub-sector, such policies will help to reduce energy demand in buildings and level peak electricity loads in the power sector.

5. India

India has the world's second largest population after China, with an estimated 1.2 billion people in 2010. India accounts for nearly 17% of the world's population, and roughly 70% of India's population live in a rural area, although the country is rapidly urbanising (UN DESA, 2012). India is the seventh-largest country in the world, covering five different climatic zones. These range from cold to hot-dry climates, although most of the country has a warm climate that drives an increased use of space cooling. Space heating in India is relevant only in some regions for certain periods of the year.

In 2010, India was the world's third-largest energy consumer, and its energy demand is set to grow dramatically. Energy consumption in buildings currently accounts for roughly 40% of total final energy consumption and it is set to increase at a fast pace in the future. This growth is driven by a combination of factors, including urbanisation and an increased share of the population with access to electricity for water heating, cooling and appliances. Coupled with the country's strong economic growth, energy demand expectations imply that India will need to exploit all energy sources and technologies to advance its economic and social development goals.

India is conscious that environmental and social considerations must be kept in mind while pursuing rapid economic growth. A comprehensive set of policies have been adopted by India to move the country to a low-carbon growth path. In 2009, India announced that it would reduce overall energy intensity, in terms of energy consumption by unit of GDP, by 20% to 25% over the 2005 levels by the year 2020.

Specific measures to attain these goals are being developed through national missions identified in the National Action Plan on Climate Change of 2009. Two of the nine national missions are directly linked to energy and, to some extent, to buildings: the National Mission on Enhanced Energy Efficiency (NMEEE) and the Jawaharlal Nehru National Solar Mission (JNNSM). The NMEEE aims to achieve 23 million tonnes of oil equivalent (Mtoe) of fuel savings over a period of five years through various policy initiatives and instruments. This saving would be equal to an avoided electricity capacity addition of 19 gigawatts (GW) and emissions reduction of about 100 $MtCO_2$ per year. The JNNSM foresees the installation of the equivalent of 20 GW of solar power by 2020.

A major step towards exploiting energy efficiency potential in India was the enactment of the Indian Energy Conservation Act in 2001, under which a dedicated Bureau of Energy Efficiency (BEE) was created. The BEE has since launched a number of policies targeting the buildings sector, including the development and introduction of MEPS and labelling for equipment and appliances; the launching of the Energy Efficiency Building Code (2006); the promotion of the energy efficiency in household lighting through a Clean Development Mechanism (CDM) project to introduce compact fluorescent lamps (CFLs); and a dedicated project to enhance technical capacities and access to finance for small and medium enterprises.

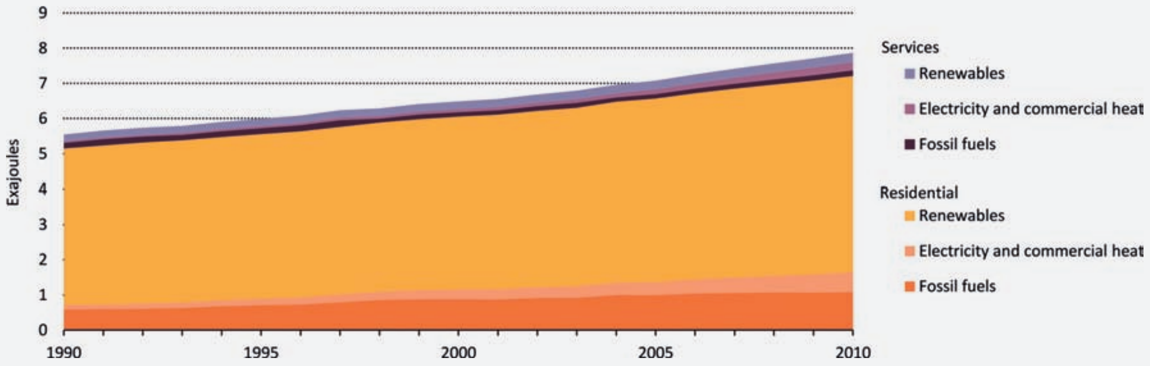
Recent trends

Population growth, economic development, greater access to diversified energy sources and migration from rural to urban areas have resulted in many changes in energy consumption in the buildings sector in recent years. Between 1990 and 2010, energy demand in buildings grew by 1.7% per year in the residential sub-sector and 2.6% per year in the services sub-sector. Most of the energy used in buildings is for the residential sub-sector, which accounts for over 90% of total energy demand in buildings today.

By 2010, the residential and services sub-sectors accounted for about 40% of total final energy consumption in India. This was less than the share of 53% in 1990, partly as a result of faster growth in energy consumption in the manufacturing and transport sectors than in the buildings sector. Access to electricity and modern fuels also contributed to lower residential energy intensities as household demand for cooking, space heating and water heating shifted away from traditional biomass use.

The use of biomass and waste still represents the majority of final energy consumption in the residential sub-sector, where the efficiency[6] of traditional biomass[7] is typically very low (around 8% to 15% efficiency for traditional cook stoves is common). A move towards fossil fuels consumption and to a lesser extent electricity is increasingly evident in the residential and services sub-sectors (Figure 2.5.1). The consumption of oil (mainly liquefied petroleum gas [LPG] and kerosene) and electricity grew rapidly at 3.8% and 8.4% per year, respectively, between 1990 and 2010.

Figure 2.5.1 Historical energy consumption in Indian buildings by energy source



Note: renewables includes biomass, waste, solar, wind and geothermal.

Key point *Energy use in the buildings sector is dominated by the residential sub-sector, which accounts for over 90% of total energy consumption in buildings.*

A better understanding of energy consumption by different end-uses and technologies would enable a more accurate assessment of options for reducing energy use and CO_2 emissions in the buildings sector. Unfortunately, detailed data by end-use in the residential and services sub-sectors are not collected systematically in India. Regular, reliable surveys are available for cooking and lighting in the residential sub-sector, but other data are only available from bottom-up estimates or from surveys that are periodically conducted. More systematic data collection therefore would help to improve analysis of the building sector.

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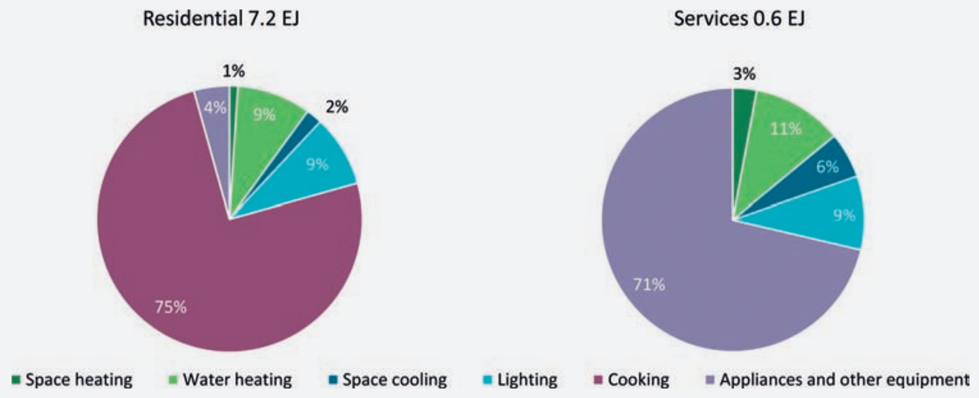
[6] The efficiency is defined as the ratio between the useful output of a device and the input, in energy terms.

[7] Traditional biomass refers to the use of fuel wood, charcoal, animal dung and agricultural residues in stoves with very low efficiencies. Modern biomass includes all biomass with the exception of traditional biomass.

In the residential sub-sector, energy demand for cooking dominates accounting for three-quarters of residential energy use in 2010 (Figure 2.5.2). Traditional biomass burned in open fires or basic cook stoves is the main energy source for cooking, and these traditional cooking techniques are highly inefficient and can release hazardous air pollutants into households. Water heating and lighting are the second largest source of energy demand by households today and account for roughly 10% each of total energy use. Appliances, space cooling and heating, which are large energy users in most OECD and other emerging countries, represent just a combined 7% of residential energy use in India.

In the services sub-sector, energy demand for the other equipment, including information technologies, office equipment, medical technologies, appliances and small plug loads, accounts for nearly three-quarters of services energy use. This high share is explained, in part, by the low requirement for space heating and the low penetration of space cooling in the services sub-sector. Other major areas of services energy are water heating (11%), lighting (9%) and space cooling (6%).

Figure 2.5.2 Residential and services sub-sectors energy consumption by end-use for India, 2010



Note: EJ = exajoule.

Key point *About three-quarters of residential energy is used for cooking. In the services sub-sector, equipment holds the largest share of energy consumption.*

Scenarios for buildings in India

Between 1990 and 2010, India's population grew by 1.7% per year (UN DESA, 2011). Population growth is expected to slow to an average of 0.8% per year between 2010 and 2050, but this still means a population increase of 467 million to 2050. Average household size in 2007-08 was around 4.4 persons per household in urban areas and 4.9 in rural areas (NSSO, 2010). Continued reductions in household size are assumed in the both the 6DS and the 2DS. As a result, the number of households increases at a faster rate than population (Table 2.5.1). Residential floor area consequently is expected to grow by 18 840 million m^2 in both scenarios. In the services sub-sector, floor area is expected to grow by 3.5% per year between 2010 and 2050.

Table 2.5.1 Indicators for energy demand in Indian buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	1 171	1 387	1 523	1 627	1 692
Share of population living in urban area (%)	31%	35%	40%	46%	52%
GDP (billion 2010 USD at PPP)	4 065	8 337	14 727	24 999	37 721
Per-capita income (USD GDP/capita)	3 471	6 011	9 667	15 365	22 294
Services floor area (million m^2)	776	1 215	1 716	2 365	3 033
Residential floor area (million m^2)	12 435	17 505	22 300	26 719	31 273
Number of households (million)	249	324	384	443	500
Occupancy rate (people per household)	4.7	4.3	4.0	3.7	3.4
Average house size (m^2/house)	50.0	54.0	58.1	60.3	62.6
Refrigerator penetration rate (refrigerator/household)	38%	55%	62%	67%	69%
Clothes washer penetration rate (clothes washer/household)	25%	34%	38%	41%	42%
Share of residential cooled floor area (as a% of total floor area)	21%	26%	32%	41%	51%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; UN DESA (2012) for urbanisation rate; IEA (2012) for GDP; number of households, occupancy rate and average house size in 2010 estimated based on NSSO (2010); other data from IEA analysis.

Future trends in energy consumption in India

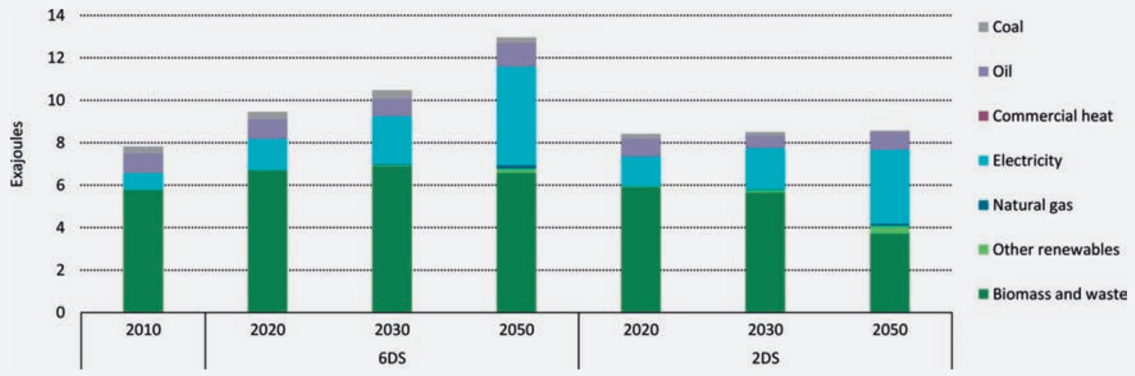
India crossed the USD 3 000 income per-capita threshold (at PPP) in 2008, and ownership of air conditioners began to rise dramatically. Under the 6DS, energy demand for cooling is expected to increase 6.7 times between 2010 to 2050 in the residential sub-sector and more than 11-fold in the services sub-sector. Higher living standards also continue to increase ownership of residential appliances, and as a result, appliances are expected to consume 3.4 times more electricity in 2050 in the 6DS than in 2010. Urbanisation, electrification rates and the move away from traditional biomass also drive rapid growth in electricity demand in the buildings sector, which is expected to increase 5.8-fold between 2010 and 2050 in the 6DS (Figure 2.5.3). In the 2DS, increased efficiency of electricity-using equipment limits growth to a 4.4-fold increase to 2050.

Rapid growth in the number of households and household size drive energy demand in the residential sub-sector, which is expected to increase by more than 35% in the 6DS. As India continues to develop and individuals become wealthier, demand for increased comfort leads to higher demand for appliances, space cooling and, in some part of the country, space heating. However, the reduction of traditional biomass use, even in the 6DS, offsets this increase in energy demand. Average residential and services energy intensity (energy use per household and per m^2 respectively) decreases by about 35% between 2010 and 2050 in the 6DS (Figure 2.5.4).

In the 2DS, increased efficiency of lighting and appliances and the complete switch from traditional biomass to commercial fuels and efficient modern biomass bring further reductions in residential energy intensity over 6DS levels. By 2050, households use about 13 GJ/household, which is 56% less than in 2010.

Economic growth and expansions in services floor area contribute to a fivefold increase in total energy demand in the services sub-sector between 2010 and 2050 in the 6DS. Energy intensity in the services sub-sector, expressed in GJ/m^2, continues to rise as demand for office equipment, information and medical technology and space cooling increase.

Figure 2.5.3 Energy consumption in Indian buildings by energy source in the 6DS and 2DS

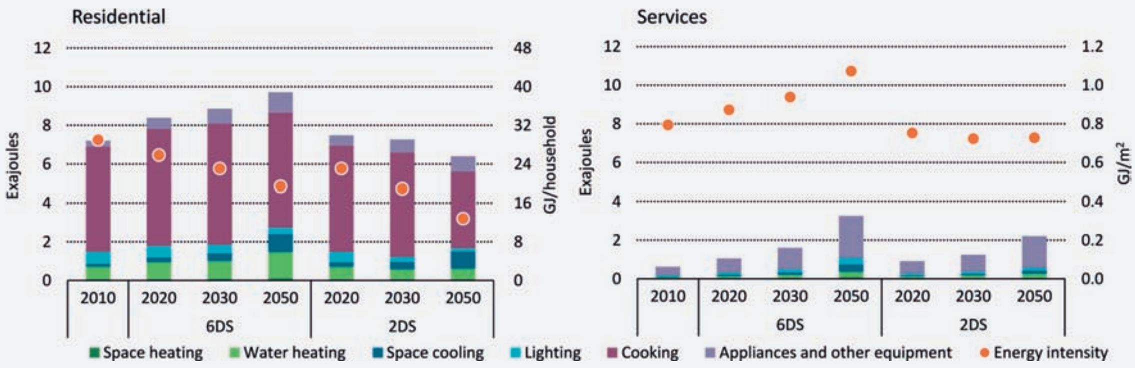


Note: other renewables includes wind, solar and geothermal.

Key point *While biomass will remain a key energy source for the buildings sector, its share will be reduced dramatically by 2050 in both scenarios.*

In the 2DS, the deployment of more energy efficient equipment, space cooling and lighting reduces energy intensity by about one-third by 2050 over the 6DS. Although demand for end-use services rises, improvements in energy efficiency still lead to a small decline in energy intensity in the 2DS in 2050 compared to 2010 levels.

Figure 2.5.4 India residential and services sub-sectors energy consumption and intensities



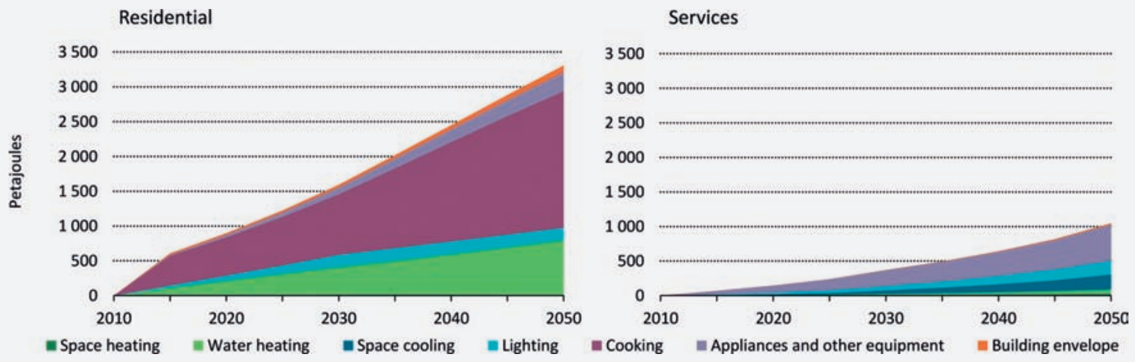
Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Residential energy intensity decreases considerably as households switch from traditional biomass to modern fuels.*

The move away from traditional biomass for cooking to modern fuels results in the largest reductions in energy use in the residential sub-sector and represents 1 965 PJ of energy savings (Figure 2.5.5), the equivalent of more than one-quarter current energy use in the Indian residential sub-sector or total energy consumption in the buildings sector in Italy in 2010. In the 2DS, more stringent MEPS are adopted and energy intensity of appliances is 26% lower in 2050 than it is in the 6DS, helping to save over 270 PJ of energy. Adoption of BAT is made a priority in the buildings sector for space cooling, lighting and water heating.

In the services sub-sector, an estimated 1.0 EJ is saved in 2050 in the 2DS compared to the 6DS. These energy savings include lower electricity consumption by approximately 111 TWh, equivalent to four ultra-mega power projects in India. The deployment of BAT for electrical equipment, space cooling (including heat pumps) and lighting (*e.g.* SSL) will be key if these savings are to be realised.

Figure 2.5.5 Energy savings from 6DS to 2DS in India in the residential and services sub-sectors



Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Over 80% of the energy savings in the residential sub-sector between the 6DS and 2DS come from fuel switching and efficiency improvement in cooking and water heating.*

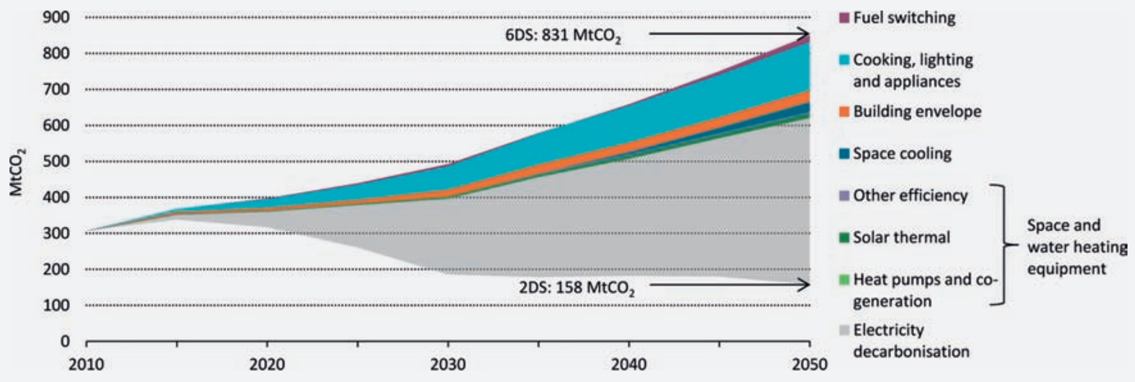
Future trends in CO_2 emissions in India

Direct CO_2 emissions in the buildings sector in the 2DS are reduced by about one-third, or 25 $MtCO_2$, below the 6DS level by 2050. When indirect emissions (emissions associated with the generation of electricity) are taken into account, total reductions amount to 673 $MtCO_2$. About one-third of indirect emissions reduction is attributable to reduced consumption of electricity in the buildings sector; the remaining two-thirds come from decarbonisation of the power sector. Emissions reduction in the 2DS is dominated by savings from electric end-uses, including particularly appliances and space cooling equipment. Improvements in appliances, cooking and lighting over and above efficiency gains in the 6DS account for 23% of the total CO_2 savings in the 2DS (Figure 2.5.6). Reduced electricity consumption for space cooling, through the improved efficiency of cooling systems and improvements in building envelopes also represent significant savings.

Recommended actions for India

India's economic development is expected to increase at a fast pace in the next decades. Such development will put heavy pressure on the buildings sector and the energy system. It also opens up great opportunities to improve energy efficiency in buildings in India.

Figure 2.5.6 Contribution of CO_2 emissions reduction options in India between the 6DS and 2DS



Key point *Electricity decarbonisation and efficiency improvement in cooking, lighting and appliances account for over 90% of the total CO_2 emissions reduction.*

The creation of the BEE was a significant step towards the implementation of energy efficiency measures in end-use sectors, including buildings. While this is an encouraging first step, further policy developments are required to tap the full potential from energy efficiency and other options that would lead to reduction in energy intensity and CO_2 emissions without compromising the growth in standards of living in Indian households.

The Energy Conservation Building Code (ECBC) was launched in 2007 and is presently implemented on a voluntary basis. It sets minimum energy standards for new commercial buildings having a connected load of 100 kilowatt (kW) or a contract demand of 120 kilovolt-ampere (kVA) (BEE, 2013). ECBC has been implemented in several states (with amendments to take into account local and regional climatic conditions). Achieving 2DS objectives will require the ECBC to be made mandatory and to extend it to residential buildings. Compliance and enforcements mechanisms also need to be implemented.

RDD&D of building envelope technologies (such as cool roofs and advanced window shadings) is required to improve the efficiency of the buildings sector and reduce expected cooling loads. Financial support for innovative technologies in this area is also needed, as is work force training to implement them.

The increased standard of living of Indian households means that more households will own an increasing number of appliances and air-conditioning devices. MEPS and labelling programmes are already in place in India. However, not all the main appliances have mandatory MEPS or labelling requirements. MEPS and labelling should be made mandatory for all main appliances and the level of efficiency should be increased as new technologies become commercially available.

The Bachat Lamp Yojana Programme of Activities, launched in 2009, is a voluntary scheme developed by BEE to promote energy efficient lighting in India (BEE, 2013). Continuous government support for the increased market penetration of efficient lighting in households is needed in the immediate term, while in the longer term the phase-out of inefficient lighting in the entire buildings sector should be mandated.

While all these measures will go a long way to improve the energy efficiency of the buildings sector, India also needs to urgently address the issue of subsidies in the energy sector, which prevent the efficient allocation and use of energy.

6. Mexico

As the world's seventh-largest oil producer, Mexico's energy mix is largely dominated by fossil fuels, where oil accounts for 45% of TPES (SENER, 2011). Natural gas accounts for another 42%. However, falling domestic oil production and climate change priorities have led to the creation of a policy framework supporting low-carbon development. This includes objectives to achieve a 30% reduction in annual greenhouse gas (GHG) emissions (in CO_2 equivalent) below total 2006 levels by 2020. A reduction of 50% compared with 2006 is aimed for by 2050 (Poder Ejecutivo Federal, 2009).

Achieving these ambitious targets will require determined government action. As oil production continues to decrease, a more diverse energy portfolio will also be critical to energy security and meeting increasing energy demand, especially as a fast-growing population and middle-class economy continue to lead to dramatic growth and changes in the buildings sector.

Mexico's geographical location and diverse climatic conditions (including arid, sub-humid and humid zones) contribute to different needs and challenges in moving towards a more efficient, low-carbon trajectory in the buildings sector. While most of Mexico has warm weather, parts of the country do experience cold temperatures (below 12°C), while other regions present extreme climatic variations throughout the year (UNEP, 2009). Heating and cooling needs consequently can vary considerably, and overall demand for space conditioning is growing with increased wealth.

Mexico's particular challenge in the buildings sector involves energy efficiency, especially in the areas of lighting, water heating, appliances and cooking. According to planning documents of the Mexican Secretariat of Energy (SENER), about 30% of total energy savings are to be achieved in the residential sub-sector. To this end, the federal government has launched several end-use energy efficiency programmes, including the distribution of 46 million CFLs to 11 million households. As of March 2012, nearly half of this goal (21 million CFLs) had already been distributed.

Recent trends

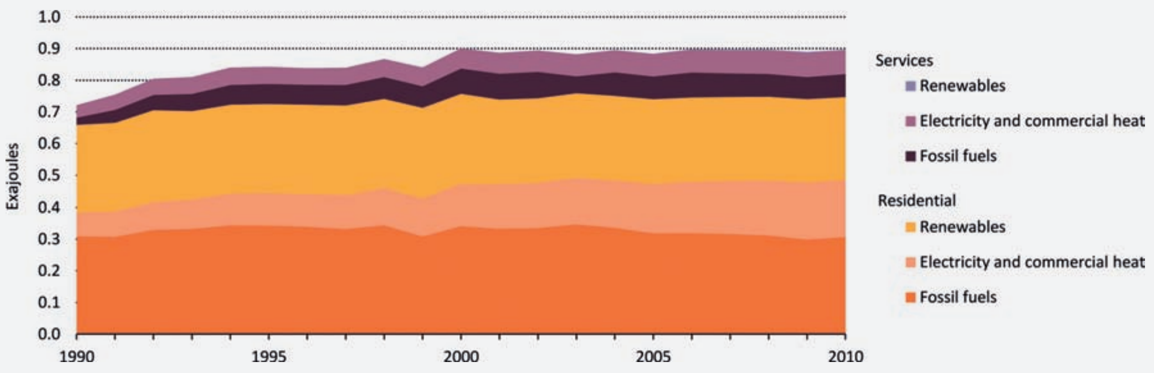
Since 1990, the population of Mexico increased by nearly one-third, while average GDP per capita rose by nearly one-quarter. Mexico's population also continued to become more urban, reaching an urbanisation rate of 78% in 2010 (UN DESA, 2012).

Overall economic activity (in terms of GDP at PPP) in Mexico increased by 65% between 1990 and 2010. As a result of this and population growth, residential households and services floor area increased considerably, where the number of households in Mexico grew by more than 80% since 1990. At the same time, average household size (in terms of persons per household) decreased by nearly 30%. In the services sub-sector, floor area increased by one-third since 2000. This reflects the increasing importance of services activity in Mexico, which has out-performed the industrial sector since 2000 (UNEP, 2009).

Energy use in the buildings sector grew by 24% between 1990 and 2010, to a total of nearly 900 PJ in 2010 (Figure 2.6.1). This figure has remained relatively constant since 2000, where in particular oil consumption in the buildings sector decreased by almost 15% since 2000. Electricity, on the other hand, increased by more than 30% between 2000 and 2010, although this still is a slower rate than growth in electricity in buildings between 1990 and 2000 (72%). Natural gas use also increased significantly between 2000 and 2010 as oil consumption in buildings continued to decline.

Total renewables, including traditional biomass, decreased by about 5% between 1990 and 2010 in the buildings sector, where most of this reduction is explained by continued decreases in traditional biomass use for residential heating and cooking. In contrast, modern renewables, such as solar and wind energy, have increased considerably since 1990.

Figure 2.6.1 Historical energy consumption in Mexican buildings by energy source



Note: renewables includes biomass, waste, solar, wind and geothermal.

Key point *Total energy use in buildings in Mexico has remained constant since 2000, where natural gas and electricity have consistently replaced decreased use of oil.*

Water heating is the largest consumer of energy in buildings, with 45% of residential energy use going to water heating in 2010 (Figure 2.6.2). The use of traditional biomass accounts for roughly 45% of residential water heating. Traditional biomass use for cooking accounts for about half of total cooking energy consumption.

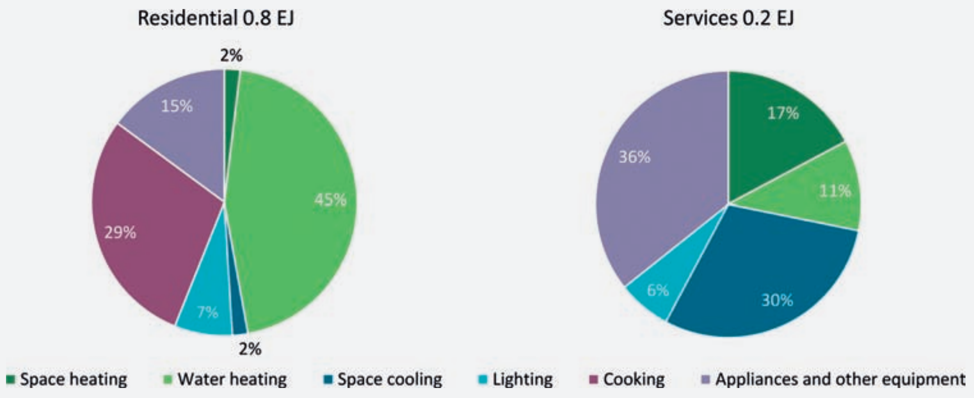
Overall space heating demand is relatively low in Mexico, accounting for less than 5% of total buildings energy use. Space cooling accounted for about 6% of total buildings energy consumption in 2010, although it is increasing rapidly, especially in the residential sub-sector. This trend is likely to continue as household demand for space conditioning continues to rise with household income.

Energy consumption by services equipment, including office machines and information technology, represented more than one-third of total energy consumption in the services sub-sector in 2010.

Scenarios for buildings in Mexico

Mexico's population is expected to continue to increase steadily to 2050, although at a much slower rate than in the past decades (UN DESA, 2011). At the same time, household incomes are expected to increase significantly in real terms, and this is expected to influence downward

Figure 2.6.2 Residential and services sub-sectors energy consumption by end-use for Mexico, 2010



Note: EJ = exajoule.

Key point *Water heating is the largest end-use in Mexico and continues to be dominated by traditional biomass use in the residential sub-sector.*

trends in the average number of persons per household (Table 2.6.1). Increased wealth also drives considerable growth in demand for services, which subsequently intensifies demand for services floor area.

Table 2.6.1 Indicators for energy demand in Mexican buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	113	126	135	142	144
GDP (billion 2010 USD at PPP)	1 551	2 227	3 026	4 035	5 210
Per-capita income (USD GDP/capita)	13 676	17 681	22 348	28 511	36 202
Services floor area (million m^2)	929	1 229	1 625	1 959	2 152
Number of households (million)	29	42	51	56	58
Occupancy rate (people per household)	3.9	3.0	2.7	2.5	2.5
Refrigerator penetration rate (refrigerator/household)	87%	92%	98%	104%	111%
Clothes washer penetration rate (clothes washer/household)	60%	64%	68%	72%	77%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

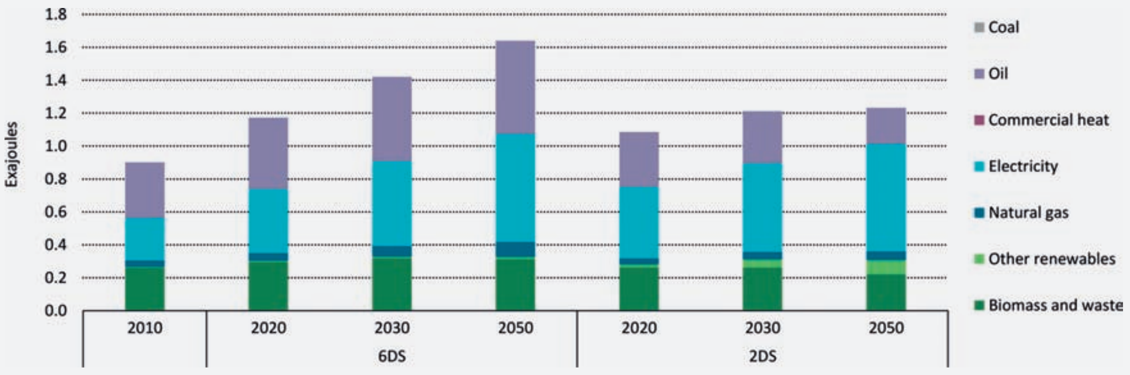
Increased urbanisation, paired with growth of household income, is likely to continue recent trends in diminished use of traditional biomass for residential space heating, water heating and cooking. At the same time, increased wealth is expected to contribute to continued demand for space cooling in both the residential and services sub-sectors. Growth in household income also contributes to increased energy consumption by lighting and appliances, especially as appliance ownership rates and other plug loads (*e.g.* computers) continue to move toward typical OECD levels.

Future trends in energy consumption in Mexico

Over the next 40 years, energy consumption is expected to grow by as much as 80% in the 6DS (Figure 2.6.3). Increasingly, electricity becomes the dominant source of energy in buildings, rising from about 30% of total final energy demand in 2010 to 40% in 2050. In contrast, traditional biomass use for heating and cooking in the 6DS is expected to continue to decrease its share of buildings energy use as households continue to move towards modern water heating and cooking appliances.

Under the 2DS, oil use declines significantly from 2010 to 2050, both in terms of total energy use and as a percentage of total buildings final energy demand. By 2050, total oil consumption in buildings is expected to be about 220 PJ, or 35% less than in 2010. Natural gas and electricity will continue to increase, while total biomass use is expected to decrease by roughly 15% over 2010 levels. This helps to offset increased residential energy demand as more households move to modern cooking and appliances. Renewables and other non-traditional energy sources rise sharply.

Figure 2.6.3 Energy consumption in Mexican buildings by energy source in the 6DS and 2DS



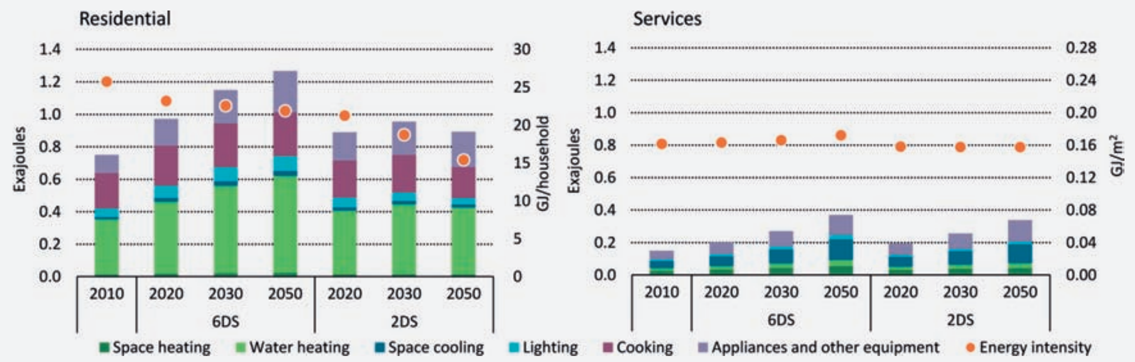
Note: other renewables includes wind, solar and geothermal.

Key point *Final energy demand increases by roughly 35% over 2010 levels in the 2DS, although oil and biomass use diminishes significantly.*

In terms of energy intensities, average residential intensity is expected to decrease to roughly 15 GJ/household in the 2DS (Figure 2.6.4), or 40% lower than 2010 intensity levels. In particular, lighting and cooking intensities in the residential sub-sector, expressed in GJ/household, are expected to decrease by more than 55% over 2010 levels in the 2DS as households shift away from traditional biomass use and towards CFLs and other low intensity lighting technologies.

In the services sub-sector, average intensity is expected to decrease to less than 0.16 GJ/m^2 in the 2DS, which is roughly 2% lower than in 2010 and nearly 10% less than in the 6DS in 2050. Lighting in particular is expected to lower average intensity levels by more than 30% over 2010 averages in the 2DS, while space heating intensity decreases by about 30% from 2010 averages. Space cooling, water heating and service equipment intensities increase over 2010 levels as the penetration rate of equipment is increasing, although they are still less intensive than under the 6DS.

Figure 2.6.4 Mexico residential and services sub-sectors energy consumption and intensities



Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Energy intensity in residential buildings in the 2DS decrease by more than 40%, while lower lighting intensity in the services sub-sector offset growing demand for space cooling and equipment.*

In terms of total potential energy savings, water heating is expected to provide the largest energy reductions in the 2DS, where about 45% of total energy savings over 6DS levels come from residential water heating improvements (Figure 2.6.5). Cooking, lighting, appliances and space cooling similarly offer significant potential energy savings in the 2DS. Residential cooking in particular accounts for about 80 PJ of energy reductions to 2050. Building envelope improvements in the services-subsector explain another 17 PJ of savings to 2050 over the 6DS.

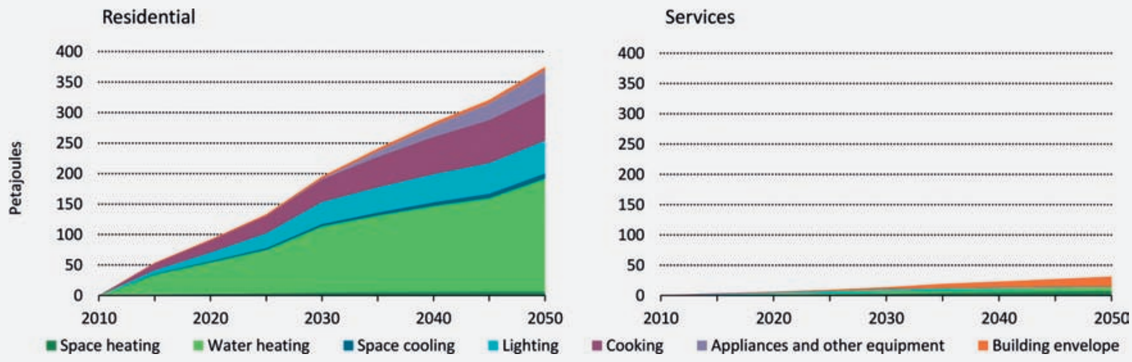
Overall energy savings from both residential and services buildings in the 2DS account for more than 400 PJ of reduced annual energy consumption by 2050 compared to the 6DS.

Future trends in CO_2 emissions in Mexico

Without concerted effort to reduce energy consumption in buildings in Mexico, total residential and services buildings annual emissions are likely to reach 124 $MtCO_2$ by 2050 in the 6DS, or nearly 115% higher than buildings emissions levels in 2010 (Figure 2.6.6). This does not include non-GHG emissions, such as local air pollutants and hazardous fumes, from traditional biomass use in residential cooking and heating.

In the 2DS, annual buildings emissions are expected to decrease to 31 $MtCO_2$ by 2050, or more than three-quarters less than 6DS levels in 2050. The bulk of these savings comes from decarbonisation of the electricity sector, where emissions reduction from final energy consumption in buildings account for the remaining emissions savings in the 2DS. More efficient cooking, lighting, appliances and other service equipment are the major contributors to emissions reduction.

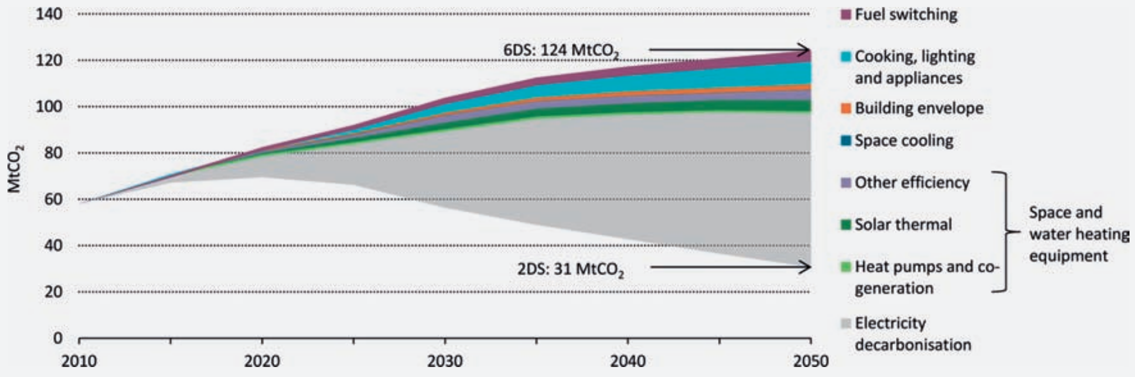
Figure 2.6.5 Energy savings from 6DS to 2DS in Mexico in the residential and services sub-sectors



Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Water heating accounts for the greatest energy savings in buildings, contributing to nearly 50% of energy savings over 6DS levels in the 2DS.*

Figure 2.6.6 Contribution of CO_2 emissions reduction options in Mexico between the 6DS and 2DS



Key point *Electricity decarbonisation accounts for the major part of emissions reduction in Mexican buildings, while cooking and lighting account for the majority of the remaining emissions reduction.*

Recommended actions for Mexico

In the short term, Mexico appears to be on track for achieving 2DS targets and national policy objectives. However, in order to reach the necessary energy efficiency related savings expected by 2050, much more decisive action will be needed. Challenges to energy efficiency include a lack of technical personnel, lack of financing for equipment and project development, relatively little involvement of energy companies, and underdevelopment of the energy services market (ECLAC, OLADE and GTZ, 2009).

In the buildings sector, considerable action is needed to address growing demand for lighting, cooking, appliances and other service equipment as household wealth and services sub-sector activity continue to increase. Part of this demand stems from switches from traditional biomass to modern appliances, although overall product efficiencies can still be improved considerably to lower average energy intensities. This includes continued efforts to improve lighting efficacies as well as additional efforts to increase appliance and equipment efficiencies through standards and labelling, mandatory phasing-out of inefficient product sales and consumer-awareness programmes.

Actions are also needed to address growing demand for space conditioning in both the residential and the services sub-sectors. As a first step, building envelope improvements, including traditional construction techniques used in Mexico for centuries, can help to reduce overall need for space cooling. This includes building orientation, the use of natural and constructed shading and cool colours on building surfaces and roofs. Improved envelope technologies, including low-e, double pane windows and external wall insulation materials, can also reduce overall cooling loads.

Where space cooling is necessary, efficiency improvements in conditioning equipment are a critical step toward achieving 2DS objectives, especially in the services sub-sector. Solar thermal technologies will play an important role in meeting cooling demand without significantly increasing cooling loads on existing electricity networks. Improved air conditioning technologies will also play an important role in meeting increased residential cooling demand to 2050.

7. Russia

Russia is the largest country in the world, with a wide range of climatic conditions. In general, Russia has very cold winters and hot summers, while many regions experience extreme-cold temperatures and have very high heating loads for a large portion of the year. Buildings are consequently responsible for a large share of final energy consumption, accounting for about one-third of total final energy in 2010.

Russia's residential buildings stock is dominated by large multi-family dwellings in urban areas, which represent approximately 70% of households (EBRD, 2011). This share is much higher than in most developed countries and it makes implementing energy efficiency measures in buildings even more complicated as investment decisions need to be agreed upon by a large number of individual owners and a well-functioning homeowner association.

The transition years of the 1990s, which resulted in overall lower investments in infrastructure in Russia, led to the ageing of the buildings stock and a strong need for renovations. While an increase has been observed in renovations of buildings in the past decade, the volume of capital repairs in buildings was still three times smaller in 2009 than in 1980 (EBRD, 2011).

District heating in Russia accounts for roughly half of total energy consumption in buildings. While improvements in district heating systems are outside the boundaries of the residential sub-sector,[8] they are a key element in achieving deep energy and emissions reduction in the buildings sector. Current district heating systems do not allow for individual controls in homes, and many homes are consequently overheated, which contributes to significant amounts of lost heat as occupants open windows to regulate temperatures.

The ageing stock of buildings, Russia's cold climate and the lack of heating controls in homes explain in part the high energy intensity of Russia's buildings sector compared to other countries. The average energy intensity of buildings in Russia in 2010 was 78 GJ/household and 1.43 GJ/m^2 in the residential sub-sector and 2.0 GJ/m^2 in the services sub-sector (compared to 100 GJ/household and 0.75 GJ/m^2 in the residential sub-sector in Canada, where houses are, on average, 2.5 times larger than in Russia, and 1.6 GJ/m^2 in the services sub-sector). Low levels of insulation and the high penetration of low-performing technologies in buildings also contributes to low average efficiencies. At the same time, Russia's "room to manœuvre" is much greater than that of many other leading industrial economies.

Recognising the benefits of more efficient use of energy, Russia has taken measures to reduce energy intensity by 40% by 2020 over 2007 levels. Since 2008, Russia has taken important steps toward creating a legal and institutional framework to enhance efficient energy use and supply. A law on energy efficiency, passed in the Duma[9] in November 2009, introduced several important measures including restrictions on the sale of incandescent light bulbs; requirements for electrical products to be labelled according to their energy efficiency rating; provisions on mandatory commercial inventories of energy resources; new energy efficiency standards for new buildings and installations; and reductions in budget spending on purchasing energy resources.

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[8] Improving and modernizing the district heating network would bring important energy savings for the country. However, these improvements are outside the boundaries of the buildings sector and are not quantified here.

[9] Russia's parliament.

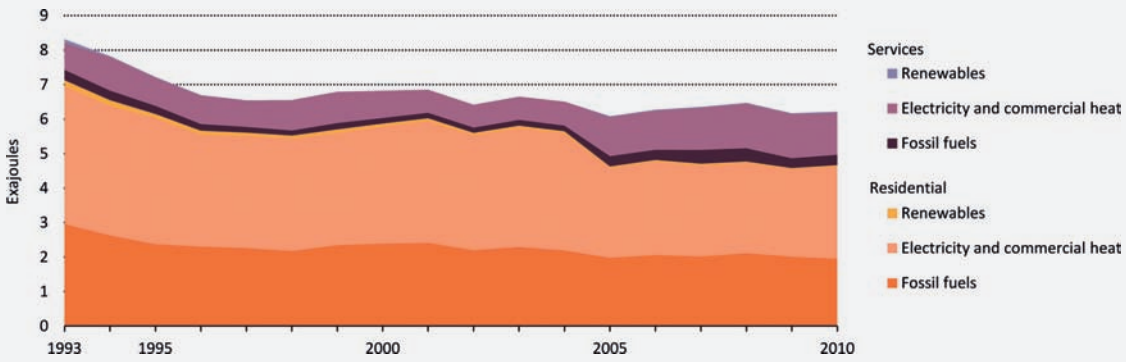
In April 2011, Russia adopted the Climate Doctrine Action Plan. This plan sets out a range of measures for different sectors of the Russian economy and consists of 31 items focused mainly on improvement of resource and energy efficiency. In the plan, the construction industry was called on to prepare pilot projects for "passive houses" in 2012 and to develop and introduce economic mechanisms to curb GHG emissions in the construction industry. However, the Action Plan is not supported by funding and is more an agenda for policy research and possible future implementation, rather than a specific declaration of policy goals.

Recent trends

Between 1993 and 2010,[10] energy consumption in buildings in Russia decreased by 1.7% per year, where energy consumption levels declined more rapidly until 2005, in line with the rapid decrease in population over the same period. All of the energy consumption decrease since 1993 occurred in the residential sub-sector. Population decrease, low growth in housing stock and stable household sizes explain much of the 2.5% per year decrease in residential energy consumption. On the other hand, energy consumption in services sub-sector, driven by the 7% increase in total Russian GDP and a 12% increase in per-capita income, increased by 1.6% per year between 1993 and 2010.

Despite the considerable decrease in total buildings energy consumption since 1993, buildings still accounted for one-third of total final energy consumption in 2010. The buildings energy mix is dominated by commercial heat, which accounted for 45% of buildings energy consumption in 2010, down from almost 50% in 1993. The share of fossil-fuel use also declined slightly, in part due to the liberalisation of coal and oil prices, which led prices to rise (Figure 2.7.1). In the residential sub-sector, electricity is the only energy source which increased over the 1993 to 2010 period (7%) due to the increased penetration of appliances and other electric equipment.

Figure 2.7.1 Historical energy consumption in Russian buildings by energy source



Note: renewables include biomass, waste, wind, solar and geothermal.

Key point *Energy consumption in the residential sub-sector decreased 35% between 1993 and 2010, but still accounts for 75% of total buildings energy consumption.*

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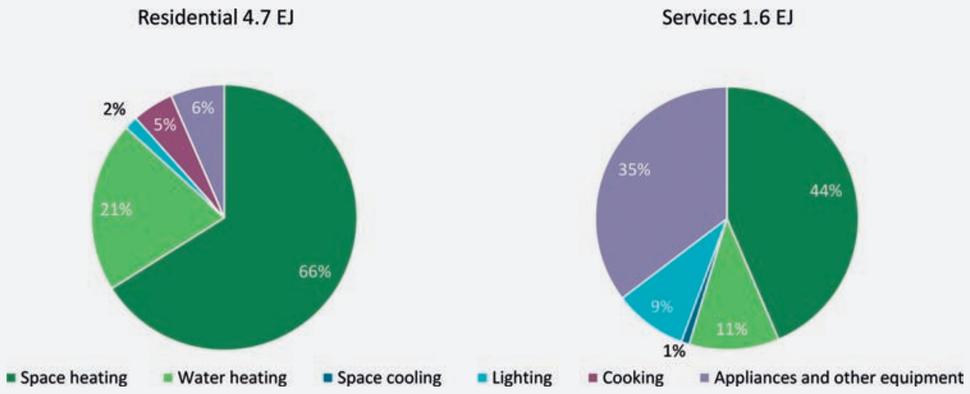
[10] Consistent data for Russia are available from 1993, after the dissolution of the Soviet Union.

Space and water heating are responsible for about 80% of Russian buildings energy consumption (Figure 2.7.2), where it is estimated that about three-quarters of all buildings are serviced by district heating networks. In the residential sub-sector, space and water heating account for 87% of total residential energy consumption. As the average Russian housing stock is estimated at 42 years and with half of the buildings needing capital repairs (EBRD, 2011), there is an important opportunity to rapidly increase the energy efficiency of residential buildings, especially through building envelope improvements, and space and water heating equipment.

The end-use mix in the services sub-sector is quite different. While space heating is still the most important end-use, other equipment accounts for about one-third of energy consumption, where more than half of energy used by other equipment is electricity. Lighting also accounts for a relatively high share of services energy consumption (9%). As a result, electricity is a major energy commodity in the services sub-sector, accounting for almost 40% of energy consumption.

Figure 2.7.2 Residential and services sub-sectors energy consumption by end-use for Russia, 2010



Note: EJ = exajoule.

Key point *Space heating is the main energy user in both the residential and services sub-sectors.*

Scenarios for buildings in Russia

Russia's population is expected to continue to decrease in the next decades, although at a slower pace than historically. Russia's population in 2050 is estimated to be around 126 million, compared to 143 million in 2010 (UN DESA, 2011). Despite this decrease, residential and services floor area are anticipated to increase by 1.0% and 0.8% per year respectively over the same period. This increase will be driven by a tripling in GDP and a fourfold increase in per-capita income, which will drive up the average size of houses (Table 2.7.1). Increases in wealth will also have an impact on the number of appliances owned by households. A higher share of households owning more appliances will have an upward impact on the total energy intensity of the buildings sector, even if the efficiency of those appliances is improving.

Table 2.7.1 Indicators for energy demand in Russian buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	143	141	136	131	126
GDP (billion 2010 USD at PPP)	2 241	3 331	4 621	6 188	7 463
Per-capita income (USD GDP/capita)	15 677	23 622	33 869	47 134	59 140
Services floor area (million m^2)	783	880	989	1 028	1 069
Residential floor area (million m^2)	3 229	3 806	4 318	4 659	4 729
Number of households (million)	60	65	63	61	58
Occupancy rate (people per household)	2.4	2.2	2.2	2.2	2.2
Average house size (m^2/house)	54.2	58.8	68.5	76.8	81.1
Refrigerator penetration rate (refrigerator/household)	72%	99%	119%	130%	138%
Clothes washer penetration rate (clothes washer/household)	92%	93%	95%	97%	99%
Dishwashers penetration rate (dishwasher/household)	69%	77%	86%	88%	89%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

Future trends in energy consumption in Russia

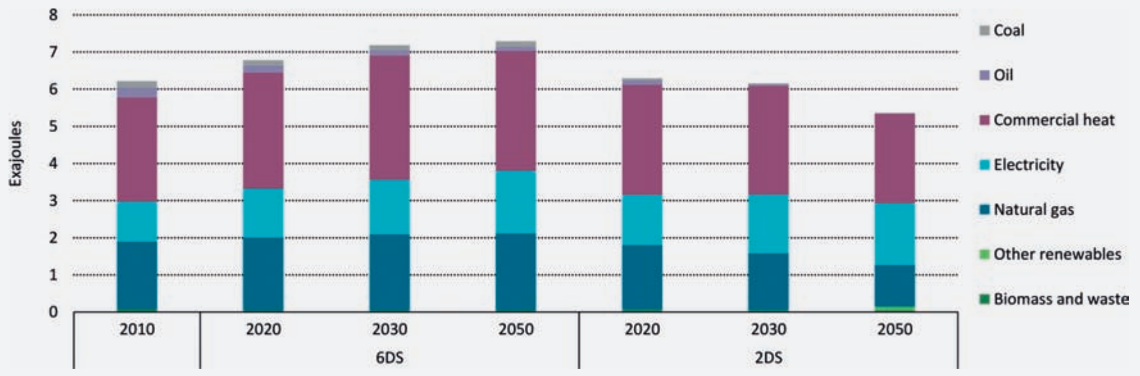
Under a business-as-usual scenario (6DS), the increase in energy consumption in the buildings sector will be limited to 0.4% per year. The trend in the energy mix in buildings is not expected to change dramatically from that observed in recent years, although electricity is expected to continue to increase its share of energy consumption in buildings. In contrast, the use of coal and oil continues to decrease to 2050 as their relative prices are higher than electricity and natural gas.

Under the 2DS, there is a phase-out of coal and oil use, and the use of natural gas decreases from about 30% in 2010 to about 20% in 2050 (Figure 2.7.3). The decrease in natural gas consumption is directly attributable to energy efficiency improvements in building envelopes and, to a lesser extent, improvements in natural gas boilers. Electricity and solar are the only energy commodity for which consumption increases between 2010 and 2050, although solar only provides a fraction of energy needs. The increase in electricity consumption is mostly driven by greater electrification of heating systems and increased penetration of efficient heat pumps.

While the number of households slightly decreases between 2010 and 2050, the average floor area per household is assumed to increase as incomes rise, growing from 54 m^2 to 81 m^2. As energy consumption for space heating is directly related to floor area, its energy consumption is expected to increase by 16% in the 6DS despite improvements in building envelope efficiencies. Energy consumption for residential appliances increases by 50% despite reductions in the number of households, driven by increased ownership levels (Figure 2.7.4).

Under the 2DS, stronger efficiency improvements are assumed for all end-uses. As a result, energy consumption of all end-uses, except appliances, decreases between 2010 and 2050. For appliances, the increase in energy consumption will be limited to just 12%. Residential energy intensity in the 2DS reaches 67 GJ/household by 2050.

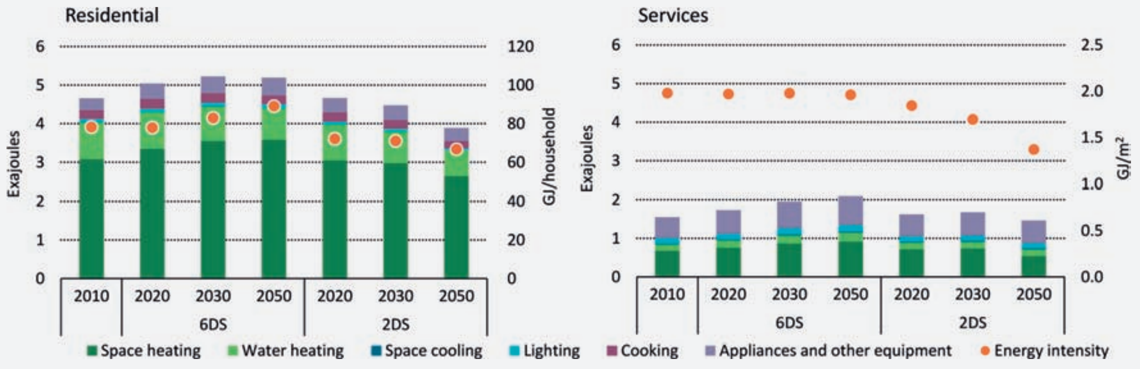
Figure 2.7.3 Energy consumption in Russian buildings by energy source in the 6DS and 2DS



Note: other renewables includes wind, solar and geothermal.

Key point *Buildings energy consumption in the 2DS will be about 15% lower than it was in 2010.*

Figure 2.7.4 Russia residential and services sub-sectors energy consumption and intensities



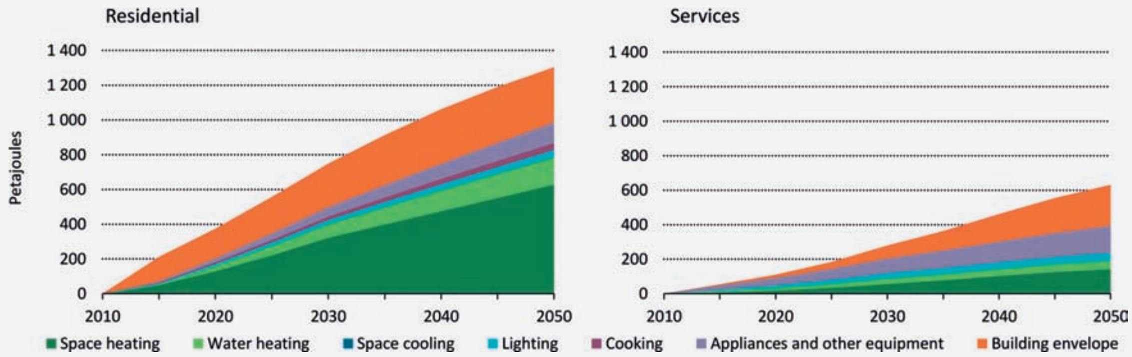
Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Residential and services energy intensities are 25% and 30% lower in the 2DS than in the 6DS, respectively.*

In the services sub-sector, energy consumption in the 6DS increases by 35% by 2050. Energy intensity remains relatively stable at less than 2.0 GJ/m^2. In contrast, services building intensities drop to less than 1.4 GJ/m^2 in the 2DS by 2050. Space heating and lighting energy consumption is 20% and 10% lower than in 2010, respectively. Overall, energy consumption in the services sub-sector is 30% lower in the 2DS than in the 6DS in 2050, or 6% lower than in 2010.

Improvements in building envelopes and energy efficiency of space heating equipment account for about three-quarters of reductions in residential energy consumption between the 6DS and 2DS (Figure 2.7.5). In the services sub-sector, building envelope improvements account for roughly 40% of reductions, while improvements in space heating account for another 22%. Increased energy efficiency of service equipment, including information technologies, office equipment, medical technologies, appliances and small plug loads, accounts for much of the remainder.

Figure 2.7.5 Energy savings from 6DS to 2DS in Russia in the residential and services sub-sectors



Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Three-quarters of energy savings in the residential sub-sector come from improved building envelopes and space heating equipment.*

Future trends in CO_2 emissions in Russia

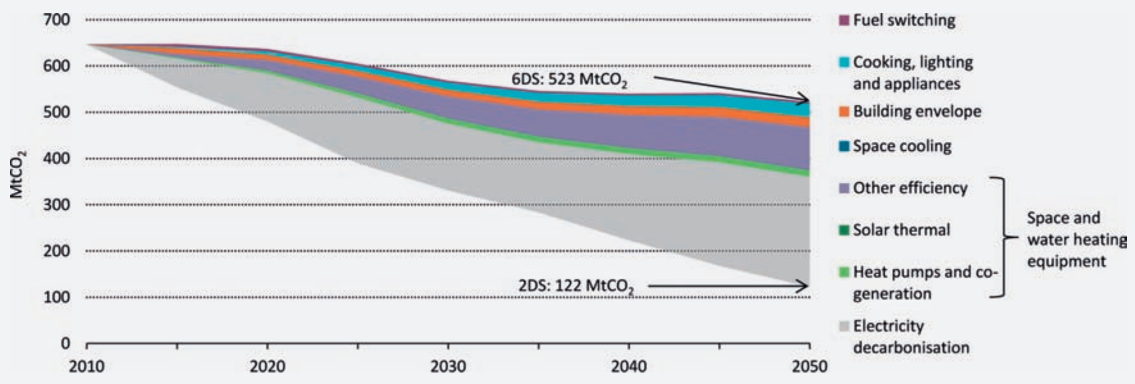
Direct and indirect emissions in Russia are reduced by more than 75% in the buildings sector in the 2DS. About 60% of these reductions are attributable to the decarbonisation of the electricity and heat sector (Figure 2.7.6), although all options will play a key role in reducing CO_2 emissions of the Russian buildings sector. In particular, savings from space heating, water heating, building envelope improvements and the wider adoption of heat pumps contributes to 80% of buildings emissions reduction (excluding reductions from electricity and heat decarbonisation) between the 6DS and 2DS.

Recommended actions for Russia

There is a vast potential in Russia to dramatically reduce energy consumption in buildings. Recognising the benefits of more efficient use of energy, Russia has made energy efficiency a priority, and measures are underway to exploit this potential. Priority has been placed on improving existing buildings, paying special attention to capital turnover repairs of residential buildings.

Reaching the goals set out in the 2DS will require Russia to strengthen current measures and address particularities in Russian buildings through specific tools and policies that are tailored to the country's unique situation. Russia currently lacks a sufficient institutional framework that would allow the country to realise significant energy efficiency gains. Major economic and non-economic barriers exist and need to be addressed by regulation, policies and energy efficiency programmes. Suitable funding mechanisms in particular are needed to address the unique ownership structure of the building stock.

Figure 2.7.6 Contribution of CO_2 emissions reduction options in Russia between the 6DS and 2DS



Key point *About 60% of CO_2 emissions reduction comes from the decarbonisation of electricity and heat, while building envelopes, space and water heating efficiency improvements account for a further 32%.*

There are some energy efficiency standards in Russia, but more are needed. Russia should adopt and mandate energy efficiency labelling of major household appliances and develop mandatory MEPS for those appliances. MEPS should be tailored to the current Russian market, but they also should be as stringent as those in the EU in the medium term.

There is also a need to reduce the payback period for investments in buildings, which in some cases can be as high as 15 years. Low-energy costs and approximately 20% higher capital costs for energy efficient equipment in Russia than in Europe make the payback periods particularly long and create additional barriers to implementation. A combination of funding mechanisms such as energy service companies (ESCOs), subsidies from the government and loans could reduce the payback period to a more reasonable timeframe.

While Russia's district heating system is outside the scope of this analysis, prompt and strong action is required to improve the system. Meters have already been installed for electricity and water consumption, but there is significant reluctance to introduce heat meters due to high losses within district heating systems.

Russia has taken important steps towards creating legal and institutional frameworks to enhance efficient energy use and supply. Despite efforts to develop Russia's institutional capacity and expertise on energy efficiency, notably in the Russian Energy Agency under the Ministry of Energy, this process is still at a relatively early stage and will require a sustained commitment of human and financial resources.

8. South Africa

South Africa is one of the world's most energy-intensive economies, with more than 94% of electricity produced from coal. With over 50 million people, South Africa has a rapidly growing buildings sector with room for significant improvement in energy and emissions intensities, both through decarbonisation and diversification of the power sector and vast efficiency improvements in building equipment, end-uses and design.

South Africa has a generally temperate climate, where space heating demand in buildings tends to be low. Space cooling demand also is relatively low, accounting for less than 5% of total energy consumption in buildings.

As residential and services sub-sector demands for electricity continue to grow – only 82% of current residential buildings are estimated to have access to electricity (IEA, 2012) – energy efficiency improvements will play an increasingly important role in meeting growing energy demand and national emissions targets. However, South Africa still faces a multi-faceted challenge in coming decades, especially with regards to providing enough electricity to supply growing demands.

In 2008, South Africa reviewed overarching energy efficiency targets in the National Energy Efficiency Strategy, which set efficiency improvement at 12% by 2015 for the country as a whole. South Africa also pledged in 2009 at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties held in Copenhagen (COP 15) to cut GHG emissions by 34% below "business-as-usual" emissions growth trajectory to 2020 and by 42% by 2025.

To date, the roll-outs of regional and national efficiency programmes, such as the CFL replacement programme by the state-owned utility, Eskom, have already achieved important gains in the South African buildings sector, including more than 35 million CFL installations over the past decade. However, significant additional gains can be made by implementing BAT in buildings and supporting investments in renewable resources, such as solar thermal technologies.

Recent trends

The population of South Africa increased by 36% between 1990 and 2010, and energy use in the buildings sector grew by nearly 50% during the same period, to a total of roughly 800 PJ in 2010 (Figure 2.8.1). Renewables (including traditional biomass use) accounted for roughly 60% of total energy use in buildings in 2010, while electricity accounted for about one-third. Traditional biomass use[11] is still common in household cooking and heating (including notably water heating), although it has continued to decline as a percentage of energy use in buildings since 1990 as households have switched to modern electric appliances. Electricity use consequently increased by nearly 45% in the last decade, where in particular electricity used for cooking, appliances and electronics rose sharply between 2000 and 2010.

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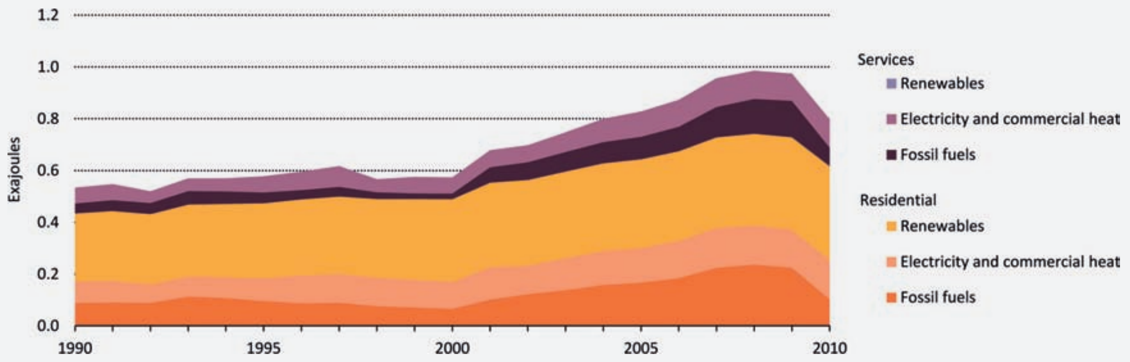
[11] Biomass and waste includes solid biomass, gas and liquids derived from biomass, industrial waste and the renewable part of municipal waste.

Figure 2.8.1 Historical energy consumption in South African buildings by energy source

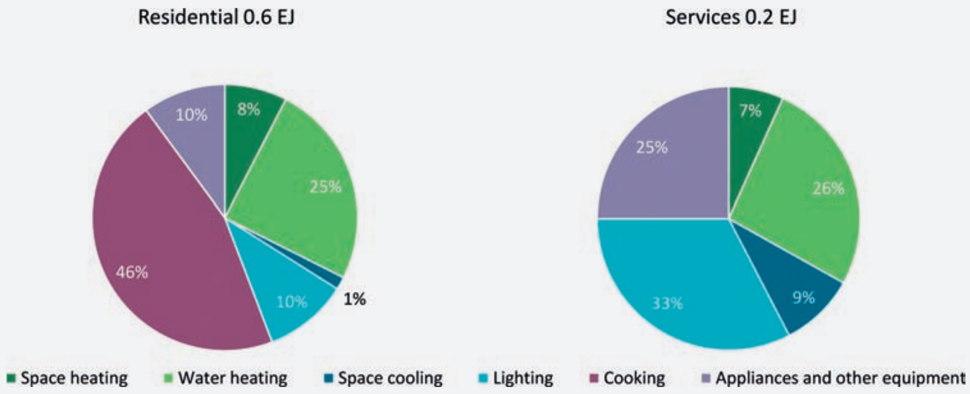


Notes: renewables include biomass, waste, wind, solar and geothermal. Decrease in 2010 is due to decreased domestic use of coal.

Key point *Biomass use in the residential sub-sector continues to dominate total energy use in buildings, while electricity use has increasingly replaced traditional biomass for cooking and water heating.*

Cooking remains the largest consumer of energy in South African buildings, with 46% of residential energy use going to cooking in 2010 (Figure 2.8.2). Traditional biomass accounts for 78% of household cooking, which is a considerable decrease from 2000. Biomass use for water heating in the residential sub-sector similarly accounts for the majority (72%) of water heating energy consumption.

Figure 2.8.2 Residential and services sub-sectors energy consumption by end-use for South Africa, 2010



Note: EJ = exajoule.

Key point *Traditional biomass continues to remain the dominant energy source for cooking and water heating, which account for about 60% of buildings energy use.*

Overall demand for space heating and cooling in South Africa is relatively low, where space cooling accounted for less than 5% of total energy consumption in buildings in 2010. Space heating similarly accounted for about 7% of energy use. Biomass use still dominates residential space heating demand, although coal use for household space heating has grown significantly since 2000. In the services sub-sector, coal accounts for nearly 55% of space heating energy use.

Lighting, appliances and services equipment are an area of considerable growth in the services sub-sector in South Africa. Lighting and services equipment accounted for nearly 60% of services energy use in 2010, while in the residential sub-sector, lighting and appliances accounted for 20% of building energy use. In both sub-sectors, energy consumption in these end-uses increased significantly since 2000.

Scenarios for buildings in South Africa

South Africa's GDP and per-capita income are expected to increase considerably to 2050, with per-capita GDP expected to triple by 2050 (Table 2.8.1). While population is expected to increase only marginally, this increased wealth drives considerable growth in demand for households. As a result, average occupancy rates in households are expected to decrease by about 35% over the next four decades.

Increased per-capita wealth is also anticipated to contribute to added demand for services, which subsequently intensifies demand for services floor area. By 2050, services floor area nearly triples (187%). This considerable growth adds significant demand for electricity supply in South Africa, especially as electricity already accounts for more than half of services final energy use.

Table 2.8.1 Indicators for energy demand in South African buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	50	53	55	56	57
GDP (billion 2010 USD at PPP)	531	755	977	1 278	1 743
Per-capita income (USD GDP/capita)	10 602	14 356	17 856	22 814	30 717
Services floor area (million m^2)	281	363	480	613	804
Residential floor area (million m^2)	883	1 184	1 399	1 569	1 680
Number of households (million)	11	14	16	18	19
Occupancy rate (people per household)	4.7	3.8	3.4	3.1	3.0
Refrigerator penetration rate (refrigerator/household)	108%	116%	123%	131%	142%
Clothes washer penetration rate (clothes washer/household)	79%	81%	83%	85%	88%

Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

Continued urbanisation,[12] paired with growth of average household income, is likely to contribute to further diminished use of traditional biomass for cooking and residential space and water heating. At the same time, diminishing biomass use contributes to increased

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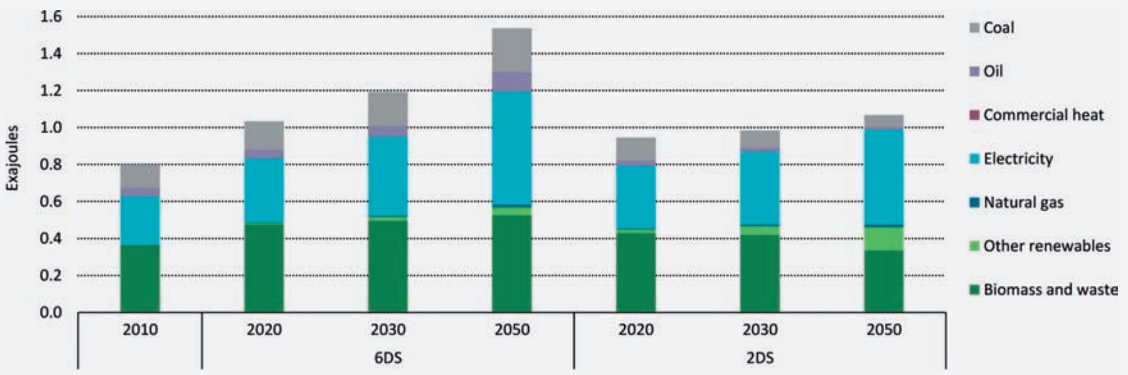
[12] South Africa's urban population is expected to grow to nearly 44 million people by 2050, or 77% of the total South African population. Urban residents accounted for 62% of the total population in 2010 (UN DESA, 2012).

demand for electricity. Transitions away from a coal-driven power sector therefore will considerably affect the intensity of this change in demand. Growth in household demand likewise will contribute to increased electricity demand for lighting and appliances, especially as appliance ownership rates and other plug loads (*e.g.* computers) continue to move toward typical OECD levels.

Future trends in energy consumption in South Africa

Energy consumption is expected to almost double between 2010 and 2050 under the 6DS, where traditional biomass and electricity continues to account for nearly three-quarters of direct energy use in buildings to 2050 (Figure 2.8.3). Electricity gradually replaces biomass as the dominant source of energy in buildings, rising from one-third of final energy demand in 2010 to nearly 40% in 2050. In contrast, traditional biomass used for heating and cooking in the 6DS is expected to decrease from about 45% of total buildings energy use in 2010 to about 35% in 2050.

Figure 2.8.3 Energy consumption in South African buildings by energy source in the 6DS and 2DS



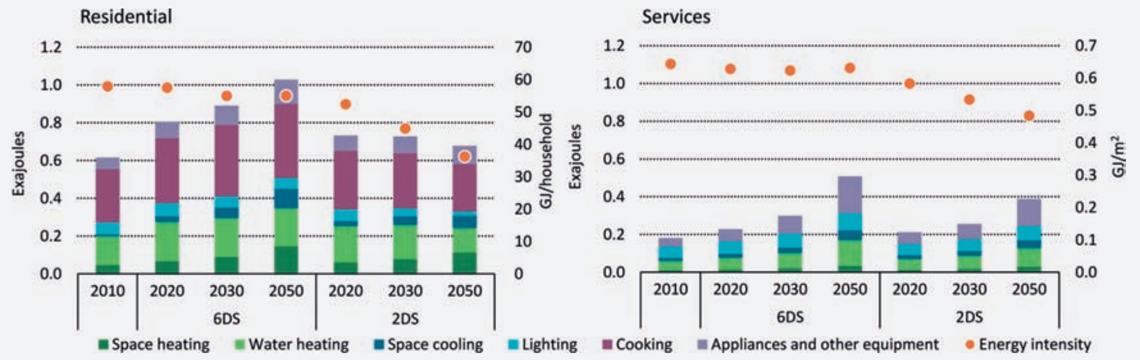
Note: other renewables includes wind, solar and geothermal.

Key point *Energy efficiency improvements and transitions away from coal and oil use decrease overall energy consumption in buildings in the 2DS by more than 30% over 6DS levels by 2050.*

In the 2DS, biomass use is expected to be less than one-third of buildings energy use by 2050, while electricity use is expected to increase to nearly half of buildings energy demand. This transition to an electricity dominated buildings sector places significant additional demand on electricity supply. Renewables, including in particular solar thermal technologies, play a significant role in meeting this transition in energy demand to 2050, where renewables, excluding biomass, and other non-traditional energy sources are expected to account for 12% of total buildings final energy demand by 2050. Total oil and coal consumption in buildings is expected to be less than 85 PJ by 2050, or roughly 50% less than in 2010.

In terms of energy intensities, average residential final energy use is expected to decrease to about 36 GJ/household in the 2DS (Figure 2.8.4), or slightly more than 35% of 2010 levels. Water heating and cooking energy consumption per household in the residential sub-sector are expected to decrease by about 50% over 2010 levels in the 2DS as households shift away from traditional biomass use. Residential lighting intensity, in GJ/household, decreases by 80% over 2010 levels as the planned phase-out of incandescent light bulbs by 2016 takes effect and households continue to adopt CFLs and other low intensity lighting technologies.

Figure 2.8.4 South Africa residential and services sub-sectors energy consumption and intensities



Notes: GJ = gigajoule. m^2 = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Significant reductions in building energy intensities in the 2DS will require considerable improvements in end-use efficiencies.*

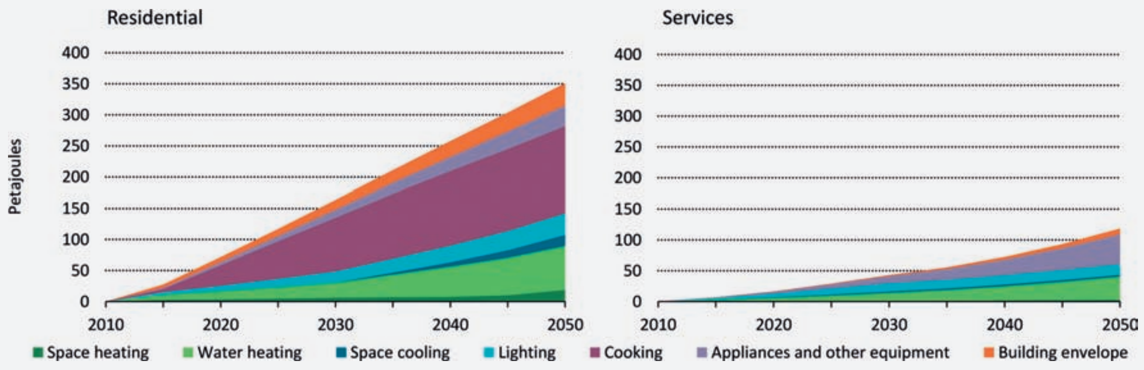
In the services sub-sector, average intensity is expected to decrease to 0.48 GJ/m^2 in the 2DS, which is 25% lower than in 2010. Space heating and cooling intensities are expected to decrease by roughly 15% over 2010 averages, while water heating intensity are expected to decrease nearly 30% over 2010 levels. Lighting intensity in particular decreases as much as 56% over 2010 levels as services buildings move to improved building designs and use more efficient lighting technologies.

Overall energy savings from both residential and services buildings in the 2DS account for roughly 470 PJ of reduced annual energy consumption by 2050 compared to the 6DS (Figure 2.8.5). In terms of total potential energy savings, cooking is expected to provide the largest energy reductions in the 2DS, where 30% of energy savings over 6DS levels comes from cooking improvements, notably from transitions to modern cooking appliances. Water heating, lighting, appliances and space cooling similarly offer significant energy savings in the 2DS. Water heating in particular accounts for more than 100 PJ of energy reductions to 2050. Service equipment explains another 50 PJ of savings to 2050 over the 6DS, accounting for 40% of services energy reductions in the 2DS and 10% of total buildings reductions to 2050.

Future trends in CO_2 emissions in South Africa

Improving overall energy intensity in the buildings sector is needed to achieve South African energy and emissions objectives and to ensure a more sustainable and reliable power supply to 2050. Total residential and services buildings annual emissions are likely to reach about 140 $MtCO_2$ by 2050 in the 6DS, or nearly 70% higher than buildings emissions levels in 2010 (Figure 2.8.6).

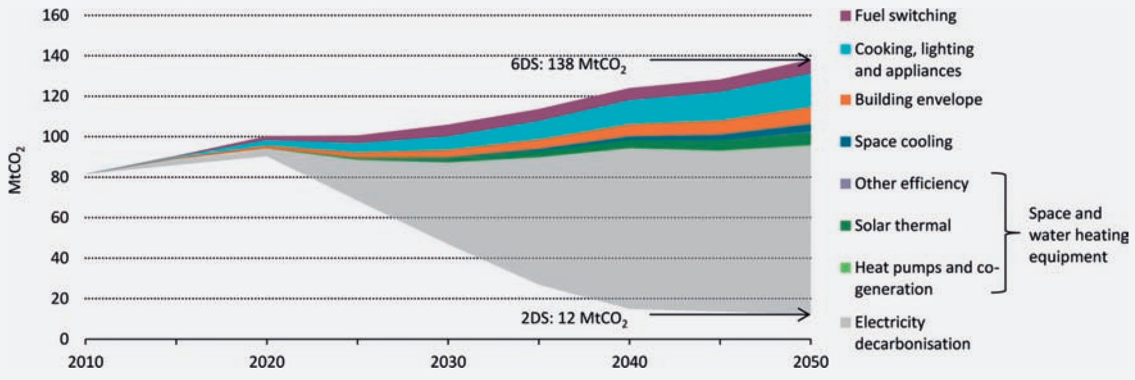
Figure 2.8.5 Energy savings from 6DS to 2DS in South Africa in the residential and services sub-sectors



Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Transitions away from traditional biomass cooking account for nearly 30% of total energy savings to 2050 in the 2DS.*

Figure 2.8.6 Contribution of CO_2 emissions reduction options in South Africa between the 6DS and 2DS



Key point *Emissions savings from building improvements account for nearly one-third of total emissions reduction to 2050, where the largest savings come from cooking, lighting and appliances.*

In the 2DS, annual emissions from buildings are expected to decrease to 12 $MtCO_2$ by 2050, or more than 90% less than in the 6DS. Two-thirds of these savings come from decarbonisation of the electricity sector, where buildings emissions reduction from final energy consumption account for the remaining savings. More efficient cooking, water heating, lighting, appliances and services equipment are the major contributors to buildings emissions savings, while solar thermal technologies and building envelope improvements also contribute.

Recommended actions for South Africa

In the short term, South Africa appears to be on track for achieving the 2DS targets and national policy objectives, particularly in terms of energy efficiency improvements in the services sub-sector. However, significant additional gains in energy efficiency are needed in the growing residential sub-sector in particular if 2DS objectives are to be achieved.

Energy efficiency targets in the buildings sector could be addressed in part through reforms in the electricity sector in South Africa, whose electricity tariffs are still among the cheapest in the world. However, regulatory measures regarding power supply and sales are only a kick-start to address overall building efficiencies and intensities in South Africa. Further action is needed to deploy rapid adoption of BAT and to provide support for renewables, where costs often are a barrier to adoption. Policy coherence also is important to gain investor confidence in South African markets.

In the residential sub-sector, considerable action is needed to address growing demand for cooking, lighting and appliances as household wealth continues to increase rapidly. This is particularly important as household demand transitions from traditional biomass use to modern electric appliances, where it is critical to improve overall electric product efficiencies to offset this shift in demand. Continued efforts to improve lighting and appliance efficiency through standards and labelling and mandatory phase-outs of inefficient products will also be critical to sustaining increasing electricity supply demand.

Water heating is another major area of critical support, especially as households continue to switch from traditional biomass use to electric water heating. Efficiency mandates and policy support of BAT, including instantaneous and heat pump water heaters, are a first step toward improving the intensities of increasing demand. Policy support of advanced and renewable technologies, such as the South African Department of Energy and Eskom solar water heating (SWH) programme to install one million SWH units by 2014, will also support energy and emissions targets while helping to achieve a more reliable, sustainable power supply.

9. United States

The United States is the world's largest economy and consumes roughly 17% of global final energy consumption. The buildings sector constitutes a major portion of energy use, accounting for one-third of total final energy use and with over 70% of electricity used by buildings. Considerable differences in regional climates – from hot, humid and arid climates to severe cold – also contribute to high energy demand for space cooling and heating, where conventional oil and natural gas heating and cooling equipment are still widespread.

The United States is the world's third most populous country, and its population continues to grow as a result of birth rate and immigration, averaging around 2.5 million to 3 million additional people per year over the last few decades. While the past five years have seen a stagnant building market due to the financial crisis and a sharp decline in real estate prices, construction starts in 2012 indicate a reversal in this trend.

Significant advancements in the buildings sector have been achieved over the last three decades with incentives for efficiency investments, voluntary labelling of many high-efficiency buildings, substantial renovation programmes for low-income housing and government buildings, and numerous technology development and deployment initiatives. Policy activity has also resulted in more aggressive appliance and equipment standards and more rigorous building codes.

Energy codes for new residential and services buildings, while voluntary at the national level, are mandated by most jurisdictions throughout the country. However, these advancements in building energy efficiency codes have not resulted in reductions in energy use by buildings, as larger homes, increased services floor space per capita and additional amenities, such as more space cooling and consumer electric products, have offset many efficiency gains.

In recent years, the United States has placed a very high priority on improved building efficiency with aggressive rulemaking for new product efficiency standards, major investments in R&D and several whole-building voluntary marketing programmes. There also is significant interest in photovoltaic (PV) research and investment that envisions major deployment on building roofing systems.

The large influx of stimulus funding initiated in 2009, on the order of USD 16 billion[13] related to energy efficiency, weatherisation and state grants, is likely to be fully spent before the end of 2013. While future funding is expected to be modest, policies and funding for efficiency programmes for buildings continue to enjoy significant support across the political spectrum.

Recent trends

Between 1990 and 2010, energy consumption in buildings in the United States increased by 1.3% per year (Figure 2.9.1). Electricity and natural gas are the primary forms of energy use in the United States buildings sector, accounting for more than half and nearly 40% of final energy use, respectively. With much of the country requiring heating, natural gas is the primary fuel choice for space heating in conventional and condensing gas boilers and furnaces. Natural

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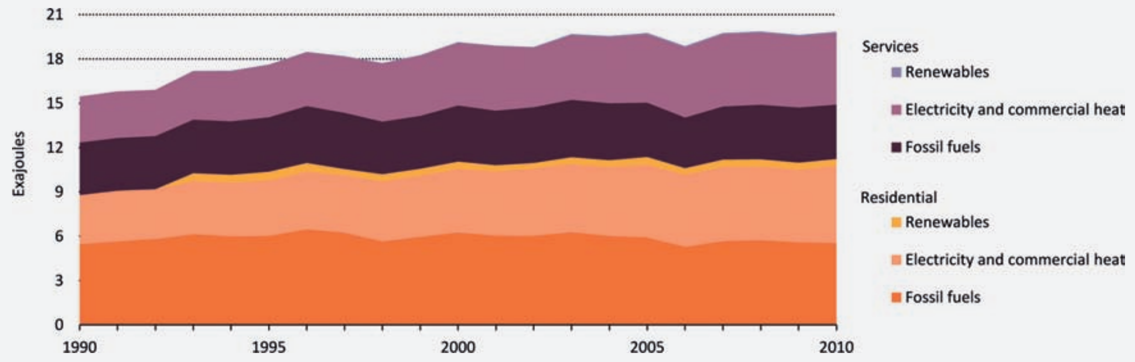
[13] Prior funding ranged on the order of USD 1 billion to USD 2 billion per year.

gas is also the primary fuel choice for water heating, although a large stock of electric resistance water heaters (41%) (EIA, 2009) are still in service and they continue to represent a large share of new installations (46% in 2010 [Navigant, 2011]).

Figure 2.9.1 Historical energy consumption in the United States buildings by energy source



Note: renewables include biomass, waste, wind, solar and geothermal.

Key point *The United States has a stable energy supply with a growing share of renewables.*

Space heating is the largest end-use in terms of final energy consumption, accounting for 37% of residential energy use and more than one-quarter of services energy consumption (Figure 2.9.2). Advances in building heating equipment and envelope technologies have helped to reduce overall space heating intensities in the last decades, although considerable work is still needed to seek improvements in the large stock of existing buildings.

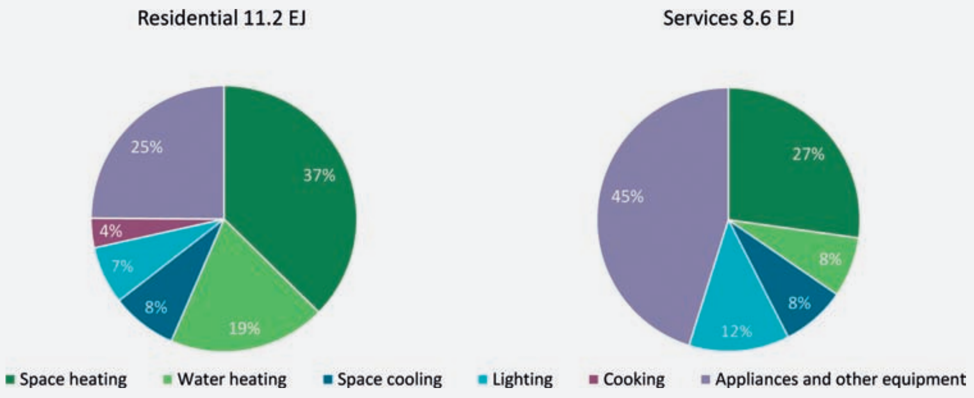
Water heating is another major end-use in buildings, where about 15% of total buildings final energy use and nearly 20% of energy consumption in residential buildings went to water heating in 2010. Water heating in the services sub-sector represents a smaller load, where service equipment, including information technologies, office equipment, medical technologies, appliances and small plug loads, accounted for 45% of services energy use.

Lighting, cooking and household appliances accounted for more than 35% of total final energy use in residential buildings in 2010, while space cooling was less than 10% of final energy demand. Household appliances, like service equipment, constitute an increasing share of energy use in buildings as ownership of consumer products, information and communication technologies and appliances continues to grow. By 2010, household appliances and miscellaneous plug loads accounted for one-quarter of energy use in residential buildings, up from 20% in 2000. This represents a 30% increase in appliances energy use in households, while in the services sub-sector, energy use by service equipment grew by more than 65% between 2000 and 2010.

Scenarios for buildings in the United States

Future energy consumption in buildings in the United States will continue to be driven by increases in population and GDP. Population is anticipated to grow by 30% between 2010 and 2050 (UN DESA, 2011), while GDP is expected to increase by 2.4-fold (Table 2.9.1). As a result,

Figure 2.9.2 Residential and services sub-sectors energy consumption by end-use for the United States, 2010



Note: EJ = exajoule.

Key point *Space and water heating continue to be the largest energy consumers in residential buildings.*

GDP per capita (in real value) is expected to grow by nearly 90% by 2050, which will impact demand for appliances, consumer products and services. Residential stock is also expected to grow by 43 million new households by 2050, driven both by rising population and decreasing occupancy rates (people per household), while services floor area increases by about 45% over the same period. In contrast, average house size is expected to remain similar to today's average.

Table 2.9.1 Indicators for energy demand in the United States buildings sector

Indicator	2010	2020	2030	2040	2050
Population (million)	310	337	362	383	403
GDP (million 2010 USD at PPP)	14 678	18 902	23 551	29 036	35 588
Per-capita income (USD GDP/capita)	47 289	56 071	65 116	75 721	88 284
Services floor area (million m^2)	7 534	8 278	9 123	10 038	11 045
Residential floor area (m^2)	22 950	26 290	28 613	30 455	32 042
Number of households (million)	113	126	138	148	156
Occupancy rate (people per household)	2.8	2.7	2.6	2.6	2.6
Average house size (m^2)	203.6	208.3	207.7	206.1	204.8

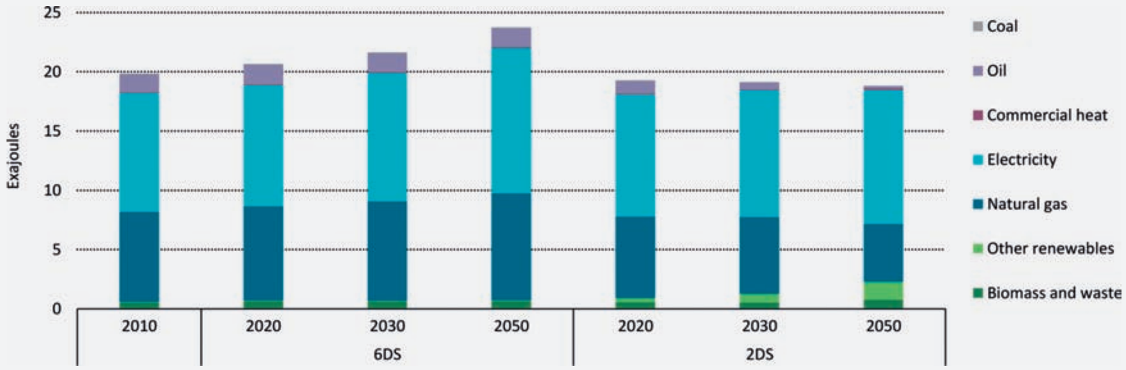
Notes: GDP = gross domestic product, USD = United States dollar, PPP = purchasing power parity, m^2 = square metre.
Sources: UN DESA (2011) for population; IEA (2012) for GDP; other data from IEA analysis.

Future trends in energy consumption in the United States

Advanced heating and cooling technologies, such as ground-source and cold climate heat pumps, have the potential to improve building efficiencies considerably, although recent trends in shale gas production, resulting in lower natural gas prices, may encourage adoption of more conventional heating and cooling equipment. United States domestic forecasts show low natural gas prices through 2018 then higher prices in the future as lower-cost resources are depleted (AEO, 2013).

Under the 6DS, total final energy use in buildings is expected to increase 20% over 2010 levels, despite continued improvements in product efficiencies and new buildings (Figure 2.9.3). Electricity in particular accounts for over 50% of this growth, where continued trends in appliance and electronics ownership are assumed to 2050. In the 2DS, total buildings energy consumption decreases by roughly 5% over 2010 levels by 2050, or more than 20% over the 6DS. Oil and natural gas consumption in buildings is expected to decline by 86% and 36% over 2010 levels, whereas electricity use in buildings increases slightly by 13% compared to 2010.[14]

Figure 2.9.3 Energy consumption in the United States buildings by energy source in the 6DS and 2DS



Note: other renewables includes wind, solar and geothermal.

Key point *Oil and natural gas are reduced significantly in the 2DS, while electricity, although higher than in 2010, is still lower than in the 6DS due to efficiency improvements in buildings.*

Space heating reductions in the 2DS account for about 35% of total potential energy savings compared to the 6DS, while improvements in appliances and service equipment represent another 34% (Figure 2.9.4). These savings are attributed to large improvements in heating and cooling equipment and building envelope technologies that are easier to implement in hot climates, including low-e window films, cool-coloured roofs and walls, and exterior shading.

Lighting energy consumption in buildings is reduced by about 25% over the 6DS by 2050. Improvements in space cooling and water heating also provide significant energy savings. As a result, building energy intensities are nearly 18% and 24% lower than in the 6DS by 2050 in the residential and services sub-sectors, respectively. Compared to 2010 intensity levels, energy savings in the 2DS equate to an intensity reduction of nearly 33 GJ/household in the residential sub-sector and 0.39 GJ/m^2 in the services sub-sector, or roughly one-third lower than in 2010 in both sub-sectors.

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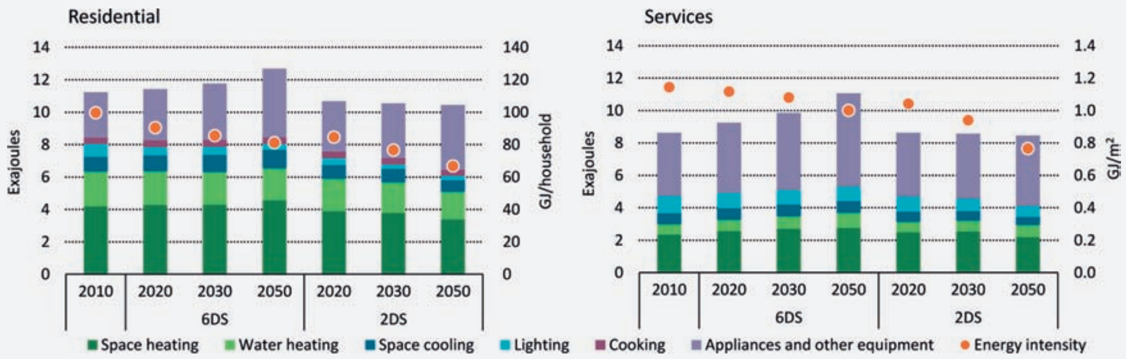
[14] Natural gas for the power sector including co-generation will be a major component of the electricity generation fuel supply that is not accounted for in final energy consumption.

Figure 2.9.4 United States residential and services sub-sectors energy consumption and intensities

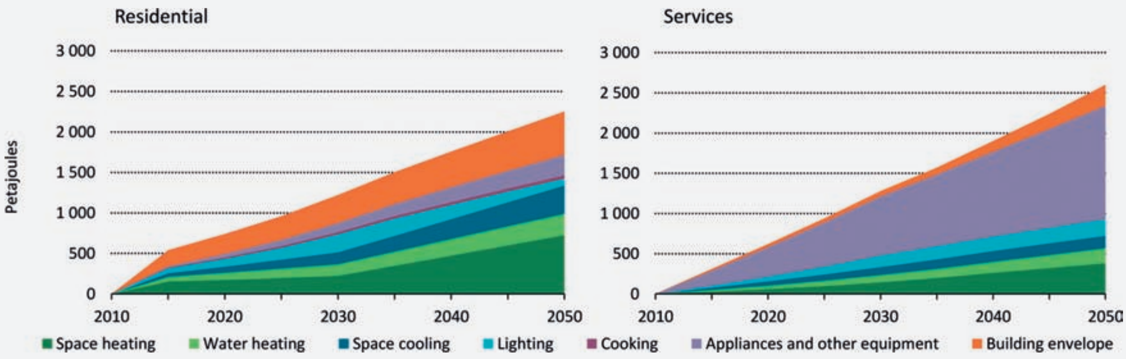


Notes: GJ = gigajoule. m² = square metre. For the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Energy use and building intensities are reduced considerably in both the residential and services sub-sectors under the 2DS.*

Total energy reductions in the residential and services sub-sectors in the 2DS represent nearly 5 EJ of potential savings compared to the 6DS by 2050 (Figure 2.9.5). 40% of these savings are attributed to efficiency improvements led by innovative products and mandatory standards for electrical end-uses, such as lighting, appliances and service equipment. Space heating equipment improvements represent another 23% of energy savings, while building envelope improvements account for roughly 16%.

Figure 2.9.5 Energy savings from 6DS to 2DS in the United States in the residential and services sub-sectors



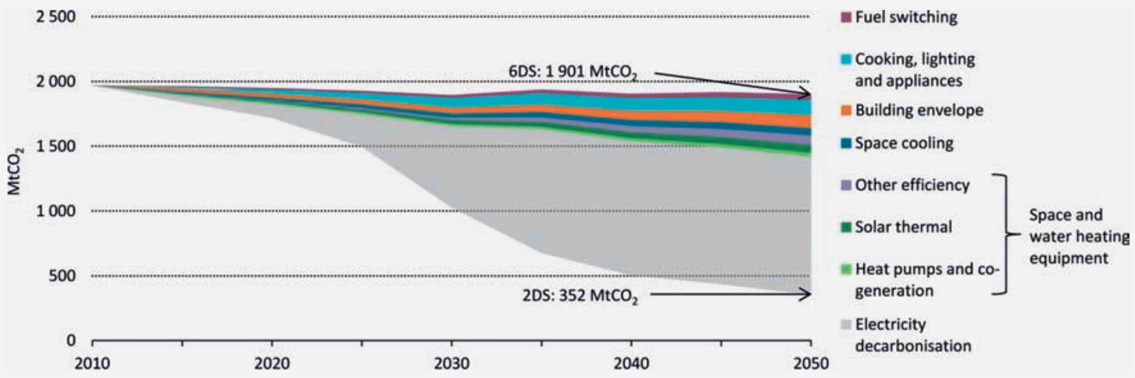
Note: for the services sub-sector, cooking is reported under the category "appliances and other equipment".

Key point *Improvements in electrical end-use efficiencies, space heating equipment and building envelopes are expected to contribute a major portion of energy savings in the 2DS.*

Future trends in CO_2 emissions in the United States

Total building sector emissions are expected to decline slightly in the 6DS. In the 2DS, buildings sector efficiency improvements and greater use of solar thermal can reduce buildings emissions (direct and indirect) to about 350 $MtCO_2$ (Figure 2.9.6). Decarbonisation of the electricity sector accounts for roughly 70% of emissions reduction, while efficiency improvements in cooking, lighting and appliances (excluding reductions from decarbonisation of the power sector) account for roughly one-quarter of buildings emissions reduction. Building envelope improvements, solar thermal and heat pump technologies also contribute significant savings.

Figure 2.9.6 Contribution of CO_2 emissions reduction options in the United States between the 6DS and 2DS



Key point *Energy efficient appliances and lighting account for the largest share of direct emissions reduction.*

Recommended actions for the United States

The United States has one of the most aggressive mandatory appliance and equipment standards programmes in the world. Advancements in research in the near term will help drive more efficient products in the market place, although even more stringent standards in the future will be necessary to promulgate those advanced technologies. For example, once heat pump water heaters have achieved greater market saturation, standards that no longer allow the installation of electric resistance water heaters should be implemented. Condensing boilers in cold climates should be required by standards or building codes today, while longer-term standards should require adoption of best available, highly efficient advanced heating technologies.

Considerable work is needed to address large space heating and cooling loads in buildings in the United States. Building envelope improvements, including better insulation, dynamic highly insulating glazing façade systems, low air infiltration and highly insulating windows, have significant potential to reduce overall building energy intensity. Recent progress on national voluntary building codes is encouraging, although expanded mandatory codes are needed to achieve this potential. Financing for buildings improvements also is a barrier; the United States has a very effective “needs based” programme for low-income residential renovations. However, the programme is nearly entirely government funded and does not address the large stock of existing buildings that could be improved.

Lighting, appliances and other electric end-use loads can also be substantially reduced through a wide range of equipment and system efficiency improvements. For instance, SSL improvements and advanced facades with day lighting can significantly reduce lighting energy demand. A significant challenge is to address the increasingly large share of miscellaneous electricity use, and R&D and stringent efficiency policies are needed to limit energy growth in this area, particularly with regards to product standby and network standby power consumption.

The large existing building stock in the United States needs to be addressed if energy efficiency targets are to be achieved. The United States should explore possibilities of new programme designs that target deep renovation in existing buildings particularly with regards to space heating and cooling loads. Currently, whole-building research targeted towards large energy savings exists in the United States, but a higher priority should be placed on deploying such programmes. If combined with initiatives such as the existing solar PV programme in the United States, these actions could achieve significant energy and emissions savings in buildings. Replication of programmes such as California’s vision for ZEBs should likewise be expanded nationally.

Part 2

Technology Solutions and Policy Instruments for the Transition

Part 2 outlines the technologies and policies needed to achieve major reductions in energy consumption and CO_2 emissions in the buildings sector through 2050. It discusses the options related to building components, including building envelope technologies, heating and cooling equipment, appliances, cooking, lighting and systems integration.

Chapters 3 to 5 provide the current status of building components and equipment technologies, identify research and development needs to advance them and indicate the near-term actions and future pathways to ensure their wide deployment.

Chapter 6 provides the policy instruments that are required to overcome barriers to technology uptake and to achieve the deployment and full commercialisation of energy efficient buildings.

Chapter 3 **Building Envelopes** **117**

Building envelopes comprise a range of elements, with roofs, walls, windows, foundations and air leakage being the primary elements that affect building heating, cooling and ventilation loads. With over a third of global energy used to make buildings comfortable for occupants, advanced building envelopes will be essential to reduce energy consumption.

Chapter 4 **Heating and Cooling Technologies** **151**

Space heating, water heating and space cooling account for nearly 55% of global buildings energy use and represent the single largest opportunity to reduce buildings energy consumption in most regions of the world. A systems approach, including integration of heating and cooling needs with improved building envelopes, is necessary to achieve higher energy efficiencies and a low-carbon heating and cooling supply.

Chapter 5 **Lighting, Cooking and Appliances** **189**

Significant potential remains to achieve higher energy efficiencies in lighting and appliances, while cooking efficiencies, especially using traditional biomass, can be vastly improved. Greater effort is needed to ensure that existing best available technologies are adopted at a much faster rate in the immediate term, leading to more stringent standards in the future.

Chapter 6 **Policies for Buildings** **217**

Building-specific and product-specific policies, in conjunction with broader systems-level policies, will be essential to achieving large energy savings and emissions reduction. Policy makers are encouraged to place a high priority on implementing building codes and accelerating the rate of renovation with deep efficiency improvements. Policies also need to support whole-building approaches to achieve cost-effective, market-viable solutions.

Chapter 3

Building Envelopes

Building envelopes comprise a range of elements, with roofs, walls, windows, foundations and air leakage being the primary elements that affect building heating, cooling and ventilation loads. With over a third of global energy used to make buildings comfortable for occupants, advanced building envelopes will be essential to reduce energy consumption.

Key findings

- The building envelope is critical in determining the energy required to heat and cool a building. Building envelope design needs to be optimised to minimise heating and cooling loads as a critical part of any long-term energy reduction strategy.
- Passive heating and cooling technologies[1] are important design considerations. In hot climates, low-cost solutions, such as reflective roofs and walls, low-emissivity (low-e) window coatings and films, and exterior shades, can curtail expected sharp increases in cooling loads. In cold climates, passive heating contributions can be increased with improved building design and from windows with dynamic solar control.
- Integrated facade systems need to be pursued for office buildings to optimise performance of day lighting while minimising heating and cooling, artificial light and peak loading.
- Greater focus on air sealing with validated results is critical during new construction and is also important for deep envelope retrofits.

Near-term recommendations

- Urgent action is required to enforce stringent building codes for new buildings, particularly in developing countries. Building material testing and rating mechanisms, capacity building, and education are essential to support enforcement.
- Refurbishing existing buildings should be made a priority in OECD member countries, where approximately 75% of current building stock will still be standing in 2050. Deep envelope retrofits can have major systems benefits that reduce the capital cost of mechanical equipment.
- Mandating roof/attic insulation up to latest standards, including proper air and duct sealing is a major opportunity and can occur quickly.
- Research and development (R&D) is needed for highly insulated window technology, especially in cold climates. Inefficient, single clear glazed windows remain a feature of many existing buildings and should be upgraded and avoided in new construction.

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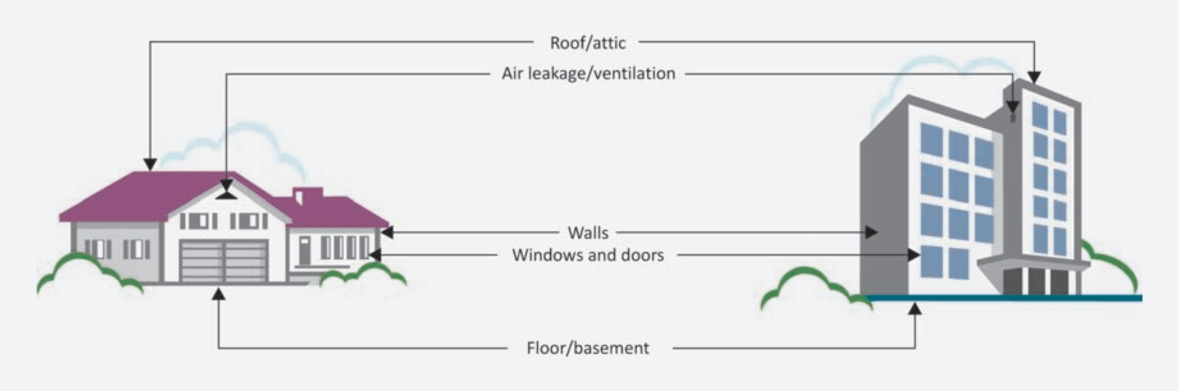
[1] Passive technologies reduce heating and cooling loads through improvements to and optimisation of the building envelope, and have the greatest opportunity for deployment during new construction.

The building envelope or shell represents the boundary between the conditioned part of a building and the outdoors. Components of the building envelope, including the external walls, floors, roofs, ceilings, windows and doors, are a critical factor in determining heating and cooling loads (Figure 3.1). The energy consumed by building envelope components is highly variable depending on building type, climate, construction practice, geographic location and vintage.

Figure 3.1 Building envelope components



Key point *All elements of the building envelope are important.*

The importance of the building envelope should not be underestimated, as globally space heating and cooling account for over 30% of all energy consumed in buildings, rising to as much as 50% in cold climate countries. In the residential sub-sector, the share of energy consumption used for heating and cooling in cold climate countries is over 60%.

A number of critical elements will be required to achieve deep reductions in space heating and cooling energy consumption:

- high levels of insulation in walls, roofs and floors to reduce heat losses in cold climates, optimised using life-cycle cost assessment;
- high-performance windows with low thermal transmittance and climate-appropriate solar heat gain coefficient (SHGC);[2]
- highly reflective surfaces in hot climates, including both white and cool-coloured[3] roofs and walls;
- properly sealed structures to ensure low air infiltration rates with controlled ventilation for fresh air;
- minimisation of thermal bridges (components that easily conduct heat/cold), such as high thermal conductive fasteners and structural members;
- passive solar design that optimises the orientation of the building and placement of windows and shading, and allows for natural ventilation.

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[2] Thermal transmittance is a term to describe heat transfer across a material or assembly over a specified difference in temperature, the most common descriptor being a U-value. Solar heat gain coefficient is the fraction of incident sunlight transmitted through an entire window or door system, including its frame. Higher numbers have greater passive heating benefits but also increase cooling loads.

[3] White surfaces strongly reflect both visible sunlight (wavelengths 0.4 µm to 0.7 µm) and invisible near-infrared sunlight (0.7 µm to 2.5 µm) to attain high solar reflectance. "Cool-coloured" surfaces offer choice of colour by strongly reflecting only the near-infrared radiation. They reflect more sunlight than conventional colours, but less than white. For example, an ordinary grey roof might reflect 20% of sunlight; a cool red roof, 40%; and a bright white roof, 80%.

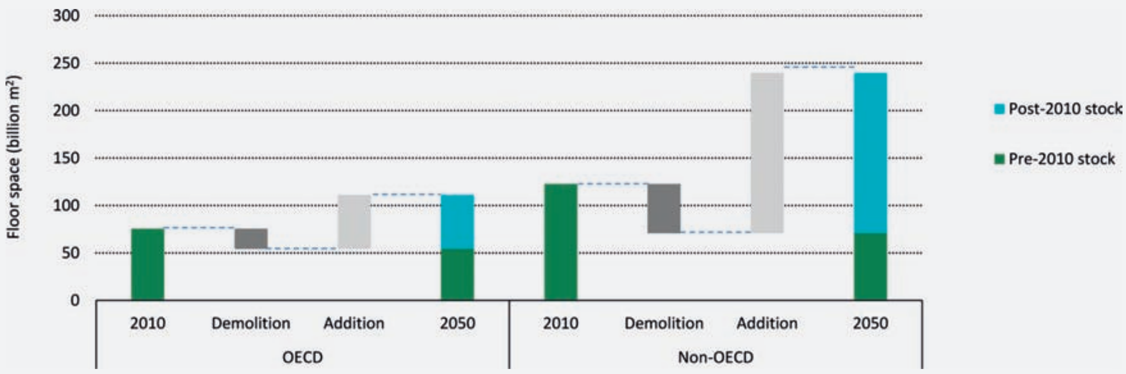
Analysis of building envelopes is complicated by the extremely diverse range of building materials used globally, different climates, and different standards and practices with regard to building design and construction. There is a vast difference between construction practices for traditional dwellings in developing countries and houses constructed in OECD countries, yet they both provide basic shelter for the occupants. As populations grow, housing demand also increases; fast increases in wealth will also drive greater increases in floor area per capita (see Chapter 1). Making sure the building envelope is built using the most efficient options for new construction is essential since retrofits can be difficult and cost prohibitive.

Vision for building envelope improvements

Given the differing vintage of the building stock and its expected development (Figure 3.2), non-OECD countries face huge growth in expected construction. OECD countries have a large stock of residential buildings, most built before 1970, that is not growing quickly and will be retired slowly. Currently, the rate of residential building refurbishment to improve envelope efficiency is low, estimated to be 1% per year (BPIE, 2011). Urgent policy action is required, because energy efficiency refurbishments are potentially expensive and likely to make economic sense during major refurbishments that occur only every 30 or more years.

By contrast, buildings in developing countries tend to have shorter life spans of the order of 25 to 35 years. The rate of growth of the overall building stock is also very rapid. Consequently, policies should focus on improving the energy performance of new buildings, especially with respect to their cooling loads. Building codes that reduce the cooling load of buildings through better design and building envelope performance need to be implemented rapidly to avoid the continued construction of high energy-consuming buildings that will be standing for decades to come.

Figure 3.2 Evolution of building stock between 2010 and 2050



Source: unless otherwise noted, all tables and figures in this chapter are derived from IEA data and analysis.

Key point *More than 50% of the current global building stock will still be standing in 2050; in OECD countries, that figure is closer to 75%.*

The entire building stock is expected to be refurbished within 65 years, with deep renovation occurring between 35 and 45 years in the life of a building. While the retrofit rates are the same in both the 6°C Scenario (6DS) and the 2°C Scenario (2DS), the 2DS assumes that efficiency will be the main component of the retrofit.[4] Over the forecast

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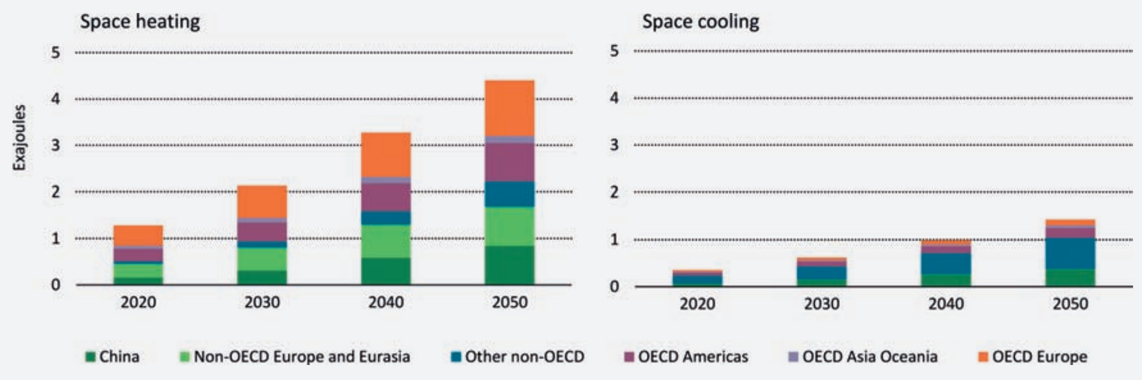
[4] The 6DS and 2DS are set out in the IEA *Energy Technology Perspectives 2012 (ETP 2012).*

period of the 2DS scenario, deep energy renovations will bring heating and cooling load improvements of between 50% and 65%. The heating load of new residential buildings in OECD countries will fall to 25 kilowatt-hours per square metre (kWh/m^2) by 2050 in the 2DS, an improvement of over 40% compared to today's level. In the services sub-sector, the heating load of new buildings will improve by 30% from today's level to 25 kWh/m^2 in 2050.

From the 14.5 exajoules (EJ) of reductions in heating and cooling energy demand between the 6DS and the 2DS, 40% will be directly attributable to the improvement in building envelopes. These envelope improvements will also contribute to a reduction in heating and cooling capacity, as they will allow a downsizing of the equipment.

Overall, savings from envelope improvements between the 6DS and the 2DS will amount to 5.8 EJ (Figure 3.3), equivalent to almost 20% of the overall savings in the buildings sector. Building envelope improvements will have a major role to play in reducing the consumption of energy for heating in OECD countries, non-OECD Europe and Eurasia and China. It will also be a key option for restraining the growth in space cooling energy consumption in developing countries.

Figure 3.3 Energy reductions from improvement in building envelopes between the 6DS and 2DS



Key point *Building envelope improvements are significant in the context of overall savings under the 2DS, with heating savings around four times higher than cooling savings.*

Opportunities to improve building envelopes

Minimising heating and cooling needs requires an integrated view of building design. Sunlight is free, and maximising its benefits to reduce heating and lighting needs is part of an integrated design. Similarly, thermal mass, insulation, shading, reflective surfaces and natural ventilation can help minimise heat gains in summer and thus energy needs for cooling. Recent innovation in new dynamic window technology will allow for both passive heating in winter and shading in summer once the technology is mature and becomes economically viable.

These design principles can significantly reduce heating and cooling loads at modest additional cost when constructing a new building. This is particularly the case when life-cycle costs are taken into account. Advanced building envelope design can reduce the capital costs of heating and cooling systems since required heating and cooling loads can be reduced by up to 60% (Winbuild, 2012). Most researchers believe the target for envelope improvements are more like 40%.[5]

While efficiency advocates put energy conservation as a top priority, policy makers cannot ignore that the primary purpose of the building envelope is to protect occupants from numerous elements. The building envelope performs many different functions (Figure 3.4). The key challenge is to optimise the design of the overall building and the thermal envelope to meet the needs of the occupants while also reducing energy consumption.

Figure 3.4 Functions provided by the building envelope

Key point *The building envelope is critical to reducing heating and cooling loads, but this is only one of the functions it performs.*

For new construction and for deep retrofits, all components of the building envelope need to be addressed. However, large-scale opportunities for a holistic approach in existing buildings do not come that often since major building upgrades may occur only every 30 years or so, if ever. More frequently, there is the opportunity to address one particular area as the situation arises. For example, if a building is being reroofed because of leaks, then it is an opportunity to make energy efficiency upgrades associated with the roof, such as air sealing, adding insulation and possibly selecting a reflective roof surface.

Another common opportunity is when homeowners experience very high utility bills and they seek ways to reduce their energy consumption. Alternatively, they could also receive information from an energy performance certificate,[6] or they may be very uncomfortable in

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[5] Generally many advanced building renovation programmes are calling for heating and cooling improvements of 75% to 80%. Approximately half of these expected savings (40%) are from envelope, and the remainder are from mechanical equipment.

[6] Energy performance certificates are prominent in Europe and are growing around the world; they are discussed in more detail in Chapter 6.

the dwelling. Ideally, the objective is to look at all the energy-saving opportunities that exist, with the first step to look at the building envelope (Box 3.1) together with heating and cooling equipment and other components (*e.g.* lighting, appliances). While this is a great opportunity to pursue a deep renovation for the entire building, it may be economically viable to finance only the immediately affordable energy efficiency retrofits. While a deep renovation can yield energy savings in the range of 50% to 75% (GBPN, 2013), a typical efficiency upgrade will have more modest savings, generally of the order of 15% to 30%.

Box 3.1 Energy consumption variability of envelope components and the need for better assessment

Energy losses through different building envelope components vary significantly by building type, configuration, climate, vintage, level of construction sophistication, etc. In the United States, for example, roofing performance building codes have been more advanced compared to other components, while window performance in Northern Europe has been better than in other parts of the world. While these facts cannot be supported with extensive data, several studies illustrate this point, with United States residential roofing representing 14% of heating and cooling loads and European data showing an average of around 32%. For windows, the United States residential heating and cooling impact represents 31%, with Europe showing 15% (Winbuild, 2012 and SEI, 2007).

Comprehensive detailed data for energy performance and market share by building envelope component are very difficult to obtain, and consequently, saving opportunities are even more difficult to predict because they are highly dependent upon base loads. Obtaining better data for existing building stock and for new construction will allow for better building envelope programme development and enable policy makers to address the most important elements for their particular climate, building characteristic and market.

Typically, modest retrofits include insulation in easy-to-access locations like attics and crawlspaces, air sealing and possibly heating and cooling equipment replacements. Since windows and insulation in difficult-to-reach locations can be very costly, they will likely be ignored. However, the advantage of a deep renovation is that synergies can be realised when all systems are upgraded together, covering mechanical equipment and building envelope improvements. For example, it is possible to reduce heating and cooling equipment capacity by half or more if a deep renovation is completed. More policy and technical innovation work is needed to find ways to make deeper renovation more viable other than when a major upgrade will be completed.

For new construction, advanced building practices are now starting to become code in progressive cold European countries. The “Passivhaus” programme was initiated in 1990 in Germany and has grown worldwide in recent decades. It specifies very stringent building envelope requirements to ensure that the building is comfortable independent of the climate. These buildings require very little energy for cooling and heating. This is achieved through extremely high levels of insulation and very low infiltration. Specifications set in 1990 (less than 15 kWh/m^2 for heating, cooling and ventilation per year) are still among the best performance being achieved today (PHI, 2013). The Passivhaus programme has really been the driver behind the concept of zero-energy buildings (ZEBs).[7]

This chapter reviews the major technologies and building products that are needed to construct and upgrade buildings to reduce heating and cooling loads. Fundamentally, every building will need to be upgraded with insulation and be sealed to reduce air infiltration. Exact criteria and performance levels will be based on local and regional climatic conditions, energy

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[7] See Chapter 6 for more details on zero-energy building programmes.

prices and the level of building sophistication. At the broadest level, the selection of building envelope technologies should take into consideration the type of economy, climate (heating or cooling dominated) and whether it is new construction or retrofit (Table 3.1). Any given region will be required to conduct specific analysis to determine the best options for that particular region and what should be promoted as a high-level policy. The following sections explain in detail the current status of each component, the energy efficient options available for new construction and deep renovations, as well as information on new and innovative technologies that are on the horizon.

Table 3.1 High-level technology considerations based on economy, climate and construction type[8]

Type of economy	Climate	New construction	Retrofit
Developed	Hot climate	• Advanced roofs (integrated design/BIPV). • Very low-SHGC windows (or dynamic windows). • Reflective walls/roofs. • Architectural shading.	• Reflective roofs and coatings. • Reflective wall coatings. • Window film and reflecting exterior shading, etc. • New low-SHGC windows.
	Cold climate	• Highly insulated windows. • Passive heating gain (architectural feature /dynamic glass). • "Passivhaus" equivalent performance.	• Low-e storm panels and window films. • Insulated shades and other attachments. • Exterior insulating wall systems. • Interior high-performance insulation.
Developing	Hot climate	• Low-SHGC windows (whole window). • Exterior shading and architectural features. • Reflective roofs and wall coatings.	• Reflective coatings (roof and wall). • Low-cost window films and exterior shading. • Natural ventilation.
	Cold climate	• Highly insulated windows (possibly double glazed with low-e storm panel). • Passive heating gain (architectural feature). • Optimised low-cost insulation and air sealing.	• Low-e storm panels and window films. • Insulated shades and other attachments. • Exterior insulating wall systems. • Cavity insulation, lower-cost (*e.g.* expanded polystyrene) interior insulation.

Notes: BIPV = building-integrated photovoltaic; SHGC = solar heat gain coefficient.

Windows and doors[9]

Windows have an important impact on energy consumption. While it is difficult to estimate, windows are most likely responsible for 5% to 10% of the total energy consumed in buildings in OECD countries. They fulfil multiple functions, including access to the building, outlook, entry of daylight and safety egress, and in many cases they provide ventilation as a fresh air inlet. In most cases, windows should let in as much light as possible, but this needs to be balanced by the fact that heat gain in summer needs to be minimised, while in winter it should be maximised.

One of the challenges for windows is to optimise the heat flow depending on the season. If the building is heated and the outdoor temperature is cold, the window should retain heat in the building, minimise losses and let in as much solar radiation as possible. On the other hand, if the temperature inside the building is too hot and cooling is needed, the windows should keep out heat from the sun and if possible provide opportunities to shed heat from the building.

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[8] Insulation and air infiltration are required everywhere for buildings that are heated or cooled but are not included here to reduce redundancy.

[9] This section discusses windows in detail, but the majority of inefficient doors are glass doors that can really be considered as a type of window for energy efficiency. Also, many countries combine windows and doors as a common "fenestration" product category.

The overall thermal performance of a building material or window is specified as thermal transmission (typically described as a U-value). It is a measure of the rate at which heat passes through a component or structure when a temperature difference is maintained across the material. Its measurement involves difficult concepts and techniques, and includes conduction, convection and radiation losses. There are many technical measuring considerations for windows (Box 3.2). Another common term is thermal resistance (typically shown as an R-value), which for all practical purposes is the inverse of thermal transmission. R-value is mostly meant to be a performance metric for consumers of a building material such as insulation. The higher the R-value, then the lower the heat loss will be. Conversely, lower U-values are best.

Whole-window performance is highly dependent upon its design, including whether it is fixed or is one of a variety of operable types to allow for natural ventilation. Window construction includes framing materials, glazing, coatings, spacers between panes of glass, inert gases[10] to reduce convection within cavities, thermal breaks and operating hardware. While the technical characteristics of windows are very complex, it has been simplified for policy makers and consumers through the use of window rating programmes. The standards specify the methodology to derive U-values and SHGC for the entire window. Today, it is still common to see windows being specified by the centre-of-glass characteristics rather than for the entire window system. It is important to specify whole-window performance to ensure the true energy characteristics are considered.

Box 3.2

Window rating programmes: critical to promote high-performance products

Window energy performance is highly complex to establish, but fortunately, due to the hard work of many global experts, it is easy to specify for policies if a rating programme has been established. Historically, thermal transmittance or U-value ratings were tested in a sophisticated test chamber called a "hot box", which functions like a calorimeter and requires full-scale prototypes to be built and tested. Today, window performance is simulated with sophisticated computer tools in accordance with International Organization for Standardization (ISO) standards. These tools have the ability to take into account heat transfer of framing materials, spacer materials, geometry, inert gas fills and glazing characteristics. The United States Lawrence Berkeley National Laboratory (LBNL) has established an international glazing database. It requires specialised measurements in accordance with specifications and spectrophotometers that characterise optical properties, including surface emissivities. These properties are also used by simulation programmes to calculate whole-window (frame, spacer and glass) U-values and SHGC. The database currently includes glazing systems from four continents, and the data are peer reviewed. This database goes beyond glass and includes window films that have been applied to standard glass samples prior to testing.

LBNL maintains a suite of software tools that have been supported by the United States Department of Energy and are free in the public domain; see http://windows.lbl.gov/software/ for more information (Figure 3.5). These software tools provide detailed window U-value and SHGC ratings and also include whole-building (residential and commercial) simulation tools that predict energy performance and savings from upgrading older to more sophisticated window designs. These simulation tools have been developed in accordance with the ISO 15099 standard. An older simulation standard with less accuracy regarding advanced window systems is ISO 10777. Generally, higher-performing window systems result in a more stringent rating if ISO 15099 is followed. However, for less sophisticated windows, that is not always the case.

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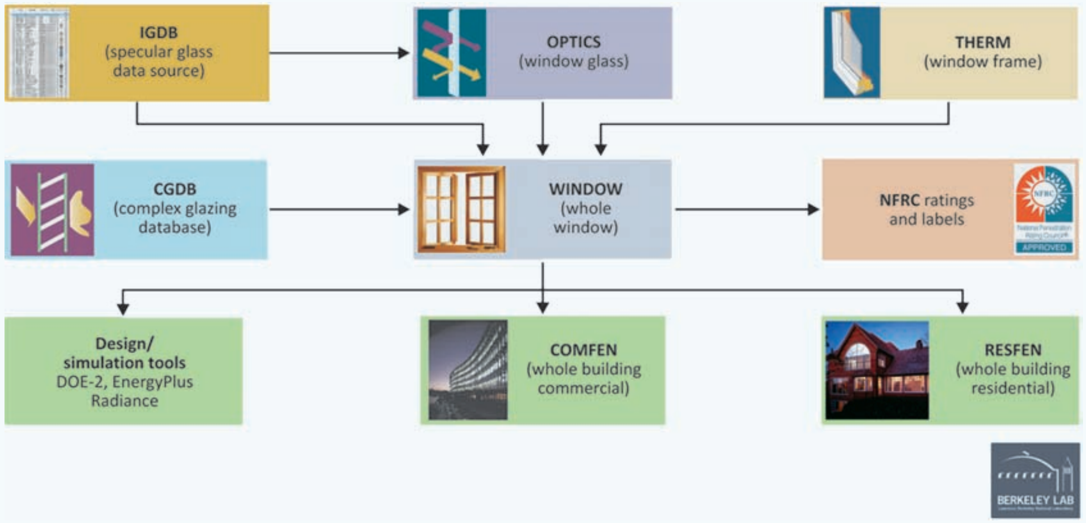
[10] Argon gas is commonly used and is affordable. Krypton gas has better performance but is very expensive and is generally not cost effective for its added value. Research is underway to reduce its extraction cost. Different inert gases have different minimum glass pane gap width for optimal reduction of convection.

Leading scientists and researchers have supported the newer ISO 15099, but some manufacturers, mostly in Europe and Japan, have resisted it.[11]

To solve this problem of multiple ISO standards, a new effort to harmonise them to one final set of criteria has been initiated recently, although it is likely to take years to resolve. The use of multiple standards creates unnecessary barriers to getting more countries around the world to adopt a window testing and rating programme. Today, beyond Europe and North America, certain countries have programmes in place. Japan has an ISO 10777 programme, but it only addresses U-values. Australia, South Africa and India have programmes in place using ISO 15099. China has a programme in place that uses a hybrid of both ISO standards (Parker *et al.*, 2011 and LaFrance, 2011).

Figure 3.5 LBNL suite of software tools to design and rate windows, along with building impacts



Note: ISO 15099 Compliant, http://windows.lbl.gov/software.
Source: figure courtesy of LBNL Windows Group, in Selkowitz, 2012.

Key point *Windows are difficult to test, and free ISO 15099-compliant software tools can be used to design and rate them for performance metrics such as U-value and SHGC.*

Unfortunately, there are still many windows being sold in the world today that are only single glazed with clear glass and inefficient metal framing. These have U-values of approximately 5.6 watts per square metre kelvin (W/m^{2}K). The majority of OECD countries in cold climates have moved to double glazed windows with low-e coatings, non-metallic frames and inert gas for the residential sub-sector, with U-values of approximately 1.8 W/m^{2}K. Several European countries have recently passed even more stringent building code requirements that are around 1.1 W/m^{2}K.[12] However, due to high structural requirements for many services sub-sector buildings, aluminium framed windows are still the material of choice. Services sub-sector windows are generally larger and framing

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[11] A primary concern is that ISO 15099 will result in lower (about 10% to 15%) product ratings for advanced windows.

[12] Window performance numbers in this publication are based on ISO 15099, thus an ISO 10777 standard of 1.0 W/m^{2}K is roughly equal to 1.1 W/m^{2}K per ISO 15099.

materials are less important with large glazed areas, and many new aluminium frames have thermal breaks so the total performance degradation is not as poor as one might believe.[13]

With very high new construction rates in China, there has been a global effort by suppliers to promote low-e glass and window materials. While they have been successful in large cities like Beijing and Shanghai for the most prominent buildings, much work remains to be done in other areas of China. In India, a new window testing and rating centre has been established that has been promoting the need for better windows. The key attribute for most of India is to promote very low SHGC. Using the latest state-of-the-art low-e coatings, solar heat gains can be low while maintaining natural light to reduce lighting energy consumption. Many other regions of the world are starting to adopt low-e glass, but there is a long way to go before it is mandated in building codes, as is commonplace in cold OECD countries.

Energy efficiency options

Replacing poorly performing windows is the most direct way to improve their energy efficiency. While window replacement for the sole purpose of saving energy is rarely cost effective, in situations where the window is being replaced due to structural instability, inoperability, appearance, obscured glass from broken seals, or a variety of other reasons, it is almost always cost effective to upgrade to more efficient windows. Significant progress has been made in recent years for windows used in the services sub-sector (Box 3.3).

Shading attachments

Beyond replacing windows, there are ways to upgrade existing window systems when replacement is not possible. Reducing solar heat gain in hot climates is much easier than reducing U-values in cold climates, because the sun's energy can be reflected. Shading materials perform best when they are installed on the exterior of the building, and these include shutters, awnings, solar shades and a variety of other shading devices. Interior shading with highly reflective surfaces, such as a bright white colour, can also be effective but has less of an effect if low-e glass is installed. A very effective technology is window films that can significantly reduce solar heat gain while maintaining a view to the outdoors. Window films have full product performance ratings in the United States in accordance with the National Fenestration Rating Council,[14] but in general more work is needed on the full complement of window attachments globally.

Insulating technologies: low-e coatings and attachments

A significant advance in window technology over the last 20 to 30 years has been the development of low-e window coatings that are very thin transparent metal films. Low-e coatings have the ability to reduce the thermal loss from windows and also to reflect solar energy. There are two primary types of low-e glass: sputtered, which has lower emissivity and less heat loss but is required to be protected within a double glazed unit, and pyrolytic, which does not have to be protected from ambient air and is best suited to storm window panels.

New low-e window films can also reduce U-values by as much as 42% when installed on single glazed clear glass windows, (US DOE, 2012). Insulated cellular shades (that look like honeycomb) can also reduce U-values on windows and are more effective in cold climates.

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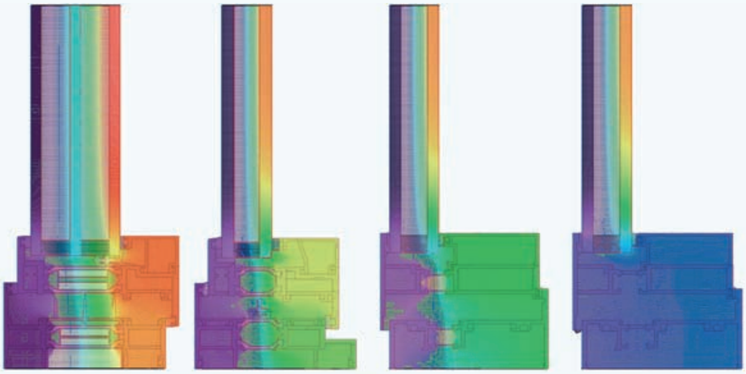
[13] Overall, services sub-sector windows with double glazed, low-e glass and aluminium thermally broken frames have typical U-values of approximately 2.3 W/m^{2}K.

[14] The National Fenestration Rating Council is a voluntary non-profit programme in the United States that rates windows and also has an international partner member programme. See www.nfrc.org for more information.

Box 3.3 Energy efficient windows with aluminium frames for high structural requirements

For the services sub-sector with high structural requirements,[15] recent developments in advanced frame design have resulted in a high-performance window. The window has a triple glazed low-e glass package and aluminium framing that incorporates state-of-the-art thermal breaks, low-e interior frame coatings and advanced insulation within the frame cavity. This window has achieved a U-value of 1.1 W/m^{2}K that is impressive for a high structurally rated window. A thermal graph of the advanced frame alongside older technologies demonstrates the progression of aluminium frame windows (Figure 3.6). The existing building stock throughout the world has many window frames without any thermal break. These windows have mostly single or double glazed clear glass. These inefficient frames are still being installed in many countries, especially non-OECD countries.

Figure 3.6 Thermal graphs of high structural performance windows, most advanced to typical stock



	Advanced	High performance	Traditional thermally broken	Non-thermally broken
Window U-factor (0.6mX1.5m) W/m^{2}K	1.1	2.4	3.1	4.6
Frame U-factor W/m^{2}K	2.0	3.5	4.8	7.8
Average interior frame temperature °C	13.5	8.7	4.1	-5.7
Market entry	2010's	2000's	1970's	1930's
Technology detail	▪ Wider thermal break, 40 mm ▪ Advance cavity interruption ▪ Foam filling ▪ Optimised design	▪ Strip thermal break (24 mm wide) ▪ Cavity interruption	▪ Pour and debridge (fill and debridge) thermal break – 6 mm wide	▪ No thermal break

Notes: the colours refers to temperatures that are coldest on the left (outside) to the warmest on the right (inside) for the most efficient advanced frame. The other frames have colder interior surfaces.
Source: figure courtesy of Kawner/Alcoa, in Kawneer, 2012.

Key point *Energy efficient windows are possible for applications with very high structural requirements; all four windows meet tall high-rise wind load requirements.*

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[15] Taller buildings require much stronger windows due to wind loading conditions.

Proper installation is essential to minimise air flow between the shade and the window to ensure that full improvement is achieved. A well-known method to improve the performance of existing windows is to add a storm window panel. Performance of a single glazed clear glass window with a low-e storm window is very close to the performance of a new double glazed low-e window with a wood or vinyl frame. This is important since the large stock of inefficient, single glazed windows can be modified to perform comparably to the performance of new building code-compliant windows at about half the cost.

Air leakage

Windows, especially in older buildings, are also responsible for a major portion of air leakage or air infiltration. This subject is discussed in more detail below, but storm panels have been proven to reduce whole-building infiltration by 5.7% to 8.6% (Drumheller *et al.*, 2007). New windows are generally much tighter fitting than existing windows. However, there are concerns that as windows age they may permit greater air leakage than when first manufactured. This is predominately due to thermal cycling from high-temperature exposure under direct sun conditions in the summer and during cold winters. Materials such as vinyl, which are becoming very prevalent and have low thermal conductivity, unfortunately have high thermal coefficients of expansion. Manufacturers have to consider this when developing window designs. Generally, European windows have operating hardware that allows for a gasket to be closed very tightly and achieve very low infiltration rates.

Triple glazed windows

Currently, in most cold climate OECD countries, there is significant effort to promote high-performance windows. Triple glazed windows have been available for many decades but have not achieved large market share in any country. Triple glazing that was more prevalent in Northern European countries has diminished due to the development of low-e coatings. However, this trend may be changing with recent more stringent building regulations.

Furthermore, newer more affordable higher-performing double glazed windows have two low-e coatings, one on the inside of the outer pane and a second pyrolytic coating on the room interior side of the inner pane of glass. By combining this new glass package with a higher-performing frame, total performance can equal triple glazed low-e windows with standard frames. The recommended policies for windows relate to climate and technology maturity (Figure 3.7).

Best available technology (BAT) and future developments

Many researchers and manufacturers have worked on multiple glazed windows (triple or quadruple) with multiple low-e coatings, exotic inert gases, such as krypton and xenon, and advanced insulated frames to develop very high-performance windows. These windows have been promoted as having performance comparable to many wall assemblies. To date, these windows have not generally been able to achieve economic viability. Greater effort is needed to find optimal designs that can provide performance better than a conventional triple glazed[16] window at around 1.1 W/m^{2}K and that can be economically viable. The goal for high-performance windows is a U-value of 0.6 W/m^{2}K or lower.

A key economic perspective is that builders and policy makers need to look beyond the specific energy-saving benefits of the window and look at system efficiencies. For example, if much higher-performing windows significantly reduce heating, ventilation and air-conditioning

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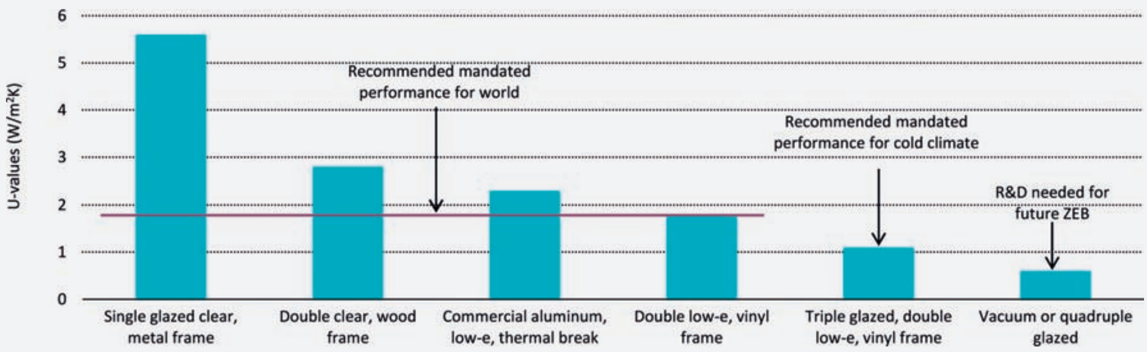
[16] A conventional triple glazed window is defined as having double low-e coatings, argon gas-filled and a basic low-conductivity material frame (wood or vinyl).

Figure 3.7 Typical window U-values for common products in the market place



Notes: ZEB = zero-energy building, performance in accordance with ISO 15099 standard.

Key point *Low-e double glazed window performance levels are recommended for worldwide application, and advanced windows for cold climates.*

(HVAC) or thermal distribution system costs, then these benefits need to be factored in. While a systems perspective is often considered by advanced builders and researchers, it has yet to be implemented on a wide-scale basis or adopted by building codes.

Vacuum glazing

Vacuum glazings have been looked at as a way to achieve dramatic performance improvement while maintaining a thin, easy-to-install glazing unit. Japan is the only country with an established market and has been selling vacuum glazings for many years, but they have limitations on size and restrictions in severe cold due to concerns with thermal expansion. While vacuum glazing windows are high performance, they do not exceed that of conventional triple glazed windows.

Researchers in Germany have worked on vacuum glazings and have invested EUR 10 million in the technology. Despite this, a high-performance market-viable vacuum glazing system has yet to be developed. Several research efforts are under way in the United States. The objective is to develop a vacuum glazing process that will be compatible with the main manufacturing processes found in window production and to be viable in all climates. So far, a successful product has not been developed. China also has been working on vacuum glazings, but there are limitations on product applicability and large-scale production has not been initiated.

To achieve market viability for very high-performance window systems with U-values below 0.6 W/m^{2}K, significant additional R&D will be needed. While there are several independent efforts underway globally, this subject may be best expedited through international collaboration. If successful, the potential market is enormous for high-performance windows in cold climates, including northern North America, Northern Europe, Russia, Northern China, Japan and Korea. There are additional smaller markets in extreme Southern Hemisphere cold climates as well as mixed or moderate climates that can benefit from high-performance windows.

Advanced solar heat gain

Static SHGCs are problematic for most climates. Cold climates often have reasonably warm summers and can have many hot days. Having a high solar heat gain will be too warm in summer. Passive designs, with proper orientation and large overhangs on equator-facing exposures that only allow the sunlight to enter the space in the winter, are ideal for new construction. However, there are many existing buildings for which this option is not practical. Furthermore, in hot climates, very low SHGCs may prove to be too dark when direct sunlight is not hitting the glass or on overcast or rainy days, requiring more artificial light to be used.

The current solution is to have automatic shade control, including solar shades that allow a small amount of vision to the outdoors. Exterior shades have very good performance but are expensive to install and maintenance can be a concern. Interior shades offer very good visible light control but do not achieve very low SHGCs. All of these options can be integrated with automatic dimming lights to save lighting energy, but performance is usually not optimal. Today, these are the best widely available solutions but consumer and building operators would prefer better options such as dynamic glazings (Box 3.4).

An overview of BAT in key categories, including technologies that are already cost effective/market viable and those that are not yet market viable, is presented in Table 3.2. It also includes future technologies and the need for R&D. The table is a generalisation and unique applications may differ.

Table 3.2 Best available window technology and classification based on market readiness and R&D

Key technical attribute	BAT (market viable)	BAT (pre-market viable)	Future technology / R&D
Low U-value	Triple glazed, dual low-e coating, advanced frames.	Quadruple glazed, exotic inert gases, aerogel filled frames.	Vacuum insulated glass; market-viable multiple glazed cavity system (U-value 0.6 W/m^{2}K or lower).
Variable SHGC	Automated shade control; exterior shading; architectural features.	Dynamic glazing (still high price premiums).	Dynamic solar control with vacuum insulated glazing.

Insulation (walls, roofs, foundations and floors)

Walls, roofs, foundations and floors represent the largest external area of most residential and services sub-sector buildings and are where most heat losses from buildings occur. Proper insulation reduces heat loss in cold weather, keeps out excess heat in hot weather and helps maintain a comfortable indoor environment. There are many types of insulating material, and certain types are better suited to different applications. A variety of insulation types and additional information relative to their performance and application are presented in Table 3.3. Decisions on specific applications are best taken at the local and regional level, while taking into account a variety of factors, including fire and safety standards, material and labour costs.

As the greatest energy savings are obtained from the initial installation of insulation, existing buildings in cold climates with no or very little insulation offer the greatest savings potential. There is also significant energy savings potential from new construction in developing countries where insulation is often not being installed.

Higher levels of insulation, or the last marginal unit of insulation, have a reduced effect compared to the initial level of insulation that is installed (Figure 3.9). It is a fundamental principle to insulate to the greatest level that is justified, based on life-cycle costs, when constructing a building or when retrofitting an existing building. The marginal cost of installing additional insulation is generally low. If a minimal amount of insulation is installed, it may have

Box 3.4 Dynamic solar control

The solution to allow for optimal solar heat gain control in all climates and under all seasonal and diurnal conditions is dynamic solar control. Dynamic solar control allows for variable light and heat transmission through the glass. Researchers have been working on this for well over 30 years but recently there has been significant progress. The current market leader has been selling products for over five years and opened a large new factory in 2013.

A large-scale demonstration building was constructed in California from an early production line (Figure 3.8). Note, that while the space is large, the panes of glass are fairly small. Products from new factories will be much larger. Several companies are working on R&D, but another company has also built a new factory to produce electrochromic glass coatings, with its products just starting to enter the market. Private sector investment in this new technology over recent years exceeds USD 250 million. Electrochromic glazings work like an electrical battery circuit with a very small amount of current to move ions into and out of an electrolyte. This results in a change in the light and heat transmission through the coating. Light and heat that are absorbed rather than transmitted through the glass are mostly rejected back outside, since the devices are usually capped with a low-e coating.

Another viable option also on the market is thermochromic coatings that change optical properties based on the temperature of the glass. These coatings do not have active control, which may limit their optimal savings, although they do have the simplicity of having less systems equipment. If the temperature point of tinting can be tuned to different climates, significant savings may be realised compared to static glazings. The Energy Resource Station of the Iowa University Energy Center is currently conducting an evaluation of the thermochromic window films. Total building energy savings range from around 2.2% to 4.6% (Pleotint, 2012).

Figure 3.8 Large-scale demonstration of electrochromic glazing at Chabot College, California

Source: Sage, 2013.

Key point *Dynamic windows are on the cusp of market viability and will fundamentally change how people design buildings to optimise solar control.*

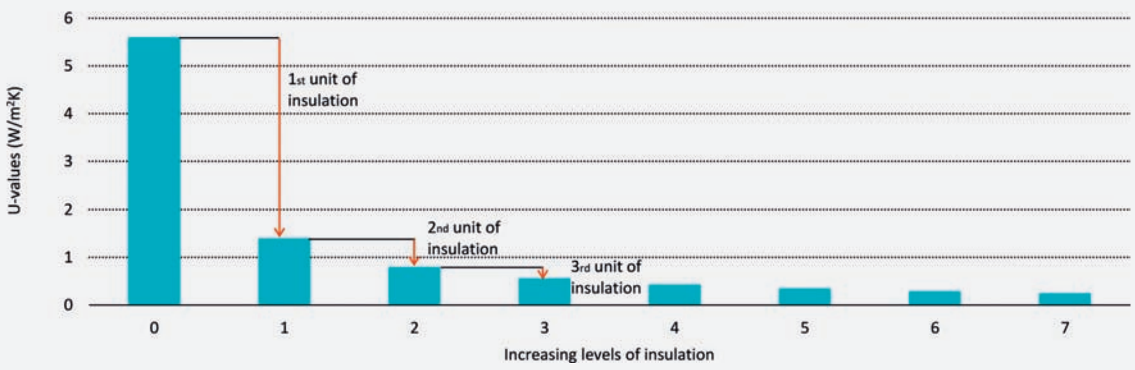
an immediate efficiency improvement, but large savings will not be realised and future retrofits are unlikely to be cost effective. Higher levels of insulation can be justified during new construction or deep renovation by considering full-system impacts that allow for downsizing of mechanical equipment in accordance with life-cycle cost assessment.

Table 3.3 Insulation types, thermal conductivity and typical applications

Thermal performance level	Highest		High	Moderate	Low	Applications/Comments
Thermal conductivity (W/mk)	0	0.01	0.02	0.03	0.04	0.05
Vacuum insulated panel (VIP)	▬					Research underway in EU and North America to embed VIPs in EPS or XPS as part of EIFS systems with adhesives to avoid fastener penetrations. High material cost.
Aerogel		▬				For highly constrained space and thermal bridges, such as stud caps. Case studies underway for interior installations with wall board to reduce labour and offer lower systems level cost. High material cost.
Polyurethane boards and spray			▬	▬		Wide applications for value-added performance with space limitations. Roof decking, cathedral roof structures, wall cladding, SIPS, basement, slab edge, and spray foam for cavities also offers air sealing benefits. Higher price premiums with many cost effective applications.
Extruded polystyrene (XPS)			▬	▬		Wide applications for value-added performance with space limitations. Roof decking, wall cladding, SIPS, basement, slab edge, and also offers air sealing benefits. Moderate price premiums with many cost effective applications.
Expanded polystyrene (EPS)				▬	▬	Wall cladding and a dominant choice for EIFS, SIPS, ICFs, and interior applications. Moderate price premiums with many cost effective applications.
Glass fiber				▬	▬	Widely used as cavity insulation alone or with spray foam ("flash and batt") to offer more affordable but sealed applications. Used in attics with less space constrained applications, generally lower cost and lower performing applications.
Stone fiber				▬		Used as cavity and in attics with less space constrained applications, generally lower cost and lower performing applications.
Cellulose				▬	▬	Used as cavity and in attics with less space constrained applications, generally lower cost and lower performing applications. New formulations doped with phase change material and passed fire rating tests but has very limited market.
Wood fiber, flax, hemp, cotton, other					▬	Variety of generally lower cost and lower performing insulation applications.

Notes: W/mK = watts per metre kelvin; EIFS = exterior insulation finish systems; SIPs = structural insulated panels; ICFs = insulated concrete forms; PCM = phase change material.
Source: adapted from EST, 2010.

Figure 3.9 Representation of insulation performance with diminishing returns



Key point *It is critical that all buildings be insulated to optimal levels using life-cycle cost assessment. If not, future upgrade may be cost prohibitive.*

Optimal insulation levels

The primary drivers that determine optimal levels of insulation are climate, the cost of energy, the heating system type and efficiency, and the installed cost of the insulation. Analysis is often conducted at the national or local level to establish recommended or required levels of insulation in accordance with various building policies such as mandatory building codes.[17] A European study was conducted and derived optimal levels of insulation for various cities using specific climatic data and expected energy costs (ECOFYS, 2007). These results, along with recent building codes implemented in Germany, the coldest region of Canada, and for electrically heated homes in Sweden, are provided for reference in Figure 3.10. However, the values are not directly comparable because the climates vary significantly. For example, Sweden has three times the number of heating degree days on average than does Spain. This shows the complexity of deriving optimal levels of insulation and implementing building codes. Put into perspective, uninsulated walls or roofs have U-values that may range from 3 W/m^{2}K to 10 W/m^{2}K. Insulated walls from the 1960s and 1970s in developed cold climates may be in the range of 0.5 W/m^{2}K to 0.8 W/m^{2}K.

Walls

The majority of the world's wall construction involves a "stick built" framing structure (wood or metal studs) or a high thermal mass structure (stone, masonry or concrete).[18] Framing structures allow for cavities to be filled with insulation but the structural members remain as thermal bridges or areas with significantly higher heat transfer properties. High thermal mass structures were often built without any insulation but benefit from their thermal mass. Older framed structures often did not have insulation in cavities.

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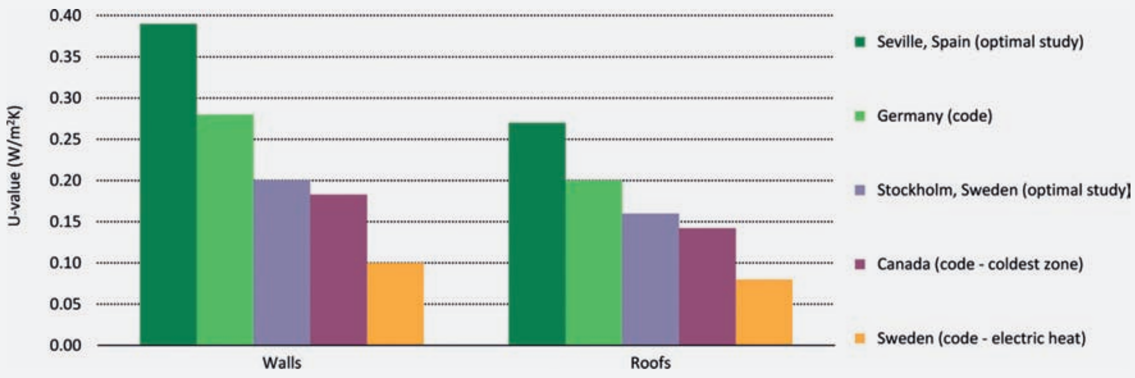
[17] Chapter 6 explains these policies in detail.

[18] The term "stick built" is common in North America for structural framing made of wood or steel. Another common name used is "structural member," which provides the primary support of the building. In high thermal mass structures, the entire wall provides the structural support.

Figure 3.10 Wall and roof U-value comparisons for reference perspectives



Sources: IEA 2013; ECOFYS, 2007.

Key point *Insulation levels need to be determined by climatic and local conditions, but most areas of the world can justify much greater levels of insulation that result in low installed U-values.*

Exterior wall insulation

In most developed countries, insulating walls is common practice and is generally done fairly well. There are concerns with proper workmanship and not installing optimal levels of insulation, but for the most part, new buildings are far more thermally resistant to heat flow than the existing stock of buildings. There are efforts to increase insulation levels, and the most effective approach to date is to add insulation that will be applied to the entire wall. This is ideally an added layer of exterior insulation that is applied to the structural sheathing but before the rain screen or cladding is added. A very common approach on most recent buildings in Europe and on services sub-sector buildings in North America is to add EIFS, also called external thermal insulation composite system (ETICS), which embed insulation under a stucco or cementitious type of finish.

Exterior insulation is very effective and can be applied to existing buildings. However, it requires recladding of the building and is rarely cost effective unless doing a major refurbishment or a full "deep" renovation, where other system benefits can be realised, such as significantly reducing the capacity of the space conditioning equipment. EIFS can be installed on old as well as modern buildings and are widely available in mature markets. They offer significant efficiency improvement by eliminating thermal bridges and adding additional insulation to the entire wall (Figure 3.11). Other types of viable retrofits include blowing insulation into cavities that are not insulated. This can be done with insulation that functions as an air barrier or one that does not serve this function. Interior insulation can be added but generally requires extensive interior renovation. It is often the only option for renovating historic, classified buildings.

Energy efficiency options

New approaches to wall design are growing in popularity but still only represent a small portion of new walls being constructed. One increasingly common approach is to use SIPs, which consist of an insulating foam core (*e.g.* polyurethane, or polystyrene) sandwiched between two structural facings, typically oriented strand board (OSB). These panels are manufactured in a factory and are assembled on site with the help of a crane, usually in a few days. Another new

Figure 3.11 Wall retrofit for energy efficiency with EIFS

Note: before (left) and after (right).
Source: Sto, 2013.

Key point *Retrofit of walls is most viable during wall recladding and is often used to maintain architectural integrity.*

technique consists of ICFs, resulting in cast-in-place concrete walls that are sandwiched between two layers of insulation, such as polystyrene. The forms are interlocking modular units that are dry-stacked (without mortar) and filled with concrete on site. While these systems provide excellent performance and have the flexibility of adding varying levels of insulation to achieve the optimum for the location, they are usually limited to new construction.

For retrofit options, new insulation materials have improved application procedures. For example, spray foam can be installed more effectively in wall cavities and additionally provides air sealing. It is also useful for difficult-to-access places, such as crawl spaces and certain attics. Installing insulation can be made more complex owing to concerns with air permeability and water vapour permeability. It is very important not to create an environment that will have high relatively humidity and result in the growth of mould. The best time to retrofit walls is during major renovation when a full systems perspective can be applied. Researchers from Fraunhofer Institute of Building Physics (IBP), Holzkirchen, Germany and Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, United States have developed a moisture design tool to help predict system performance and eliminate potential issues associated with building retrofits.[19]

Significant opportunity exists to introduce enforceable building codes that require insulation in developing countries and updated codes requiring higher levels of insulation in cold climate developed countries. Many Northern European countries require higher insulation levels for new construction. However, the global savings offered by better insulation in new construction are not exceptional, especially in places that already require fairly high levels of insulation for new construction (most OECD countries). Deep renovation in buildings with low or no insulation will derive the greatest overall savings. While insulation is increasingly common in

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[19] The WUFI (Wärme und Feuchte Instationär) programme was jointly developed by Fraunhofer IBP and ORNL (see www.wufi-pro.com/ for more information). Free versions are available for academia and in North America.

developing countries and starting to be added to building codes, much work is needed especially on enforcement. While this is quite challenging, the opportunity is great (see Chapter 6).

BAT and future developments

Higher-performing insulation is being developed and commercialised. So far, these products have not reached market saturation because the cost remains high and most builders tend not to look at the full-system benefits. These include aerogel, a nano-structure silica-based product comprising mostly air, although some manufacturers include a structural blanket to make it stronger and less brittle. Another key area is VIPs. VIPs can comprise a variety of low thermal resistance core materials that are inserted into a thin film pouch or bag. They have very low thermal conductivities, but their use is complex and the industry is researching where the best applications are. VIPs requiring containment of vacuum are sensitive to puncture, and thus current research is underway in Europe and North America to embed them within expanded polystyrene as part of an EIFS to avoid the use of fasteners. The cost is still high and will need to be reduced to become widely market viable.

The core benefit of these advanced systems is in applications that will bear greater investment while having large system savings. For example, if very low thermal conductivity insulation can be applied to the interior of external walls of buildings, then less labour and fewer structural materials will be needed. The net effect may be a retrofit system that is very cost effective as a holistic process, not just the cost of insulation on a competitive U-value/unit area basis.

Spray foam insulation also provides air-sealing benefits, although its installation can be problematic at low temperatures. With cold climates needing the most insulation, the application of these systems needs to be improved to allow for a greater applicable temperature range. Overall, the need for greater R&D for insulation is moderate, and there are not large targets or major step changes required. Effort is predominately needed on deployment.

Roofs

There are two predominant roof geometries: pitched (sloped) roofs and flat roofs (or low-sloped roofs).[20] Most pitched roofs have an attic space that allows for buffering of the thermal impacts of roofs and are used to install mechanical equipment in some countries. This can be a problem where the mechanical equipment is in unconditioned space that can be extremely hot in summer. Sloped roofs with cathedral ceilings (pitched roofs without attics that are open to the living space) are probably the biggest challenge for insulation because the primary location for insulation is within the depth of the structural members. Pitched roofs are most common in locations with significant snow loads. Flat roofs are predominant on large services sub-sector buildings and on many urban buildings around the world.

Flat roofs

Flat roof constructions are generally classified as either “cold” or “warm” roofs depending on the position of the thermal insulation. Although no longer recommended, cold flat roofs were fairly common and remain so in some parts of the world. In such roofs, the thermal insulation is laid between the joists below the structural deck. The structural elements of a cold roof easily suffer the damaging effects of thermal movement and the insulation layer is more sensitive to moisture build-up. In a warm roof, the insulation is positioned above the structural deck. No

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[20] Technical practitioners use the term low-sloped because even flat roofs have a very small pitch to shed water.

ventilation of the insulation layer is required. This approach is very effective as limitations on thermal performance are not determined by the roof structural and joist height.

Optimal insulation thickness is determined predominantly on the basis of life-cycle cost effectiveness. For existing roofs, parapets (low surrounding walls) and access doors can limit the thickness of insulation added, but generally most areas of a roof can be subject to additional insulation without major difficulty or excessive cost. Adding insulation to attics of pitched roofs is fairly common practice. Air leakage between the conditioned space of the building and attic can be very significant due to the chimney effect, wiring, piping, chimney and attic access penetrations, and interfaces with partitioning walls. Proper insulation and air sealing of attics are critical for both new construction and retrofits. While this is being done by some builders and insulation installers, it is not a highly validated process in most of the world.[21]

Pitched roofs

For pitched roofs with cathedral ceilings, insulation is commonly installed between the rafters. Since the rafters are not deep enough to accommodate a high level of insulation, an additional structure, above and perpendicular to the rafters can be added with additional insulation. Another approach is to use higher-performing insulation such as foam within the rafters. Depending on the roofing materials being used and the roof design to ventilate accumulated moisture, there are concerns over whether a closed cell or open cell foam should be used.[22] Due to high cost and concerns about moisture, many pitched roofs with cathedral ceilings have inferior insulation compared to other roofing designs. However, if possible, a viable solution is to add insulation on the interior side of the structural members. When this is not possible, and if reroofing will occur, it may be possible to add rigid board insulation above the roof deck similar to a flat roof, although care is needed to ensure proper fastening of roofing materials.

All pitched roofs should be considered for retrofit of added insulation and air sealing in the attic, as these measures generally have sufficient rates of return to warrant retrofit prior to reroofing or major building renovation. In energy efficiency programmes, this measure is consistently shown as a cost-effective, high-priority measure, however it is not being widely done (BA-PIRC, 2012).

Cool roofs

In hot climates, it is best to reject as much heat as possible from the roof surface and to prevent any heat build-up from migrating to the attic or conditioned space. Cool roofs, which can be simply white in colour, reflect visible and near-infrared light very well. Roof performance degrades with environmental particulate soiling and biological growth over time, so to ensure accurate energy-saving measurements, aged ratings are specified in policy programmes. Recently, the concept of a cool roof has included detailed roofing rating requirements that provide performance criteria of solar reflectance and thermal emittance after a roof sample has been aged (weathering tests in a variety of climates) for a specified period, such as three years.[23]

The highest-quality aged white roofs can reflect 80% of the sun's energy compared to black roofs that reflect only 5% to 10% (CRRC, 2013). There are also cool-coloured roofing products that visibly look the same as typical roofs, but which reflect the near-infrared portion of sunlight. Depending on colour and performance, these products reflect about 30% to 50% of the sun's energy (Figure 3.12).

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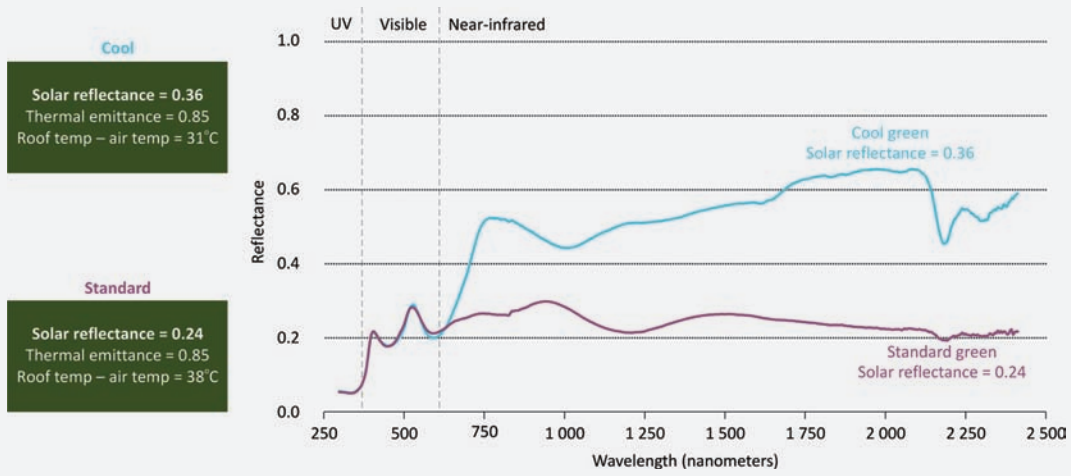
[21] See air sealing section for more information.

[22] Open and closed cell refers to the insulation's ability to allow vapour migration, in essence "to breathe".

[23] Solar reflectance measures the fraction of sunlight that is reflected, and thermal emittance is the efficiency with which a surface emits radiation. Higher thermal emittance allows the roof surface to reject any heat that is absorbed if it is hotter than the surrounding environment. See Cool Roof Rating Council, www.coolroofs.org for more information.

Figure 3.12 Cool-coloured material and performance



Source: figure courtesy of LBNL Heat Island Group, in Levinson, 2002.

Key point *Cool roofs can be almost any colour and still reject sunlight; thus there are no aesthetic reasons not to pursue a cool roof policy.*

Energy efficiency options

Energy efficient roofing systems need to go beyond insulation. Properly sealed ceiling planes for pitched roofs are needed for all climates, and cool roofs are important in hot climates. Efficiency programmes to promote advanced roofing should ensure that air infiltration and reflectivity criteria are included in addition to insulation requirements. Radiant barriers (with low-emissivity surfaces) on the underside of roof decks can also help in both hot and cold climates, although they are generally more cost effective in hot climates for cooling benefits. It is also important that they not be installed on the floor of an attic where they will accumulate dust and no longer be effective.

Often in North American homes, mostly in the United States, there are air distribution systems that are located in the attic. These can be quite inefficient, especially if not fully air sealed and insulated. The energy efficient approach is to construct the home with the ductwork integrated into the conditioned space. However, many builders have rejected this since it can conflict with architectural designs. A new concept to mitigate this problem has been to convert the attic into a semi-conditioned space by insulating the roof plane instead of the ceiling plane (floor of the attic). This solution is a significant improvement over traditional attics with leaky ceiling planes, but the designer must be careful not to create a moisture problem in the structural sheathing of the roof.

Roofing materials and designs beyond cool roofs can contribute to improved energy efficiency. For example, clay or concrete tiles are very common in many parts of the world. The tiles usually offer two advantages. First, they provide thermal mass that helps mitigate solar energy, and second, they are usually installed on counter battens that provide a vertical ventilation path below the tile. Thermal mass retards the heat gain and much of it can be removed by ventilation. As the sun sets, remaining stored energy will flow back out to the environment. In addition unglazed tiles, which are common in many regions, have a naturally high solar reflectance (about 0.40). These tiles also store moisture that can have an added cooling benefit.

Garden, vegetated or green roofs refer to a roof that has soil or planting media that hold various types of vegetation. The roofs serve as a cool roof through transpiration, similar to evaporation, to provide cooling of the area. Most garden roofs have enough soil to serve as additional thermal mass, so they also function as a higher level of insulation. A primary benefit is that they store rain water and prevent storm water run-off. Generally, garden roofs have very high price premiums compared to typical cool roofs, are pursued for environmental or aesthetic reasons and are not cost effective from an energy efficiency perspective.[24]

BAT and future developments

For flat roofs, there are few advanced technologies that go beyond high levels of insulation, cool roofs, radiant barriers and proper sealing. The biggest advancement to date is the integration of photovoltaic (PV) cells into roofing designs. With the promotion of very low-energy consuming buildings, roofs are becoming a typical location for the installation of PV cells. Conventional PV panels are installed on rack mount systems and can help improve the thermal performance of the roof by offering shading, while also producing electricity. Most are installed well above the roof surface with natural ventilation below the solar panel to provide heat rejection of the absorbed energy and to maintain PV efficiency. The challenge is to ensure that roof penetrations do not cause water leaks, and where PV systems are installed on existing buildings, it is critical to ensure that 30-year PV systems are not installed on older roofs that may only have five or ten years of useful life remaining. Guidelines for appropriate and sustainable building practices should be established.

Building-integrated PV systems

The installation of PV panels on roofs can be complex and adds significantly to the installed cost of solar systems. There has been significant interest and funding to develop BIPV systems. These systems use thin film designs that have much lower cost, but are also less efficient. The PV cell is encapsulated within a protective, flexible layer that actually serves as the roofing surface. The intent is to install these systems over the majority of the roof area with a much easier installation technique to derive a more cost-effective PV system. However, there are two possible negative impacts of this approach: first, the PV cell will not reject its heat as well and may have lower output due to higher cell temperatures, and second, if the roof is not well insulated, the absorbed energy will flow into the building and increase cooling loads. The latter issue can be fairly easily mitigated with proper insulation levels, and there are research efforts underway to look at ways to keep BIPV systems cooler while operating.

BAT for flat roofs beyond PV systems is predicated upon optimal or higher insulation levels. As reroofing of the waterproofing membrane or roof cover occurs every 15 to 25 years, the first step is to establish mandatory building codes that derive optimal levels of insulation. Roof retrofit requirements can be established that require the roof to be brought up to current building code requirements at the time of reroofing. Due to the nature of reroofing, additional labour to install higher levels of insulation for flat roofs is very low for most installations. Therefore, this recommendation can be pursued fairly easily, and it is feasible that all flat roofs in the world could be installed with optimal insulation by 2050.

Advanced pitched roofs

Pitched roofs are more challenging, since reroofing does not present the same easy installation opportunity that is the case with flat roofs. Research has sought to improve performance by adding insulation, ventilation and radiant barriers above the roof surface. The

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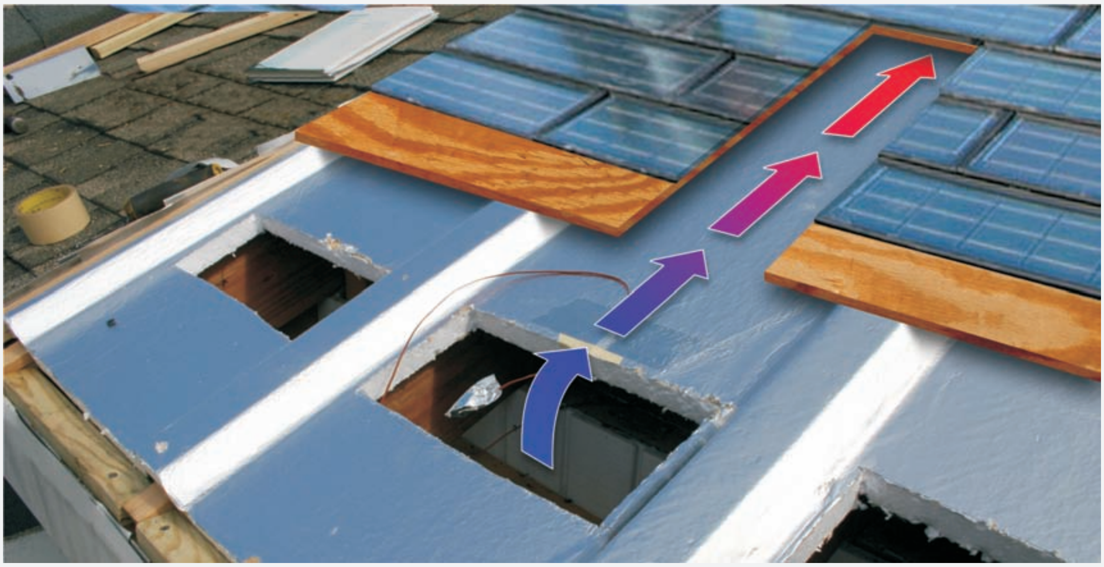
[24] See Box 3.6 regarding global cooling benefits of cool roofs. Unfortunately garden roofs do not reject solar energy back to space, whereas typical cool roofs do.

combination of these features may be used on any roof, including BIPV installed on pitched roofs. Researchers at the ORNL in the United States using these integrated technical features have demonstrated a reduction of over 87% in peak heat flow through the roof surface, compared to conventional dark asphalt shingles that are fastened directly to the roof deck (ORNL, 2010). ORNL has expressed interest in combining the features of a semi-conditioned attic roof with above-deck features to develop total optimal performance. These systems would be applicable to both new and retrofit applications and may offer a viable solution for the future, including integration with BIPV (Figure 3.13).

Figure 3.13 Advanced BIPV installation with vented, insulated, and radiant barrier cavity



Source: figure courtesy of ORNL, in LaFrance, 2012.

Key point *Advanced roofing will move toward BIPV systems while providing advanced thermal performance.*

Foundations and floors

Foundations include a variety of basic configurations, including full basements, crawl spaces and slabs on grade. All configurations exist in all climates, but certain configurations are more prevalent in certain regions. While it is important to consider adding insulation in all applications, it is most important in colder climates. In hotter climates, foundations offer ground coupling and can actually be a source of heat rejection. The portions of the basement, crawl space or slab that are exposed to the environment above the grade are the greatest concern.

Similar to walls, adding exterior insulation is a preferred option and is included in mandatory building codes in many cold countries. However, compliance is problematic because adding insulation during foundation backfilling can be labour intensive. Adding insulation to slab edges also can be difficult for buildings that may not be adding exterior insulation to above-grade wall sections. The interface between the slab edge and the wall is an important construction detail that needs to be carefully addressed.

The vast majority of crawl spaces and basements in cold climates are in need of retrofitting. Insulating on interior walls is viable, but careful attention has to be taken to mitigate any moisture problems. This concern has been the subject of continuing debate among global building researchers and is receiving more attention as problems with other components of the building envelope have been solved.

Insulating floors that are over basements or crawl spaces is an easy measure for new construction and in some retrofits. This turns the basement into semi-conditioned space which serves as a buffer zone and is useful. However, if the space is used and conditioned, then the insulation value will be wasted. Prior to insulating, any floor penetrations should be properly sealed. Similarly to attics, if ductwork is located in the basement or crawl space, then it should also be properly sealed and insulated.

Energy efficiency options

Foundation and floor options are limited beyond appropriate insulation with water vapour and air barriers. Proper sealing is critical to prevent hot warm air being in contact with cold concrete that will condense and cause moisture problems. Greater attention to design details is needed for retrofits. For new construction, insulated concrete forms are ideal because they provide insulation on both the interior and exterior of the foundation wall. Advancements in various types of higher-performing concrete have reduced their thermal conductivity. These formulations generally offer similar structural capability while using less material. From a sustainability standpoint, this can be used to reduce the embodied energy of the concrete, but the small thermal performance improvement is not significant enough to achieve large energy savings. Through appropriate building code regulation and enforcement, new-build foundations can be properly insulated without any negative financial impacts.

BAT and future developments

Retrofitting exterior foundations and slabs poses a significant challenge. The largest area for energy loss is above grade and the top 0.5 meters (m) to 1.5 m below grade. For new construction, the entire depth of a basement can be insulated, but for retrofits the majority of the heat loss can be saved if just this critical zone is insulated. Retrofit strategies include excavation for insulation to be installed vertically along the basement surface, as well as a horizontal shelf-type of insulation application that is parallel to the grade but buried a few centimetres. There is interest in finding better and cheaper ways to insulate the exterior of structures. As buildings become more efficient, the relatively small portion of energy loss attributed to foundations and floors today will become a greater portion of the remaining energy being wasted. Thus, this area is expected to gain more attention for product development than it has seen in the past.

Air sealing

In buildings, it is normal for air to move in (infiltration) and out (exfiltration) of the structure. A common name for this is called air leakage and is usually measured using a term called air changes per hour (ACH).[25] Natural weather conditions, such as wind and temperature differences, can increase air leakage. Also, mechanical duct systems can create pressure differences between the inside and outside of a building, which can also contribute to the problem. To measure ACH the structure is pressurised and multiple air leakage rates are

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[25] Air changes per hour (ACH) is equal to the volume of air in a structure at a specified pressure rating that is exchanged with the outside. ACH of 5 would be a flow rate that equals five times the volume of the building leaking in one hour.

collected over a range of pressures. The most common specification to rate air leakage is at 50 Pascal (Pa), and at this high pressure it is not uncommon for old leaky homes to have ACH of 10 to 20 (ORNL, 2011). Actual pressures during normal building operation are much lower.

Simulations on a large number of building types in widely varying climates concluded that the potential for heating and cooling energy savings attributable to reduced air leakage ranged from 5% to 40%. However, with reasonably tight structures in cold climates, the typical savings were around 20% to 30% (Zhivov *et al.*, 2012). There has been significant progress on air sealing requirements in recent years (Box 3.5).

Box 3.5

Air sealing in Europe and North America is showing progress but is still a challenge

Many new building codes in Northern Europe require air leakage rates of 2.5 ACH at 50 Pa or 3 ACH at 50 Pa for buildings without mechanical ventilation, and 1 ACH at 50 Pa or 0.60 ACH at 50 Pa with mechanical ventilation. The Passivhaus requirement is 0.60 ACH at 50 Pa (IEA, 2013). The most recent United States residential building code requires 3 ACH at 50 Pa for mixed and cold climates, and 5 ACH at 50 Pa for hot climates (IECC, 2012). Air leakage requirements can be confusing because they can also be specified in a leakage rate per square metre of building surface area or at higher pressures such as 75 Pa, especially for large buildings. This can make them difficult to compare from one programme requirement to another.

New, very airtight buildings may only have a rate of 0.2 ACH at 50 Pa, and they consequently require mechanical ventilation systems to provide fresh air. It is more efficient to air seal the buildings and to control the ventilation rate than to allow excessive air leakage (a common slogan used is "build tight, ventilate right"). In many services sub-sector buildings, fresh ventilation air is already required, so there is no additional expense. However, as residential building standards are continuously tightened, it will become increasingly the norm in new residential buildings.

In most Northern European countries, air sealing has been done for a long time, and validation testing is more common. It has gained momentum in North America and testing has improved over the years, although there is still resistance to complete validation tests except for in advanced building programmes. The recent adoption of air leakage testing requirements in building codes is likely to change that.

Validation testing requires special equipment, most commonly a blower door test apparatus that pressurises or depressurises the structure and is used to determine the leakage rate (Figure 3.14). This test takes time and can be expensive. Attempts have been made to establish techniques to reduce the test burden, but so far it still remains a fairly intensive endeavour. Work has been done on air sealing for advanced buildings around the world, but greater effort is needed to make standardised validated air sealing mandatory in all countries. Air sealing is needed in all buildings independent of climate unless the building will not have mechanical equipment and will be fully conditioned with natural ventilation.

Energy efficiency options

New construction is the best time to air seal a building. Strong building codes are therefore essential. Air barriers for walls include sheet materials, membranes, spray-applied foams, liquid applied coatings and properly sealed drywall. Window installations with proper flashing and sealants are important, along with the installation of low air infiltration operable windows. All penetrations and connections through the building envelope need to be sealed. These include wires, pipes, chimney flues, access panels and structural member interfaces.

Figure 3.14 Blower door test apparatus

Source: ORNL, 2013.

Key point *Measuring air infiltration and post-sealing effectiveness is critical to reducing heating and cooling consumption. More work is needed to make validation testing a common practice, such as using a blower door test.*

Retrofitting for air sealing involves all building envelope components and is a challenging and tedious job. Significant research has demonstrated how tight existing structures can become. Generally, significant improvements can be made fairly quickly with relatively low cost. However, higher levels of air sealing become much more expensive. For example, the National Renewable Energy Laboratory's (NREL's) data base of energy efficient building measures shows that the average cost of reducing air leakage by 25% costs USD 4.52/m^2, whereas achieving a 50% reduction costs USD 24.75/m^2. Since the goal is to reduce air leakage to very low rates, more research is needed to find the most cost-effective methods to achieve low air leakage in existing buildings (NREL, 2012).

When mechanical ventilation is required, additional energy can be saved by installing a heat recovery system. These systems are heat exchangers that either recover heat from exhaust air to preheat incoming air in the heating season, or remove heat from the incoming air in the cooling season. Also, in large services sub-sector buildings, there are desiccant wheels that attempt to dry incoming air, which are then recharged with exhaust air.[26] Another related area of consideration is the use of economisers[27] for services sub-sector buildings that use outside

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[26] More details on dehumidification can be found in Chapter 4.

[27] An economiser is a device that allows the use of outside air to be mixed with recirculation air and is controlled for interior temperature and humidity levels.

air for “free cooling” when the weather is appropriate, and these may be integrated with a heat recovery system.

BAT and future developments

Achieving very low infiltration rates in existing buildings without a major renovation can be time consuming and costly. Research continues on finding better ways to air seal structures at the lowest possible cost. To validate performance, pressurisation tests are conducted before and after completing the work. However, to achieve very low infiltration rates, additional air sealing measures will be needed along with subsequent validation testing. Use of thermal imaging cameras can also be beneficial. This process may need to be repeated multiple times. The objective of the research is to help identify the greatest opportunities to reduce infiltration, while reducing or eliminating the need for subsequent validation testing (ORNL, 2011).

During major renovation or deep retrofit, many easy applications for air sealing are accessible and cost effective. A typical measured value of around 1 ACH at 50 Pa to 3 ACH at 50 Pa is achievable. For normal building envelope upgrades, air sealing is possible and needs to be part of any energy efficiency buildings programme. However, expectations of achieving very low infiltration rates may be unrealistic until additional more cost-effective approaches are developed and implemented.

Building design optimisation

Building design optimisation is very important for new construction, especially in developing countries that have much faster new construction growth. Building orientation is a fundamental consideration for any new residential or services sub-sector project. Land restrictions, zoning requirements and economic imperatives may not allow for energy efficiency optimisation, but it should at least be a consideration early in the design and development process.

Passive solar design

For residential buildings, care must be taken to optimise window orientations by climate, which usually minimises windows on a western façade unless in a very cold climate. As discussed in the previous window section, solar energy can be much better controlled from equator-facing orientation with lower-cost technology. Thermal mass, if installed appropriately where solar energy will be harvested, can be better utilised rather than overheating the building during the day time. The thermal mass will release stored energy later into the evening when it can be used to reduce energy consumption. For cooling loads, it can also retard solar energy by storing it before it flows inward to the structure. Energy that eventually makes it into the structure many hours later can be categorised as peak cooling load shifting, and any stored energy that is rejected back out to the environment when the sun’s intensity is reduced is cooling load reduction that also achieves energy savings.

Services sub-sector buildings with high internal loads and a requirement for lighting deeper into the space than offered by normal daylight from windows need to be designed with narrower depths. This can reduce internal gain with lower lighting densities, while harvesting natural daylight and reducing cooling loads as much as possible. These concepts are very complex and are optimised through the use of building simulation software where building designers simulate various scenarios of building orientation, glazing packages, window-to-wall ratio and a variety of other features.

While the concept of integrated designs with optimised orientation has been well established within the research community and is widely deployed in high-performance buildings, for the first time it has been adopted as part of a building code by France. To ensure effective consideration of the building design, shape, orientation and openings at the design stage, a weighted coefficient called "Bbio"[28] is included in the code whereby heating, cooling and lighting needs are divided by the net floor area of the building. To comply with bioclimatic requirements, designers have to calculate the Bbio value of each new project and make sure that it is lower than the maximum allowed value (Bbiomax) for the climate zone and the building type considered (EPBD, 2012). Bbio calculations are expected to encourage compact building and reduce the need for artificial lighting and HVAC systems (IEA, forthcoming).

Solar reflective technologies

Cool roofs are effective at reducing cooling loads in hot climates. In colder climates, cool roofs are not as important and can actually incur a heating penalty by preventing heat gain from the sun. With less heat being absorbed from the sun, cool roofs have less drying potential and can result in moisture concerns if not designed and installed properly. In developed countries with moderate and cold climates, insulation levels are so high in newer construction that net cool roof benefits are much smaller.

While cool roofs may have limitations on building energy efficiency, they can, along with cool pavements, reduce the urban heat island effect and make the entire city cooler (Box 3.6). Experts predict that a reduction of 2°C to 4°C is possible, reducing overall energy consumption as air-conditioning equipment would run more efficiently and the total cooling loads would be reduced. These benefits are starting to be promoted by cities; for example, New York City in the United States has adopted a cool roof policy. An ancillary benefit cited was that a cooler city would enable the population to be more active and economically productive.

Box 3.6 Cool roofs and reflective urban surfaces can cool the planet

Reflective surfaces can improve building energy efficiency, reduce urban heat island effects and cool the planet. Cool roofs have long been validated to reduce air-conditioning loads and to reduce interior temperatures in buildings without air conditioning, thus avoiding the need for cooling. Reflective urban landscapes including cool pavements can reduce urban temperatures between 2°C and 4°C. In the past five years, several studies have been conducted to predict global cooling potential, with conservative estimates for total global urban land area and modest improvements in albedo from installing cool roofs and improving the reflectivity of roadways and parking lots. These studies concluded that rejected heat from the planet could have the cooling effect of approximately 1.5 years of global man-made carbon emissions, or around 44 gigatonnes of CO_2 ($GtCO_2$) (GCCA, 2013). However, this is a onetime total effect of converting urban landscapes to more reflective surfaces.

In the past year, progress has been made towards achieving this carbon savings potential. A detailed scientific research study was completed in India that attempted to validate the upward radiation flow from cool roofs using satellite and land-based measurement techniques. A key consideration is the impact on atmospheric pollutants that absorb solar energy in both the downward and upward directions. Clouds also affect radiation flows. The key finding is that the ability to reject radiation (heat) from the earth from reflective surfaces has now been validated through measured data and is no longer just a theory (LBNL, 2012).

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[28] Bbio is a term used in the French building code.

Advanced reflective technologies for roofs, windows and walls can reduce indoor temperatures in hot climates and are most effective on older structures that have lower levels of insulation. With the cooled floor area projected to triple in non-OECD countries, implementing these passive cooling strategies will be critical to achieving the 2DS. There are examples of countries that have experienced significant increase in air-conditioning sales in recent decades, such as Australia and China. Usually this growth is coincidental with higher incomes, where occupants can now afford to buy cooling appliances. To manage this growth, efforts need to focus on developing and implementing integrated passive solar packages for developing countries, so that air-conditioning loads are minimised or are never realised. Even if demand for high levels of personal comfort rises, the air-conditioning capacity needed after a proper envelope package has been installed first may be on the order of 30% to 50% of what it would have been otherwise. The primary function of these air conditioners will be to provide humidity control with a small sensible[29] cooling load.

Future pathways and RDD&D priorities

Extensive improvements are needed for each individual component of the building envelope, and the importance of each will vary by building type, vintage or geographical location. However, action is particularly needed on strategies to optimise new construction through proper design, and a strategy for deep retrofits that can improve cost effectiveness and produce larger energy savings. This section discusses the principal areas that need to be addressed to turn this great technological opportunity into reality and to achieve the 2DS objective.

Development of new technology

Looking across the components of the building envelope, windows stand out as an area that is lacking cost-effective, high-performance products. While major progress has been made on the development of more affordable and market-viable double and triple glazed low-e windows, a competitively priced very high-performance window still remains elusive. Action is needed to initiate comprehensive R&D efforts. International collaboration among cold climate countries may be a way to accelerate it.

Advanced residential building programmes need to communicate more effectively the value and benefit that a very high-performance window could contribute to the goal of achieving very low and ZEBs. Currently, there is a lack of detailed case study data on very low-energy buildings that demonstrate the systems benefit of low U-value windows. For example, since some very high-performance products exist, it should be possible to conduct field evaluations to demonstrate the energy-saving and peak-load reduction benefits of high-performance windows. Their evaluation within an integrated system of improvements will be key to their eventual commercialisation.

New construction in developing countries

The largest growth in new buildings will occur in developing countries. Experience shows that the most effective way to reduce the energy consumption of new buildings is with mandatory, stringent building codes that are properly enforced. At the core of enforcement are several considerations that need to be assertively addressed in fast-growing developing economies. Product performance metrics, energy ratings and overall material specifications need to be at the forefront of any efficiency programme, including mandatory building codes. Important

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[29] Sensible load refers to the change in temperature as compared to latent load that refers to the moisture in the air. Convential air conditioners have both latent and sensible cooling loads.

lessons can also be learned from OECD countries. In the case of windows, the existence of different ISO standards[30] that are in competition with each other sends a mixed signal to the rest of the world and reduces uniformity and efficiency. Greater effort should be made to harmonise building material standards globally.

Other key elements of building code development and enforcement include capacity training to educate designers, builders, building code officials and other key stakeholders about the opportunities of advanced products and technologies for developing countries. Availability of efficient products will slowly grow as demand for imports increases, potentially leading to eventual large-scale manufacturing in the host country, often with help of global investors. Effective policies and training programmes will foster and expedite private sector investment.

Global suppliers with policy support from governments can play a key role in making enforceable codes a reality. Since global suppliers can receive significant benefit from value-added, high-performance building codes, they should be a primary resource of funding their development together with the host country. Competing companies organised by industry associations working in collaboration with governments have the ability to transform the market in a much shorter timeframe. The net result will be much greater business for all suppliers, economic prosperity for the developing country and significantly less energy demand for the world.

Retrofitting the existing stock of buildings

With over 48% of heating and cooling energy consumption accounted for by buildings in OECD countries in 2010, and with about 75% of these buildings still expected to be in service in 2050, upgrades and retrofitting are critical challenges facing the world. If progressive policies that have been successful continue, significant energy can be saved. Deep energy renovation will be needed to achieve large reductions in heating and cooling loads. When very advanced envelope components are combined with much smaller, highly efficient space heating and cooling equipment, the net result can be dramatic. It is possible to reduce heating and cooling loads by 75% or more (ECOFYS, 2012).

Work on several fronts is underway to address this opportunity, but it needs to be better co-ordinated. Several OECD countries have adopted policy incentives to jump-start the building renovation process. While these are well intended, a comprehensive multi-policy approach is needed that will ensure that the programmes are designed to be effective in the long term and can be sustained. Greater effort needs to be focused on comprehensive technical and economic case studies and pilot programmes that derive actionable results. These initiatives should provide the following:

- Validated results of the new, cost-effective technologies that are needed (*e.g.* very low U-value windows, retrofit air sealing capability, optimised advanced pitched roof solutions and advanced insulations).
- Validated economic benefits and associated cost effectiveness of measures that can be achieved without the need for policy incentives.
- Beyond energy or environmental benefits, demonstration of the business model and economics associated with refurbished buildings compared to older stock.
- The cost of CO_2 abatement if a building is renovated earlier than its normal refurbishment cycle.

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[30] See Box 3.2 for more information on window ratings. A new effort to harmonise these was initiated at the ISO meeting in France, September 2012.

While the opportunity presented by deep renovation has not received extensive interest, it is starting to grow. To achieve the 2DS, a major endeavour with increased resources and global co-ordination will be required to focus on achieving large energy savings from the existing stock of buildings. Low-level retrofits using the easiest and least-cost options will not be enough, and could in fact render future upgrades cost prohibitive. Full deep renovations present the greatest opportunity to be economically and market viable, and they need to be initiated as soon as possible.

Recommendations

Investment in better envelopes that last a very long time will allow for greater economic efficiency by reducing costs associated with space heating and cooling systems, especially for new construction or as part of major deep renovations. Case studies for insulation and air sealing technologies are needed to showcase examples in fast-growing developing economies.

Windows are the weakest link in the building envelope, and cost-effective, highly insulating windows are needed. Dynamic windows should be supported as part of an advanced technical option that can offer passive heating attributes while reducing peak cooling loads.

Upgrading roofing insulation to the latest building codes when reroofing can save significant amounts of energy, while adding criteria for highly reflective roofing surfaces in hot climates will see most of the heat rejected before it can be absorbed. There is a need to harmonise test standards to enable greater global investment in high-performance building materials. A summary of the recommendations is presented in Table 3.4.

Table 3.4 Building envelope recommendations

Technology	Immediate recommendation	Future requirements
New walls	Extend aggressive standards currently in place for very cold climates to moderately cold climates.	Conduct research to make high-performance walls market viable (*e.g.* Passivhaus criteria/VIPs).
Existing walls	Initiate programmes to encourage retrofit to bring walls up to minimum performance levels comparable to moderately cold current building code standards.	Conduct research to bring existing walls up to very high levels of performance.
Roofs	Optimal attic insulation with air sealing, cool roofs in hot climates.	Explore advanced research to bring levels of performance up to best available.
Windows	Mandatory performance levels in cold climates equal to triple glazed performance, and low SHGC in hot climates, low-e windows mandated everywhere, promote retrofit window attachments.	Develop high-performance windows (U-value of 0.6 W/m^{2}K or lower) and dynamic windows.
New foundations	Enforce mandatory codes.	Find more affordable solutions.
Existing foundations	Find market-viable retrofit solutions.	Find more affordable solutions especially for interior applications.
Air sealing	Implement market-validated air-sealing requirements for new construction and apply to retrofits.	Find more cost-effective approaches and promote to less sophisticated markets.
Building material standards	Harmonise window ISO standards.	Develop harmonised ISO standards for new materials such as cool roofs, PCM, advanced insulation, etc.

Chapter 4

Heating and Cooling Technologies

Space heating, water heating and space cooling account for nearly 55% of global buildings energy use and represent the single largest opportunity to reduce buildings energy consumption in most regions of the world. A systems approach, including integration of heating and cooling needs with improved building envelopes, is necessary to achieve higher energy efficiencies and a low-carbon heating and cooling supply.

Key findings

- Space heating reductions account for 25% of buildings energy savings potential to 2050. Water heating and space cooling improvements together account for another 24% of savings.
- Inefficient use of biomass for space and water heating can be better utilised in high-performance stoves and fireplaces.
- Conventional electric storage water heaters need to be replaced with improved solutions, such as instantaneous gas-fired water heaters, heat pumps or solar thermal technologies.
- Greater effort is needed to dramatically increase investment in solar thermal heating, and barriers to greater implementation need to be eliminated.
- Co-generation equipment should be properly sized with building loads to avoid unnecessary costs and energy use. Modern optimised district heating and cooling systems that utilise waste heat and renewable resources need to be pursued, especially in fast-growing economies with major urban development.

Near-term recommendations

- Countries need to move towards mandatory standards for condensing boilers. As most heating and cooling installations are typically long-lived investments, it is critical that best available heating and cooling technologies are installed today in new buildings and deep renovations.
- Policies need to be put in place to avoid the use of electric resistance heaters as the primary source of heating in both new and existing buildings.
- Heat pumps are viable and cost effective and should be promoted through aggressive policy implementation.
- Development, commercialisation and deployment of cold climate heat pumps and small-scale thermal heat pumps are needed to reduce the large share of fossil-fuelled conventional heating systems. When powered from a lower carbon electric supply mix, electric heat pumps will have very low emissions.

Global energy consumption for space and water heating accounts for over half of energy use in the buildings sector. Space cooling accounts for an additional 4% of final energy use and has increased steadily as a portion of total energy consumption in buildings over the past decade, as buildings continue to add both heating and cooling capacity.

In OECD member countries, non-OECD Europe and Eurasia, energy consumption for space and water heating dominates building energy use (see Chapter 1). Energy consumption for cooling tends to be modest, although overall energy demand for space cooling has continued to increase steadily in both the residential and services sub-sectors. In most other non-OECD countries, other end-uses such as cooking and lighting typically represent a larger share of total buildings energy consumption, although space and water heating still represent more than half of overall buildings energy use in those regions. Water heating in particular may soon emerge in non-OECD countries as a significant energy consumer as incomes rise. Cooling also represents a significant potential source of future energy growth, especially as demand for space conditioning and comfort increases in non-OECD countries.

In both OECD and non-OECD countries, conventional heating and cooling technologies continue to dominate the buildings market. In 2010, 85% of global residential space and water heating was produced using fossil-fuel and traditional biomass-based equipment. In the services sub-sector, more than 65% of space and water heating was produced using fossil fuels, while an additional 25% was produced using electricity (Figure 4.1).

Increasing the energy efficiency of heating and cooling equipment is a critical step towards reducing energy consumption and emissions in the buildings sector. Heating and cooling loads in buildings need to be addressed through best available and advanced technologies that are significantly more efficient, both in terms of energy input and heat output. Effort is also needed on both technical and market maturity. Advanced products that have been commercialised but only serve niche markets need to be improved to become market viable, requiring a combination of efforts related to cost reduction, ease of installation and market conditioning. New technologies and products that have not yet been pursued or are in the initial development phase will need to be fully commercialised.[1] This will require significant policy intervention, including increased support for research, development, deployment and demonstration (RDD&D) of advanced heating and cooling technologies.

The IEA has highlighted the following three areas as being critical to advanced heating and cooling:

- heat pumps;
- solar thermal technologies;
- co-generation systems and modern distributed energy systems.

Vision for heating and cooling

In the 6°C Scenario (6DS), as set out in the IEA *Energy Technology Perspectives 2012 (ETP 2012)*, building heating and cooling needs continue to be dominated by conventional technologies and fossil fuels. By 2050, heating and cooling loads in buildings are expected to increase by roughly 40% over 2010 levels, where nearly 70% of additional space heating demand and

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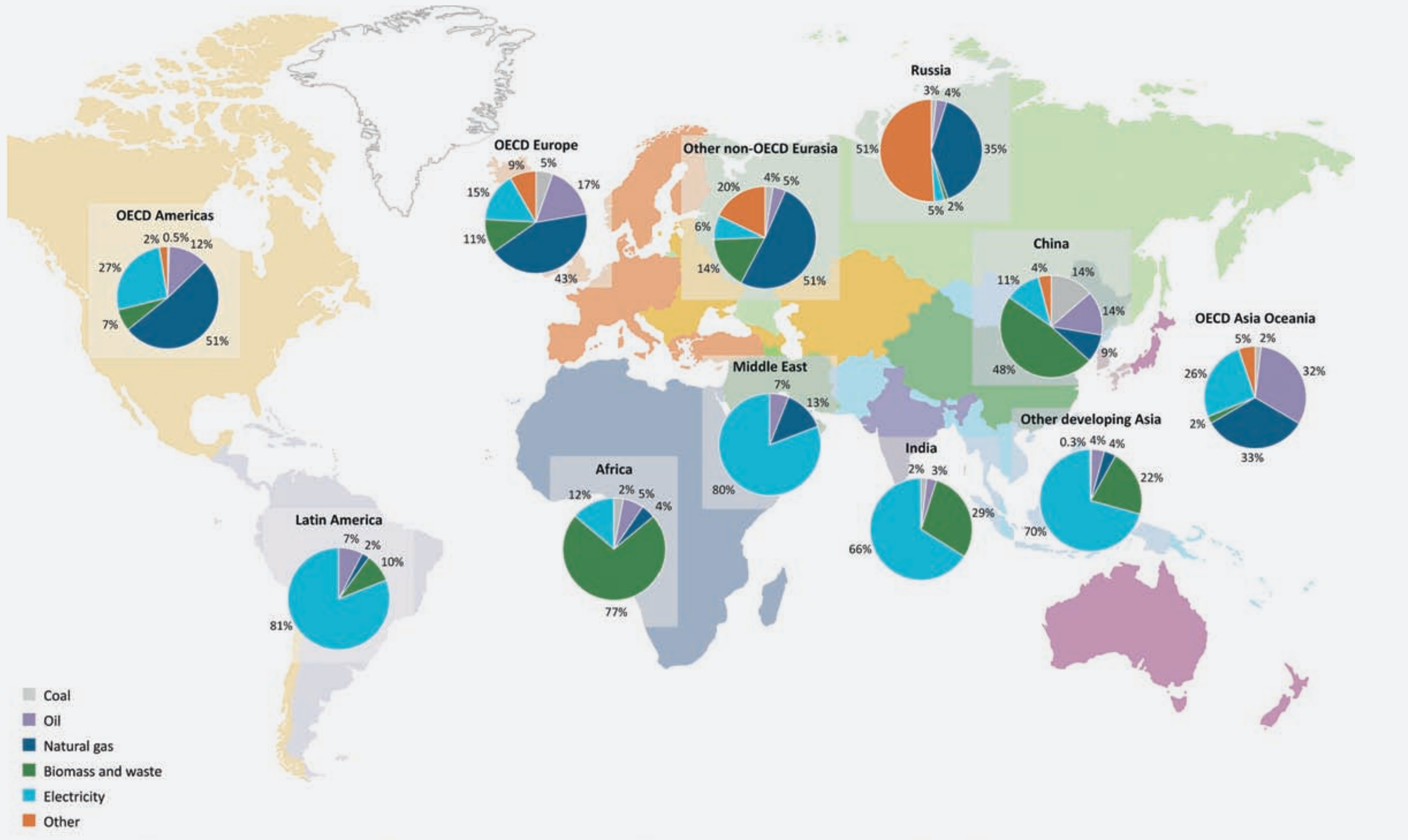
[1] Chapter 6 (Policies for Buildings) discusses the full commercialisation path in detail.

Figure 4.1 Heating and cooling consumption by region for different types of fuel in 2010



This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

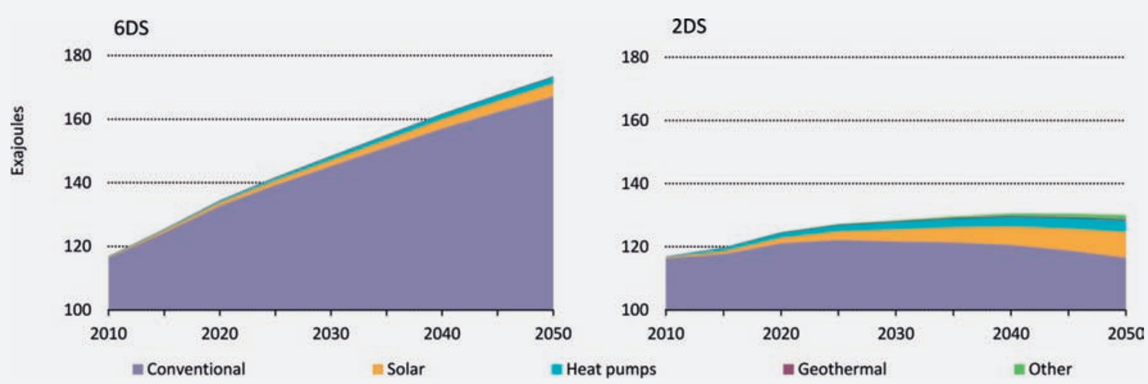
Source: unless otherwise noted, all tables and figures in this chapter are derived from IEA data and analysis.

Key point *Conventional technologies using fossil fuels and electricity continue to dominate heating and cooling in the buildings sector.*

more than 60% of additional water heating demand will come from the residential sub-sector. Space cooling energy use is expected to increase by 150% between 2010 and 2050, with cooling demand in non-OECD regions in particular expected to increase as much as 5.5-fold.

To achieve a 2°C Scenario (2DS) target, total energy consumption for space heating, cooling and water heating in the buildings sector needs to decrease by more than 25% over 6DS levels by 2050 (Figure 4.2). These savings are attributed to a combination of improved building energy intensities (*i.e.* decreased heating and cooling loads from improved building envelopes) and widespread adoption of advanced heating and cooling technologies. It is notable that conventional heating and cooling systems, such as condensing boilers, high-efficiency gas-fired water heaters and high-efficiency biomass heating equipment, will still play a role in energy savings through efficiency improvements to 2050. However, there is limited improvement potential left in most of these conventional technologies with respect to theoretical and practical efficiency boundaries, and long-term solutions will require their progressive phasing-out in favour of advanced technologies.

Figure 4.2 Heating and cooling energy use through improved technologies in the 2DS



Note: other includes non-conventional heating and cooling energy sources, such as gas thermal heat pumps and advanced district heating and cooling (DHC).

Key point *Efficient heating and cooling technologies, such as heat pumps, solar thermal and co-generation units, need to be scaled up significantly in order to meet energy and emissions objectives.*

First and foremost, building envelope improvements, distribution improvements (*e.g.* properly sealed and insulated pipes and ventilation ducts) and whole-building policies are critical to reducing the underlying need for space heating and cooling (see Chapter 3 on building envelopes and Chapter 6 on building policies). These improvements are especially critical in new buildings and deep renovations, where there are immediate opportunities to achieve higher building efficiencies and implement best available technology (BAT). Given the long lifespan of buildings and most heating and cooling equipment, it is vital that opportunities to significantly improve building efficiencies are not wasted.

Technical improvements in heating and cooling systems are also needed. The objectives set out in the 2DS will not be feasible without significant investment in RDD&D of advanced heating and cooling technologies. In existing buildings, heating and cooling energy demand can be addressed through the progressive replacement of conventional, inefficient heating and cooling technologies with more efficient equipment and readily available, cost-effective advanced technologies (Table 4.1). This includes condensing boilers and water heaters, high-performance air- and ground-source heat pumps and instantaneous gas water heaters. Traditional biomass stoves and water heaters should be replaced at the very least with high-efficiency fireplaces and stoves, while electric resistance heaters should increasingly be replaced with heat pumps. Gradually, heat pumps and other advanced heating and cooling equipment should replace these conventional technologies.

Table 4.1 Examples of typical efficiencies and costs of heating technologies today

	Efficiency (%)	Typical capital cost (per joule of useful heat)	Fuels	Operating cost (per joule of useful heat)
Conventional boilers/furnaces	60-84	Low-medium	Oil, natural gas	Medium-high
Condensing boilers	85-97	Medium	Oil, natural gas	Medium-high
Wood stoves/furnaces	< 70	Low	Biomass	Low-medium
High-efficiency fireplaces	70-80	Low-medium	Biomass, natural gas	Low-medium
Pellet stoves	75-85	Low-medium	Biomass	Low-medium
Masonry heaters	80-90	Medium	Biomass	Low-medium
Electric resistance heaters	100[1]	Low	Electricity	Medium-high
Heat pumps (electric)	200-600[2]	Low-medium (air conditioning)/ medium-high (space/water heating)	Electricity	Low-medium
Heat pumps (gas-driven)	120-200[2]	Medium-high	Gaseous fuels	Low-medium
Sorption chillers	70-180[2, 3]	Medium	Natural gas, oil, bioenergy, solar, waste, heat, etc.	Medium-high
Solar thermal[4]	100	Low-high	Solar	Low-medium

[1] Most electricity supply in the world is very inefficient and has high carbon emissions. Even though an electric furnace may be 100% efficient, in general, electric forced-air systems tend to have low efficiencies.

[2] Efficiencies above 100% indicate that for every unit of energy consumed, more than one unit of energy-equivalent output is achieved. For instance, a 300% efficient heat pump outputs three units of heat equivalent for each unit of energy consumed (or 2-to-1 output).

[3] Today's sorption chillers used for space cooling typically have efficiencies around 70%, while heating using sorption chillers typically ranges from 130% to 180%.

[4] Refers to solar thermal systems and not solar photovoltaic (PV) equipment used for electricity production.

Note: capital and operating costs (per joule of useful heat) depend on local energy prices and are estimates compared to average lifecycle costs.

Space heating

Conventional heating systems, including boilers, biomass-fired stoves and electric resistance systems, are regularly used in the buildings sector for space and water heating needs, either as individual application technologies or as combination water and space heating systems. Considerable efficiency improvements in space and water heating are possible through available, high-efficiency conventional technologies that are already market viable, including condensing boilers and heat pumps. This is a critical first step as heating equipment in existing building stocks is replaced. However, progressive shifts to highly efficient technologies, such as advanced heat pumps and solar thermal technologies, are necessary.

The following sections describe the main heating technologies used in the buildings sector as well as their typical efficiencies, limitations and expected technical developments.

Traditional boilers and furnaces

Traditional boilers and furnaces tend to have low to medium efficiencies of less than 80%. In addition to the limitations of their technical design (as compared to condensing boilers and furnaces, discussed later in this chapter), distribution losses and high combustion temperatures can significantly increase energy use, especially in large buildings. System design can similarly affect heating efficiencies. For instance, combination space and water heating boiler systems are typically less efficient than separate boiler and water heating distribution systems, especially in warmer months when hot water demand requires boiler operation that would otherwise not be needed. Forced steam heating systems are also generally less efficient than hot water boiler systems, as they operate at higher temperatures to produce steam.

Conventional furnaces and boilers dominate heating markets in most OECD countries because of relatively modest capital costs and historically low operating costs. They are also versatile in that they can be used in almost any type of property. For instance, central heating systems that use building-scale boilers continue to be one of the most popular options for space heating in both residential and commercial applications in Europe. An estimated 59% of households in the European Union in 2005 had natural gas boilers for heating purposes, and an additional 20% had oil-fired boilers (Kemna *et al.*, 2007a). Between 2007 and 2011, boilers continued to lead market sales in Europe, and the share of boiler sales with respect to other heating technologies increased by 2% in 2010 (Eljidi, 2011).

Nearly 72% of energy consumed for space heating in the United States and Europe in 2010 was from fossil fuels used in traditional heating technologies. Gas-fired systems in particular accounted for nearly half of total heating energy use (Table 4.2), although overall sales of gas and oil boilers have been decreasing in recent years. In other OECD regions and non-OECD European and Eurasian countries, natural gas remains one of the most common fuels for space and water heating, especially in regions with strong gas distribution networks. The share of fossil fuels and natural gas in Russia and China are smaller than in OECD countries. However, these lower shares can be explained by greater use of conventional district heating (Russia) and biomass (China), which could be improved considerably through improved heating and co-generation technologies.

Condensing boilers and furnaces

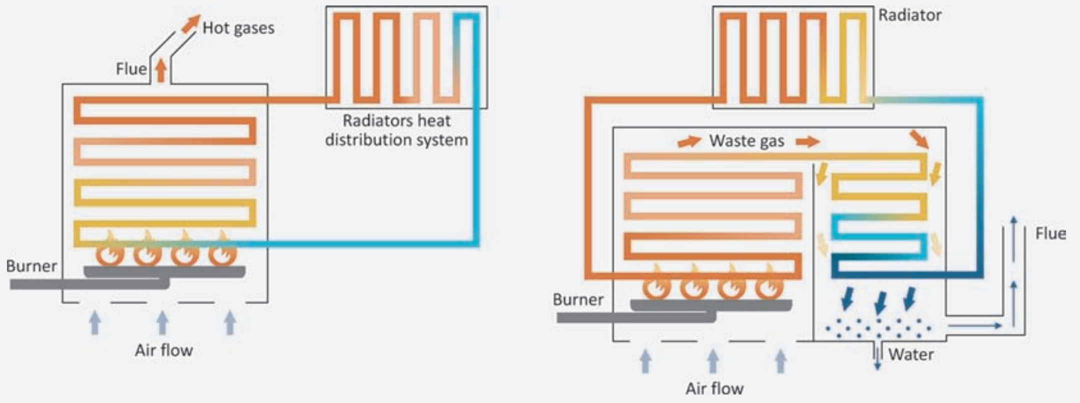
In a traditional, non-condensing boiler or furnace, hot gases from the combustion process are passed through a heat exchanger and vented out through a flue. Condensing boilers and

Table 4.2 Share of fossil fuels and biomass in space heating for selected regions in 2010

Principal heating regions	Share of fossil fuels (of which natural gas)	Share of biomass
OECD Americas	77% (62%)	8%
OECD Europe	69% (46%)	12%
OECD Asia Oceania	74% (33%)	3%
Non-OECD Europe and Eurasia	62% (52%)	15%
Russia	42% (35%)	2%
China	41% (10%)	53%

furnaces utilise the latent heat of water to increase system efficiency. Hot gases are passed through a second heat exchanger to condense water vapour produced in the combustion process. As the water vapour is condensed, heat is transferred back to the system return, which lowers the combustion temperature gradient. Remaining gases are expelled through a fan-assisted balanced flue (right-hand side of Figure 4.3).

Figure 4.3 Flow system of non-condensing boiler (left) and condensing boiler (right)



Source: Microgreening, 2012.

Key point *Condensing boilers take advantage of latent heat in water to increase system efficiency.*

The efficiency of a typical non-condensing boiler or furnace is around 70% to 84% (very old boilers and furnaces can have efficiencies as low as 60%), whereas condensing boilers and furnaces typically have efficiencies above 90% (ACEEE, 2012). Natural gas is the most common fuel used with condensing boilers, but they can also operate using fuel oil or liquefied petroleum gas (LPG).

In the United States, boiler systems have been given ENERGY STAR[2] ratings that indicate that products meet strict energy efficiency guidelines set by the United States Environmental Protection Agency. ENERGY STAR qualified boilers have annual fuel utilisation efficiency (AFUE) ratings of 85%[3] or greater (US EPA, 2012). Condensing boilers can have an AFUE that is 95% or more, where additional boiler technology improvements can raise the AFUE to as high as 97% (US DOE, 2012a). These improvements include:

- electronic ignition, which eliminates the need to have the pilot light burning all the time;
- new combustion technologies that extract more heat from the same amount of fuel;
- sealed combustion using outside air to fuel the burner, reducing drafts and improving safety.

Condensing boilers offer a unique systems approach that is beneficial to new construction and some retrofits. With lower flue temperatures, exhaust chimneys can be made of lower-cost materials. For example, low-cost polymers can be used and exhausted horizontally, which can

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[2] ENERGY STAR is a voluntary labelling programme that initiated in the United States but is now used in several countries. More details are provided in Chapter 5 on buildings policies.

[3] While the criterion is set at 85%, the vast majority of condensing products are at least 90% efficient.

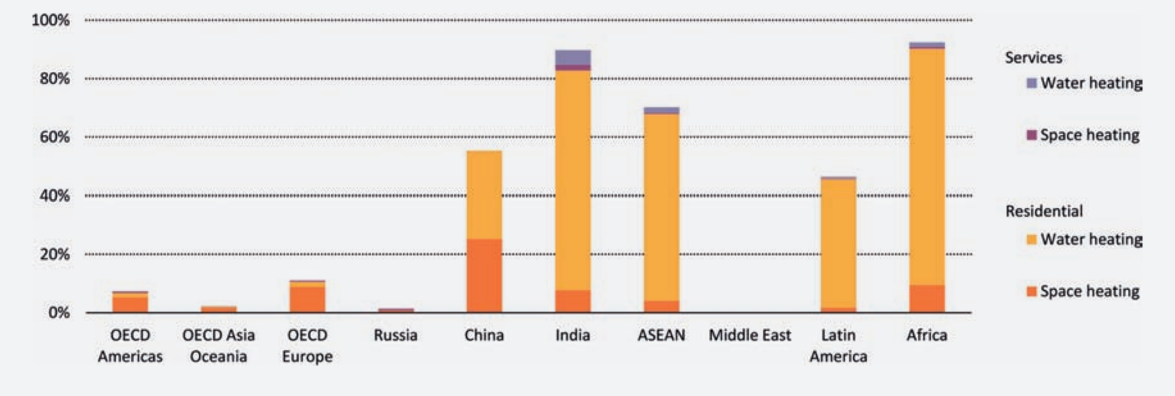
be much easier and less costly to install than conventional chimneys. In retrofit applications with existing chimney or flue stacks, installing a condensing boiler can be more complex, although if chimney upgrade is needed anyway, a low-cost polymer, horizontally vented system or a non-corrosive[4] polymer chimney installation often can be used to reduce the price premium associated with the condensing boiler.

Additional improvements that can be applied to both regular and condensing boilers and furnaces include flue or vent dampers to prevent chimney losses from incoming air when the equipment is not firing, and intermittent ignition devices that replace continuous pilot lights in older boilers and furnaces. Modulating aquastats, also known as outdoor resets, can also be applied to hot water boilers to control and adjust the temperature of hot water in the boiler depending on exterior temperatures (*e.g.* during warmer summer months). The devices can save between 5% and 10% on fuel consumption for space and hot water heating (US DOE, 2012b). Programmable thermostats that adjust heating and cooling needs according to a preset schedule likewise can save between 5% and 15% on existing heating and cooling systems (US DOE, 2012c).

Biomass heaters

Nearly 30% of global space and water heating is produced using biomass. Broken down by end-use, this means that roughly 25% of global energy used for residential space heating and nearly 55% used for residential water heating is produced using biomass. Biomass used for water and space heating ranges from open fires to high-efficiency stove technologies. In OECD countries, biomass use ranges from less than 5% of space and water heating to as much as 35% in cold northern and Nordic climates, although the OECD average remains less than 10% (Figure 4.4). In many non-OECD countries, solid fuel (*e.g.* wood and cattle dung) is still a common means of heating buildings and water. Traditional biomass accounts for as much as 90% of space and water heating energy use in some developing regions. In India, Association of Southeast Asian Nations (ASEAN) countries and Africa, more than 70% of household space and water heating is produced using biomass.

Figure 4.4 Share of biomass in space and water heating energy consumption for selected regions in 2010



Key point *Biomass use for space and water heating remains high in many non-OECD regions and often includes the use of open fires to heat rooms and water.*

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[4] Condensing boilers have acidic condensate than can be problematic for mortar joints in some existing chimneys and can add cost to installation compared to a conventional boiler.

Significant efficiency improvements in the use of traditional biomass are possible, especially in regions where its share in space heating is high. This includes not only many non-OECD regions, where biomass remains the principal means of heating residential spaces, but also many colder OECD regions, such as Canada and Nordic European countries, where biomass is often used as a primary or secondary means of heating homes. For instance, 40% of total heat demand in Sweden in 2008 was supplied by biomass (IEA, 2010a).

The adoption of more efficient biomass burning technologies, such as high-efficiency fireplaces, advanced catalytic combustion wood stoves and pellet stoves can drastically improve the efficiencies of biomass burning applications in the buildings sector. They likewise can significantly improve the emissions of exhaust gases, including dangerous pollutants, such as carbon monoxide and particulate matter. Modern biomass applications also include combined heat and power production (see section on co-generation and waste heat opportunities), which is more efficient than production of electricity or heat alone and can achieve conversion efficiencies of around 70% to 90% (IEA, 2010a).

Traditional fireplaces and wood stoves

Open fires, traditional masonry fireplaces and wood stoves are commonly used for space and water heating, especially in developing regions. Open fires and unvented wood stoves are inefficient and emit large quantities of air pollutants, including carbon monoxide, particulate matter and nitrogen oxides. Open masonry fireplaces are also energy inefficient and draw in large amounts of heated room air for combustion and release it as exhaust. Vented wood stoves are more efficient than traditional open fires, although they still generally have efficiencies less than 70%. They also tend to emit high quantities of hazardous air pollutants. By contrast, new catalytic stoves have higher efficiencies of between 70% and 80% and produce significantly fewer exhaust gases (US DOE, 2012d). These advanced combustion stoves also tend to be safer because the burning of combustible gases helps to prevent build-up of creosote (flammable chimney deposits). The same technology (a catalytic damper) can be applied to existing wood-burning appliances to raise energy efficiency and lower combustible emissions.

High-efficiency fireplaces and masonry heaters

High-efficiency fireplaces and fireplace inserts significantly improve fireplace efficiency by applying burning technologies similar to advanced combustion wood stoves. These include fitted flue collars and tightly fitted fireplace doors, a firebox with an insulated convection shell and heat exchangers. Some advanced fireplaces can also be adapted with ducts to distribute heat throughout a building (US DOE, 2012d).

Masonry stoves are generally much more efficient than traditional wood stoves and produce more heat and less pollution. The combination of a masonry mass (*e.g.* refractory concrete) with a system of exhaust channels inside the firebox allows masonry heaters to achieve burn efficiencies of as much as 90% while maintaining high temperatures over long periods of time (US DOE, 2012d). A small hot fire built once or twice a day can be enough to heat a house for as long as 12 hours to 20 hours. However, the absorption and heat release process of masonry heaters means that they cannot produce heat quickly from a cold start.

Pellet stoves

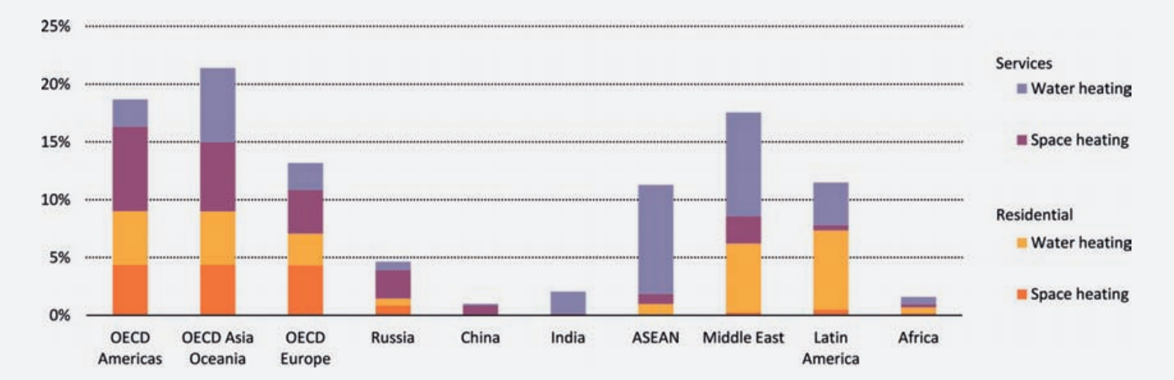
A pellet stove is a biomass-fired space heating device that burns small pieces of solid fuel, or pellets. Pellets can be made from numerous biomass sources, including sawdust, waste paper, corn kernels and small wood chips. Wood pellet stoves, which are the most common, burn wood pellets made mostly of wood sawdust that has been compacted under high pressure. There are also multi-fuel pellet stoves capable of burning combinations of biomass pellets with other solid fuels.

In general, pellet stoves have higher combustion and heating efficiencies than other conventional wood-burning technologies and they tend to produce fewer emissions because of cleaner burning. Most pellet stoves have combustion efficiencies in the range of 80% to 85% (US DOE, 2012d) and they typically have a capacity large enough to heat a house or an apartment building. When they are operated at nominal thermal output, efficiencies of 90% or higher can be achieved (van Loo and Koppejan, 2007).

Electric resistance heaters

Roughly 15% of global space and water heating is produced using electricity. In OECD countries, electricity accounts for between one-quarter and one-third of total water heating energy consumption and 5% to 15% of household space heating. In China, India, ASEAN countries and most of Africa, electricity accounts for less than 5% of residential water and space heating, although this rises to as much as 21% in other non-OECD regions (Figure 4.5). In the services sub-sector, electricity accounts for nearly one-quarter of global services water and space heating.

Figure 4.5 Share of electricity in space and water heating energy consumption for selected regions in 2010



Key point *Nearly 10% of global space and water heating energy use is from electricity and can be significantly higher in many OECD countries.*

Electric resistance heating is highly efficient, in principle, because nearly all of the electrical energy is converted into heat (US DOE, 2012e). Electric resistance heaters can have several forms, although they are most commonly used in electric furnaces, baseboard or wall heaters and increasingly radiant floor heating. Electric furnaces in forced-air systems deliver heated air by blowers through ventilation networks, while baseboard, wall and radiant heating systems generally provide heat directly to a space.

Forced-air systems are more common in North America than in other regions and they are generally used in dual heating and cooling applications. While electric furnaces may have high operating efficiencies as a heating system, electric forced-air systems tend to have low to moderate energy efficiencies because heating, ventilation and air-conditioning (HVAC) distribution systems are often inefficient (Box 4.1). Radiant heat losses and air leakage in distribution systems can reduce HVAC efficiencies considerably and make them more expensive to operate than other electric resistance heaters (*e.g.* electric baseboards). This is particularly true if the electric furnace or system ductwork is located in unheated areas (*e.g.* attics or crawl spaces).

Electric baseboards and wall heaters generally distribute heat using a local heating element to a surrounding grid of fins (*e.g.* aluminium casing) or a reflective element with insulation on the back of the unit. These units can also have a fan to distribute heat throughout a space. Both electric baseboards and wall units can be slow to respond to temperature changes, and their energy consumption is highly dependent on the thermal insulation of the space (*i.e.* the building envelope).

While electric resistance heaters have high technical efficiencies (*i.e.* high efficiency in the conversion of electricity to heat), this does not imply that they are efficient with respect to overall energy consumption. The source of electricity generation (*e.g.* coal, gas or oil), conversion and heat losses in the electricity generation process and transmission losses from electricity supply all play a strong role in the relative energy effectiveness of electric resistance heaters. It is also not the most effective form of electric space and water heating: electric heat pumps (described later in this chapter) can achieve the same heat outputs using significantly less energy.

Box 4.1 Distribution system consideration for heating and cooling loads

Distribution systems that deliver heating and cooling to conditioned spaces can significantly affect total energy consumption. HVAC systems in the services sub-sector are often installed on the roof or exterior of buildings, which reduces system efficiencies owing to exposure to solar heat and environmental conditions. Large services buildings also routinely use air distribution systems, and duct leakage has a major impact since air flow and air blower motor power have a “cube”[5] effect. Thus, proper duct sealing through application of mastics and appropriately rated sealing tapes are essential and should be validated with duct leakage testing.

In some regions, distribution systems are routinely installed in unconditioned spaces, such as attics and crawl spaces. Older, unsealed ductwork with improper insulation can reduce cooling and heating system efficiencies by up to 20% (US EPA, 2009). For new construction, ductwork therefore should be incorporated within a building’s thermal shell. While the number of builders adopting this approach has increased, it is still not common practice. Renovations should include sealed and insulated ducts with validated test performance.

Distribution concerns are not limited to air ducts. Older thermal piping systems for hot water and steam distribution have similar concerns, with piping being installed in exterior walls with minimal or no insulation. Retrofitting insulation to piping in exterior walls is difficult, but during major building renovations, piping insulation can be significantly improved. Chapter 3 describes improving thermal envelopes by adding exterior insulation during wall recladding, and this would significantly improve problems with old, uninsulated distribution pipes and ductwork. New hot water systems can also be installed within the thermal shell.

Another increasingly common form of heating in buildings is radiant heat. Generally in the form of hydronic floor systems, modern radiant heat systems provide heat directly to floors through a tube network that is generally laid in a concrete layer underneath the floor. Electric resistance radiant systems also exist, although these should be avoided unless the source of electricity is from a low-carbon source, and heat pumps are a better alternative. In both cases, it is critical to sufficiently insulate the floor to ensure heat is distributed to the intended space and not lost to the ground or surrounding environment.

Heat pumps

Heat pumps are a versatile technology that can be used to provide space heating, cooling and hot water, with the possibility of providing all three services from one integrated unit. In 2010, heat pumps accounted for roughly 8% of global space heating and cooling energy

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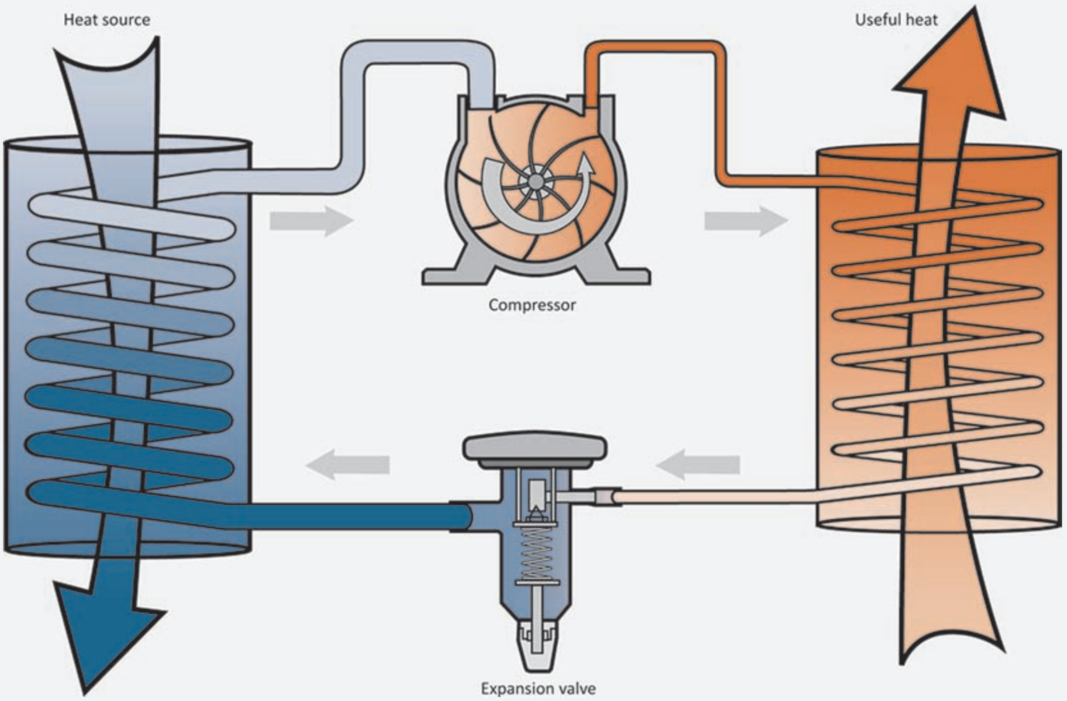
[5] The equation for fan power requires an increase to the third power for every additional unit of air flow. If there is a requirement for a minimum amount of fresh air being distributed to a space at the end of the duct run, then any leakage in the ducts will require much more power to satisfy the requirement.

consumption, where more than three-quarters of heat pumps are used for space cooling (*e.g.* air conditioners). Asia dominates the total installed number of heat pumps, with an estimated 400 million room air conditioners in the residential and services sub-sectors in 2009 and an additional 46 million packaged air conditioners (IEA, 2011). Heat pumps are also increasingly used for heating or combined heating and cooling systems, although their share of the global heating market is still less than 1%.

Heat pumps are a mature technology that transfers thermal energy from a heat source to a heat sink using a vapour compression cycle that takes advantage of natural heat gradients (Figure 4.6). Most heat pumps use an electric motor to drive the vapour compression cycle, although other cycles exist, including thermally driven heat pumps that are used predominantly for air conditioning. There is a limited number of solar thermal heat pump cooling systems installed globally.[6]

Figure 4.6 Basic concept of a heat pump



Source: Heat Pump Centre, 2012.

Key point *Heat pumps move heat, rather than generating heat, and typically achieve coefficients of performance (COPs) of three or more.*

Heat pumps stand out from other technologies because they convert low-grade heat into useful heat using a natural temperature gradient. Even in winter, heat can be extracted from outside air, water and the ground so long as the working refrigerant in the heat pump is lower than heat source temperatures. They typically achieve point-of-use efficiencies greater than

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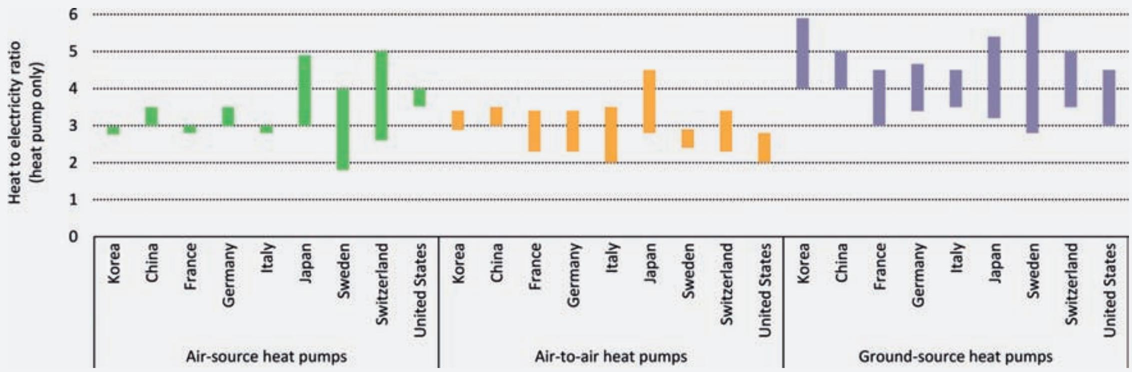
[6] While solar thermal cooling is basically a heat pump technology, it will be addressed in detail within the solar thermal section later in this chapter. 2010 data showed only 1 000 units installed globally (IEA 2012a).

250%: that is to say, they provide more useful heat input or output (in energy terms) than the equivalent energy (*e.g.* electricity input) used to run the appliance.

Heat pump efficiencies can be described by their performance under test conditions using a coefficient of performance (COP). For example, a heating COP of three is equivalent to 300% efficiency[7] (*i.e.* three units of useful heat for one unit of commercial energy input). Heat pump performance and efficiencies have increased considerably over the past 30 years. For instance, the COP of the best performing air conditioners (ground-source heat pumps) has increased from less than three to between five and six, with typical air-to-air COPs ranging from two to four in most regions (Figure 4.7).[8] These performance improvements have been achieved through advances in individual components as well as through better system integration.

Figure 4.7

Typical operating efficiency ranges for heat pumps in heating and cooling modes by technology[9]



Source: IEA, 2012b.

Key point *The efficiency of heat pump technologies varies greatly by region and specific installation, and it is generally higher for GSHPs than for ASHPs.*

Room for improvement still remains despite recent improvements in heat pump efficiencies. Current heat pump designs have yet to approach the theoretical limits of performance, and the prospects for significant cost reductions and efficiency improvements, particularly for space heating applications, are good (Martinus *et al.*, 2005). Cost reductions and heat pump efficiency improvements in immature markets are also likely to be rapid and follow the pattern established in countries with strong heat pump markets.

Currently, ground-source heat pumps (GSHPs) tend to be the largest and most expensive systems, while air-source heat pumps (ASHPs) for water heating (*i.e.* air-to-water) fall between GSHPs and split reversible air-to-air units (Table 4.3). Water-to-water and water-to-air heat pumps (not shown in Table 4.3) are typically more efficient than ASHPs, although they also

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[7] However, annual performance does not always result in the efficiency equivalent to a COP rating because performance degrades in colder and below freezing temperatures. Consequently, a seasonal performance factor (SPF) is increasingly used to distinguish performance under typical operating conditions and average annual operating efficiencies, taking into account seasonal operating performances. SPF data is not widely available.

[8] COPs are not directly comparable across countries due to differing technical specifications and test procedures.

[9] The standards and names used to express annual energy performance differ between Asia, North America and Europe. The International Organization for Standardization (ISO) is working on a global standard for a standard performance calculation called the annual performance factor (APF).

tend to be more expensive. Wide variations exist for typical values in different regions, due to different sizing and specification of systems, local standards and consumer preferences. The maturity of local markets also has a big impact on heat pump costs, particularly for larger GSHP systems.

Table 4.3 Technology and cost characteristics of heat pumps for residential heating and cooling in 2008

	North America	Europe	OECD Pacific	China and India
Typical size (kW_{th})	2-20	2-15	2.2-10	1.5-25
Economic life (years)	15-20	7-30	8-30	7-20
Air-to-air installation cost (USD/kW_{th})	360-625	558-1 430	400-536	180-225
Typical efficiency (%)	220-350	220-350	250-450	220-350
Air-to-water installation cost (USD/kW_{th})	475-650	607-3 187	560-1 333	300-400
Typical efficiency (%)	250-440	250-440	250-410	250-350
GSHP installation cost (USD/kW_{th})	500-850	1 170-2 267	1 000-4 000	439-600
Typical efficiency (%)	280-500	280-500	280-500	280-500

Note: kW_{th} = kilowatt thermal.
Sources: IEA, 2011; Kemna *et al.*, 2007b, c; Navigant Consulting, 2007.

ASHPs

ASHPs are the most common form of heat pump and are most commonly used in air-conditioning systems. They are typically relatively inexpensive and are applicable almost everywhere, although they tend to have lower performance levels in colder climates. This is mainly due to high-temperature differences and the energy needed to defrost the evaporator as temperatures fall below freezing levels. In warmer regions, ASHPs generally have COPs of three or higher (US DOE, 2012f), while COPs of five or more have been achieved in some countries. Cold climate ASHPs (discussed below) are also increasingly entering the market. For instance, some Japanese companies already provide heat pumps that can be used in temperatures as low as -25°C with COPs of up to three (ETSAP and IRENA, 2013).

Technical advances have greatly improved ASHP performance and efficiencies over the past 30 years. Improvements include multi- and variable-speed compressors and improved electric motors, as well as variable-speed blowers and thermostatic expansion valves for more precise control of refrigerant flow. Overall, the efficiency of modern ASHPs is about 1.5 to 2 times greater than models available 30 years ago (US DOE, 2012f), and additional technical improvements promise to improve seasonal performance at below freezing temperatures.

Water-based and GSHPs

Water-based heat pumps and GSHPs use a heat exchanger loop in a local body of water or buried in the ground as a source of heat for space heating and cooling, where relatively constant water and ground temperatures often provide a more stable heat source for heating and cooling. As a result, they typically have higher efficiencies than ASHPs, although they are generally more expensive to install and maintain because of the necessary looping systems. Additional electricity for any necessary pumping of fluids in the looping system can also raise operational expenses, although high efficiencies, typically above 300%, mean that investment and maintenance costs are generally returned in energy savings over a relatively short period (US DOE, 2012g).

Both water-based heat pumps and GSHPs offer additional advantages over conventional heating and cooling systems and ASHPs. For instance, deep-water lake systems can be very attractive for cooling large buildings, where deep-water temperatures are often low enough that the heat pump does not need to be operated to transfer heat (*i.e.* "free cooling"). Similarly, one particular advantage of water-based heat pumps and GSHPs is that they can produce natural thermal storage. During warm months, when the system is in active cooling mode, heat can be rejected to the ground or water source (*e.g.* a local aquifer) through geothermal loops, which, to varying degrees depending on local geology, can keep the ground or groundwater substantially warmer than the surrounding area into the winter. This raises the performance of the heat pump when used for heating in colder seasons. In regions were cooling loads are modest, ground temperature can also be sufficient to meet cooling needs without the use of the heat pump.

Cold climate ASHP

Conventional heat pumps are not highly efficient in very cold climates because of large temperature lifts[10] and often the need to heat (defrost) system coils at sub-freezing temperatures. ASHPs in moderately cold climates function with a defrost cycle that is an energy penalty, because electric resistance heat is used to provide adequate supply temperature to the conditioned space while the heat pump coil is defrosting. Despite this, their efficiency over the entire heating season that includes fluctuating temperatures is usually at least 2.5 times greater than a heating system relying purely on electric resistance heaters. When ambient temperatures drop too low (approximately -10°C to -25°C), ASHP performance deteriorates, causing the heat pump to have the same efficiencies as a typical electric resistant heater.

Cold climate and all climate heat pumps are two notable developments that are increasing the useful temperature range of ASHPs in colder climates. They generally use a secondary booster compressor and a plate heat exchanger to extend performance range well below freezing temperatures. Currently, the Implementing Agreement (IA) for a programme of research, development, demonstration and promotion of heat pumping technologies (HPT) has a research project underway to improve the performance of heat pumps in cold climates. The core area for improved performance is highly technical and involves a variety of options related to the refrigeration cycle (Figure 4.8). Initial modelling analysis on the HPT IA project for a northern United States application shows a reduction in energy consumption of 15% over a conventional ASHP, with operating cost reduced by 25% and CO_2 emissions by 33% (Groll, 2012). In Japan, AHSPs that can be used at -25°C are already on the market (ETSAP and IRENA, 2013).

Thermally driven heat pumps

Thermally driven heat pumps operate on the same principle as a vapour compression cycle. Instead of mechanically compressing a working fluid using a motor, thermally driven technologies use heat to drive the heat pump process. In recent years, large-scale, thermally driven heat pumps have become more common, especially where using gas incurs lower costs than using electrically driven chillers. Regulations and incentives to reduce electricity demand during peak hours have also encouraged increased adoption of thermally driven gas heat pumps.

Absorption heat pumps are the most common sorption-based technology and are commercially available in a wide range of capacities and designs. Absorption heat pumps (and chillers) use a

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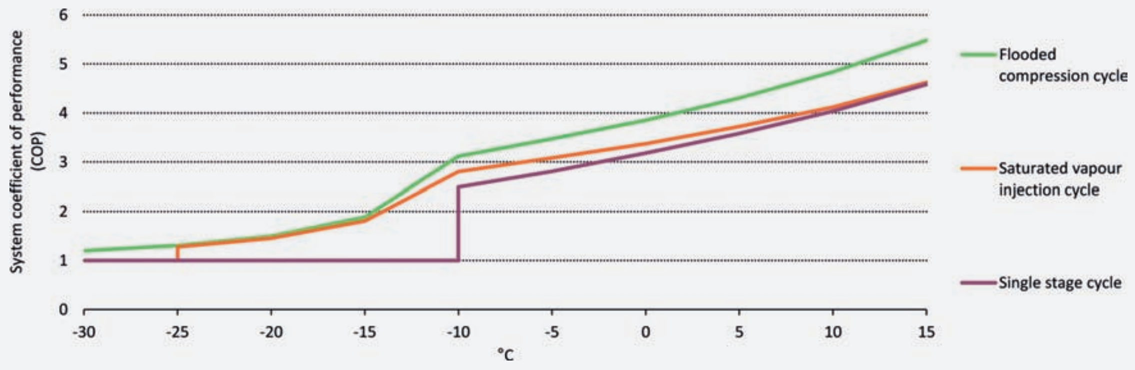
[10] The lift (or required transfer of heat by the heat pump) increases with larger difference between heating temperature demand and exterior temperatures. Increased lifts require more energy input and reduce overall heat pump performance.

Figure 4.8 Cold climate heat pump performance compared to conventional heat pump



Source: Groll, 2012.

Key point *Cold climate ASHPs can extend performance into a much colder range, making them viable for more applications, especially when combined with low-carbon electricity sources.*

refrigerant and an absorbent that have high affinity for each other (*i.e.* one dissolves easily in the other). The two most common systems are ammonia and water, in which ammonia is the refrigerant and water the absorbent, and water and lithium bromide, in which water is the refrigerant and lithium bromide is the absorbent. The heat to drive the process is normally provided by burning oil or natural gas, although waste heat can also be used.

Absorption heat pumps can be direct-fired or indirect-fired, and they can be single-effect or double-effect.[11] Single-effect pumps, using a simple refrigerant-sorbent absorption process, typically need heat with temperatures in the range of 80°C to 100°C and achieve a COP of about 0.7. Double-effect cycles use two generators working at different temperatures and operating in series. This more efficient double-effect cycle, currently used in large systems, obtains higher COPs in the range of 1.1 to 1.2 for cooling and a COP of two for heating. It typically requires driving temperatures in the range of 140°C to 160°C. Indirect-fired, double-effect absorption pumps require steam at around 190°C, while less efficient (but also less expensive) single-effect indirect-fired systems require hot water or steam at 75°C to 132°C. This background is important since it shows that higher source temperatures generally produce higher COPs. Higher temperatures also have higher pressures and generally lead to higher manufacturing cost due to the need for more robust equipment.

Recent developments in thermal heat pumps for small-scale purposes (*e.g.* single dwellings) are promising. In buildings with existing natural gas equipment, these small-scale, thermally driven heat pumps have the potential to outperform condensing gas boilers. Two pre-commercial gas adsorption thermal heat pumps developed for field testing under the HPT IA have demonstrated COPs in the range of 1.1 to 1.2, which is potentially 20% more efficient than the best natural gas heating technologies. With additional research and development (R&D), small-scale gas thermal heat pumps with COPs of 1.2 or higher can become available to replace gas boilers.

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[11] Double-effect absorption cycles capture some internal heat to provide part of the energy required. The capture of this heat reduces the steam or natural gas requirements and increases overall efficiency.

Hybrid heat pump systems

Hybrid heat pump systems offer the potential for very high efficiencies for heating and cooling by taking advantage of other heat sources to help reduce temperature lifts. This can include geothermal, solar-assisted and thermally-driven technologies, as well as a combination of traditional heat pump technologies (*e.g.* GSHPs and ASHPs) paired with co-generation units using waste heat from the production of electricity. When heat and power loads are in balance, these hybrid systems would reduce overall electricity load profiles while meeting heating and cooling needs (Figure 4.9). Co-generation and heat pump hybrid systems would also reduce the impact of peak electricity demand on energy grids.

Figure 4.9 Daily electricity load profile using a mix of heat pumps and co-generation for space heating

Source: IEA, 2012b.

Key point *The simultaneous use of co-generation and heat pumps flattens the load profile and reduces the upstream impact of both energy technologies on the electricity system.*

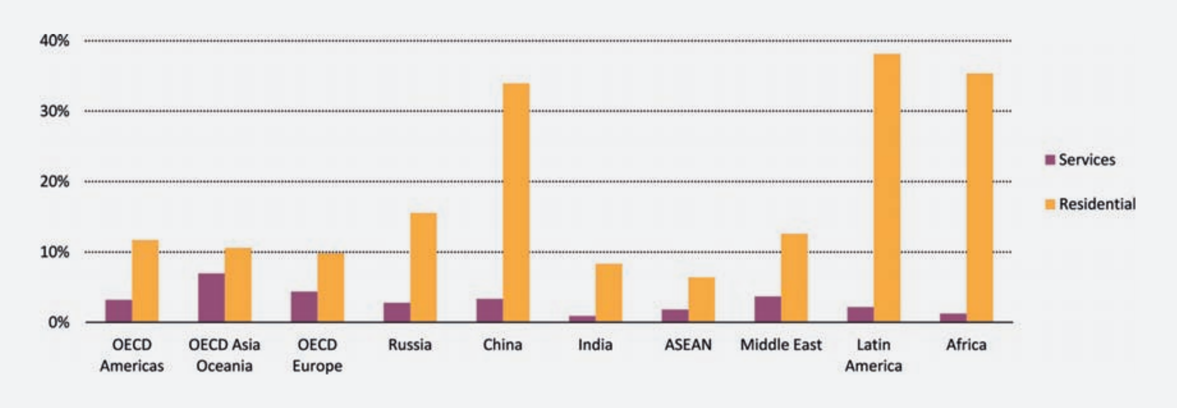
Water heating

Water heating for domestic purposes (*i.e.* potable water) is a major buildings energy consumer in most OECD countries, especially in the residential sub-sector (Figure 4.10). In non-OECD countries, conventional water heating energy consumption is rising quickly as household wealth increases. For example, energy use for water heating in the Middle East grew by nearly 40% between 2000 and 2010, with nearly 90% produced using traditional oil and natural gas technologies. In China, Africa and Latin America, nearly 40% of buildings energy use goes to water heating, where traditional biomass still remains a common form of heating water.

Throughout most regions of the world, water heating is produced using conventional heating and storage technologies, with the exception of some non-OECD regions where hot water is still produced using traditional biomass. Conventional water heating systems include individual gas or electric storage water heaters, where hot water is produced and stored in the same unit, and combination boiler units that are used for both potable water and space heating. These combination units often have a separate storage tank.

Conventional storage water heating systems tend to be low to moderately efficient because of standby heat losses through the tank walls when hot water is not being demanded.

Figure 4.10 Water heating as a percentage of total buildings energy consumption for selected regions, 2010



Key point *Water heating is a major energy consumer in buildings, especially in the residential sub-sector, and demand is rising quickly in non-OECD regions.*

Improvements in tank insulation can significantly reduce standby heat loss, and newer high-efficiency storage tank water heaters can have an efficiency rate as high as 90% with standby losses. The location of storage tanks (*e.g.* cooler basements or garages) can also cause standby heat losses; it is therefore important to consider tank placement in building system design.

Progressive implementation of advanced hot water solutions, including instantaneous and heat pump water heaters, is needed to address growing energy demand for hot water, especially in the residential sub-sector.[12] Other considerations include reducing the demand or usage of hot water. Examples of demand reduction options include the installation of low-flow showerheads and taps (faucets), reducing the length of piping runs, reducing central water pressure and the purchase of more efficient appliances.[13] Changing occupant behaviour to promote shorter showers, choose showers over baths and set water heater temperatures lower are also effective in reducing water heating energy consumption.

Instantaneous water heaters

Instantaneous water heaters provide hot water on demand using a gas burner or electric heating coil. They can also be used in combination with a system boiler (tankless systems) using a heat exchanger, although these tankless combination systems can have lower seasonal efficiencies if boilers are not operating on a normal basis (*e.g.* during summer months). Instantaneous water heaters are commonly used as a point-of-use water heater (*e.g.* kitchen and bathroom sinks) and are increasingly being installed as whole-building appliances in lieu of a conventional storage water heater.

The advantage of instantaneous water heaters is that storage losses are eliminated and pipe losses are often substantially reduced. A 2010 study by the Center for Energy and Environment in the United States found that tankless water heaters in combination with

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[12] Solar thermal is a major opportunity for water heating and is covered extensively in a following section.

[13] North American dishwashers and washing machines use central hot water rather than being heated electrically by the appliance. See Chapter 5 for more details on this subject.

high-efficiency boilers can be as much as 40% more efficient than a typical storage water tank (Bohac *et al.*, 2010). At the same time, while electric instantaneous water heaters save energy compared to conventional electric storage water heaters, they can have high operating costs and their high electricity demand can increase peak electricity loads.

Gas instantaneous condensing water heaters (see space heating for basic condensing technology) offer the greatest energy savings potential and are widely available in most regions. They can be fairly expensive, although they have very high efficiencies and low standby losses. They also have the ability to serve high water flow rates, so there is no need to install a storage tank. If a storage water heater is necessary, condensing gas technologies can be used with a highly insulated tank.

Heat pump water heaters

Another major opportunity to reduce energy consumption for water heating is the use of heat pump water heaters. Heat pump water heaters have been commercialised and are continuing to grow in popularity, although they still represent a very small share of the world's installed water heaters. Japan has made significant progress with annual sales growing from over 100 000 in 2004 to over 0.5 million units in 2011 (JRAIA, 2012). This includes recent water heat pump technologies, such as Japanese Eco-Cute electric water heat pumps that use CO_2 as a refrigerant (Figure 4.11).

Figure 4.11 Eco-Cute electric heat pump water heating and supply system

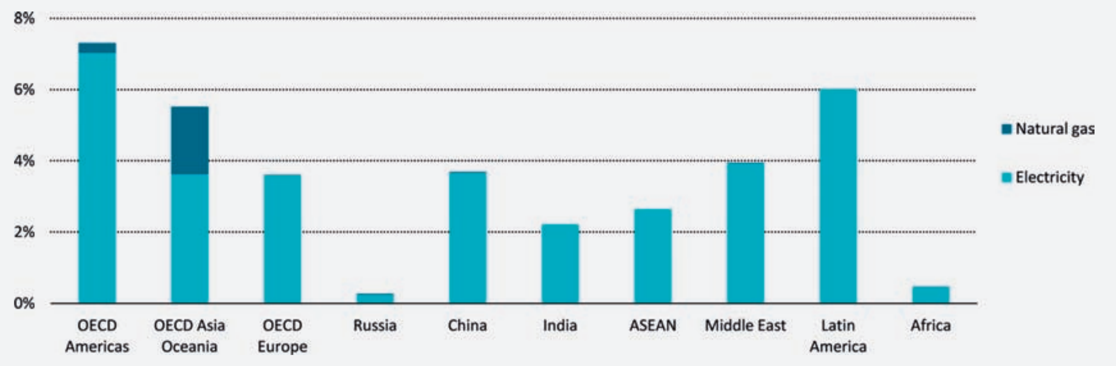
Source: Heat Pump & Thermal Storage Technology Centre of Japan, 2013.

Key point *Heat pump water heaters, such as the Eco-Cute, have made significant progress in sales in recent years and can significantly reduce energy use for hot water production.*

Space cooling

Space cooling energy consumption in buildings increased by nearly 60% between 2000 and 2010 and accounted for roughly 4% of total global buildings energy use in 2010.[14] In OECD countries, cooling energy consumption as a share of total buildings energy use tends to be higher than in non-OECD regions, although cooling energy use is rising quickly in non-OECD countries as demand for comfort continues to increase. Cooling energy use is also dependent on regional climates: in warmer climates, cooling accounted for as much as 10% of total buildings energy use, while in cooler regions with greater heating demand, such as Canada, cooling is typically less than 3% of buildings energy consumption. Global space cooling is typically produced using electricity, although in some regions, such as OECD Pacific, natural gas cooling equipment accounts for a considerable share (Figure 4.12).

Figure 4.12 Space cooling energy consumption as a share of total buildings energy use in 2010



Key point *Cooling demand accounted for less than 5% of global buildings energy use in 2010, although demand is increasing rapidly in many regions of the world.*

Conventional space cooling technologies, including air conditioners and chillers, are standardised products in the residential and services sub-sectors throughout the world. Asia and the Pacific remain the largest regional markets for sales of air-conditioning units, followed by OECD Americas and OECD Europe (BSRIA Limited, 2011). Air conditioner sales in China represented more than 25% of global sales (by value) in 2010, with Japan and United States following closely behind.

Most air conditioners today operate at less than maximum efficiencies, and significant energy efficiency gains are possible through system improvements and design. A key energy efficiency opportunity lies in the fact that many cooling systems today are oversized due to a lack of rigorous analysis of building cooling needs and design. Since many services buildings, even in cold climates, require some level of year-round cooling (*e.g.* for internal heat sources, such as servers, office equipment and occupants), the use of appropriate equipment capacities could reduce overall energy demand for space cooling. Further R&D may be warranted as space cooling demand increases in hot climates, given that technical specifications in many current space cooling technologies are driven by demand in temperate climates.

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[14] This is final energy. Cooling would have a greater share if fuel used to generate electricity were considered.

Another factor in the increase of space cooling demand in recent years has been building design, particularly the increased use of glazed surfaces in services buildings. Improved building design, including advanced building envelope and window technologies, and correct sizing and optimal design of cooling systems, will help to minimise cooling energy use (see Chapter 3). Sources of "free cooling", such as ground or water sources, are another means of increasing system efficiencies. There are also research efforts to use low-grade ground coupling (*i.e.* heat exchanged with the ground) with other passive strategies to avoid the need for cooling equipment. District cooling (discussed later in this chapter) is another approach to reducing space cooling energy consumption.

Split systems and packaged unit cooling

A vapour compression refrigeration cycle is the standard technology for air conditioning throughout the world. Units are available in different configurations, including ducted or ductless units and packaged or split units. Single-space packaged unit conditioners are the most common form of air conditioning throughout Europe and North America, especially in the residential sub-sector (BSRIA Limited, 2011). Large packaged air-conditioning units (also known as central air conditioning) with ducting to distribute air are standardised products in which a packaged central unit contains the evaporator condenser and compressor all in one cabinet, often on a roof or side of a building. They often include electric or natural gas heating units as well.

Split systems are typically characterised by an indoor unit that distributes cooled or heated air and an outdoor unit that houses the heat pump compressor with heat exchanger and fan. Mini-split systems are very common throughout most of Asia and are very similar to normal split systems but have small capacities. It is common to have multiple mini-split units per dwelling or apartment. The big advantage of mini-split systems is that they are ductless, and the interior unit is completely inside the thermal shell. Another benefit of mini-splits is that only desired spaces are cooled. Both larger and mini-split systems can be reversible, allowing them to provide heating as well as cooling.

Air conditioner COPs tend to be in the range of 2.5 to 4.0 in most parts of the world, with COPs for small (2.2 kilowatt [kW] class) units approaching six in some countries. Given the increasing demand for space cooling in both OECD and non-OECD regions, it is critical that buildings reduce cooling energy consumption through both building envelope technologies (see Chapter 3) and properly sized, high-efficiency air conditioners. Technical improvements in existing cooling technologies include variable-speed fans that lower electrical draw when the refrigerant cycle is not working, high-efficiency motors that operate the fan using less electricity, improved heat exchangers and more efficient compressors.

Chillers

Chillers produce chilled water and distribute it throughout a building through pipes to cool indoor air. They can be water-cooled units or air-cooled units. Water-cooled chillers transport heat rejected by condensers with water and cool it in a cooling tower or a dry cooler, which is a heat exchanger with a secondary refrigerant, such as a brine or glycol. Air-cooled chillers have condensers that are cooled by ambient air using one or more fans to cool refrigerant coils. A key issue with chillers is the partial load efficiencies of the equipment. In large facilities, chillers can account for as much as 35% of a building's electrical energy use, particularly as they can spend most operating hours running at partial load (ETSAP and IRENA, 2013).

Inverters offer significant partial load savings by changing the frequency of the alternating current in the device in order to vary the speed of the compressor. Advances in centrifugal chillers include improved heat exchanger flows and a double refrigerant cycle. Performances have increased to rated COPs of seven,[15] with maximum part-load performances as high as 29 in high-efficiency centrifugal chillers using inverters (Hasegawa *et al.*, 2011). In hot regions where year-round cooling is required, BAT centrifugal chillers can achieve annual COPs of ten or more (ETSAP and IRENA, 2013).

Additional energy efficiency gains for chillers can be achieved through system design and technical changes. In large commercial buildings, multiple chiller operations can often be more efficient than a single unit, especially if cooling loads change substantially throughout the day. Module-type chillers, which are already available, can be designed to meet demand by connecting smaller heat pumps based on building size and cooling loads. Electric-driven heat recovery heat pumps can also be used in buildings with high cooling demand or with concurrent need for heating and cooling.

Absorption chillers are another technology that can be used in lieu of traditional electric chillers. Absorption chillers use mixtures of water and ammonia (or lithium bromide) with natural gas or co-generation heat sources to drive the chiller refrigeration cycle. This can be particularly useful in buildings with high demand for cooling and in buildings with concurrent need for both air conditioning and heating. When thermal or electric demand loads in buildings are high, absorption chillers can shift cooling from an electric load to a thermal load, and vice-versa, thereby increasing efficiencies based on available energy.

Dehumidification systems

With high levels of fresh air required for building ventilation, moisture removal is increasingly important in buildings across the world, especially in the services sub-sector. As building envelopes are improved with higher thermal resistance, humidity control can also become a larger portion of cooling loads. Dehumidification can therefore improve the overall feeling of comfort in buildings while reducing the need for space cooling.

Desiccant air-conditioning systems are an emerging technology that provides a method of drying air before it enters a conditioned space. The primary advantage of desiccant dehumidification systems is that they remove moisture from outdoor air, allowing conventional air-conditioning systems to deal primarily with temperature control. Separating dehumidification from cooling load allows much higher evaporation temperatures and therefore much higher heat pump COPs.

Desiccant dehumidification systems work by rotating a wheel comprised of desiccant (moisture trapping) material through a supply or process air stream that is then dried by the desiccant before being directed into the building. As air is dried, the wheel continues to rotate through a reactivation or regeneration air stream that dries out the desiccant using waste heat from the heat pump condenser. Desiccants can be reactivated with air that is either hotter or drier than the process air.

Desiccant cooling systems are mature commercial technologies and have reached a visible market penetration in particular areas (*e.g.* supermarkets in the United States and Japan). In general, desiccant cooling systems are an option if centralised ventilation systems are used, and ongoing developments in advanced cycles promise to increase their applicability in combination with solar thermal energy.

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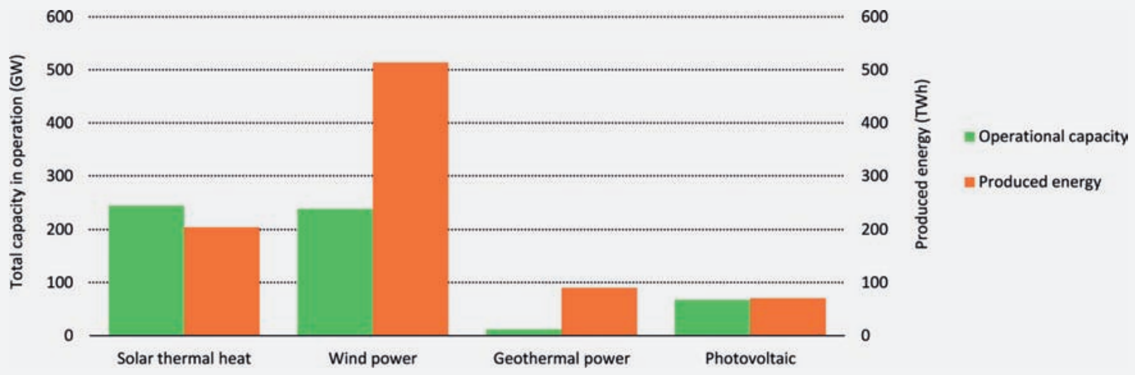
[15] Rated performance is in accordance with Japanese test procedures and may differ from country to country.

Solar thermal technologies

Solar heating and cooling (SHC) describes a wide range of technologies, from mature domestic hot water heaters to new technologies, such as solar thermally driven cooling. SHC can include both passive[16] and active solar technologies, although only active heating and cooling technologies are discussed in this chapter. Active solar thermal (AST) systems collect incoming radiation from the sun to heat a working fluid (*e.g.* water, oil or glycol) in a heat exchanger or to heat water directly (*e.g.* hot water for swimming pools). Unlike PV systems, which use solid-state semiconductor materials to convert sunlight directly into electricity,[17] AST systems create hot water (or air) that can be used for sanitary hot water, space heating and even cooling with thermal sorption cooling systems. They can be installed on all building types, including single-family homes, multi-family residences, office and industrial buildings, schools, hospitals and other public buildings.

In recent years, PV cells have become the focus of renewable energy discussions for buildings as they generate electricity and often have greater versatility than AST. However, solar thermal systems are a valuable resource that needs to be expanded in the buildings sector, especially as large thermal loads in buildings can be met using AST technologies. Solar thermal heat production already has a strong global capacity and could be expanded significantly given the right policy discussions and incentives (Figure 4.13).

Figure 4.13 Overview of renewable energy resources and importance of solar thermal



Source: Weiss and Mauthner, 2012.

Key point *Solar thermal accounts for a fairly large portion of existing renewable energy and is poised to grow rapidly given appropriate policy support.*

Most AST systems installed to date are used to prepare hot water in the residential sub-sector, where they can be cost competitive with conventional heating fuels, especially in countries with high energy tariffs. Solar thermal systems are also a means of generating hot water in areas without access to modern energy supply. AST systems can be scaled up for industrial

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[16] Passive solar technologies use the free inputs of solar energy as heat during cold seasons and protect building interiors from too much sunshine during warm seasons through building orientation and design. While passive solar technologies can be very effective and cost-efficient, they are distinctly different from active solar heating technologies. Chapter 3 on building envelopes discusses passive solar design in greater detail.

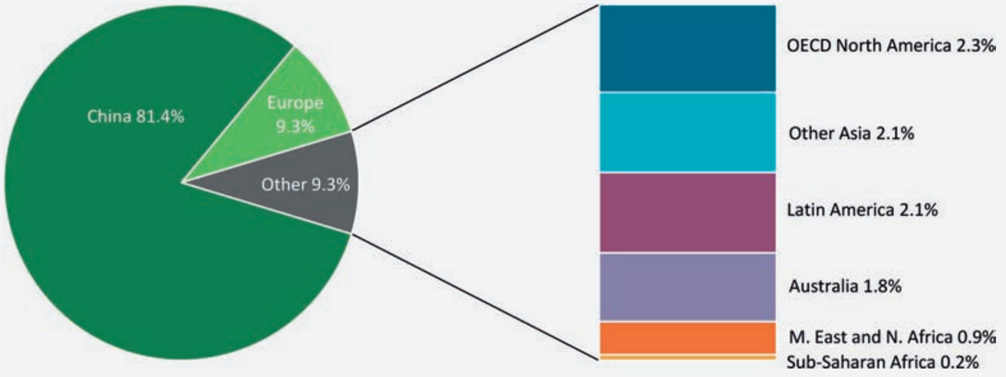
[17] More information can be found in the IEA *Technology Roadmap* on *Solar Photovoltaic Energy* (IEA, 2010b).

processes and as multi-megawatt plants that generate steam-driven electricity for energy companies, with notable examples deployed in the United States and Spain.

The IEA *Technology Roadmap* on *Solar Heating and Cooling* envisages that the development and deployment of SHC could produce nearly 18 exajoules (EJ) (4 583 terawatt-hours thermal [TWh_{th}]) by 2050, accounting for more than 16% of total final energy use for low-temperature heat and 17% of total energy use for cooling by that time (IEA, 2012a). This includes solar collectors to achieve 2DS objectives of a 3 500 gigawatt thermal (GW_{th}) global AST capacity for solar hot water and space heating in the buildings sector by 2050. It also includes a potential contribution of 1.5 EJ per year in installed capacity for space cooling. By achieving these deployment levels, SHC could avoid roughly 800 megatonnes (Mt) of annual CO_2 emissions by 2050 (IEA, 2012b).

Most of these projected savings can be realised with current technology. The worldwide market for AST systems has grown strongly in the past two decades as a result of introduction of subsidies and renewable energy obligations as well as improvements in cost-competitiveness. However, the global increase of solar thermal systems has been predominantly driven by China (Figure 4.14), and a strong increase in the use of solar thermal technologies will require greater investment, standardisation and policy formulation, especially in countries with lower energy tariffs. Significant R&D will also be needed to enable the commercialisation of market-viable products in diverse regions, including colder regions requiring freeze protection systems.

Figure 4.14 World solar thermal glazed and unglazed collector sales in 2010



Source: Weiss and Mauthner, 2012.

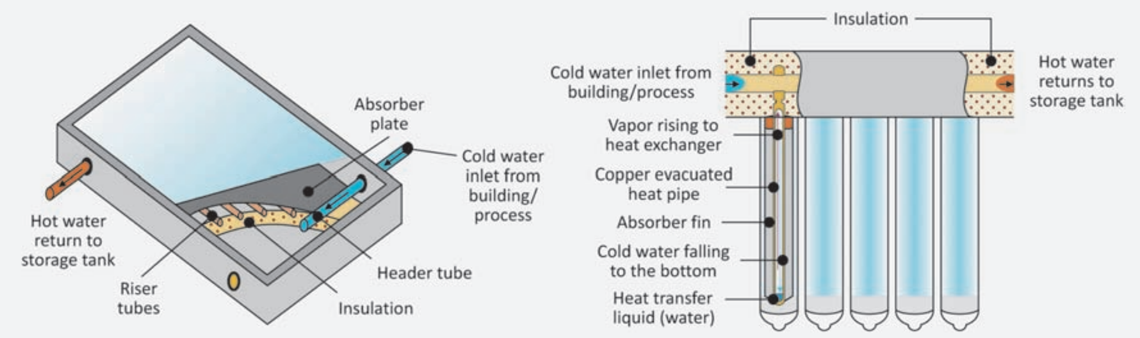
Key point *The global solar thermal market is currently being driven by low-cost solar thermal systems in China, although there is significant potential to increase solar thermal technologies in other regions.*

Collector design

Today, the overwhelming majority of applications for solar thermal systems use rooftop collectors. The principal types are glazed and unglazed. Glazed collectors are used to retain the heat gained from the actual absorbing elements, commonly a highly conductive material like copper with a selective coating that absorbs the sun's energy. Unglazed collectors are polymers (in essence simple plastic) or metal collectors that are usually only useful for the energy that is collected during or at the end of the day. They do not offer any improved ability to retain heat and are not applicable to areas that experience freezing temperatures.

Another form of glazed collector that represents the vast majority of new global sales is an evacuated-tube collector. These collectors usually have two large vessels of glass that look like a large double walled test tube that retains a vacuum to significantly reduce heat loss back out of the collector. In the centre of the tube is the absorbing collector, often copper, which operates as part of a circulation system or as a thermal siphon[18] system (Figure 4.15).

Figure 4.15 Flat-plate collector (left) and evacuated-tube collector (right) AST technologies



Source: Sustainability Victoria, 2009.

Key point *AST technology choice depends largely on energy needs and local conditions, although evacuated-tube collectors tend to perform in a broader range of conditions than flat-plate collectors.*

Currently, evacuated collectors represent the majority of the installed base of collectors, where China dominates global sales and total global solar thermal capacity. Globally, the annual installed glazed water collector area of AST systems nearly tripled between 2004 and 2009, and by the end of 2010, global solar thermal collector capacity in operation equalled 196 GW_{th}. The vast majority of collector installations were in China (118 GW_{th}), followed by Europe (36 GW_{th}), the United States and Canada (16 GW_{th}), which all together accounted for nearly 87% of the total installations (Figure 4.16). Unglazed collectors tend to remain more common in areas with hotter climates, including some parts of the United States, Australia and Africa.

AST systems vary significantly in scope and complexity and can be split between conventional collector systems and concentrating solar thermal technologies. Concentrating solar technologies focus sunlight from a large aperture area to a concentrated area and are typically used to produce high-temperature heat to drive large-scale steam turbines for electricity production. The choice of solar thermal collector generally depends on the application and the required temperature (Figure 4.17). In the buildings sector, non-concentrating flat-plate and evacuated-tube collectors are most commonly used for space and water heating, although they can also be used for space cooling using a thermally driven sorption process.

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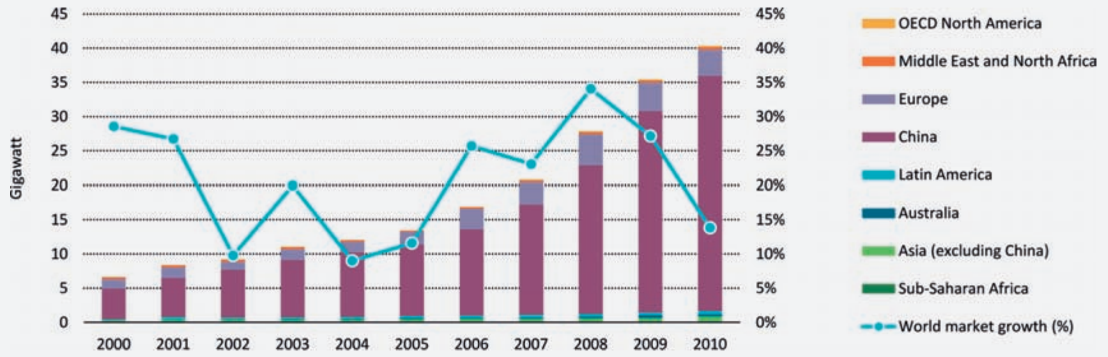
[18] A thermal siphon does not have an active flow with pumping or pressure, but instead relies on heat transfer by liquid convection and conduction from heat rising to create movement of heat. Usually these systems have a manifold with an active loop that collects the heat from the different tubes.

Concentrating solar collectors are typically used when highly efficient cooling machines (*e.g.* double-effect absorption chillers) are part of the space heating and cooling system. They can also be used to provide district water and space heating, but new district heating systems now typically use lower grade temperature collectors.

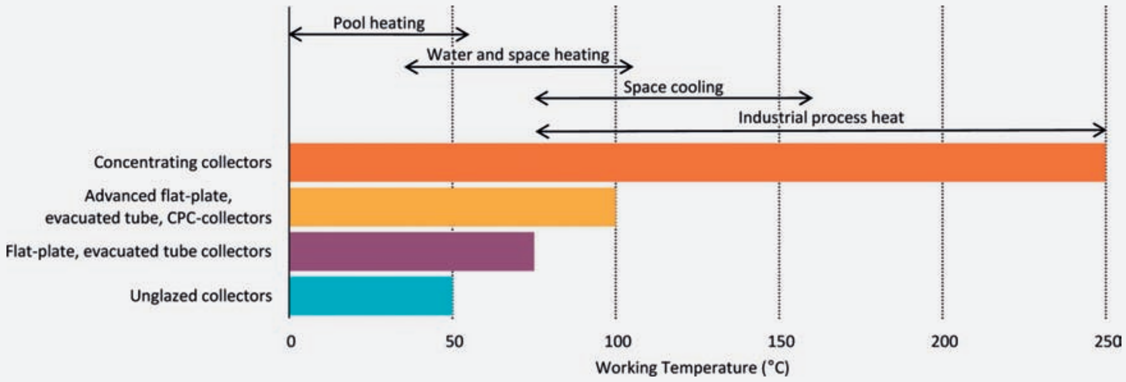
Figure 4.16 Installed capacity of solar collectors (flat-plate and evacuated-tube) and market growth to 2010



Notes: Sub-Saharan Africa = Namibia, South Africa, Zimbabwe. Asia = India, Japan, South Korea, Chinese Taipei. Latin America = Brazil, Chile, Mexico. Europe = Albania, EU 27, Norway, Switzerland, Turkey. Middle East and North Africa Region = Israel, Jordan, Morocco, Tunisia. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.
Source: Weiss and Mauthner, 2012.

Key point *Newly installed AST capacity is dominated by domestic water heaters in China, and market growth has slowed in recent years.*

Figure 4.17 Solar collectors and required working temperatures of different end-uses in buildings



Note: CPC = compound parabolic concentrator.
Source: adapted from IEA, 2012a.

Key point *AST systems should be chosen for system needs and sizing with respect to operating temperatures.*

In non-concentrating solar thermal applications, evacuated-tube collectors that are well insulated tend to perform better than flat-plate collectors where higher temperature loads are required and where ambient temperatures are lower. They also work better than flat-plate collectors in low irradiation conditions, so they are likely to be favoured in locations with overcast skies. Tests conducted in Switzerland showed that evacuated-tube collectors produce rather consistent energy yields, with a narrow gap between the lowest and highest yielding collectors (Table 4.4). By contrast, the range between lowest yielding and highest yielding performance in flat-plate collectors was greater than 100% depending on the local climatic conditions. At the same time, the comparison of overall system efficiencies does not indicate which system is the most cost effective for specific local needs.

Table 4.4 Yields of different AST flat-plate and evacuated-tube collectors for water heating in Switzerland

	kWh/year	Difference (high/low)
Flat-plate collectors		
Highest yielding collector	570	+ 134%
Lowest yielding collector	244	
Evacuated-tube collectors		
Highest yielding collector	669	+ 47%
Lowest yielding collector	455	

Sources: IEA, 2011; Kemna *et al.*, 2007a, b; Navigant Consulting, 2007.

More RDD&D is needed to promote greater investment in AST so that it can become the mainstream choice for water and space heating. While there do not appear to be any major science or material breakthrough requirements, in the near future it is obvious that much more conserted effort will be needed for solar thermal objectives to be realised. With the large success of evacuated collectors in China, more international collaboration and research should focus on expanding the applicability of this technology to more regions of the world.

Solar cooling

Solar cooling is an emerging technology that is an attractive source of zero-emission or very low-emission cooling. It is a potential means of providing cooling for hot climates where the demand will grow with increased wealth and the desire to be comfortable. Apart from ordinary air-conditioning systems driven by solar electricity from PV units, solar thermal cooling can provide cooling needs through a thermally driven heat pump cycle. Similar to thermal heat pumps, solar energy is harvested through a collector system to provide heat for the thermal heat pump system.

Solar cooling has a number of attractive features when compared to other cooling alternatives. Since solar radiation usually coincides closely with cooling loads, it can help to prevent peak power demands associated with cooling. It remains in the very early market development phase and costs are likely to come down over time, but significant research is still needed to make it widely market viable. A comprehensive position paper completed by the SHC IA underscored the need to obtain higher temperature sources of solar energy to drive the most efficient thermal cooling systems (Henning, 2010). To achieve this, low-cost concentrating collectors will be needed to deliver the thermal performance that is required to provide cost-competitive products. Research on basic thermal heat pump system design is also needed in the gas heating sector, and research success in that area will improve the future viability of solar cooling.

Solar combination systems

Solar thermal combination systems can be used to increase heating and cooling efficiency in buildings. As with hot water heating, solar thermal technology can be paired with an auxiliary heating or cooling source (*e.g.* high-efficiency biomass, condensing gas boiler or heat pump) to cover the part of heating and cooling demand that is not met by the solar thermal system. Thermal storage devices (*e.g.* highly insulated water storage tanks) can also be applied in solar combination systems to capture and release heat from solar thermal collectors in response to fluctuations in demand. Storing solar heat (*i.e.* maintaining working fluid temperatures in a storage device) is a common practice with an acceptable cost. It is especially useful in climates with prolonged periods of low solar irradiation levels.

Solar combination systems are well suited to middle and high latitudes, due to significant solar radiation in the transitional periods around winter (September to October and March to May) and the significant heating demand in these latitudes at that time. The combination of these two factors allows these systems to cover a large part of the heat demand at the beginning and end of the space heating season.

Solar thermal capacity in combination systems varies depending on typical applied size. In the Netherlands, a typical solar combination system consists of four to six square metres (m^2) of solar collectors and a 300-litre storage tank. The share of space and water heating met by solar energy is therefore generally between 15% and 22% of total demand. In countries such as Switzerland, Austria and Sweden, larger combination systems, consisting of 15 m^2 to 30 m^2 of collector area and a 1 000 to 3 000 litre storage tank, can meet 20% to 60% of domestic space and water heating demand (IEA, 2011).

Solar thermal technologies for district heating and cooling

District heating and cooling (DHC) systems are used in many countries, notably including Denmark, Canada, South Korea, the Netherlands, Sweden, the United Kingdom and the United States. District cooling systems also are becoming common in some hot-climate countries, particularly in the Middle East, because they reduce peak-load demand on the electricity system.

Solar-assisted district heating systems are used to provide low-temperature heat (below 100°C) on a diurnal or seasonal timeline. Such technologies include large-module (flat-plate or evacuated-tube) collectors mounted on roofs or on the ground with different sources of heat storage, including water-filled steel tanks used for diurnal storage. Seasonal storage is also possible using large pits in the ground, boreholes or aquifers.

Several technologies are already applied in the central and northern parts of Europe, including Sweden, Denmark, Germany and Austria. They also are increasingly popular in Canada, China and South Korea. In Europe, there are presently approximately 175 large-scale solar thermal plants above 350 kW_{th}, with a total installed capacity of nearly 320 megawatt thermal (MW_{th}) in operation (Weiss and Mauthner, 2012). The largest plant to date is designed with 25 MW_{th} in Saudi Arabia.

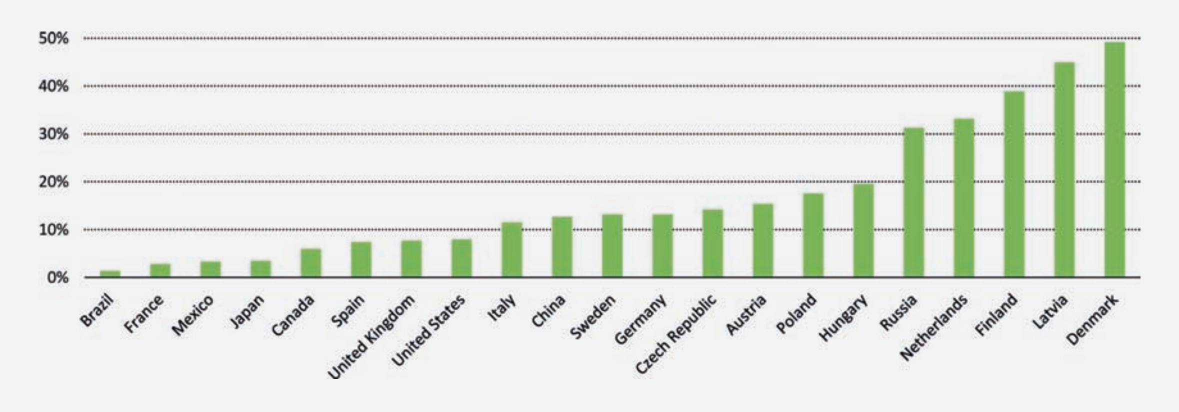
Since cooling demand usually increases with solar thermal radiation intensity, thermally driven solar cooling systems, including air-conditioning and refrigeration systems run using solar radiation technologies, have a huge potential in the growing market for space cooling. They are a promising alternative to conventional electrically operated cooling technologies, and they can be combined with waste heat, district heating and co-generation plants. They can also be used for space heating or domestic water preparation during periods without cooling demand.

Co-generation and waste heat opportunities

Co-generation, also known as combined heat and power, is the production of electricity and heat at the same time. It can also be the production of electricity from the waste heat of a process. Often associated with DHC networks, co-generation encompasses a range of proven, reliable and cost-effective technologies that can improve the efficiency of heat and electricity generation. Globally, co-generation provides around 10% of total electricity generation (Figure 4.18). It provides more than 20% of generation in only five countries: the Netherlands, Latvia, Russia, Finland and Denmark. There are significant opportunities to expand the use of co-generation, particularly in cold climate countries.

Waste heat from power generation is also another area of significant co-generation potential. The average global efficiency of fossil-fuelled power generation has remained stagnant for decades at 35% to 37% (IEA, 2009). As a result, about two-thirds of the primary energy that is converted to produce electricity is lost as waste heat (IPCC, 2007), while transmission and distribution losses account for an additional 9% of net generation, meaning that only around one-third of the primary energy is delivered to the end customer. Part of this wasted energy could be used to satisfy heating demand. Based on available data, total co-generation capacity installed worldwide is about 360 gigawatt electrical capacity (GW_e) and of the order of 440 GW_{th} of heat energy.[19]

Figure 4.18 Co-generation's share of electricity generation by country



Key point *Co-generation represents a significant share of electricity production in only a handful of countries.*

Systems performance and benefits

Co-generation systems are generally more efficient, from a systems perspective, than the separate, centralised production and distribution of electricity and local production of heat, as co-generation requires less primary energy, although this depends largely on the overall efficiency of the distribution network. Typical co-generation efficiencies in operation range from 75% to 85%, with state-of-the-art plants achieving efficiencies of 90%. In single-family dwellings, this equates to a typical output of 1 kilowatt electrical capacity (kW_e) to 10 kW_e,

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[19] Data were collected from a variety of sources including Eurostat, the United States Department of Energy, and the Japan Gas Association and Japanese Ministry of Energy Technology and Industry. Not all countries surveyed by IEA are included; some countries do not collect capacity data; others collect but cannot fully count capacity because many plants operate for part of the year as conventional power plants.

while in multi-family dwellings or housing estates, systems tend to range from 30 kW_e to 500 kW_e. In the services sub-sector, most opportunities fall in the 30 kW_e to 500 kW_e range. Larger systems are possible, but commercial buildings and office parks capable of supporting 1 MW_e are less common and represent a small share of services sub-sector energy consumption (IEA, 2011).

There are many mature co-generation technologies on the market, and performance and costs have improved over the last several decades. The majority of co-generation capacity installed in the world is for industrial applications, but there is significant opportunity within the buildings sector for effective, efficient co-generation systems to be deployed.[20] New developments, including microturbines, Stirling engines and fuel cells, all promise to improve co-generation cost-competitiveness and efficiency while also bringing co-generation opportunities to smaller-scale building applications. However, real world applications indicate that these developments are probably still in the early phases and continued RDD&D is necessary.

While all co-generation units perform the same broad task, the heat and electricity ratio differs from device to device. Conventional co-generation technologies, with an internal or external combustion engine or a turbine prime mover, have high overall efficiencies but tend to provide more heat than electricity. Fuel cells, an emerging technology, provide a higher proportion of electricity than other co-generation technologies. In Japan, more than 20 000 units of polymer electrolyte membrane fuel cells (PEMFC) have been sold since they came into commercial use in 2009, and residential PEMFC and solid oxide fuel cells (SOFC) have also been marketed as their ten-year durability has been guaranteed (JGA, 2012). Reducing cost is one of the biggest challenges facing the future deployment of fuel cells. Their high costs are partly a function of the small number produced. The US DOE is targeting an equipment cost of USD 1 000 per kW for a 2 kW-class fuel cell by 2020 (US DOE, 2011). Operational experience therefore is limited, although there is significant R&D in other fuel-cell systems.

Barriers to increased co-generation in buildings

There remain challenges to the widespread uptake of co-generation technologies in the residential sub-sector, including high upfront costs, scaling issues[21] and regulatory and information barriers. In the services sub-sector, some buildings have proportionately larger water and space heating and cooling loads with more stable loads throughout the year, which significantly improves the competitiveness of co-generation solutions.

In recent years, the use of co-generation in service buildings and multi-residential complexes has increased steadily. This is due largely to technical improvements and cost reductions in smaller-scale, often pre-packaged systems that can satisfy a wide range of thermal and electrical loads. Previously, co-generation was confined mostly to large institutional-type organisations that had large heat loads and/or the need for secure electricity supplies in the event of grid failure, such as hospitals, hotels, large business parks and electricity critical services.

The challenge for building-scale co-generation is to match thermal and electric generation with respective building heating, cooling and electric loads. The heat-to-power ratio (average annual heat load divided by electricity load) is often used to help choose co-generation system and operation design. Co-generation technologies generally have heat-to-power capacities in the range of 0.4 to 2.5 (Medrano, *et al.*, 2008), where co-generation plants will operate near

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[20] Detailed industrial system analysis is beyond the scope of this publication.

[21] Sizing to meet hot water demand allows higher load factors, but at an individual building level, this means that space heating demand will need to be met to a greater or lesser extent by other heat sources.

full-load efficiency at load factors of around 75% or more. At half their rated output, the efficiency of electrical generation may drop by 10% to 35%, and therefore it is important to have high utilisation, which requires careful system design and operation.

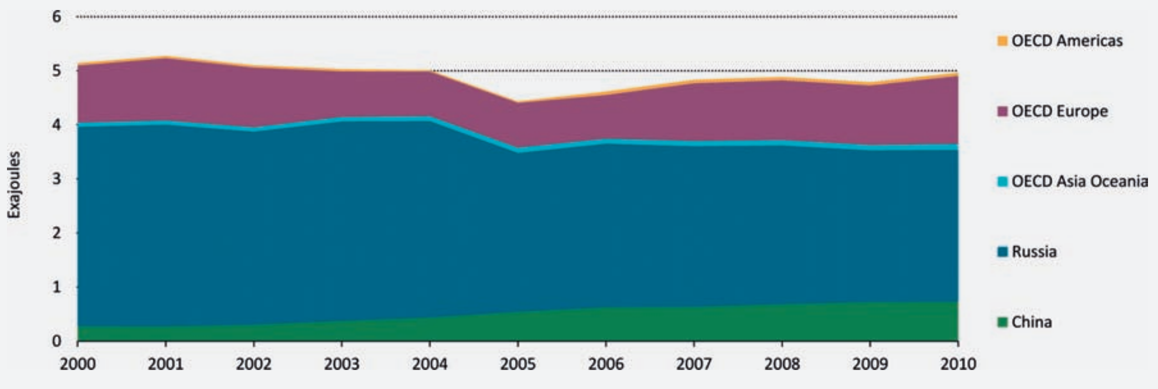
Another key consideration is daily load balancing. While more efficient building envelopes will reduce night-time peak heating loads, there may still be a mismatch between electricity demand that is greater in the day compared to thermal demand that is greater during the coldest night-time hours. Integration with electric vehicles may provide a core balancing component, where electricity generated by co-generation during the night can charge the vehicle while the heat is used for space and water heating. While co-generation will not eliminate the need to be connected to the grid, if it is installed with very high utilisation factors for a major portion of the loads, then the macro impact can be dramatic. As a result, the potential for co-generation in buildings is significant, but design of integrated systems with optimised control will be essential.

District heating and cooling with waste heat utilisation

The fundamental advantage of modern DHC is that it connects multiple thermal energy users through a piping network to efficient or renewable energy sources, such as co-generation, industrial waste heat, biomass, geothermal and other sources of heating and cooling. DHC systems make more economic sense in countries with high-density heating and cooling loads, as increased throughput improves the economics of such systems.

Worldwide, district heating has only a small fraction of the total heat market, while in some countries, particularly in Scandinavia, district heating represents over half of the heating market. Russia and China account for the majority of purchased heat in the world, with roughly 65% of total purchased heat consumed in the services sub-sector and 79% of purchased heat in the residential sub-sector (Figure 4.19). OECD Europe is the next largest heat consumer, with significant quantities consumed in Austria, the Czech Republic, Hungary, Finland, the Netherlands, Denmark, Poland, Sweden and Slovakia. District cooling is less common, although DHC systems are increasingly being implemented for cooling needs, either through distribution of chilled water or by using the district heating network to deliver heat for heat-driven chillers at the building scale.

Figure 4.19 Residential and services sub-sector purchased heat consumption by country and region to 2010



Key point *The consumption of purchased heat is concentrated in non-OECD Europe and Eurasia.*

In the 24 countries for which data are available, the extent of DHC networks totals 406 000 km. Russia and China dominate these figures, with 173 000 km and 110 000 km, respectively. The density of the network and the amount of energy delivered per kilometre throughout each year varies enormously: in countries with district heating network data, it appears that there is a factor of 14 between the least and the most intensively used systems.

There are many old networks in place that have large piping losses with inefficient systems. Key capital decisions are based on the economics associated with the remaining life of the central system and whether to upgrade the piping systems to modern standards. If the entire system is reaching its full life maturity and it does not access waste heat, renewable energy sources or "free" cooling, then a serious alternative approach should be considered. This includes reducing overall building thermal loads (discussed in Chapter 3) combined with smaller-capacity individual building equipment that may result in a much more cost effective and energy-saving solution. In the future, small-scale micro co-generation may be a viable solution for old networks that are too expensive or uneconomic to upgrade.

For applications warranting large-scale co-generation systems that offer greater utilisation of waste heat, modern distributed heating systems can be highly effective. These systems include high-performance insulation with optimised piping flow to reduce frictional losses. Newer systems use lower temperatures to reduce heat loss, and this is fully compatible with modern or upgraded buildings with smaller heating loads. These systems also have the ability to distribute heat generated from biomass that is not practical or efficient for burning at individual sites. They can also distribute low-grade heat from geothermal sources.

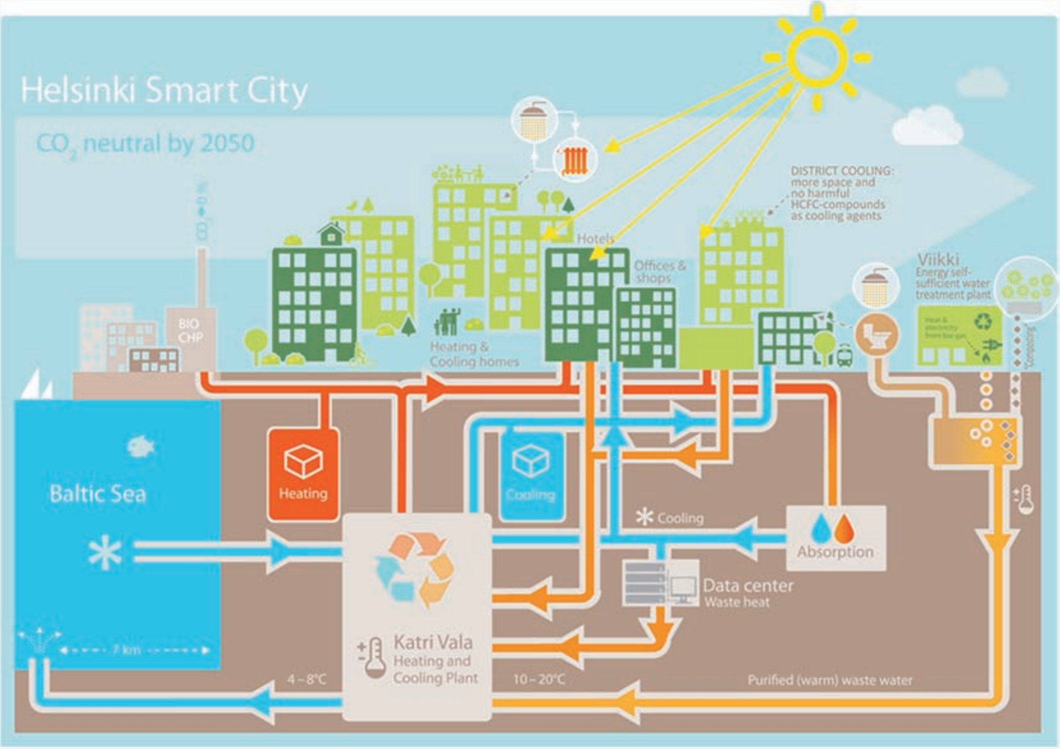
In the future, advanced integrated systems could bring dramatic energy savings (Figure 4.20). For instance, a significant new possibility is to use fairly low-grade heat that may not be suitable for space heating but that might be suitable as a heat source for an electric heat pump in a cold climate where ambient air is too cold for optimal performance. This approach may be more cost effective than a GSHP. Other cost-effective solutions could similarly improve net system performance by pairing available heat sources with co-generation opportunities through a highly efficient DHC network.

Thermal energy storage

Thermal energy storage (TES) systems will play an increasingly important role in the successful, wide-scale application of thermal heating and cooling technologies. TES systems can be charged with heat (or cold) and hold energy over time, most commonly using highly insulated water tanks. Thermal mass (*e.g.* ground source and building materials such as stone and cement) and phase change materials (PCM) can also be used for TES. Water tank storage systems can store heat for days, or even a week, at acceptable costs. However, they tend to be bulky and are not an ideal solution for long-term storage.

Ideally, energy resources and supply will match building end-use demand. Significant effort is required to design and optimise building systems to minimise the need for thermal storage. For instance, this can be done through electricity and heat balancing for co-generation. There is also the advantage of matching solar resources with advanced solar thermal cooling systems. However, in reality, load matching will not be perfect, and advanced TES can play a key role in making viable systems that are not currently economic without advanced storage. For instance, if "free" waste heat is being used at a later time and may have a storage penalty associated with it, it may be more economic to use TES technologies that will save greater energy than an individual system that generates heat with the burning of fossil fuels.

Figure 4.20 CHP and DHC plans for Helsinki, Finland



Source: Helsinki Energy, 2012.

Key point *DHC, paired with co-generation opportunities and an efficient distribution network, can connect energy users while taking advantage of waste heat and reducing overall system energy consumption.*

In the buildings sector, there are three major reasons for using TES:

- Improving system efficiency by avoiding partial load operation or operation at other sub-optimal times or by taking advantage of waste energy (*e.g.* heat released from chillers). This can involve storage over hours, days or months.
- Shifting demand over time to reduce peak loads. This can help improve overall energy system efficiency, reduce investment in energy infrastructure and reduce costs. Storage is typically required for hours or several days.
- Facilitating the greater use of renewable energy by storing the energy produced so it can coincide with demand (storing solar thermal energy over days, weeks or months to match water and/or space conditioning demand).

TES systems will play an important role in the achievement of 2DS goals, especially the last two points mentioned above. As the share of variable renewables in electricity generation increases, there will be continued need for greater system flexibility through energy storage capacities.

Developments in advanced PCM and chemical reactions are making new applications possible, including PCMs embedded in building materials such as bricks, insulation, wall boards and flooring. PCMs are well suited to space cooling because of the relatively low-temperature change required for release of energy.[22] Hybrid systems are also possible; for instance, plastic PCM nodules can be put into a tank where the heat-transfer fluid (usually water) melts or solidifies the PCM. The storage density of this hybrid system is higher than that of water, but less than that of a pure PCM system.

Current RDD&D is focused on reducing the specific costs of high-density storage, which are still too high for many applications in buildings. Another key challenge is to verify and improve the number of cycles that can be achieved by emerging storage technologies. Integrating the storage volumes underground, particularly for large-scale stores, is still a challenge for low-cost storage volumes, especially in urban areas. Research and development of new materials and construction methods promise to help bridge this gap.[23]

Future pathways and RDD&D priorities

Heating and cooling technologies are expected to play a significant role in the achievement of energy and emissions targets in the buildings sector. This requires acceleration in the rate at which technological advances in the heating and cooling market are adopted. Such a transformation will reduce energy demand, emissions and costs in the buildings sector, while also improving energy security.

RDD&D priorities for heating and cooling technologies in buildings have been examined in the IEA *Technology Roadmap* on *Energy Efficient Buildings: Heating and Cooling Equipment* (IEA, 2011). Priorities include improving the components and system efficiencies of existing technologies and designing systems that maximise technology performance across a wide range of applications, climates and operator behaviour to widen potential markets. Achieving energy and CO_2 emissions reduction in the buildings sector will also require demonstration programmes and technologies that go beyond what is currently BAT. Greater international collaboration in research, development, best practices and deployment programmes will also strengthen transfer of technical knowledge, while encouraging increases in the global uptake of more efficient heating and cooling technologies.

Governments, utilities, industry and researchers should collaborate on heating and cooling RDD&D, which will help to accelerate learning through shared experiences while avoiding the need to “reinvent the wheel” and use scare resources ineffectively. The IEA has numerous multilateral technology initiatives, which bring together researchers from across countries and regions. Other useful partnerships include collaborations between multilateral organisations and national governments with universities, research organisations and manufacturers.

Heat pumps

RDD&D priorities for heat pumps are to continue improving existing technologies while designing systems that maximise COPs across a wide range of applications, climates and building heating and cooling demands. This will require improving the operation, control and sizing of systems as well as increasing heat pump integration in building design. In particular, research and market transformation activity is needed in the following areas:

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[22] Additional applications for buildings include dehumidification, temperature control of electronic equipment, conservation of temperature-sensitive goods and cold/warm bags, medical wraps, etc.

[23] For more information, see the Implementing Agreement on Energy Conservation through Energy Storage, www.iea-eces.org/.

- **Heat pump water heaters:** greater effort is needed to ensure multiple suppliers offer improved models at lower costs. They need to be promoted, ultimately leading to mandatory standards when appropriate.
- **Cold climate design:** design ASHP systems to operate in much colder climates with limited degradation in efficiency performance and heating capacity.
- **Thermally driven systems:** a key focus should be on smaller capacities for the residential market that have advantages over existing fossil-fuel condensing boilers.
- **Equipment and components:** decrease costs and increase reliability and performance through more efficient components, such as heat exchangers and compressors.
- **Systems/applications:** optimise component integration and improve heat pump design to achieve higher seasonal efficiency in a wider range of capacities. Improve optimisation with ventilation systems in larger applications.
- **Control and operation:** develop intelligent control strategies to adapt operation to variable loads and optimise annual performance. Develop automatic fault detection and diagnostic tools. Improve communication with buildings energy management systems and smart energy grids.
- **Integrated and hybrid systems:** develop integrated heat pump systems that combine multiple functions (*e.g.* space conditioning and water heating) and hybrid heat pump systems that are paired with other energy technologies (*e.g.* waste heat, solar thermal and DHC systems) to achieve very high levels of performance.
- **Improved design, installation and maintenance methodologies:** develop and disseminate information defining and quantifying benefits for good design, installation and maintenance of systems in order to realise the full efficiency potential of the heat pumps.

Solar thermal

Further development is needed to provide new solar thermal products and applications while reducing the cost of systems and increasing market deployment. Key areas for RDD&D include high-efficiency market-viable solar collectors, small affordable solar thermal cooling systems and large capacity thermal systems for distributed energy networks. In particular, research and market transformation is needed in the following areas:

- **Thermal cooling systems:** affordable small capacity systems are needed for the expected increase in demand for air conditioners in developing countries with hot climates.
- **Alternative materials:** the development of new components for use in collectors (*e.g.* polymers, the coating of absorbers and new materials to resist ultraviolet degradation) could help to reduce solar thermal costs.
- **Integration of solar collectors in building components:** building envelopes need to become solar collectors themselves. Both the performance of collectors and their direct integration into buildings need to be further explored and optimised.
- **Improved and compact TES technologies:** these will enable solar thermal systems with relatively low solar fractions (*i.e.* share of energy load) to realise greater share of space and water heating loads. Work is needed on improved and new compact thermal materials, on novel thermochemical devices with dedicated solar collectors and on system integration.
- **Intelligent control systems:** control systems that communicate with building energy management systems will increase use of available solar energy. Centralised and integrated control systems need to be able to benchmark and self-diagnose problems, while facilitating the integration of complementary systems (*e.g.* hybrid solar thermal/heat pump systems).

- **Manufacturing:** greater automation will help to reduce initial system costs and expand the economic application to a wider range of customers, particularly for retrofitting existing buildings.

Co-generation, waste heat utilisation and distributed networks

Co-generation technologies, such as fuel cells, microturbines and Stirling engines, have yet to be widely deployed in buildings. In some cases, significant opportunities exist for reducing costs and improving performance, especially for small-scale residential application.[24] Key challenges include optimising components and lowering costs, and engine research needs to address existing engineering challenges. Integration of micro-co-generation into smart grids is another focal area, and RDD&D should also focus on flexibility of operation and variable heat/electricity balance in co-generation systems.

RDD&D for advanced distributed energy systems that better utilise waste heat, renewable and other resources, and that can become more economically viable with advanced TES, will be essential to achieve considerable market presence. A significant challenge is the cross-sectoral integration that is needed, which will require co-ordination of multiple players and increased policy support. Advanced system designers need to interact with power sector regulatory bodies, local bodies with infrastructure planning jurisdiction and officials responsible for building efficiency and building codes. Without an overarching strategy, integration is unlikely to occur. In particular, research and market transformation is needed in the following areas:

- **New power generation:** new generation should not be approved unless the system is optimised to better utilise waste heat and alternative innovative solutions have at least been considered.
- **Advanced materials:** new low conductivity insulation, such as aerogels and vacuum panels, have the ability to reduce thermal loss in piping significantly, as does distribution optimisation for temperature gradients based on service requirements and on reduced piping frictional losses.
- **Advanced storage:** new materials, such as low-cost reliable PCM and other storage media, have the ability to offer thermal storage to improve the market viability of projects.
- **Integration with heat pumps and renewable resources:** using resources that are highly usable by non-conventional end-use equipment can lead to dramatic system efficiency performance improvement. These integrated systems need to move from niche applications to commodity-based solutions through standardisation and uniformity measures.

Recommendations

The need to eliminate inefficient fossil-fuel and electric resistance heaters for space conditioning and water heating is critical to reaching 2DS objectives. Even in countries with very high rates of renewable electricity use, moving from current electric resistance heaters to heat pump technology will increase efficiency by a factor of at least two or three. This will free up electricity that can be better utilised in other areas, including transformation of the transport sector using electric vehicle technologies.

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[24] Large-scale co-generation technologies are generally mature and will not experience major improvements in either their performance or costs, but they need integrated cross-sectoral policies to increase market share.

In the very near term, countries with significant gas and other fossil-fuel heating loads need to mandate performance standards that require condensing technologies to achieve at least 95% efficiency (Table 4.5). In moderate climates, condensing fossil-fuel heaters may be a viable option, but other technologies, such as ASHPs with high COPs could also be viable and cost effective. In colder climates, RDD&D is needed to obtain higher performance of ASHPs.

A major effort is needed to encourage immediate adoption of modern biomass stoves that reduce hazardous air pollution, improve health and release biomass resources for use in central systems for a variety of applications. As time progresses, very low-cost solar systems should be pursued.

Existing conventional storage water heaters need to be replaced at a minimum with gas instantaneous or condensing technologies through minimum efficiency standards. Continued RDD&D and policy support are also necessary to encourage increased adoption of solar thermal systems, while TES systems for water heating need to be developed to address peak-load demand issues for heating and cooling needs. Solar thermal systems should be designed and marketed so that they can become self-sustaining without the need for long-term incentives.

Table 4.5 Heating and cooling recommendations

Technology	Immediate recommendations	Future requirements
Electric resistance space heaters	Prevent sale for primary heating sources, promote/ regulate heat pumps.	Advanced heat pumps, cold climate heat pumps and solar thermal technologies.
Electric resistance water heaters	Prevent sale, promote/ regulate solar thermal, heat pump water heaters.	Low-cost integrated space conditioning heat pumps and solar thermal technologies.
Gas boilers and furnaces	Upgrade required standards for condensing boilers to ~95% efficiency or higher.	Invest in gas heat pumps with COPs of 1.2 or higher; micro-co-generation in the future.
Gas water heaters	Promote/regulate standards for condensing water heaters and promote instantaneous condensing water heaters.	Combine function with gas heat pumps and TES systems to increase system performance.
Conventional biomass for space and water heating	Promote low-cost, high-efficiency fireplaces and stoves.	Shift to low-cost solar thermal and modern, clean forms of energy. Better use of biomass in central systems.
Air conditioners	Implement minimum efficiency standard programmes.	Develop higher-performing cost-effective products.

Chapter 5

Lighting, Cooking and Appliances

Significant potential remains to achieve higher energy efficiencies in lighting and appliances, while cooking efficiencies, especially using traditional biomass, can be vastly improved. Greater effort is needed to ensure that existing best available technologies are adopted at a much faster rate in the immediate term, leading to more stringent standards in the future.

Key findings

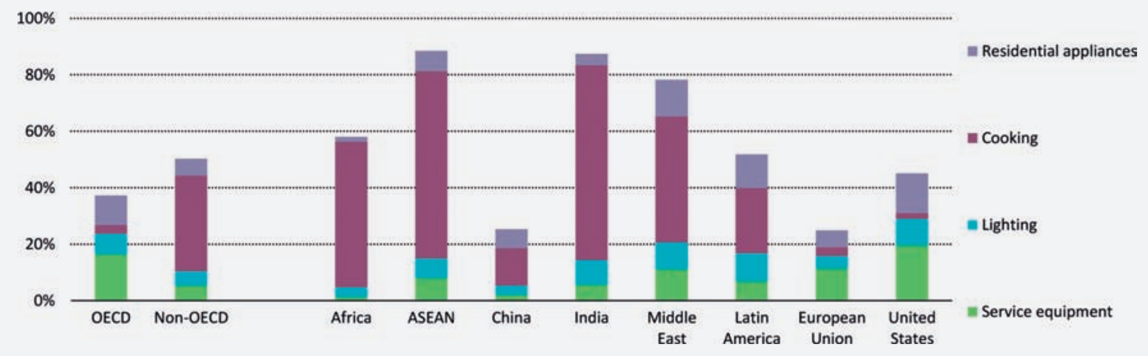
- Global final energy consumption for lighting, cooking, appliances and other buildings equipment accounts for roughly 45% of total final energy used in buildings. Energy efficiency improvements have the potential to reduce this by nearly 25% by 2050.
- Cooking is one of the largest energy uses in households. More efficient technologies, such as advanced biomass cook stoves, can significantly reduce cooking energy use.
- Global lighting energy consumption can be reduced by more than 40% compared with 2010 levels by 2050 using readily available technologies, such as compact fluorescent lamps (CFLs) and solid-state lighting (SSL).
- Available, cost-effective improvements in appliances, such as high-performance insulation in refrigerators, can improve appliance efficiencies by as much as 30%. Continued research and development (R&D) is needed to achieve further improvements that are cost effective.
- Computer and television efficiencies have improved significantly in recent years, although increased ownership and technical specifications (*e.g.* screen size) have offset many of those gains. Continued developments in liquid crystal display (LCD) technologies suggest that a 40% reduction is possible from the most efficient LCD televisions on the market today, while optimal use of power-management settings can further reduce electronic equipment energy use.

Near-term recommendations

- Promotion of low-cost, efficient cooking technologies is critical to reducing the use of traditional biomass in developing countries.
- Excellent progress has been made on standards and labelling for appliances, equipment and lighting, but more is needed. Greater international collaboration will encourage global adoption of energy efficient products and best available technology (BAT).
- Governments should prioritise deployment of readily available advanced lighting technologies. Continued R&D in advanced lighting technologies promises significant efficiency improvements.
- R&D is needed to develop smart electronics to curtail growing electricity loads. Low-cost sensors and controls offer significant potential to reduce power loads and manage peak energy demand.

Global energy consumption for lighting, cooking, appliances and other buildings equipment accounts for roughly 45% of energy use in the buildings sector. In OECD member countries, service equipment[1] (*e.g.* computers, audio-visual appliances and office machines) accounts for more than 15% of final energy use in buildings, while household appliances and cooking account for another 10%. In non-OECD countries, service equipment and household appliances constitute a far smaller energy load, accounting for roughly 10% of total energy use in buildings. By contrast, cooking in non-OECD countries accounts for one-third of total energy consumption in buildings (Figure 5.1).

Figure 5.1 Lighting, cooking and appliances as a percentage of total energy consumption in buildings for selected regions in 2010



Source: unless otherwise noted, all tables and figures in this chapter are derived form IEA data and analysis.

Key point *Appliances and service equipment account for roughly 25% of buildings energy use in OECD countries, while cooking in non-OECD countries accounts for nearly 35%.*

Of the four end-uses illustrated in Figure 5.1, cooking is by far the largest: more than 25% of global household energy use and 20% of total final energy consumption in buildings in 2010 was for cooking. Globally, nearly 70% of cooking used conventional biomass (*e.g.* dung and fire wood). The major part of bioenergy consumed for cooking occurred in developing countries in Asia and Africa, where traditional use of biomass in basic cook stoves or three-stone fires[2] remains the main source of energy. In these regions, cooking typically accounts for between one-third and one-half of residential energy consumption.

Lighting and household appliances (excluding cooking) accounted for roughly 14% of residential sub-sector buildings energy use in 2010. In OECD countries, lighting and appliances (including household electronics) generally accounted for 15% to 25% of household energy consumption, although in Japan it reaches 40% due to lower demand for space heating. In non-OECD countries, lighting and appliances typically constitute less than 15% of residential energy use, although they can be as high as 20% in Latin American countries.

In the services sub-sector, lighting and service equipment accounted for more than half of energy use in 2010. In regions with greater heating needs, such as OECD Europe, OECD Americas, China and Russia, lighting and service equipment typically account for between 30%

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[1] Service equipment in this book refers to a wide variety of end uses, such as information technologies, office equipment, medical technologies, miscellaneous retail and services appliances and small plug loads.

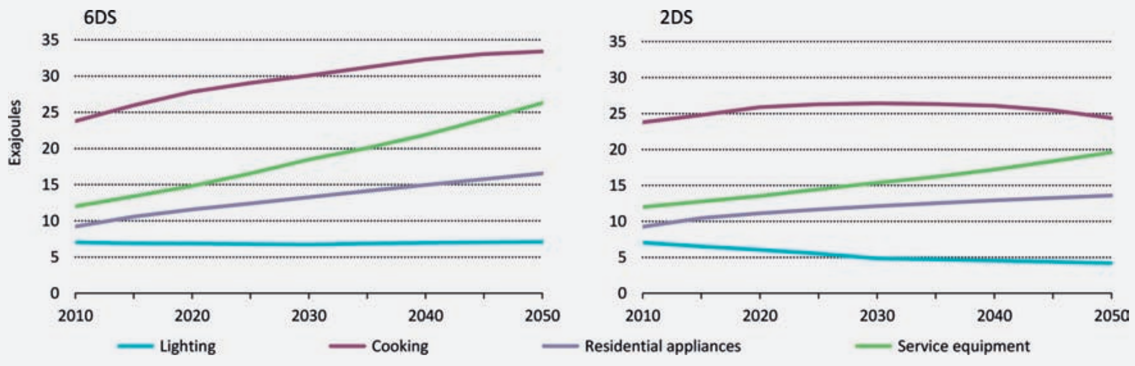
[2] Three-stone fires are the most traditional means of cooking, in which three stones (roughly of equal height) are used to balance a cooking plate or pot over a fire.

and 50% of energy use in services sub-sector buildings, while in warmer regions (*e.g.* India and the Middle East), it can be as high as 80%. Energy use for space cooling in these regions is also increasing as a share of energy use in buildings as demand for comfort continues to rise.

Vision for lighting, cooking and appliances

In the 6°C Scenario (6DS), as set out in the IEA *Energy Technology Perspectives 2012 (ETP 2012)*, energy use for cooking, lighting and appliances in buildings is expected to increase by more than 60% over 2010 levels by 2050 (Figure 5.2). By contrast, energy use for the same applications under the low-carbon *ETP 2012* 2°C Scenario (2DS) is nearly 25% lower in comparison to 6DS levels by 2050. Service equipment energy use decreases by roughly 25% compared to the 6DS, while lighting decreases by 40% and cooking by nearly 30%. The bulk of energy reductions in the 2DS come from efficiency improvements in appliances and lighting, although continued research, development, demonstration and deployment (RDD&D) is needed to achieve those gains by 2050.

Figure 5.2 6DS and 2DS projections to 2050 for lighting, cooking and appliances energy use



Key point *Efficiency gains in cooking, household appliances and service equipment will play a major role in achieving 2DS buildings energy and emissions objectives.*

Significant improvements in energy consumption for lighting, cooking and appliances are possible today using existing, cost-effective technologies. A critical first step to achieving this is to reduce cooking energy consumption in non-OECD regions by moving away from traditional inefficient biomass cook stoves to clean cook stoves,[3] efficient conventional cooking appliances (*e.g.* induction cooktops and microwave technologies) and solar cooking. This shift will also significantly reduce hazardous air pollutants, improving quality of life for households in developing regions, while freeing up biomass for more efficient purposes.

More efficient appliances and improved standby power for electrical devices can offset increasing plug loads in buildings. The use of more efficient lighting technologies, such as CFLs and SSL, and increased application of lighting demand technologies, including improved controls and sensors, can also significantly reduce energy demand in buildings. At the same time, improved building design (Chapter 3) will avoid the underlying need for lighting.

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[3] More information on the Global Alliance for Clean Cookstoves can be found at www.cleancookstoves.org/.

Ownership and energy consumption

In most OECD countries, large appliances have achieved or are approaching ownership saturation.[4] The same is true for many smaller household appliances and plug loads, including televisions, personal computers and mobile telephones. In other regions of the world, ownership levels vary considerably. However, increases in per-capita wealth almost ubiquitously imply increases in ownership of traditional appliances and consequent household energy demand. As income levels continue to rise, ownership in those regions will continue to approach saturation levels, and this will have a significant effect on energy use in buildings, especially in the residential sub-sector.

Demand for new large and small appliances has contributed to significant increases in electricity consumption since 2000 in both the residential and services sub-sectors. In the residential sub-sector, appliances accounted for nearly 2 500 terawatt-hours (TWh) of global electricity consumption in 2010, or around 8% of total buildings sector energy use. That figure represents nearly half of electricity consumed in the residential sub-sector in 2010 and is a 43% increase over 2000 levels. In the services sub-sector, appliances and other service equipment, including information technologies, office equipment, medical technologies and small plug loads, accounted for more than 3 300 TWh of electricity consumption – a 50% increase over 2000 levels.

In OECD countries, large appliances and televisions are still responsible for the majority of household electricity consumption by appliances (Figure 5.3). However, their share is falling, due to energy efficiency improvements in most major appliances and the slowing growth in ownership relative to growth in other household electricity uses, as large appliance saturation is reached. Small appliances and miscellaneous plug loads, including electronics and computer-related equipment, continue to add to electricity demand and now account for roughly 40% of residential electricity consumed by appliances in most OECD countries. This represents a nearly three-fold increase since 1990.

While most large appliances have become more efficient over the past two decades, these gains have been offset by growth in ownership and changes in consumer purchase choices, such as increased functionality and a preference for larger appliances. For instance, flat-screen televisions[5] are more efficient than cathode ray tube televisions, but energy savings to date have been offset by growth in the number of televisions per household and by larger screens that consume more electricity.

In non-OECD countries, ownership levels for many large appliances are still low, with significant potential for growth. For example, only 4% of rural households in India had refrigerators in 2002, compared to the norm of 95% to 100% of households in OECD countries (Figure 5.4). In China, urban household appliance ownership has increased considerably in recent years, especially for refrigerators and clothes washers. However, rural household ownership of appliances in China remains low and represents a large market potential, as per-capita wealth and urbanisation continue to increase.

As global ownership levels continue to increase, especially in non-OECD countries, significant energy efficiency gains will be needed to offset overall growth in demand. Energy efficiency improvements in both large and small appliances will be necessary to offset increases in energy demand, as consumer preferences continue to change (*e.g.* larger television screens and more frequent clothes washing). This will require co-ordinated action in support of 2DS

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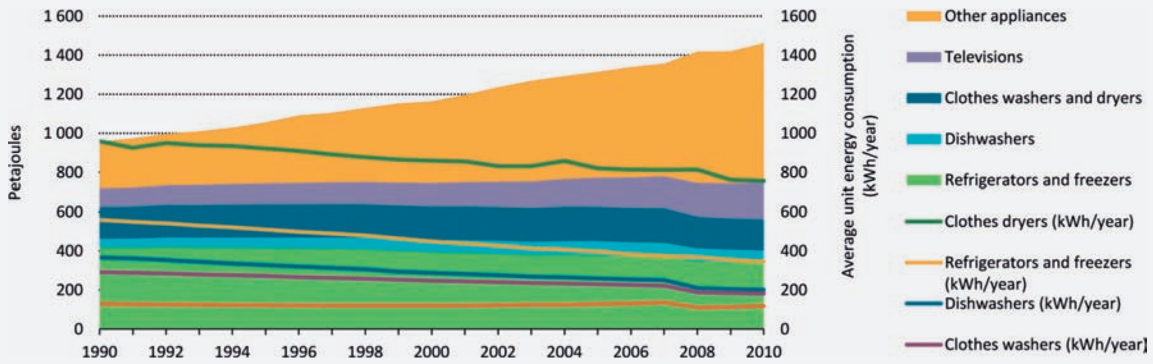
[4] In this chapter, large appliances refer to refrigerators, freezers, refrigerator-freezer combinations, clothes washers, clothes dryers and dishwashers. Cooking is not included in large appliances.

[5] Note that there also is a wide range of performance among flat screen televisions that is discussed later in this chapter.

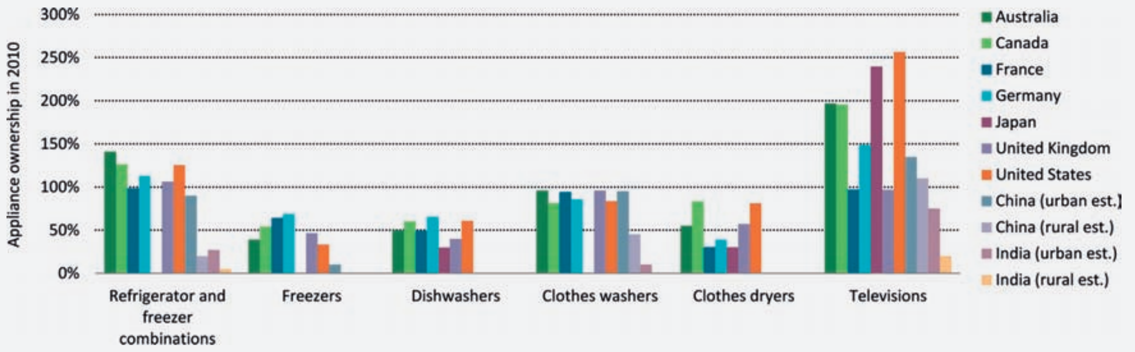
Figure 5.3 Electricity consumption by appliance type (left axis) and average annual electricity use by type (right axis) in selected OECD countries



Note: data are for Australia, Austria, Canada, Czech Republic, Denmark, France, Germany, Greece, Italy, the Netherlands, Switzerland, Sweden and the United Kingdom.
Source: IEA Energy Efficiency Indicators database, 2012.

Key point *Most growth in household electricity consumption since 1990 in OECD regions came from other appliances, including computers, small electronics and entertainment devices.*

Figure 5.4 Selected appliance ownership by country in 2010



Notes: ownership levels above 100% indicate more than one unit per household. For instance, 150% television ownership indicates an average of 1.5 televisions per household. Missing bars do not indicate 0%; rather, data were not available for those indicators.
Source: IEA Energy Efficiency Indicators database, 2012.

Key point *Large-appliance ownership levels have reached saturation levels in most OECD countries, while in non-OECD countries potential for growth in ownership and energy consumption is considerable.*

objectives, including policies that progressively eliminate inefficient technologies (*e.g.* incandescent lamps) and that prioritise the adoption of BAT at competitive, cost-effective prices. Consumer-awareness programmes, standards and labelling are also effective tools to encourage the purchase of the most efficient available technologies (see Chapter 6), while energy management systems will support better co-ordination of all end-uses (including lighting and appliances) in buildings (Box 5.1).

Box 5.1 Energy management systems to integrate all building components

Building automation systems (BAS) integrate technical features within buildings, including heating, cooling and ventilation systems, hot water, lighting, advanced facades and other loads, such as elevators. BAS monitor these features and periodically evaluate energy performance with the help of key performance indicators. Using this information, BAS identify energy-saving potentials to ensure that energy is only consumed when actually needed (*e.g.* office space is only heated or cooled when actually occupied). BAS can also improve operational comfort by regulating temperature, CO_2 concentration, humidity and brightness, and they can be designed to avoid utility peak penalties or ratchet clauses.[6]

The impact of BAS varies based on existing building conditions and applied technology solutions. Typically, BAS achieves higher energy savings through thermal efficiency improvements, although electrical savings from appliance, equipment and plug-load management can also be considerable (Table 5.1). Total savings as high as 40% have been reported in some common building types, although typical savings appear to be in the range of 10% to 30%.

Table 5.1 Range of energy savings from BAS for electrical and thermal applications

Building type	Electrical efficiency improvement		Thermal efficiency improvement	
	High	Advanced	High	Advanced
Office	7%	13%	20%	30%
School	7%	14%	12%	20%
Hospital	2%	4%	9%	14%
Hotel	5%	10%	15%	32%
Restaurant	4%	8%	23%	32%
Retail	5%	9%	27%	40%*
Residential	7%	8%	12%	19%

Note: * Highly dependent upon ventilation demand for heating and cooling.
Source: Siemens, 2009.

Lighting

Lighting is a major energy consumer in the buildings sector. Globally, lighting in buildings consumed roughly 7 000 petajoules (PJ) of energy in 2010, with more than 95% of lighting produced using electricity. Although electricity is the predominant global lighting energy source, alternatives such as kerosene are often used in developing countries or in areas without access to electrical grids. For example, fewer than half of rural households in India have access to electricity, and kerosene is commonly used for lighting (Mahapatra *et al.*, 2009). Oil-based products, including kerosene, accounted for nearly 500 PJ of energy use in 2010, or approximately 7% of global residential lighting energy consumption.

Lighting represents around 15% of electricity consumed in the residential sub-sector and nearly one-quarter of electricity used in the services sub-sector. In OECD countries, lighting typically represents less than 20% of residential electricity consumption and less than

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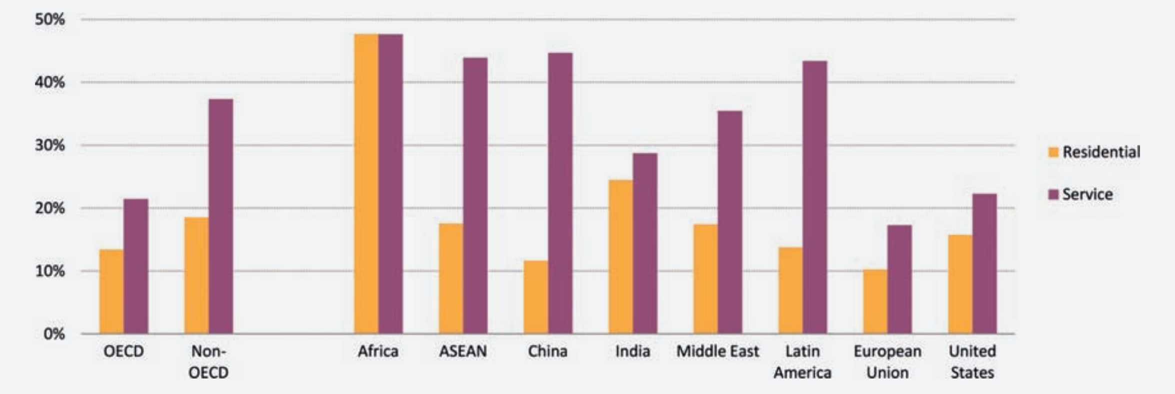
[6] A ratchet clause is a pricing mechanism that may apply for the entire year if a large building compound or industrial facility exceeds a pre-determined peak electricity demand.

one-quarter of services electricity consumption (Figure 5.5). In non-OECD countries, lighting can represent as much as 45% of electricity consumption in buildings. Worldwide, electric lighting is estimated to have accounted for about 1 800 TWh of electricity in 2010.

Figure 5.5 Estimated regional share of electricity consumption used for lighting in 2010



Key point *Lighting accounts for nearly one-quarter of global electricity consumption in buildings.*

Lighting has significant potential for energy efficiency improvement, especially in the services sub-sector. Illumination in services sub-sector buildings accounts for more than 60% of total global lighting energy consumption and 11% of total electricity consumption in buildings. Retail and office spaces are typically the largest lighting end-uses in the services sub-sector. While significant gains have been made through efficiency programmes and lighting technologies (*e.g.* motion sensors and SSL), much more is possible through the adoption of BAT, better matching of lighting intensity to needs and continued technical and behavioural solutions that turn off or reduce lighting when no longer needed.

There is also significant potential to reduce demand for lighting through improved building design, including building orientation and advanced fenestration technologies, such as dynamic windows (see Chapter 3). Through improved use of natural lighting and adoption of highly efficient lamp technologies, global lighting energy consumption in buildings can be reduced by more than 40% over 2010 levels by 2050.

Incandescent lighting needs to be progressively replaced in all regions of the world with more efficient technology. This includes best available fluorescent lighting and SSL technologies that are cost competitive in certain applications. In the future, several market barriers will need to be overcome to achieve the full potential of energy efficient lighting. Fluorescent and SSL lamps are typically much more expensive to buy than incandescent lamps,[7] even though prices have decreased significantly in recent years. Upfront cost, lamp size, shape and start-up times still appear to influence consumer decision making, although recent sales (Figure 5.6) suggest that consumer-focused initiatives are encouraging progressive adoption of CFLs and SSL lamps (Box 5.2). These initiatives include information campaigns regarding the lifetime

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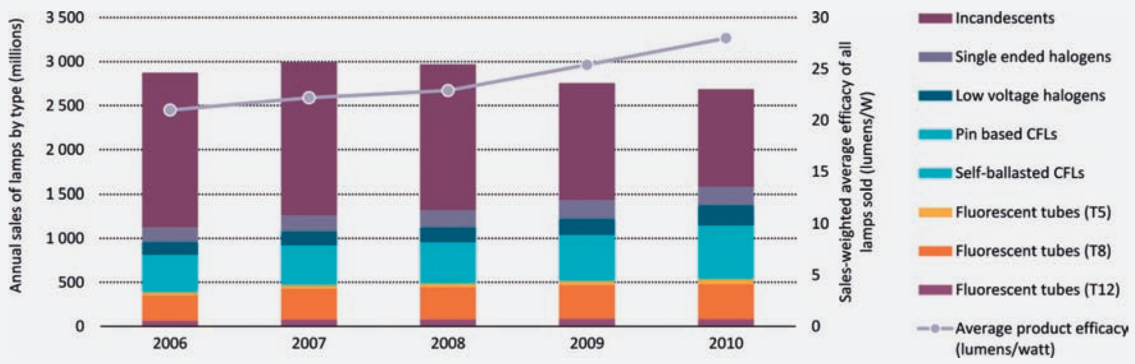
[7] Fluorescent lamps and SSL are typically more expensive than traditional incandescent lamps from an up-front purchasing cost perspective. On a life-cycle basis, however, these lamps are generally much less expensive than incandescent lighting.

benefits of advanced lighting technologies and promotional programmes (*e.g.* rebates and financial incentives). Additional R&D focusing on consumer perception and cost effectiveness will support increased adoption of these technologies.

Figure 5.6 Lamp sales and average efficacy of lamps in the European Union, Switzerland and Norway



Note: T5, T8 and T12 fluorescent tubes refer to the lamp category (size and shape).
Source: 4E IA, 2011a.

Key point *Average lamp efficacy has improved by nearly 35% since 2006 as a result of planned phase-outs of incandescent lamps.*

Box 5.2 Country experience with phase-out of incandescent lamps

In recent years, many governments, including the United States, European Union, Australia, China, Korea and Brazil, have passed measures (*e.g.* bans and energy efficiency standards) to restrict or phase-out the sales of conventional incandescent lamps for general lighting. These measures aim to increase the use and technological development of more energy efficient lighting, such as CFLs and light-emitting diodes (LEDs), and the planned phasing-out of incandescent lamps has encouraged the rapid adoption of more efficient lighting technologies. For instance, the sale of conventional incandescent lamps in the European Union, Switzerland and Norway decreased by nearly 40% between 2006 and 2010, while the sales of low voltage halogen lamps increased by 60%.[8] Fluorescent tube (*e.g.* T5, T8 and T12 lamps) sales similarly increased by nearly 40%, while average lamp efficacy for all lamps sold in these countries increased by nearly 35% (4E IA, 2011a). Similar progress has been made in other countries that have adopted planned phase-outs of incandescent lamps, and greater progress is still possible using even more efficient, increasingly common SSL technologies.

Energy efficiency options

Conventional electric lamps, which dominate today's market, produce visible light through three typical processes: incandescence, gas discharge and electroluminescence. The latter is an emerging technology that is already economic in certain niche markets and includes increasingly common SSL, including LEDs.

The performance of a lighting system is characterised by the efficiency of its different components, and it is generally expressed in terms of lumens (visible light emitted) produced

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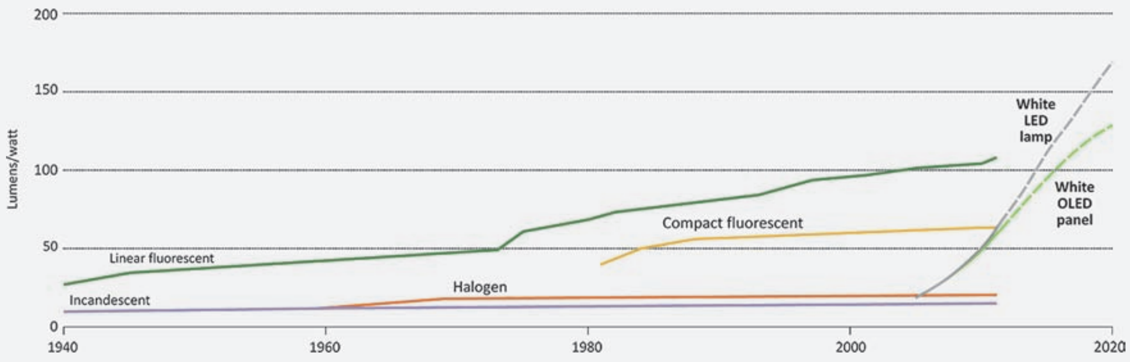
[8] Halagen lamps improve efficiencies over conventional incandescent lamps, but further action is required to improve efficiency performance equal to that of fluorescent lamps or better.

per watt (W) of electricity. Traditional incandescent lamps, in which a wire filament (typically tungsten) is heated inside a bulb filled with an inert gas (*e.g.* argon), are generally the least efficient and tend to have short life spans of less than 1 000 operating hours. The most common type of incandescent lamp is an argon-filled general lighting service (GLS) lamp. It typically emits 12 lumens (lm) per watt, representing an energy-to-light conversion efficiency of less than 5%. By contrast, the most efficient general lighting sources available today can achieve efficacies of 50 lm/W to 140 lm/W (US DOE, 2012a).

Tungsten halogen lamps are another form of incandescent lamp and they achieve higher efficacies (lm/W) than standard argon GLS lamps. However, even the most advanced halogen GLS substitute lamps on the market today (which can use between 30% and 50% less energy than a conventional GLS) are three to four times less efficient that existing CFL and LED alternatives in most applications.

Many alternatives to incandescent lamps are already available and cost competitive when viewed from a life-cycle perspective (*i.e.* purchase and operating costs over the total life of the lamp) (Figure 5.7). Fluorescent lights and other discharge lamps (*e.g.* low- and high-pressure sodium, metal halide and mercury lamps) are more efficient and can have significantly longer life spans. SSL systems currently have efficiencies similar to highly efficient fluorescent lamps, although they have the potential to be much more efficient in the future. SSL lamps could also achieve lifetimes over 100 000 operating hours.

Figure 5.7 Typical lamp efficacies and expected technology developments to 2020



Source: adapted from US DOE, 2012b.

Key point *Existing fluorescent lighting technologies can significantly improve lighting efficiencies, while continued advancements in LED lighting promise to bring even greater improvements to the field.*

Gas discharge lamps

Gas discharge lamps typically offer a longer life and higher efficiencies than incandescent lamps. The most common gas discharge lamp is a fluorescent lamp, which uses a fluorescent coating on the lamp's glass surface to convert ultraviolet light emissions to visible light. Nearly two-thirds of total delivered lighting in services sub-sector buildings today is produced by fluorescent lamps, which have efficacies of 30 lm/W to 110 lm/W (US DOE, 2012c).

Linear fluorescent lamps (LFLs) provide the bulk of global lighting and are common in office buildings and other service applications. LFLs typically achieve luminous efficacies of between

30 lm/W to 100 lm/W and can last 10 to 20 times longer than an incandescent lamp of comparable light output. CFLs, which operate in the same way as LFLs but in a condensed form, have lighting efficacies of 50 lm/W to 70 lm/W (Box 5.3).

Other types of gas discharge lamps include low-pressure sodium lamps, metal halide lamps and high-pressure sodium lamps. Low-pressure sodium lamps have the highest photopic (visible light) efficacy rating (up to 150 lm/W), but they render colours in tones of yellow or grey. High-intensity discharge (HID) lamps produce a broader light spectrum with better colour rendering, although they produce less light output and typically operate in the 50 lm/W to 140 lm/W range (US DOE, 2012d).

Box 5.3 CFL costs, efficacies and future technology development

For the past two decades, governments have promoted CFLs. This has allowed them to pursue strategies to phase-out conventional incandescent lighting. When compared to incandescent lamps, CFLs produce the same amount of visible light using as little as one-quarter to one-third of the electric power. CFLs also generally have significantly longer lifespans (6 000 to 15 000 operating hours) than conventional GLS lamps, although to date they have come at higher cost. Additional barriers in the consumer market have included slow start-up times, lighting quality (rendering) and lamp design (shape), although overall CFL design has improved. Other issues with CFLs include light output decay (less light output over time), lack of effective dimming capability and inability to function fully with lighting control systems (*e.g.* motion detectors). Overall, however, CFLs are typically very cost effective, with as much as a ten-fold return on investment in utility savings (Lavelle, 2007). Concerns about life expectancy and quality have also been addressed in many countries through mandated test provisions for CFL sales. Real world savings, depending on lamp costs, price of electricity and lamp usage, may be less. Nonetheless, CFLs are a more efficient option than incandescent lamps and will support energy efficiency goals until other advanced technologies, such as SSL, are cost competitive and useful in a wide variety of applications.

Solid-state lighting

SSL, or light emitted by electroluminescence in LEDs, has the potential to provide lighting more efficiently than currently prevalent technologies at competitive lifetime cost. Unlike incandescent and gas discharge lamps, SSL creates visible light through small electric diodes without electrical filaments, plasma or gases. This reduces heat generation and energy dissipation while also making SSLs more resistant to shocks and vibrations. SSL also presents many potential advantages over conventional incandescent and gas discharge lighting sources, including lower energy consumption, longer lifetimes, smaller sizes and instant-on performance.

There are three common forms of SSL:

- **Semiconductor LEDs**, which are often used in traffic signals and remote controls, produce monochromatic light that is typically blue, red or green. To produce high-intensity white light, phosphor material (or more recently quantum dots) are used to convert light from a blue or ultraviolet LED to broad-spectrum white light.
- **Organic light-emitting diodes (OLEDs)**, which use a thin film of organic molecules or polymers that emit light in response to electric current. OLEDs are common in mobile devices, although they lag standard semiconductor LEDs in the lighting market. Research indicates that OLEDs could produce better quality and more consistent white light than standard LEDs, although continued R&D is needed to demonstrate that OLED lighting can be deployed at comparable efficiencies and costs.

- **Polymer light-emitting diodes (PLEDs)**, which operate in a similar manner to OLEDs, except PLEDs use an electroluminescent conductive chemical substance in lieu of an organic film to produce light. PLED technology is a promising field because polymers can be produced inexpensively and are lightweight and flexible. PLEDs also promise a number of inherent qualities ideally suited for lighting, including full-spectrum colour displays, high brightness at low voltage and long operating lifetimes. Continued R&D is needed to demonstrate that PLEDs can be deployed at comparable efficiencies and costs to standard LEDs and conventional lamps.

In the future, SSL systems are expected to achieve efficiencies significantly higher than today's conventional technologies for a broad range of lighting applications. The United States Department of Energy (DOE) Solid-State Lighting Program has set target efficiencies for LED systems of between 166 lm/W and 204 lm/W by 2020, depending on light quality, and between 140 lm/W and 180 lm/W for OLED systems in 2030 (US DOE, 2012b). Costs are expected to be between four to eight times higher than GLS lamps with a lifespan that is 18 times longer. While advanced light sources are critical to saving energy, the most efficient light source is one that is not turned on (Box 5.4).

Box 5.4 The most efficient light source is one that is not turned on

A key method to reduce the amount of energy used for lighting is to install integrated building sensors and controls that allow for lights to be turned off when not needed and for the power to be substantially reduced when high levels of light are provided from the outdoors. While there have been concerns over commissioning such systems, modern energy management systems have been effective and accepted by building occupants. Often, these systems can be integrated with whole-building energy management and advanced façade systems to allow for greater natural daylight harvesting while reducing cooling loads to optimise energy use. Top lighting with skylights and new dynamic glazings offer approaches to greater use of natural light (see Chapters 3 and 6 for further information).

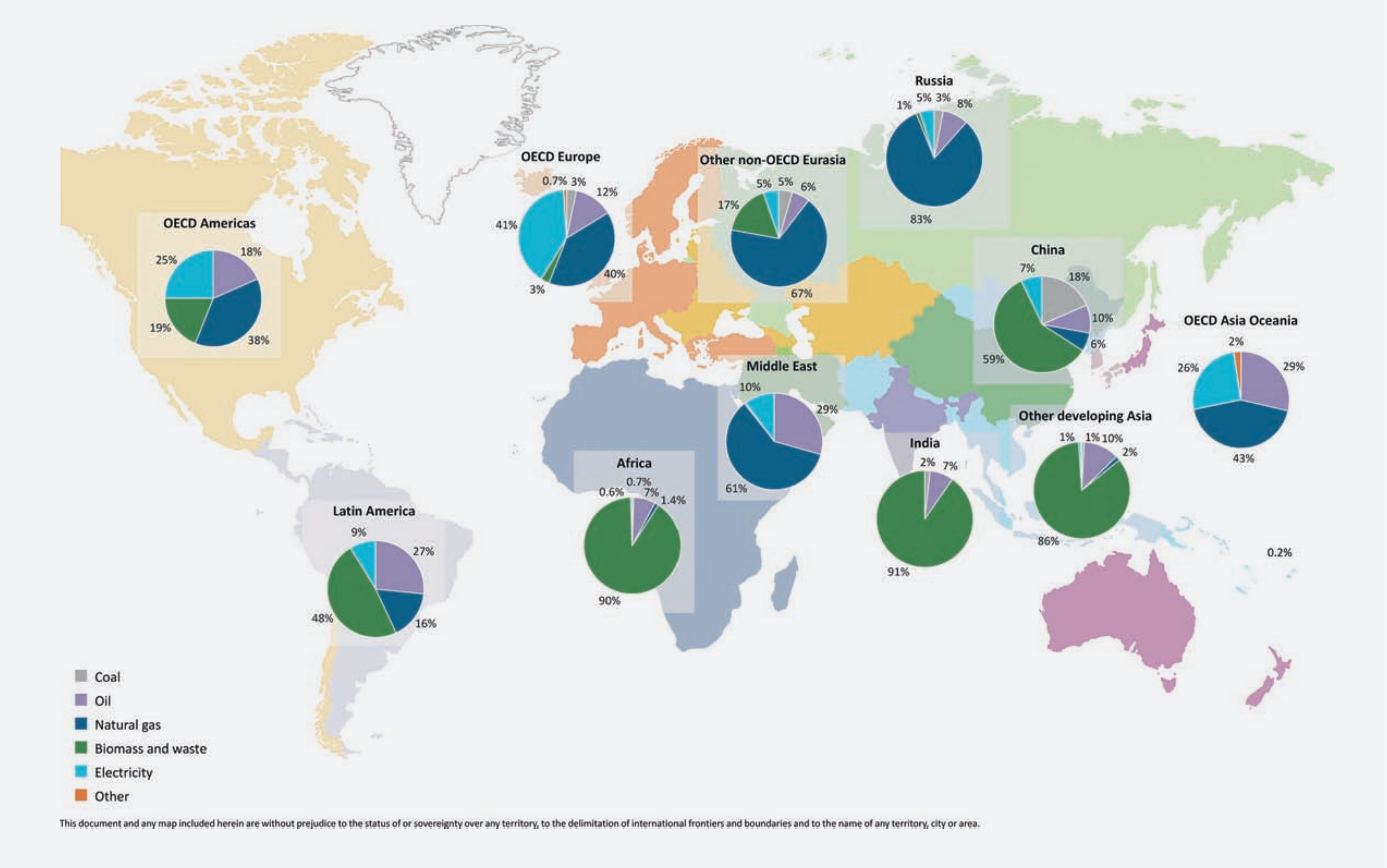
Cooking

Cooking is one of the largest energy uses in the residential sub-sector, accounting for nearly one-quarter of global residential energy consumption and 20% of total buildings energy use. In OECD countries, where cooking is typically done using electric or gas appliances, cooking represents between 5% and 10% of total residential energy use. In non-OECD countries, cooking represents one-third of residential energy consumption, while in some regions, such as India, the Middle East and Africa, it can account for as much as 80% (Box 5.5). Traditional biomass cooking is still prevalent in these regions (Figure 5.8), and total cooking energy use in some non-OECD countries could double by 2050 in the 6DS, despite cooking intensity improvements, as cooking demand continues to increase with expected growth in households.

Biomass for cooking

In non-OECD countries, traditional biomass techniques dominate cooking, accounting for nearly three-quarters of cooking energy consumption. Overall, biomass use has slowly decreased as a percentage of total cooking energy use since 2000, although it still represents two-thirds of energy consumption for cooking globally. Biomass is typically used either in an open fire or a basic cook stove. These traditional cooking techniques are highly inefficient and can release hazardous air pollutants into households and the local atmosphere. They also often create economic burdens that disproportionately affect women and children, especially as cooking and fuel collection can be a woman's responsibility in many developing countries (GAFCC, 2012).

Figure 5.8 Residential cooking energy consumption by region for different types of fuel in 2010



This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Key point *Cooking accounts for 20% of global residential energy use, with cooking in developing regions typically dominated by conventional biomass use.*

Box 5.5

Access to clean cooking and energy for all

The IEA *World Energy Outlook (WEO)* has for many years been focusing attention on modern energy access to provide the international community with quantitative, objective analysis. It estimates that nearly 1.3 billion people (19% of the global population) did not have access to electricity in 2010, and 2.6 billion people relied on the traditional use of biomass for cooking. *WEO* estimates that the number of people without access to clean cooking facilities declined by nearly 40 million in 2010 compared to the previous year. Despite this progress, more than 80% of people in sub-Saharan Africa (95% in rural sub-Saharan Africa) and more than half of those in developing Asia rely on biomass for cooking.

Without additional global action to address access to energy, *WEO* projects that the number of people without access to clean cooking facilities will still be around 2.6 billion people in 2030 – 31% of the global population at that time. In an Energy for All Case, in which all of the world's population gains access to clean cooking facilities by 2030, it is estimated that around USD 88 billion of investment is required to provide access to either advanced biomass cookstoves, LPG stoves or biogas systems. In global terms, the level of investment required is relatively small but the target population is large and the related operational challenges significant. The United Nations declared 2012 as the "The International Year of Sustainable Energy for All" and the Secretary-General has included universal access to clean cooking as part of his Sustainable Energy for All Initiative.

Sources: IEA, 2011 and 2012.

As energy demand for cooking continues to grow in non-OECD regions, more efficient, less polluting and less time-intensive cooking techniques will be necessary. Financing is often an issue, where initial cook stove costs of USD 15 or more are often too expensive for consumers. Size, weight and fragility of cooking technologies also affect the successful penetration of more efficient, less polluting cooking methods.

This pressing need has led to a recent surge in cook stove technologies. In response, the United States Department of State and the United Nations Foundation launched the Global Alliance for Clean Cookstoves in 2010. The Alliance seeks to foster the adoption of clean cook stoves and cooking fuels in more than 100 million households by 2020. This includes low-cost efficient and advanced biomass, alcohol, biogas, electric, LPG and solar cook stoves (Figure 5.9). Many of these technologies are already available on the market and can be relatively inexpensive, although these costs are still often too high for many households. Other potential cook stove technologies require continued testing and development.

Energy efficiency options

Modern electric, oil and gas cooking appliances are expected to continue to be the predominant cooking device in OECD regions, and energy efficiency improvements are not expected to be significant. Appliance size and design continue to be the major influences on cooking appliance efficiency, although some small efficiency improvements are possible. For example, convection ovens are typically more energy efficient than conventional ovens due to the continuous circulation of hot air. Induction and halogen elements on cooktops can also increase device efficiency, although better cookware (*i.e.* pots and pans) using traditional electric or radiant cooktops is often more cost effective (ACEEE, 2012). Increased oven insulation and microwave oven technologies can also improve cooking efficiencies, although again these improvements tend to be marginal and often simply require better consumer awareness (*e.g.* heating water using microwave technologies rather than a traditional cooktop).

Figure 5.9 Example of low-cost efficient cook stove

Source: LBNL, 2012.

Key point *Low-cost, more efficient cook stove technologies can significantly improve cooking energy efficiency in developing regions while reducing harmful local pollutants and improving quality of life.*

Continued support of more efficient, inexpensive cooking options for developing regions (Box 5.6) is critical to reducing overall energy consumption, as well as reducing the social, environmental and economic impacts of traditional biomass cooking techniques. Achieving the Global Alliance for Clean Cookstoves' objective (the adoption of clean cook stoves and cooking fuels in more than 100 million households by 2020) will significantly reduce the energy intensity of cooking in developing regions, while also reducing overall energy demand and air pollution related to biomass cooking.

Appliances and buildings equipment

Household appliances and electronics – including televisions, computers and other plug loads, such as radios, printers and hand-held electronics – account for 8% of total buildings energy use and 12% of buildings electricity use. In OECD countries, where household appliances have high penetration rates, appliances and electronics typically account for 5% to 10% of total energy use in buildings and roughly 15% of residential energy use. In non-OECD countries, household appliances and electronic equipment tend to account for less than 10% of energy use in buildings.

In the services sub-sector, computers, office machines and other electric plug loads constitute another 10% of total buildings energy use and more than 40% of services sub-sector electricity consumption. Unlike the residential sub-sector, there is no clear divide between OECD and non-OECD countries with respect to service equipment as a share of electricity consumption: office appliances and service equipment in most regions of the world tend to account for 30% to 40% of electricity consumption in services sub-sector buildings.

Box 5.6 Low-cost cook stove options for developing regions

Significant gains can be made in developing countries by shifting from traditional biomass to advanced biomass cooking technologies and low-cost, more efficient cook stoves (see Figure 5.9). Possibilities include (GAFCC, 2012):

Advanced biomass cook stoves. Forced-air stoves using traditional raw or processed biomass can significantly increase cooking energy efficiencies, reducing fuel use by as much as 60% over a traditional open fire. Forced-air, advanced biomass stoves use a fan to blow high-velocity, low-volume jets of air into the combustion chamber of the cook stove, which encourages a more complete combustion of the biomass. The fans can be powered by a battery, an external source of electricity or a thermoelectric device that captures heat from the stove to generate electricity.

Alcohol cook stoves. These can burn ethanol or methanol in a liquid or gelled/wax form using a pressurised or non-pressurised chamber. Stove efficiency depends on the fuel source, with liquid alcohol typically more efficient than gel fuels.

LPG and biogas cook stoves. Gas cook stoves, like modern gas cooking appliances, can be extremely efficient, with energy efficiencies as high as 90%. LPG canisters can be used to fuel small LPG cook stove devices, although access and costs are often barriers in many developing regions. Biogas also can be used as a fuel, and it can be particularly useful in developing regions since it can be produced domestically using animal manure and human waste. Biogas cook stoves generally achieve efficiencies of 50% to 65%, depending on the gas pressure and stove design.

Rocket cook stoves. These cook stoves use insulated, L-shaped combustion chambers to allow for partial combustion of gases and smoke inside the stove. The L-shape also improves cooking efficiencies by directing the flow of hot gases close to the cooking surface (*i.e.* a pot or griddle). Field studies of rocket stoves show that they can achieve 40% to 50% reductions in fuel use compared to traditional biomass cooking.

Solar cook stoves. Solar cookers include three principal technologies: panel cookers (the most common), and box and parabolic cookers. Panel cookers are the least expensive and most portable and use reflective foil bound to a panel (*e.g.* plastic, metal or wood) to collect sunlight and heat a cooking pot. Box cookers work on a similar principle and heat a pot, which can itself hold several pots. Parabolic cookers use a dish-like surface to concentrate sunlight on the bottom of a cooking pot. The efficiency of all three solar stoves depends on the intensity of solar rays, and cost remains a major issue.

Over the next 40 years, global energy consumption for appliances and buildings equipment is expected to nearly double. Under the 2DS, this increase could be limited to just 55% over 2010 levels by 2050, although achieving this will require significant improvements in major appliances and electronic goods. Rapid adoption of BAT and continued development of super-efficient equipment and appliances[9] is needed, while demand management (*e.g.* smart appliances) will help to limit peak energy loads (Box 5.7).

Refrigeration

Global sales of non-commercial[10] refrigerators and combination refrigerator-freezers increased to nearly 100 million units in 2009, with another 15.6 million individual freezer units also sold that year. Refrigerators sales grew particularly strongly in Asia and South America (Gfk, 2010). There is a wide variation in refrigeration product size and price by region, where refrigerators in the United States and Canada typically have average internal volumes nearly twice those of the

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[9] More information on the Efficient Electrical End-Use Equipment (4^E) Implementing Agreement on Super-Efficient Equipment and Appliance Deployment (SEAD) initiative can be found at www.iea-4e.org/news/sead.

[10] Non-commercial refrigeration does not include large-scale appliances, such as supermarket refrigeration systems, walk-in coolers and freezers, beverage and ice machines, vending machines and food service equipment.

Box 5.7 Smart buildings, lighting and appliances

Smart buildings (also known as automated, integrated or intelligent buildings) are a recent but rapidly evolving technological development. A smart home or building is equipped with an information and communications technology (ICT) based system that enables occupants to remotely control or programme electronic devices. For example, a homeowner can use a smart phone to activate the home security system, control temperature gauges, switch appliances on or off, control lighting, or programme the entertainment system. Smart buildings can also programme appliances to respond to external influences, such as changes in temperature or signals from an electricity supplier. There are even technologies that enable the use of sensors and software to anticipate the needs of building residents and offer services that improve health, comfort, security or energy efficiency.

The number of network-connected products in homes is still limited, although it is increasing as appliance manufacturers integrate smart technologies into new products. Some categories of products have seen a fast uptake. For instance, smart phones that can be used to interact with other household devices and the broader network have seen a rapid increase in sales in recent years. In the United States, smart phones account for more than 50% of market share in new mobile telephone sales (Dutta and Mia, 2011). These devices can be used to improve building efficiencies through compatible products and "smart" applications.

Smart buildings can make use of network connections to provide more efficient practices, including automating heating, cooling and lighting systems that are demand-responsive. These systems could reduce building energy consumption significantly and help to reduce projected peak demand by as much as 20% (FERC, 2009; 4E IA, 2012a). Voltage optimisation by means of networked solutions could also reduce existing electricity losses in transmission and distribution networks. Similarly, standby waste technologies that identify equipment that is not being used could switch off unused equipment through remote power management.

Perhaps the most significant ICT advancement in recent years is smart grids, which make possible two-way, real-time data and power transmission between provider and consumer. By means of network technologies, smart grids allow generators to route power more efficiently, while also allowing demand-side management by the consumer. Smart grids can also incorporate emerging technologies, such as distributed generation from renewable sources and energy storage capabilities, to reduce the need for excess generation capacity during peaks in demand. While all these technologies are promising, there also is a concern that any new equipment complies with the IEA 1-watt standby power recommendation (IEA, 2007). A balance of smart devices and additional energy demand will be critical to reducing overall buildings energy consumption.

European Union, China and Australia. At the same time, the average size of refrigeration units throughout most regions of the globe has grown steadily since 2000 (4E IA, 2013).

Refrigeration technologies are very similar across refrigerators, refrigerator-freezer combinations and individual freezer units. Most refrigeration appliances across the globe are electrically driven vapour compression devices (see Chapter 4 on heat pumps and air conditioners) that use compressors, working liquids (*i.e.* refrigerants) and heat exchangers both inside and outside of the appliance. Insulation in the walls and doors helps reduce thermal loss and energy consumption, while compressor efficiency and the accuracy of control devices also influence appliance energy consumption.[11] Additional factors that influence energy efficiency include the frequency of door opening, interior (user set) temperature, ambient temperature, the size and volume of the appliance, and additional appliance functionalities, such as ice makers or cold water dispensers.

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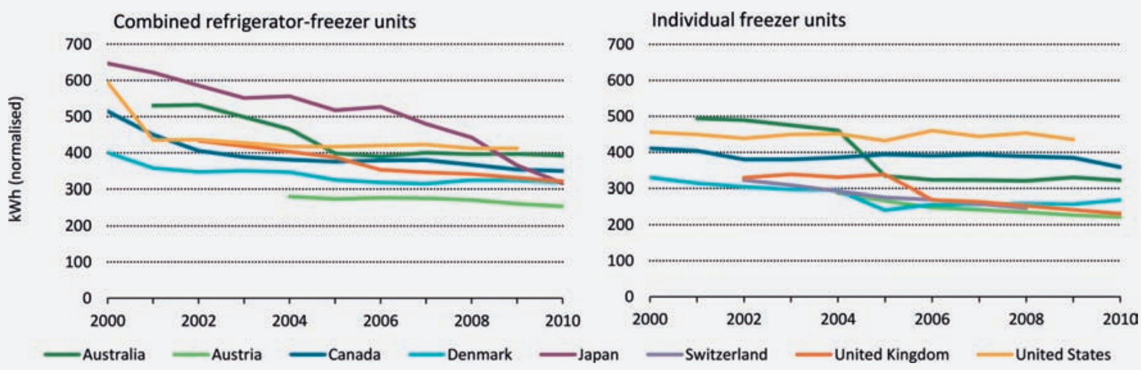
[11] Appliances that use alternative principles, such as heat-driven absorption cycle and water evaporator type refrigerators that do not have compressors, represent a very small part of the global market and are excluded from this analysis.

Over the past decade, average refrigeration energy efficiencies (in terms of energy consumed per year) have improved for most new units (Figure 5.10). Reported refrigeration energy consumption decreased by as much as 25% over 2000 levels in some countries, while in the United States reported energy efficiency gains were marginal.[12] Part of this trend is explained by increased consumer preferences in the United States for larger units with more amenities (*e.g.* double-door units and through-the-door water and ice dispensers). Overall, however, global refrigeration energy efficiency, in terms of energy consumed per volume of space, has continued to improve since 2000.

Figure 5.10 Trends in annual energy consumption of freezers and refrigerator-freezers



Note: data is as declared by manufacturers using local test methodologies in kilowatt-hour (kWh) per year.
Source: 4E IA, 2013.

Key Point *Since 2000, energy consumption per unit volume of refrigeration has declined.*

Energy efficiency regulations have also played a strong role in shaping product efficiencies in the refrigeration market. For instance, mandatory efficiency standards in the United States for refrigerator energy use were extremely successful over the past two decades, with average unit energy use decreasing by nearly 50% between 1990 and 2010 (Letschert *et al.*, 2012). These gains were considerably greater than the relative increase (less than 10%) in average refrigerator volume, while average product prices during that same period also decreased by nearly 25%.

Energy efficiency options

Several technical improvements for refrigeration are readily available and can be applied at relatively low cost. These include high-performance insulation, increased surface areas for evaporators and condensers, higher-efficiency compressors, variable-speed compressor controls and individual compartment temperature controls. Many of these improvements can be applied to existing appliance models through use of different components or improved controls, although significant energy improvements on both new and existing appliances can be expensive with respect to efficiency gained (Table 5.2).

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[12] The United States has previously had very aggressive refrigerator standards leading to some of the most efficient products (per unit of space cooled) in the world. Although the current level of improvement is slow, further minimum energy performance standards are likely to come into effect in 2014, which would lead to significant improvements in new products.

The optimum mix of efficiency options varies according to the type of refrigeration appliance and the overall target reduction in energy use. In general, increasing door and cabinet wall insulation thickness by up to 15 millimetres (mm)[13] is cost effective and can achieve as much as 10% savings in typical refrigeration units (ISIS, 2008). Increasing compressor efficiency is also generally cost effective, with savings as high as 10%, while increasing condenser and evaporator surface areas similarly can achieve cost-effective savings in the range of 3% to 4%. However, to achieve efficiency gains of 30% or more, more advanced technical improvements (*e.g.* vacuum insulated panels [VIPs] and variable-speed compressors) will need to come down in price to be cost effective.

Table 5.2 **Selected technical improvements with production price increases and annual electricity savings for refrigerators and refrigerator-freezers**

Technology	Refrigerators		Refrigerator-freezers	
	Unit production price (USD)	Electricity savings (kWh/year)	Unit production price (USD)	Electricity savings (kWh/year)
VIPs on door	29	6.5	50	16.2
VIPs on cabinet walls	57	16.4	71	32.4
Additional 10 to 15 mm insulation on door and cabinets walls	14	19.6	17	29.2
Increasing surface area of the evaporator by 10% to 20%	4	4.9	7	9.7
Increasing surface area of the condenser by 5% to 10%	3	1.6	3	3.2
Higher-efficiency reciprocating compressor (COP 1.5)	7	16.4	7	32.4

Notes: Savings achieved cannot simply be added together arithmetically as the measures interact to alter the achieved savings, depending upon the combination in place; COP is the coefficient of performance (see Chapter 4 on heating and cooling efficiencies).
Source: ISIS, 2008.

Longer-term technical improvements include linear free-piston compressors using gas bearings and advanced insulations, such as VIPs or aerogels that have two to six times the thermal performance of conventional polyurethane foams. Alternative cooling technologies, such as thermoelectric cooling, in which heat is "pushed" away using heat pump technologies, and hybrid thermoelectric-vapour compression systems could also lead to improvement in both unit capacity and efficiency.

Washing machines and clothes dryers

An estimated 84 million washing machines were sold globally in 2009 (GfK, 2010). Growth was highest in Asia, where annual sales increased by more than 25% between 2006 and 2010. By contrast, clothes dryer sales continue to be dominated by OECD countries, with the North American market accounting for nearly 60% of world sales. Nearly one-quarter of dryers in the North American market are gas-driven (US DOE, 2009). The bulk of remaining dryer sales were in the European Union (4E IA, 2011b).

The average capacity of washing machines and clothes dryers has increased in almost all countries over the past decade, and there is no apparent indication that these increases are

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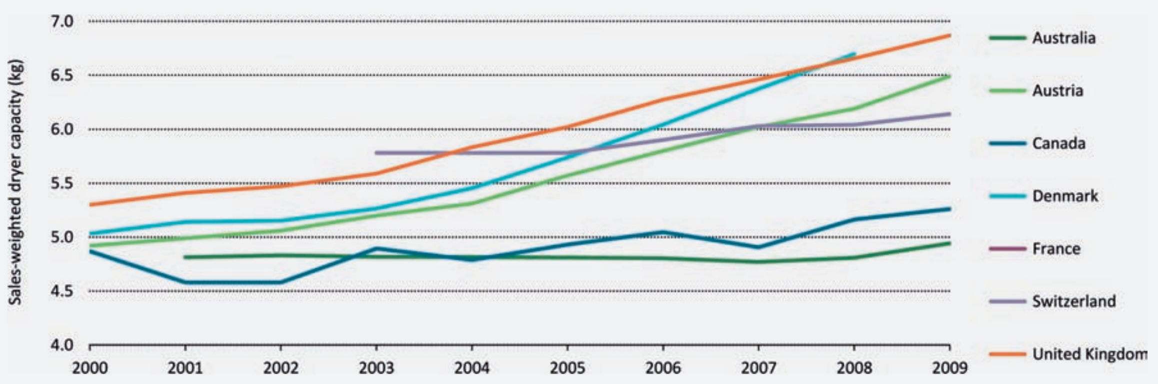
[13] For many applications, increased external dimensions are not a problem. However, in markets with kitchens that have space constraints, increased insulation can necessitate reducing internal capacity. This can be a barrier for adoption by manufacturers.

reaching a plateau (Figure 5.11). To some extent, the ongoing increase in machine volume has contributed to increased product efficiency, where larger, fully loaded machines typically achieve greater energy efficiency per kilogram of load because the required energy is proportionately lower. However, the benefit of increased capacity-driven efficiency improvements is dependent on consumer behaviour and machine use.

Figure 5.11 Trends in average dryer load capacity



Note: United Kingdom data used up to and including 2006 are sales weighted, while data for 2007 to 2009 are only product weighted according to a commercial provider of reference data on product performance.
Source: 4E IA, 2012b.

Key point *Since 2000, average washing machine and clothes dryer capacity has continued to increase.*

It is difficult to make robust comparisons of energy consumption for washing machines and clothes dryers given the wide variation in product type, test methodology, typical temperature and number of cycles per year. However, overall trends indicate that new washing machines and dryers are considerably more energy efficient. Sales-weighted data since 2000 show that the normalised average unit efficiency for washing machines improved to roughly 0.5 kWh per wash cycle, while dryer efficiencies in new machines appear to have converged toward 0.7 kWh per kilogramme (kg) of dry load (Figure 5.12) (4E IA, 2012c).

Energy efficiency options

The efficiency of washing machines depends notably on three main machine processes: heating water, mechanical action (*i.e.* agitation during washing and fast rotation during the spinning process) and pumping. The largest share of energy used is for water heating. When heat losses are taken into effect, water heating accounts for as much as 85% of energy consumption in the wash cycle of a typical 60°C front-loader (ISIS, 2008). Areas for improvement include:

- **Hot water.** The source of hot water plays a significant role in washing machine efficiency. More efficient sources of central water heating and instantaneous water heaters can help to reduce system losses, while heat pumps and solar thermal technologies will increasingly play a role in meeting household hot water demand (see Chapter 4).[14] Further

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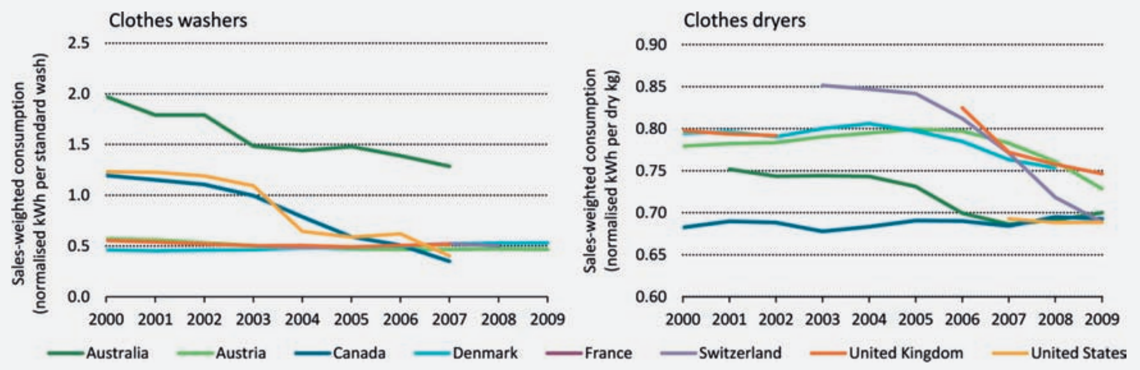
[14] Note that many clothes washers heat water within the machine with electricity that is more efficient than central electric storage water heaters due to storage and distribution losses. However, with improved central water heating sources, in the future this may no longer be the case.

Figure 5.12 Average washing machine and dryer unit energy consumptions



Note: United Kingdom data used up to and including 2006 are sales weighted, while data for 2007 to 2009 are only product weighted according to a commercial provider of reference data on product performance.
Source: 4E IA, 2012b,d.

Key point *Since 2000, average new washer efficiency has increased, where new machines typically use around 0.5 kWh per wash cycle.*

improvements rely on switching from warm to cold washing, which depends largely on consumer behaviour and the cost and availability of low-temperature detergents.

- **Optimised wash cycle.** Further improvements in machine efficiency are possible through optimised mechanical action, temperature control sensors and rinsing phase optimisation. Incorporating these technologies is generally cost effective over the economic lifetime of the product. Remaining efficiency improvement for most high-efficiency washing machines on the market today appears to be limited to about 10% to 15%, barring new technological leaps (ISIS, 2008). This is largely due to water heating needs.
- **Advanced washing technology.** Longer-term technological improvements include reduced thermal mass, electrolytic disassociation of water, ultrasonic washing, bubble action and ozonated laundering. Alternative washing systems that re-use water or that use none at all are another area of potential washing improvement. For instance, Electrolux and Sanyo have products that use pressurised air to disinfect, deodorise and remove light stains. However, continued development of these alternative technologies is required to demonstrate their commercial potential as a widespread washing option.

The main improvement options for clothes dryers include exhaust air heat recovery, improved motor efficiency and improved insulation, all of which offer opportunities for marginal energy savings at reasonable cost. Improved moisture extraction in washing machines is becoming more common and reduces energy consumption, while increased use of natural air drying could cut energy consumption considerably. Alternative dryer technologies, such as microwave drying, have also been proposed, although they have never been commercially established.

Major opportunities for energy savings include:

- **Heat pump clothes dryers.** This is a promising technology with potential to cut typical dryer energy use by as much as 50%. Cost remains a barrier to bringing them to a widespread market scale, although costs are likely to decrease as heat pump technologies continue to become more widely available. If applied to today's typical vented dryers, heat pumps could reduce dryer energy consumption by nearly 40% (PWC, 2009).[15] This is a significant improvement over marginal improvements available from current clothes dryer technology.

- **Fuel switching** (*e.g.* electric dryers to gas dryers). This can significantly reduce CO_2 emissions in countries with a high mix of fossil fuels for electricity generation.

Televisions

Televisions were estimated to consume as much as 168 TWh of electricity in 2010 (Park *et al.*, 2011). Around 248 million televisions were sold in 2010 (NPD DisplaySearch, 2012), with very high market growth in countries such as China and Brazil. By 2016, annual sales are projected to reach nearly 265 million units.

In recent years, LCDs have come to dominate television sales, accounting for around 80% of global sales in 2010 (NPD DisplaySearch, 2012). Conventional cathode ray tube (CRT) screens still accounted for around half of sales in China, India and Brazil in 2010, while CRT sales dropped considerably in most OECD countries. Korea is an exception, with CRTs accounting for roughly 25% of sales in 2010, although the global trend is a decrease in CRT sales (4E IA, 2010).

In all markets, the share of higher-efficiency LED-backlit LCD televisions is small but growing. By 2010, LED-backlit LCDs accounted for more than 15% of global television sales (NPD DisplaySearch, 2012). Plasma televisions occupy a niche market for large screen sizes but are still a small portion of television sales. With a few exceptions (*e.g.* Korea and Australia), plasma television sales in most regions account for less than 10% of the market.

Television efficiency is often expressed in typical on-mode energy consumption (W) or annual energy consumption in kWh per year. Average annual values are generated using an assumed average number of hours per day of use,[16] and neither efficiency estimate takes into account differences in screen size, which significantly affects television energy consumption. For instance, a 40% larger screen (in diagonal measure) equates to roughly twice the screen area and roughly a 60% increase in electricity consumption when the television is on (4E IA, 2010). A better metric of television efficiency therefore would be a measure of power required per unit area of viewable screen, or watts per square decimetre (W/dm^2) in "on" mode.[17]

Variations in design have a significant effect on the efficiency of television technologies. For example, LCD displays can be lit by LEDs or cold-cathode fluorescent lamps (CCFLs), where LEDs typically have higher efficiencies than CCFL screens (Table 5.3). Screen size, resolution, colour range and refresh rate also influence unit efficiency.

CRT televisions represent the oldest and the least efficient television screen technology. While they tend to consume less energy (in kWh) than LCDs and CCFLs, they also typically have a smaller screen and have an average efficiency of about 4.2 W/dm^2. By contrast, LED-lit LCD televisions have an average efficiency that is around 1.7 W/dm^2, while CCFL LCDs have an efficiency around 2.3 W/dm^2 (Park *et al.*, 2011). PDP televisions, which employ a small plasma cell created by high-voltage plates behind each sub-pixel on the screen, have an average efficiency that is around 2 W/dm^2. OLED technologies perform similarly, although at smaller sizes.

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[15] A case study in Chapter 6 shows 50% savings but that was relative to older dryers.

[16] For example, the European Union's energy label assumption is for four hours per day for 365 days per year.

[17] In 2008, test standard IEC 62087 Edition 2 *Methods of measurement for the power consumption of audio, video and related equipment* was established as the globally accepted methodology for televisions. This methodology has been adopted for ENERGY STAR testing in the United States and for energy labelling in Australia and New Zealand. One criticism of the W/dm^2 approach, however, is that it communicates a false sense of "savings" to consumers, as larger televisions using the same technology as smaller screens have similar efficiency ratings but higher total energy consumption.

Table 5.3 Average television screen area and on-mode energy efficiency by technology type in 2010

	Average size (dm^2)	Average on-mode energy consumption (W)	Average energy efficiency (W/dm^2)
OLED	6	11	1.8
Plasma display panel (PDP)	59	120	2
LED LCD	39	67	1.7
CCFL LCD	31	72	2.3
CRT	13	55	4.2

Source: Park *et al.*, 2011.

OLED televisions have the potential to produce light 30% to 40% more efficiently than an LCD screen, although they still remain a niche market for television screens. Difficulties with production and product lifetimes have delayed OLED introduction into the mainstream consumer market, and available OLED televisions tend to have higher costs. This is likely to change quickly, as with LED and CCFL technologies in recent years.

Energy efficiency options

Screen technology and size

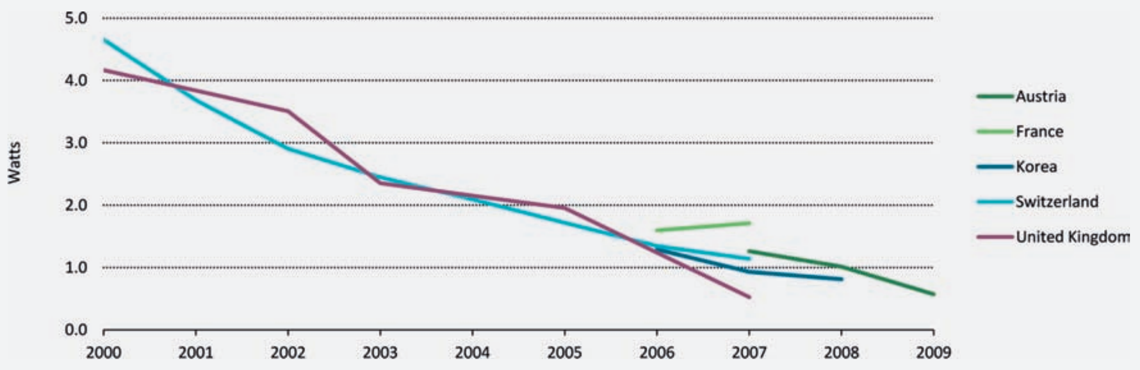
Television screen technology is the most important determinant of energy efficiency (in W/dm^2), while screen size is the most important determinant of overall television energy consumption. The average efficiency of the global television stock today is most likely around 4 W/dm^2. This estimate reflects the large presence of CRT screens remaining in use, despite decreasing sales over the past decade.

Recent shifts to more efficient non-CRT televisions have played the most significant role in improving television efficiencies. Power-management features are also helping to improve efficiency, although they are often marginal. Ambient light controls, which automatically dim television screens in low-light conditions, and automatic standby power mode without user intervention after a certain period (often four hours) are two examples of technology options that have reduced average energy demand in new televisions (Figure 5.13) (4E IA, 2010).

Recent labelling programmes, such as the European Union Energy Label, have encouraged overall efficiency improvements in televisions on the market. Since 2010, the average energy efficiency of the most efficient televisions in Europe has improved by 50% (Topten EU, 2012), while in the United States, the best performing models in 2012 used about half of the on-mode power used by the same-sized models in 2011 (Topten USA, 2012). These improvements are expected to continue as consumer demand encourages manufacturers to improve television technologies. While energy efficiency programmes and product labelling have been effective, television technology improvements often are significantly faster than expected (Toulouse, 2013).

Despite gains in screen technology and energy efficiency, on-power television energy consumption still increased considerably in the past decade. Screen sizes have increased consistently in most regions of the world since 2000, and screen size plays a significant role in net television energy demand. Given the increasing preference for larger television screens and the continued growth of television sales, especially in non-OECD countries, improvements in television energy efficiencies (in W/dm^2) will be essential to reduce expected future increases in television energy demand.

Figure 5.13 Average standby power for televisions in various OECD countries



Source: IEA4E, 2010.

Key point *Average standby power consumption of televisions has declined significantly in recent years.*

Improved LCD and PDP screens

Several television technologies promise to continue recent trends in efficiency improvements in LCD and PDP screens. High-efficiency polarising filters may improve the efficiency of LCD televisions by as much as an additional 30% (Garud, 2012), while modulating (*i.e.* dynamic dimming) LED backlights for LCD televisions could also improve television efficiency by as much as 50%. Manufacturing capacity is growing rapidly for modulating technologies, which in addition to increasing efficiency will also improve image quality. Enhanced features could have significant energy benefits in the television market, especially as projections show that LED-backlit LCD technology is expected to be nearly 95% of market sales by 2014 (NPD Display Search, 2012).

Continued developments in LCD technologies suggest that an efficiency level of 1 W/dm^2 can be achieved through high-efficiency LED backlighting. This is equivalent to a 40% reduction from the most efficient LED-backlit LCD televisions on the market today. In theory, the same efficiency level could be achieved using OLED screens, although current OLED production facilities are unable to manufacture large screen sizes and significant global investments in OLED manufacturing facilities would be required to meet continued demand for new units over the next decade.

Computers

There were approximately 1 billion computers worldwide in 2010, with considerable variation in usage among countries and categories of users (IEA, 2009). Global computer sales reached nearly 87 million units in the third quarter of 2012 (Gartner, 2012a), while tablet sales were expected to reach nearly 120 million units worldwide by the end of 2012 (Gartner, 2012b). Sales in China have caught up with the United States in the past decade, while India still remains a market with significant potential for growth.

Average energy consumption levels for desktop computers appear to vary considerably across different regions. For instance, desktop computers in the United States and Europe tend to be more efficient than desktop computers in China and India. Conversely, notebook computers in the United States tend to have higher typical energy consumption (TEC)[18] levels than those in Europe and Asia. This is most likely the result of greater demand for higher-capacity notebooks in the United States with larger screens and lower operating efficiency. Usage habits also affect energy use (Box 5.8).

Box 5.8 Impacts of computer use on energy consumption

The power demand of computers varies considerably depending on the mode in use. A computer's most intense energy demand occurs when the central processor is being used actively (*e.g.* during start-up). However, this mode represents a small portion of a computer's actual time used, as most activity for the average user typically occurs in what is referred to as "on-idle" mode. On-idle is the mode during which software and the operating system, previously loaded, are operable but do not require significant use of the central processor. Based on the usage profile applied in ENERGY STAR[19] V5 criteria, on-idle mode accounts for nearly 90% of the total annual consumption of a typical notebook and as much as 96% of a typical desktop computer (US EPA, 2012).

Internet access and networking also influence typical computer energy consumption. Internet usage varies greatly among countries, where India has one of the lowest internet usage rates in the world, with roughly 10% of its population online (Sengupta, 2012). By contrast, around 40% of China's population was believed to have internet access as of June 2012 (Kan, 2012), while more than 77% of the United States and nearly 95% of Sweden and Singapore have internet access (China Daily, 2013). As computer ownership, access and internet use increase in developing regions, this will impact global computing and networking energy demand.

In general, there has been less engineering focus on optimising the energy efficiency of desktop products than notebook computers, which rely heavily on portable rechargeable batteries and often are operated independently of external power supplies. However, technical improvements could improve desktop computer TEC levels significantly (Table 5.4), where existing BAT is considerably more efficient than the estimated global stock average.

Table 5.4 Estimated annual energy consumption for computers

	Desktop				Notebook			
	Annual TEC (kWh/year)	Idle mode (W)	Sleep mode (W)	Off mode (W)	Annual TEC (kWh/year)	Idle mode (W)	Sleep mode (W)	Off mode (W)
Base case	270	75	3.8	1.0	68	23	1.8	1.2
BAT case	50	13	1.7	0.8	20	7	0.9	0.4

Notes: screen energy consumption is included for notebooks but is excluded for desktops given the complexity of assigning monitor energy use to desktop computers. Screen energy use would therefore raise desktop TEC.

Energy efficiency options

The rapid pace of change in computer technologies makes it difficult to assess future improvements in energy efficiency, especially with regard to changes in user preferences and technical demands (*e.g.* increased video processor capabilities). Best performing products

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[18] The United States ENERGY STAR program defines a TEC metric to compare products on the basis of energy efficiency. TEC presents the electricity consumed by a product in kWh for a typical usage pattern (*e.g.* idle-on and sleep modes) over a certain period of time. This metric and ENERGY STAR test methodology are now globally accepted by manufacturers and have been used to assess energy savings potential for computers and other appliances.

[19] ENERGY STAR is a voluntary labelling program that was initiated in the United States but is used in several countries. More details are provided in Chapter 6.

available on the market, such as ENERGY STAR computers, demonstrate the potential to improve global average computer energy performance. Desktop performance in particular could be improved significantly using existing, cost-effective technologies.

Built-in power management

Another key determinant of total energy consumption for almost any computer is the configuration of built-in power-management capability. Studies have shown that fewer than 25% of users activate the sleep mode on their computers (IEA, 2009), and optimal use of power-management settings, such as automatic standby and decreased brightness on notebook screens, can cut energy consumption by as much as 30%.[20]

Power supply for desktop computers

Power supply is also an area of potential efficiency improvement, especially in desktop computers. Notebook computer power supplies often have efficiencies of between 70% and 80%, with external power supplies that are suited to notebook energy demand. By contrast, the internal power supply of desktop computers is typically oversized with efficiencies of less than 70% (IEA, 2009). Microprocessors designed for mobile applications similarly tend to be more efficient without significant performance losses.

Future pathways and RDD&D priorities

Efficiency requirements, standards and labelling programmes have all been successful in recent years at raising energy efficiency in the lighting, appliances and electronics markets. Cooking initiatives such as the Global Alliance for Clean Cookstoves have helped to reduce the use of traditional open-fire cooking methods in many developing regions. Economies of scale, due to increased demand for appliances in developing countries, and increased sharing of best practices have also contributed to overall efficiency improvements, while often resulting in lower prices for consumers.

Nonetheless, potential remains for significant further energy savings in the lighting, cooking and appliances markets. For example, the energy consumption of many ICT and consumer electronics could be reduced by an additional 30% by 2030 (IEA, 2009). In some areas, policies and consumer-awareness programmes can help to improve overall penetration of energy efficient products. In others, continued R&D is necessary to overcome technical and cost barriers to making those products cost effective and competitive.

Increased collaboration between governments, utilities, industry and researchers can accelerate the adoption of BAT while also developing more efficient, market-viable products. Recent successes, such as international collaboration on the phase-out of incandescent lighting, can be extended to other appliances and equipment, such as inefficient CRT televisions. Additional work is also needed to realise minimum efficiency requirements in appliances and electronic equipment, while global co-operation, similar to the IEA 1-Watt Initiative,[21] is needed to address increasing network and network-standby energy consumption in smart appliances and electronics. The IEA has numerous multilateral technology initiatives, including the Implementing Agreement for a Co-operating Programme on Efficient Electrical End-Use Equipment (4E IA), that address technology RDD&D to facilitate the entry of new and

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[20] UK Market Transformation Programme data as of 14 September 2010, comparing data for power managed and non-power managed notebooks and desktops in 2010 on a kWh/day basis. Savings ranged from 24% to 39% for desktop and notebook computers in both domestic and non-domestic settings.

[21] The 1-Watt Initiative was launched by the IEA in 1999 to encourage international co-operation to reduce standby power consumption in appliances to less than 1 W. In 2007, the IEA developed guiding principles for energy efficiency in networked products, which can be found at http://standby.iea-4e.org/files/otherfiles/0000/0071/Guiding_Principles_for_Energy_Efficiency_in_Networked_Products.pdf.

improved energy technologies in the marketplace. Other useful partnerships include collaborations between multilateral organisations and national governments with universities, research organisations and manufacturers.

Lighting

Concerted effort is needed to bring all regions of the world up to the latest standards of lighting technology, while working together with architects, builders and consumers to design buildings that reduce the overall need for lighting. Continuing RDD&D for future technologies, including SSL and advanced daylighting technologies (see Chapter 3) will be essential so that lighting intensities in new and major renovated spaces can be very low. In particular, research and market transformation activity is needed on the following areas:

- **Incandescent lamps:** recent initiatives and policy measures by governments to phase-out incandescent lighting should be expanded to all countries, with the goal of achieving performance comparable to CFLs, as halogen lamps are only a marginal improvement over incandescent lamps.
- **CFLs:** greater effort is needed to continue to improve CFL lamps, including quality and integration into existing lighting applications, at lower costs. Increased adoption of CFLs and SSLs in lieu of incandescent lamps is essential, while minimum efficiency standards for lamps should be mandated where appropriate.
- **SSL:** continued support of R&D programmes will help to lower SSL costs, while lighting efficiency standards and incentives will help to increase SSL market penetration.

Appliances

Labelling and energy efficiency standards need to be expanded to more product categories and countries. This would benefit from greater unified action, including support from countries with successful experience in collaboration with large developing markets. Continued R&D of advanced appliance technologies, such as heat pump clothes dryers and vacuum insulated refrigerators, and smart appliances is also necessary to reduce the increasing share of appliances and electronics as a proportion of buildings energy demand. This includes not only efficiency improvements but also the development and deployment of technologies that address standby power demand and smart buildings integration. In particular, research and market transformation is needed in the following areas:

- **Refrigerators:** the development of higher-efficiency refrigerator components, such as VIPs and improved sealing, is needed to significantly improve refrigerator efficiencies beyond existing cost-effective improvements.
- **Clothes washers and dryers:** advanced low-water-use technologies and more effective cold-wash detergents are needed to address energy demand for hot water in clothes washers, while continued R&D and policy support are needed to bring more efficient technologies, such as heat pumps for dryers, to market at competitive prices.
- **Televisions:** advancements in LCD and PDP display technologies will support improved energy efficiency in televisions, while effort is needed to address both total television energy demand and energy consumption per dm^2.
- **Computers and electronics:** greater efforts are needed to adopt power-management capability in all computers, while power supply units in desktop computers should be sized correctly to maximise energy efficiency potential. Additional effort is needed to address network and network-standby power consumption in electronics and smart appliances.

Recommendations

Policy support for lighting, cooking and appliance efficiency improvements will be critical to achieving 2DS objectives (Table 5.5). Previous and ongoing policy programmes and regulations addressing lighting and appliance energy use demonstrate the beneficial effect of standards, labelling and consumer-awareness programmes on energy efficiency in buildings. As BAT continues to become more available and cost competitive, it is important that existing policies be adapted to support continually improving product performance, while older, inefficient technologies progressively be eliminated.

In the very near term, countries without standards and labelling programmes should implement these programmes and policies to ensure that consumers are aware of choices and are able to select the most efficient technologies. Standards should also progressively eliminate the least efficient products from the marketplace, including CRT televisions and all incandescent lighting.

A major effort is needed to address technical and cost barriers in refrigeration and clothes washer and dryer appliances. In particular, clothes washing technology using less or no hot water is needed to achieve significant energy efficiency gains, while cost-effective, highly insulating refrigeration products are needed to significantly improve refrigerator efficiencies. This will require continued support of R&D programmes, while a combination of efficiency targets and appliance standards will encourage manufacturers to produce more efficient products using innovative approaches and advanced technologies.

Table 5.5 Lighting, cooking and appliances recommendations

Technology	Immediate recommendation	Future requirements
Biomass cooking	Move to modern cook stoves with affordable options that are regionally acceptable.	Progression to modern forms of energy.
Appliances	Continue and increase effort for standards and labelling.	R&D to find more efficient solutions; develop performance specifications and standards consistent with new technology.
New construction lighting	Add low power-intensity lighting requirements to all building codes and promote natural daylight with solar control to reduce heat gain.	Develop integrated advanced daylighting and SSL solutions.
Existing lighting	Add requirements to renovation programmes to install viable controls and sensor technology; replace all incandescent fixtures with fluorescent or SSL.	Develop solutions for problematic fixture types, where current solutions are unacceptable to consumers or cost prohibitive to replace.
Electronics	Continue standards and labelling programmes and extend around the world.	Develop performance specifications that can stay ahead of, or at least be consistent with, fast R&D field.

Chapter 6

Policies for Buildings

Building-specific and product-specific policies, in conjunction with broader systems-level policies, will be essential to achieving large energy savings and emissions reduction. Policy makers are encouraged to place a high priority on implementing building codes and accelerating the rate of renovation with deep efficiency improvements. Policies also need to support whole-building approaches to achieve cost-effective, market-viable solutions.

Key findings

- Whole-building performance policies are critical to moving the buildings sector along a low-energy path, but need to be supported by policies on building components to ensure that affordable, widely available products can be integrated into advanced building systems.
- For advanced but under-utilised building products, and for the introduction of high-performance products to new markets, well-drafted and effective policies are needed to address market barriers and expedite market diffusion. Demonstrations, incentives, labelling and standards have all been proven to be effective.
- New technology development strategies need to be supported by a full array of policies that will drive technical solutions from concept to full market saturation.
- New cross-sectoral policies are needed across the industrial, power and building sectors to increase diffusion of co-generation and waste heat utilisation. These policies should also encourage networks that use renewable resources and low-grade heat as thermal sources for highly efficient heat pump systems.

Near-term recommendations

- Current policies need to be modified and integrated to achieve rapid deep renovation of the existing building stock, with greater focus on optimising building envelope and space heating and cooling solutions.
- Greater attention is needed on building codes in developing countries in view of the anticipated very large growth in new buildings, along with supporting infrastructure to enable proper enforcement.
- Collaboration between countries and among government, academia and industry is essential to establish building component performance rating metrics, human capacity development and affordable advanced product availability.
- Standards and labelling for equipment, appliances and lighting products need to be pursued, strengthened and implemented in all countries.

Achieving the goal envisaged under the 2°C Scenario (2DS), as set out in the IEA *Energy Technology Perspectives 2012 (ETP 2012)*, requires buildings energy consumption to be reduced by 23% and carbon dioxide (CO_2) emissions by 28% in 2050 compared to a business-as-usual scenario (6°C Scenario [6DS]). This will only be possible through assertive public policy interventions that succeed in changing consumer purchasing behaviour and stimulate the adoption of advanced technologies and products. While building structures and occupants' behaviour are quite diverse and there is no exact set of options that will work for all applications, there are nonetheless several key considerations that generally hold true.

Consumers do not necessarily make purchase decisions based strictly on economic terms. For example, a high-performing domestic appliance may have a higher purchase price, and the economic benefit to a consumer of its energy conservation measures in any given month may be quite small. However, the overall savings can be large over the service life of the product.

Policy makers need to look at the broader perspective and make decisions that serve the best interests of everyone. Policies span the spectrum, from funding of basic and applied research for new materials and systems to regulatory actions to ensure the manufacture of efficient products.

Significant market barriers exist to the introduction of new energy efficient products and systems. Policies need to be formulated to specifically address market barriers so as to increase the probability of market success, and to shorten the adoption curve from market introduction to widespread market penetration.

The core of improving energy efficiency in buildings is the widespread adoption of existing efficient technologies, along with the development and deployment of new, more affordable technologies or products. In addition to policies to promote individual, efficient and state-of-the-art technologies and products, there are many policies that promote efficiency at a systems or whole-building level. These are critical to moving the market forward. They seek to optimise performance and lower costs by implementing the set of new products and technologies that are most effective for any particular application, climate, building type, etc. Both component-level and systems-level policies are needed to achieve cost-effective deep renovation and zero-energy buildings (ZEB) to achieve the necessary efficiency path to 2050.

The IEA *25 Energy Efficiency Policy Recommendations* include a call for governments to implement "a package of policies" to improve the energy efficiency of existing buildings (IEA, 2011). Of the 25 recommendations, ten are directly linked to the buildings sector and fully compatible with the technical and policy recommendations in this publication. One additional cross-sectoral policy recommendation is needed: better co-ordination among the industrial, electricity and building sectors to encourage greater uptake of co-generation and waste heat opportunities (see Chapter 4).

This chapter addresses what policies are needed to accelerate technology advancement, overcome the numerous market barriers and bring efficient products into effect in the buildings sector.

Policies to overcome market barriers

Market barriers are obstacles to the adoption of energy efficient buildings or products. These barriers can be "real" or "perceived." They may include simple things such as a lack of knowledge about an alternative option. They also include concerns about new product performance and expected energy savings. There may also be concerns over whether a new product will be reliable and if it will have the same service life as that of an older proven product. Import tariffs and lack of skills to implement new technology in emerging markets are additional examples of market barriers.

When formulating policies, it is critical to understand the market barriers so that appropriately tailored policies can be formulated that will address the situation. This is particularly important if one country is implementing for the first time a policy that may have been highly effective in a different country. A policy maker may start with a typical, widely used policy intended to address a market barrier, but policies have failed because they did not address specific market conditions or consumer behaviour and preferences.

Market barriers can also include entities that may be openly opposed to the change in policy. For example, a reasonable argument can be made that if prices of new buildings or products increase, then fewer consumers will be able to afford their purchase. Under typical lending practices, where the operating cost of a building or product is not considered, this argument is justified. If lending practices do not take account of reduced utility bills when more efficient options are purchased, then some percentage of purchasers may not qualify for a loan to make the purchase. Thus, builders and retailers may be resistant to a policy that will increase the sales price of equipment or a new home, even though the measures may be cost effective for the homeowner.

A key market barrier in the buildings sector involves “split incentives” – where the purchaser of the product or building is independent of the person paying the utility bill. These typically include apartments and services sub-sector buildings that are leased. In these applications, there is very little incentive for the person constructing the building or making product purchase decisions to invest in high-performance energy efficient alternatives. However, policies that provide visibility to the energy consumption of rented or leased space can be informative to consumers; mandatory construction requirements (building codes) or minimum product efficiency standards are also examples of policies that address the split incentive market barrier.

The market barriers and required policies differ depending on the technology maturity stage (Table 6.1). Any new concept or product needs to progress through all the development phases and face the related barriers.[1] Therefore, multiple integrated policies will be needed over a period of 10 to 15 years to ensure the highest probability that a technology can mature and achieve full market saturation.

Component-level policies

The commercialisation path for advancing technology through the major phases of maturity typically includes research and development (R&D), voluntary and mandatory policies (Figure 6.1). The key to saving energy in the buildings sector is the development and market saturation of high-performance components. The increasing market shares of high-performance components are directly linked to the success of various policies. For example, a voluntary labelling programme may result in a product reaching a 30% to 60% market share, but its effectiveness is likely to reach an upper limit. Achieving further market penetration usually requires the implementation of mandatory policies.

The overarching perspective is that the entire commercialisation time frame, from conducting R&D on a new technology or product until it becomes required by mandatory product efficiency standards or building codes, can easily take well over 20 years, and often over

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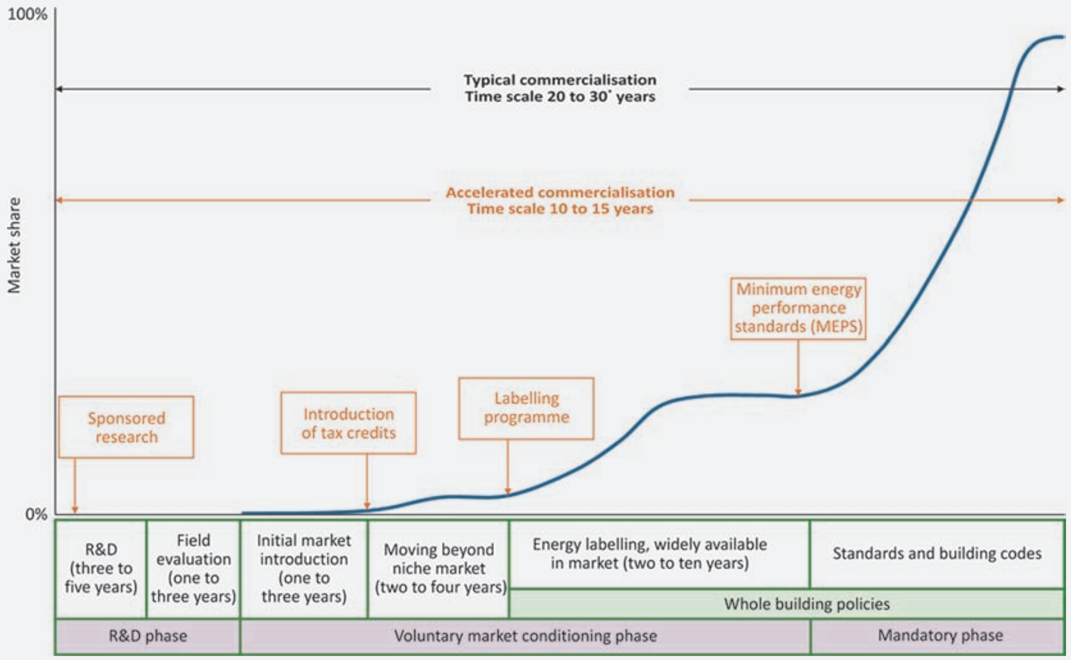
[1] This is a representative chart. Most products will face many more barriers to adoption, and not every barrier will exist in every application.

Table 6.1 Technology maturity phase, market barriers, and policies for buildings

	Research and development		Voluntary demonstrations, deployment, diffusion			Mandatory
Technical maturity	Basic and applied research	Field evaluation	Initial market introduction	Limited sales	Mature market	Standards and building codes
Barriers	Lack of private sector investment.	Safety codes, consumer expectations, and integration.	High cost, lack of information, reliability, high risk.	Reluctance by policy decision makers, high cost, etc.	Entry into mainstream marketing programmes, split incentives.	Political will of governing body, sufficient data set to convince.
Policies	Competitive R&D sponsors, collaborative research, technology procurement.	Field studies of prototype, model homes, responsibility for any human health impacts.	Award of Excellence, detailed case studies, extended warranties, loan guarantees.	Tax credits, utility incentives, financing, volume purchases.	Distinction labels, modest incentives, financing, education.	Minimum efficiency standards and practices.

30 years. To pursue a 2DS objective aggressively, the commercialisation of new technology needs to be accelerated by co-ordinating policies that will promote the key technologies highlighted in Chapters 3 to 5. Unless well-co-ordinated policies are assertively pursued, the 2DS may not be achievable without exorbitant investment.

Figure 6.1 Acceleration of the product commercialisation path to mandating new technology



Key point *Commercialisation of innovative products and building systems has many phases, and every one of these needs to be addressed to fully implement new technology.*

Research and development

Looking at the early development phase, many governments and foundations have sponsored research to develop new innovative technologies and materials. The majority of private sector equipment and building material manufacturers have a very low research investment ratio (percent of revenue spent on research) compared to other sectors of the economy. This reality is based on many factors, including the commodity-based nature of building materials and products, the long cycle to change to new technology and manufacturers with relatively low profit margins. Therefore, R&D can be spurred by government-sponsored research that will reduce the risk of investing in cutting-edge innovative technologies. Government R&D priorities should be determined in consultation with private sector industry leaders; an industry perspective can increase the chances that government-sponsored R&D innovations will ultimately make their way into commercial products (Box 6.1).

Box 6.1 Selected examples of government R&D support

The European Commission established a building technology investment fund that has sponsored R&D to develop advanced space conditioning equipment, advanced insulation, cool roof technologies, building-integrated photovoltaic cells and other technologies. The programme is committed to fund between EUR 1 billion to EUR 2 billion over ten years (EEB, 2012).

Many countries sponsor domestic R&D activities, such as an initiative in Germany to develop a vacuum glazing window that was provided with funding of EUR 10 million between 2007 and 2011. While the product is not yet commercialised, critical feasibility concerns have been resolved (ZAE BAYERN, 2012).

The US Department of Energy (DOE) has had a long-term commitment to funding R&D with fairly modest funds. However, the stimulus budget of 2009 provided a large influx of funding that was unprecedented in scale. USD 120 million was provided for new building component R&D for lighting, heating and cooling equipment, control systems, building envelope and other products (US DOE, 2012).

In addition to funding companies directly, mostly through a competitive process, a common policy is to fund research institutes that then work collaboratively with private industry partners. For example, the Japanese government, in collaboration with industry, developed innovative heat pump water heaters with coefficients of performance (COPs) around 6.0.[2] The government also continued with other incentive policies that moved the product from the developmental phase to the point where they have now reached over 500 000 sales annually (JRAIA, 2012). Singapore has competitively funded universities to work with private industry partners; Nanyang Technical University is developing advanced cooling systems and other technologies in collaboration with leading manufacturing companies (NTU, 2012).

The private sector may develop technology unilaterally or with the help of venture capital financiers. However, sometimes, even when a technology is showing very good promise, the cost to build a full-scale factory or facility can amount to 100s of millions of dollars. One policy mechanism to assist new companies with the transition from R&D to manufacturing is to help finance the new factory. There are several ways this can be done, for example by providing tax incentives, grants or loan guarantees, alone or in combination. Such mechanisms are usually only applicable to very large activities and are designed to reduce financial risk so that private sector investors will be willing to participate in the investment. It is a strategic policy that can be highly effective in appropriate circumstances (IEA, 2012).

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[2] Most heat pump water heaters' COPs range from 1.5 to 4.

Field evaluation: validation of performance

The introduction of new technologies and products will usually require a field evaluation phase. In many cases, new products may have to be evaluated for compliance with safety or fire codes. These hurdles can be significant; if not properly planned and funded, they can delay commercialisation. Many products require interface with occupants, and real world energy performance cannot be fully assessed unless evaluations include real consumers (Box 6.2). Field evaluations in homes without occupants are less of a challenge, but eventually a full field study including consumer acceptance and behavioural impacts needs to be assessed.

Conducting evaluations of prototype materials and systems can have risks associated with occupants' health, fire standards, etc. Furthermore, if evaluations do not go well, it will be necessary to rectify the situation, possibly requiring costly re-construction and/or mitigation. Manufacturers, housing partners, efficiency research or supporting organisations need to assume the liabilities associated with field evaluations of prototypes. Policies to fund and reduce risks associated with this important developmental phase can significantly expedite the commercialisation of new technology.

Demonstrations (case studies): initial market introduction

Once a product has been fully commercialised, including full compliance with all safety ratings and building code requirements, initial sales can begin. The early sales will be highly dependent upon effective marketing by the manufacturer along with any partnering research or sponsoring agencies. It is critical to document high-quality case studies that include detailed technical performance, and economic and reliability data. Some of the early data can come from field evaluations, but true case study data should be recorded by third party organisations that install the systems using common techniques.

This phase of the market will be limited to early adopters, but they can play a vital role in moving the technology to higher levels of market penetration. If a product performs extremely well technically, but is still too expensive to be truly cost effective (which is common), it can still be successful in the market. Additional policies to help the product achieve critical market penetration are most likely needed. At this point, manufacturers and research partners (*e.g.* universities, institutes, national laboratories, etc.) should have conducted cost-effectiveness analyses that show potential price points with manufacturing economies of scale. Furthermore, if multiple developers are pursuing similar end-use technologies, this can ensure that full cost reductions from economies of scale will be passed on to consumers, rather than being kept for greater profit. With all of these key ingredients in place, the product should be poised for significant market presence.

While most of this discussion refers to the development of new technology, there is also a need for case studies on products that are new to a region or country.[3] Even though a product has been developed in one country and may have passed the initial market introduction stage, case studies are still critical because they demonstrate that the technology will work in that particular environment.

Incentives: moving beyond a niche market

Once a product has established a basic market presence, it is ready for market incentives to encourage significant growth in market share. There are three typical incentives: utility rebate programmes, government-funded tax credits and financing.

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[3] While this policy mentions adapting new technology to new markets, the entire suite of policies may be needed to open up new markets to products that have been successful in other countries.

Box 6.2

Field evaluation example to assess performance of gas heat pumps in Germany

Fraunhofer Institute of Solar Energy (ISE), in collaboration with E.ON Ruhrgas AG, is conducting a field evaluation of gas absorption heat pumps at over 50 locations in Germany that will assess energy performance and consumer acceptance, as well as overall implementation issues (Figure 6.2). The initial results of the field evaluation have been positive (see Chapter 4 for further information) (Fraunhofer ISE, 2012).

Figure 6.2

Field evaluation of gas absorption heat pumps under test in Germany

This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: figure courtesy of E.ON Ruhrgas AG, in Fraunhofer ISE, 2012.

Key point *Multiple evaluations in varied locations are important to ensure acceptability of the final product design.*

Utility rebate programmes require detailed economic analysis by utility regulators to show that investment by the utility company will be less expensive than the investment needed to build new power capacity. Most utilities are required to show that the cost of the programme is less than the cost of the avoided energy consumption. More proactive utilities and regulatory bodies may have a less stringent perspective. They look to a longer-term horizon, whereby they assess the large savings from when the new technology becomes widely available, rather than over the limited time that the programme might run at the beginning of the commercialisation phase.

Government-funded tax credits, where consumers are given tax breaks for the purchase of energy efficient products and materials, are linked to product performance and are generally only applicable to very high-performing products that have very limited market presence. They can be highly effective (Box 6.3). However, over the past several years with slower global economic growth, tax credits have also been used as stimulus incentives where they have been provided for widely available, moderately more energy efficient products. While these can certainly encourage investment in energy efficient technology and products, they are generally not cost effective for the amount of energy saved. In essence, they are similar to a conventional tax rebate except they have a focus on stimulating manufacturing of efficient technologies. It is believed by many energy policy makers that expensive tax credits should be focused on very high-performance products and materials that have the potential to save large amounts of energy at cost-effective prices once they have reached market maturity.

Box 6.3 Government incentives for condensing boilers in France

France provides a good example of a successful incentive programme. It started offering tax credits in 2002 and increased the credit for condensing boilers from 15% to 25% of the purchase price in 2004. The market share of condensing boilers increased from 4% of the market in 2004 to 10% in 2005 (UNDP, 2009). In 2011, their market share reached around 30% (Eljidi, 2011).[4] In 2012, France added condensing boilers to its mandatory building code requirements (IEA, 2013).

Financing is another important policy at this stage in the market. While financing is also needed in earlier and later stages, as well as in systems-level policies, it can be a critical element in moving consumers from thinking about doing something to actually making the purchase or having the building upgraded.[5] Policies that make financing terms more advantageous can provide the required incentive to ensure a highly efficient system will be chosen, or to undergo the upgrade now rather than continuing to delay.

The IEA has completed extensive analysis of a wide range of economic instruments, and it is widely recognised that mobilising huge investment into energy efficiency is essential (IEA, 2012). While an extensive evaluation of the most advantageous uses of financing mechanisms is beyond the scope of this book, three fundamental perspectives can be provided:

- Offering advantageous financing mechanisms is likely to require public funds and these may be harder to justify with tighter public budgets. Therefore, mobilising private sector financing will be essential.
- Offering financing in the R&D phase, such as grants or loan guarantees (discussed above), is higher risk because the technology has yet to achieve basic market introduction.

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[4] While data is from different sources, the progression is consistent with the adoption of a mandatory policy.

[5] If someone is buying light bulbs or one appliance, financing may not be a concern. However, if they are having a new heating system installed, or recladding the home with the addition of exterior insulation, being able to afford the purchase is often a significant market barrier.

- Funding R&D is less expensive than building new factories. At the other end of the spectrum, if financing is used for well-established products with large market share, there will be many "free riders", or investers who seek the preferential financing but would have invested anyway.

Therefore, while a case can be made for preferential financing throughout the range of product technical maturities, the best use of such mechanisms is in overcoming the barriers to getting high-quality energy efficient products from niche application to market maturity.[6]

Appliance and equipment labelling and education

Promoting widely available energy efficient products through voluntary and mandatory labelling has been the best-known and longest-running policy in the building sector. Labelling programmes are the primary mechanism to educate the public when they make purchasing decisions. Labels come in multiple formats but the most common approach is a comparative scale or ranking that depicts the product performance on a relative ranking among the range of products available in the market place (Figure 6.3). Labels often include energy performance characteristics. As product performance continues to improve over time, labelling programmes should be designed with a mechanism that allows for re-scaling as part of a normal process.[7] There are numerous examples of labelling programmes and their success around the world.

Figure 6.3 Examples of comparative labels in Europe, Korea, and Australia

Europe Korea Australia

Source: IEA, 2010a.

Key point *Labelling formats come in many different configurations but generally play a key role in educating the public about more efficient options at the point of purchase.*

European Union appliance labelling

The European Union (EU) has promoted energy efficient products by requiring energy performance labels with "A" to "G" category ratings for over 20 years (EU, 2010). Within the first ten years of adoption, most appliance manufacturers improved their product performance

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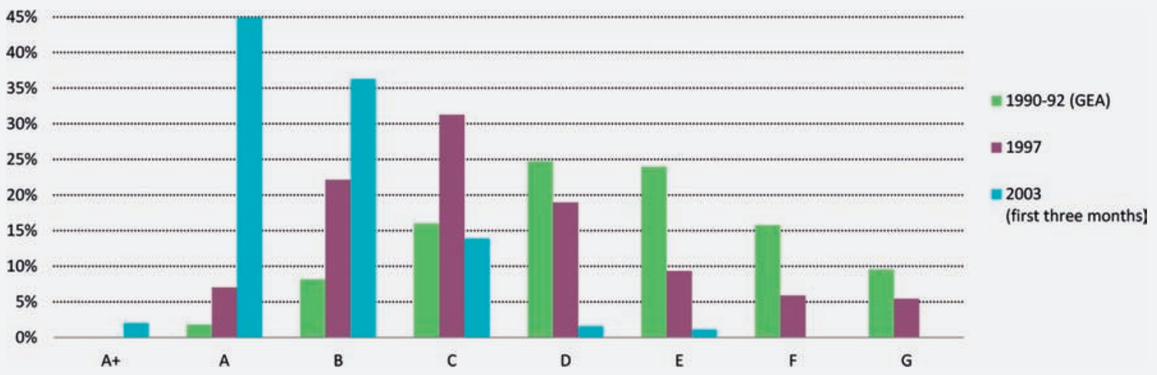
[6] Similarly, deep retrofits are niche whole-building applications that also need financing to help move them to become viable in the mainstream. Whole-building policies are discussed later in this chapter.

[7] The ENERGY STAR and Top Runner programmes (discussed later) both have mechanisms to rescale the label as part of the programme design.

to achieve “A” ratings. The EU directive was amended to add “A+”, “A++”, and “A+++” categories. With the success of the programme, many product categories have virtually all products with an “A” or better rating. Effectiveness of the programme from 1990 to 2003 with regard to refrigerators was quite significant (Figure 6.4), although there are still very few highly rated dryers (Box 6.4).

Figure 6.4 Impact of refrigerator labelling in the EU



Source: CLASP, 2013a.

Key point *Labelling programmes are very effective and can shift product offerings, especially when such programmes have never existed before.*

Efficiency advocates in Europe have tried to rescale the ratings to further improve performance, but due to concerns and pressure from manufacturers it remained unchanged for years. However, during the last few years significant activity has been under way to update the labels and final formats should be completed soon (ECEEE, 2013).

Box 6.4 High-performance dryer technology procurement project

Today, EU labels for clothes dryers show a large range of performance, with only a small portion of the market in the “A” or better category. Other product categories have many products with “A” or better ratings. A key reason is that when the labels were established, a very high-performing dryer was on the market. This dryer was the result of the IEA Demand-Side Management (DSM) Implementing Agreement technology procurement competitive project. The “Öko-Lavatherm” clothes dryer was awarded the first DSM Award of Excellence. This machine uses a heat pump to achieve a 50% reduction in energy use compared to earlier models. Washing machines, dryers and dishwashers typically account for 20% to 30% of both the energy consumption and the water consumption in the average European home. And a tumble dryer typically uses about 500 kilowatt-hours (kWh) per household per year, which is twice as much energy as a washing machine (IEA DSM, 2013).

United States ENERGY STAR programme

Another successful labelling initiative has been the United States voluntary ENERGY STAR programme. The label is applicable to a broad range of buildings products and other energy-related products and uses a different approach. Rather than showing the range of product performance with a classification system, it establishes a threshold of acceptable performance. Products that exceed the threshold are awarded the ENERGY STAR label. The general guidelines indicate that they aim for at least 20% higher energy efficiency than typical products being sold, and products must also be cost effective and available from multiple suppliers. The programme has routinely gone through the process of increasing the performance stringency. To reduce the risk associated with other market barriers, such as product reliability, ENERGY STAR has added quality testing provisions for some product classifications.[8]

The main philosophy has been to keep the purchasing decision easy for consumers by showing a distinctive label for compliance. The ENERGY STAR label has become so successful in the United States that there are concerns from manufacturers regarding the continual increase in stringency. While the programme is fully voluntary, many manufacturers view it as an essential distinction to be able to sell their premium products in the market place.

A pilot programme called ENERGY STAR Most Efficient started in 2011. It is intended to recognise the highest-performing products available on the market independent of cost effectiveness. Initial evaluation has been positive and concerns about any confusion with the core programme have not been a problem (US EPA, 2012). This policy aligns with the "Incentives – moving beyond a niche market" section above. Whereas, the ENERGY STAR core programme requires criteria that are consistent with mainstream mature market products.

Japan's Top Runner Programme

Japan has a unique programme called Top Runner. It is a combination of a voluntary label that encourages purchase of high-performance products and a mandatory average weighted minimum efficiency standards programme. The target for efficiency improvement is very aggressive but is easier to establish, as it is based on the best available technology (BAT) that is currently on the market. The net effect is that it brings all products up in performance but attempts to achieve that in a more flexible way. It eliminates the controversy of mandating a requirement for all products to meet minimum performance criteria. Thus, it does an excellent job of combining the two key types of policy, voluntary and mandatory. Japan's Top Runner Programme has resulted in significant improvements in energy efficiency, ranging from 14.6% for electric toilet seats to 80.8% for computers (METI, 2010) (Table 6.2).

Mandatory policies

Standards and labelling are well-known policy terms in the buildings sector. They refer to two policies that work well together and have been at the core of most buildings efficiency programmes globally.

The United States legislated mandatory minimum efficiency standards in 1975, but they were not fully implemented until the late 1980s. Over the last few decades, the programme has been significantly expanded and now covers over 50 product categories applicable to 90% of residential energy use, 60% of services sub-sector energy use and 29% of industrial energy use. As a result of the issued standards, energy users saved approximately USD 40 billion in 2010, and cumulative savings for the programme to 2030 will reach USD 1.7 trillion (US DOE, 2013a). The United States also initiated separate mandatory energy labelling requirements for appliances, but the two policies were completely independent of each other. The product performance data used for the energy labelling are critical to determining manufacturer compliance with efficiency standards. However, the ENERGY STAR programme mentioned above was initiated because it was believed that the energy label was ineffective in educating

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[8] For example, in the late 1990s, quality provisions including testing requirements were added to the compact fluorescent lamp (CFL) criteria for ENERGY STAR.

Table 6.2 Effectiveness of Japan's Top Runner Programme

Product category	Energy efficiency improvement (result)
Televisions	25.7% (FY 1997 – FY 2003)
Video cassette recorders	73.6% (FY 1997 – FY 2003)
Air conditioners	67.8% (FY 1997 – 2004 freezing year)
Electric refrigerators	55.2% (FY 1998 – FY 2004)
Electric freezers	29.6% (FY 1998 – FY 2004)
Vending machines	37.3% (FY 2000 – FY 2005)
Fluorescent light equipment	35.7% (FY 1997 – FY 2005)
Copying machines	72.5% (FY 1997 – FY 2006)
Computers	80.8% (FY 2001 – FY 2007)
Electric toilet seats	14.6% (FY 2000 – FY 2006)

Note: FY = fiscal year.
Source: Adapted from METI, 2010.

the majority of the public due to its technical complexity. This demonstrates the importance of the design of labels.

Recently, EU member states implemented mandatory minimum efficiency performance standards (MEPS) for energy-using equipment. These complement the EU mandatory labelling programme that has been in place for the last 20 years for product energy efficiency.

Globally, the EU and Japan have been the most aggressive at adding mandatory taxes (or tariffs) that significantly increase consumer energy prices. This has resulted in higher operating costs for heating and cooking equipment that use fossil fuel and higher electricity prices for equipment and appliances than the market conditions would bear without government intervention. The combination of higher energy prices and a mandatory labelling programme that clearly shows consumers the relative ranking of product performance has resulted in the sale of a greater number of energy efficient products. The United States has been less aggressive on energy taxation but has focused on regulating the efficiency of products directly. This approach has been effective, but the hurdle for setting more stringent standards is much higher[9] because new energy efficient technologies are not as cost effective with lower energy prices.

Historical data from the IEA *Policy Pathway on Monitoring, Verification and Enforcement* (IEA, 2010a) show how appliance electricity consumption has decreased while the consumer purchase price has also decreased on four continents (Figure 6.5). While there may be multiple

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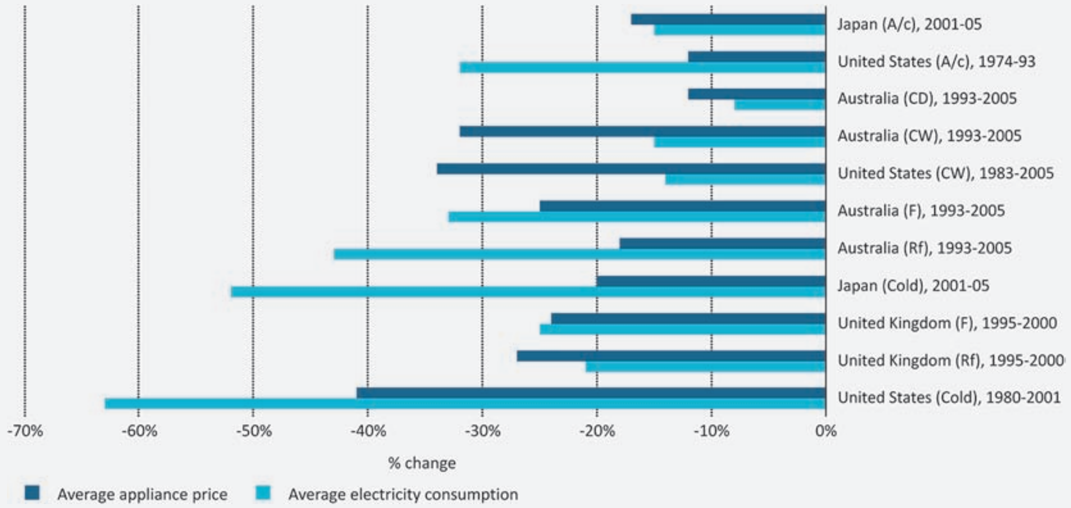
[9] Legislation stipulates that regulations must be economically justified on a life-cycle cost basis. With lower energy prices, less stringent standards will be issued.

factors in play, such as normal progression of increased manufacturing productivity over time, it is evident from the data that these policies have been very positive for consumers, while also saving significant energy.

Figure 6.5 Recorded fall in average electricity consumption and prices for selected appliances in several OECD countries with mandatory efficiency policies



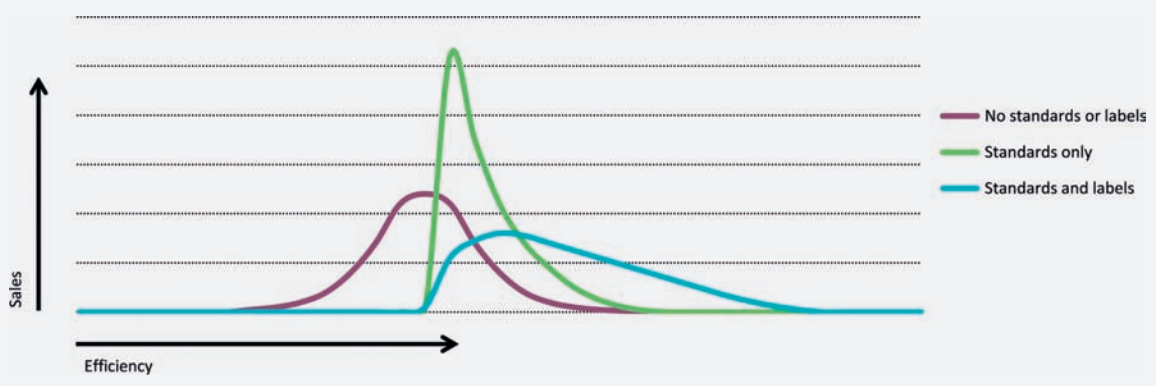
Notes: A/c = air conditioner, CD = clothes dryers, CW = clothes washers, Cold = refrigerators and freezers, F = freezers, Rf = refrigerators.
Source: IEA, 2010a.

Key point *Government-mandated labels and standards have delivered energy savings while keeping the cost of products low for consumers.*

There has been significant global effort to promote standards and labelling programmes. The Collaborative Labeling and Appliance Standards Program (CLASP) was founded in 1999 with the aim of promoting labelling and standards programmes globally. CLASP has done extensive work in many countries, enabling it to characterise the differences between markets without any standards and labels, with standards only and with a combination of standards and labels (Figure 6.6). A combination of mandatory standards that eliminate inefficient products at the bottom of the scale and a labelling programme (voluntary or mandatory) that pulls more efficient products into the marketplace is identified as the most effective approach. CLASP also maintains a comprehensive database on the various labelling and standards policies in place in countries around the globe (CLASP, 2013b).

More recently, CLASP has been acting as operating agent for the International Partnership for Energy Efficiency Cooperation (IPEEC) and Clean Energy Ministerial (CEM) Super-efficient Equipment and Appliance Deployment (SEAD) Initiative. The SEAD initiative aims to promote energy efficient building products by continuing its label and standards programme, including improved test procedures. There is also a procurement working group to encourage energy efficient institutional purchases, as well as a market transformation initiative that includes a SEAD Global Efficiency Medal to be awarded to the most efficient television. The status of the labelling and standards programmes within the SEAD initiative is presented in Table 6.3.

Figure 6.6 Standards and labelling policy impact on market



Source: CLASP, 2013b.

Key point *Multiple policies are needed to move the market towards higher energy efficiency.*

Table 6.3 Labelling and standards programme status within the SEAD initiative

	AUS	CAN	EU	IND	JPN	KOR	MEX	ZAF	USA
Phase-out of conventional incandescent light bulb	S	S, L	S, L			S, L	S		S, L
Clothes washers	L	S, L	S, L	Lv		S, L	S, L	Lv	S, L
Residential refrigeration	S, L	S, L	S, L	L	S, L	S, L	S, L	L	S, L
Commercial refrigeration	S	S			S	S, L	S, L		S
Computers	S			lv	S, Lv	Lv			Lv
Distribution transformers	S	S		L	S, L	S, L	S		S
Fans		S	S	Lv		S, L			
Motors	S	S	S	Lv		S, L	S, L		S
Room air conditioners	S, L	S, L	S, L	L	S, L	S, L	S, L	Sv	S
Standby power		S	S			Lv	S	Sv	
Televisions	S, L		S, L	Lv	S, L	S, L			L

Notes: ZAF = South Africa, S = standard (currently effective), L = comparative label (currently effective), v = voluntary, l = comparative label (finalised; pending implementation).
Source: SEAD, 2013.

Within the Asia-Pacific Economic Cooperation (APEC), there has been significant activity to promote labelling and standards in developing countries. The Cooperative Energy Efficiency Design for Sustainability (CEEDS) project worked to improve these programmes and included several workshops with experts to assist in advising how to move forward. Experts from countries with extensive experience in establishing these programmes presented lessons learned in the first workshop to key policy makers from Chile, China, Malaysia, Philippines, Thailand and Vietnam. In the second workshop, the participating countries presented plans to improve their programmes and the next steps to be implemented in their own economies. The same experts then offered advice and suggestions for improvement (APEC EWG, 2010). APEC also conducted an extensive peer review of entire individual country portfolios of energy efficiency policies, covering all sectors of the economy, including buildings. To date, these have been completed for Chile, New Zealand, Vietnam, Chinese Taipei, Malaysia, Peru and Indonesia (APERC, 2013).

Challenges to policy implementation

The process of developing a new policy needs to be adapted to country-specific or regional considerations within the political culture that exists. The difficulty of developing policies varies according to the impact in the market place. If a policy implicitly chooses "winners" and "losers", then it will be highly contentious to implement. For example, a policy to rescale labels in the EU where a manufacturer's product will be labelled "D", when it had previously been an "A" product, would be highly controversial. Similarly, implementing mandatory standards that outlaw the manufacturing of existing products would also be controversial. Conversely, issuing a call for R&D with large amounts of funding resources is less likely to be controversial. Refrigerator regulations in the United States required manufacturers to completely replace their entire product lines twice; this would not have been possible without legislation (Box 6.5).

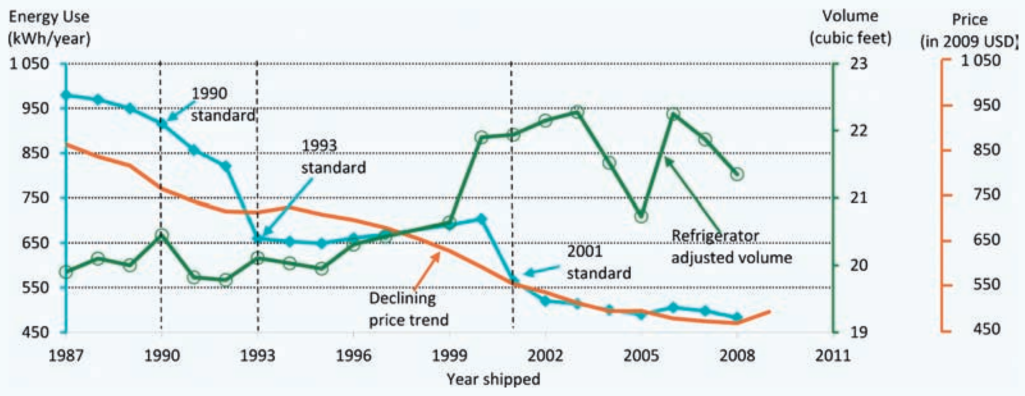
Box 6.5

Efficiency standards for refrigerators, United States

The United States has regulated efficiency standards for refrigerators over the past three decades. On two occasions the entire stock of refrigerators was outlawed and replaced with new higher-performing models. At the same time, the amenities offered to consumers improved. Refrigerators changed from manual to auto defrost, capacities were enlarged and through-the-door water and ice features were added, while energy consumption decreased dramatically. In addition to regulatory standards, there were also electric utility technology procurement policies and government-funded research to improve components, such as compressors. Furthermore, the average price in constant dollars decreased. Without government policies, these dramatic improvements would likely not have occurred (Figure 6.7).

Figure 6.7

Annual energy use, volume and real price of new refrigerators in the United States, with dates of new mandatory standards



Source: CLASP, 2013c.

Key point

Energy efficiency policies can be extremely effective while maintaining consumer features and avoiding dramatic price increases.

Integration of component-level policies

Historically, many component-level policies were developed and implemented in isolation. This approach has been successful in many instances but is not capable of delivering the changes required to achieve the 2DS. Recently, there has been a growing consensus in the policy community that it is critical to address the entire energy efficient product development cycle in an integrated way – from R&D to commercialisation and market saturation.

With the pending urgency to mitigate climate change by achieving the 2DS, policy implementation has to be streamlined to ensure success. Integrated policies offer the best approach to expedite the process of dramatically reducing energy consumption of buildings. There are two primary approaches to policy integration that need to be considered and implemented:

- Have consistent targets and goals to move a technology or high-performance product from one maturity phase to the next. For example, an R&D performance goal should be the same as that which will be supported by tax credits and by labelling programmes in the future.
- Multiple policies within a particular phase should be consistent and supportive of each other. This could include utility rebate programmes, preferred financing mechanisms, and reduced taxes for a particular specified product performance.

There is a need both for new market-viable technologies to be developed, such as high-performance windows (Box 6.6), and for the promotion of existing technologies, such as ground-source heat pumps.[10] To be successful, integrated policies will be needed to achieve high levels of market diffusion for these technologies.

The integration of policies requires a comprehensive vision to achieve market transformation of a particular building technology. Unfortunately, there usually is not a single entity that has control over all these elements. For example, government energy agencies may have funding for R&D and may have programmes for standards and labelling; however, they may not have any direct control over financial incentives that are administered by utility or tax bodies. The government certainly can play a key role by working with these other entities, but achieving full integration of policy mechanisms will require extensive co-ordination among multiple governing bodies. In some cases, policy mechanisms are politically driven and legislated, meaning that government agencies may only be able to serve in an advisory role on the need for certain policies.

To achieve deep energy and emissions reduction in the buildings sector, policy makers need to find a way to work across political boundaries to achieve cohesive and consistent policies to move technologies forward. The promotion of building technologies need not be controversial, since integrated measures represent a lower-cost option when implemented in an optimised way. Furthermore, while the need to integrate and promote multiple policies to move one technology from concept to full utilisation has been outlined, this needs to be done with an array of technologies in a wide range of building types, in multiple climate zones, and in varying administrative constructs. This emphasises how overarching systems-level policies are essential to move the entire market forward.

Systems-level policies

There are many ways to characterise energy efficiency policies for buildings. Historically, the majority of policies have been focused on end-use products such as heating equipment, lighting and appliances. These date back to the 1970s, 80s and 90s. Recently there has been

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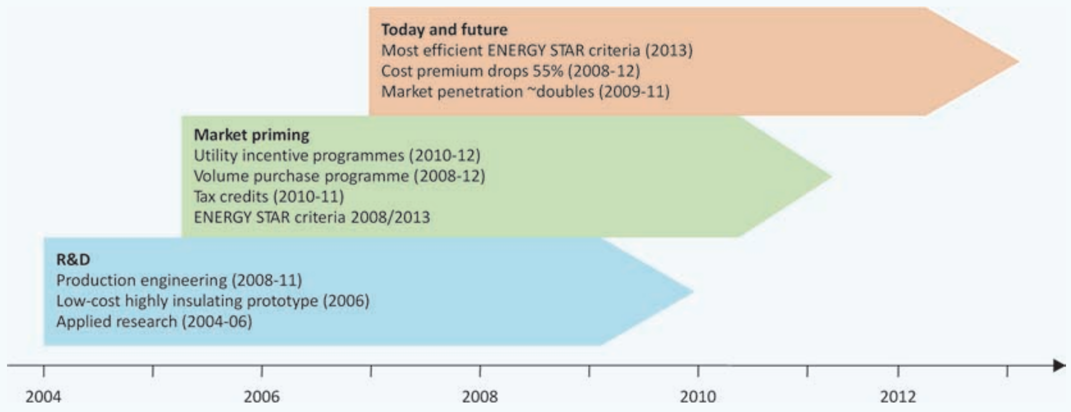
[10] See Chapters 3 to 5 for details on technology requirements and market applications.

Box 6.6 Highly insulating window integrated policies, United States

In 2006, the United States DOE initiated an integrated approach to commercialise cost-effective highly insulated windows (triple glazed double low-emissivity coating windows) (Arashteh *et al.*, 2006). Previously, highly insulated windows had been on the market for over 30 years as a limited niche market segment and were not cost effective for consumers. The integrated approach included the unveiling of an advanced prototype window that had technical features with the potential to reduce cost significantly. Aggressive phase II ENERGY STAR criteria were proposed for adoption in later years with consistent performance criteria. The core market conditioning activity, to increase consumer demand and reduce manufacturers' risk in investing in highly insulated windows, included a comprehensive volume purchase programme, which was also supported by a production engineering competitive funding opportunity. By 2010, after these multiple policies were co-ordinated and implemented, several manufacturers were selling cost-effective highly insulating windows (Figure 6.8). Tax credits that were beyond the United States DOE's jurisdiction were not well co-ordinated, but that was rectified in proposed legislation. As a result, market share more than doubled between 2006 and 2011, despite a rapidly declining construction market and challenges posed by administrative changes at governing agencies. Furthermore, in 2012, the average price premium for highly insulated windows dropped by 55% (from USD 90 per square metre (m^2) to USD 40/m^2).

Figure 6.8 Transforming the market for highly insulated windows



Source: PNNL, 2013.

Key point *Integrated policies are essential to accelerate market adoption of new technology and products, but achieving this can be difficult when it involves different governing entities.*

a significant shift towards focusing on systems-level performance or whole-building performance. Systems-level policies can be either prescriptive or performance driven. Both policies will affect the choice of end-use technology, but the prescriptive path specifies the choice directly whereas the performance path leaves the flexibility to the builder. These distinctions are not always clear and can overlap. For example, there may be a building code requirement that specifies the criteria for a series of technical characteristics that include lighting intensity, insulation levels, heating equipment performance, airtightness, windows, etc. (prescriptive path). However, there could also be a performance path for compliance that just specifies a total energy requirement for the whole building.

During construction, a building is built as an integrated system. The same is true when major renovations are undertaken. Systems-level or whole-building policies are needed when an opportunity arises that allows for all the building's components to be considered for upgrade to more efficient alternatives.

To specifically address energy efficiency in buildings, a systems-level approach is preferred to a component approach since it offers the greatest possible savings and has the opportunity to reduce overall cost through synergies.[11] At the same time, policy makers should not think that systems-level policies are all that is needed, because without policies to promote market-viable cost-effective high-performance building components and products, systems-level policies will not be effective. This section discusses the main systems-level policies and their role in promoting high-performance buildings.

Whole-building programmes to promote energy efficiency

Whole-building energy efficiency and environmental programmes exist specifically to promote the construction and purchase of more sustainable buildings. These programmes typically include a variety of criteria, including energy efficiency as well as other environmental considerations. While they are established as voluntary, it is not uncommon for government agencies to adopt them as mandatory in the procurement of all new public construction.

The Passivhaus programme was initiated in 1990 in Germany and has grown worldwide over the past decade. The programme has very stringent building envelope requirements to ensure that the building is comfortable independent of the climate. These buildings require very low energy for cooling and heating. Specifications set in 1990 of less than 15 kWh/m^2 per year for heating are still relevant and continue to lead efficient design today. Overall maximum energy consumption per unit of floor area was also specified, but in the past 20 years this has been significantly improved upon by many near-zero-energy homes. The core perspective is that it promotes super-efficient building envelopes with very small space heating and cooling energy requirements (PHI, 2013).

The Building Research Establishment Environmental Assessment Method (BREEAM) programme, initiated in the United Kingdom in 1990, sets standards and promotes sustainable buildings. It applies to a wide range of building types and over 200 000 buildings have been certified in many countries. The certification evaluates a building's specification, design, construction and use. A broad range of categories from energy to ecology are assessed, including energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste and ecology. BREEAM is the preferred designation for a number of European green building programmes (BREEAM, 2013).

The US Green Building Council (GBC) initiated the Leadership in Energy and Environmental Design (LEED) green building certification programme in 2000 to promote sustainable buildings. Today, LEED has 21 international country chapters, and buildings are being certified in over 130 countries. The programme specifies design criteria to earn credits for compliance that include energy efficiency considerations, among a wide range of environmental and sustainability considerations (GBC, 2013). One concern about whole-building efficiency programmes is that low-energy consumption has not always been achieved, thus it is important to conduct whole-building commissioning (Box 6.7).

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[11] For example, as discussed in previous chapters, conducting comprehensive building envelope measures can reduce heating and cooling capacities by 50% or more. Advanced windows can reduce lighting loads by over 50%.

Box 6.7 Whole-building commissioning

Many buildings have been designed and built with very efficient technologies and systems as described in Chapters 3 to 5. Many have been recognised with special distinction awards (such as LEED Platinum) and have been showcased as model buildings. However, energy performance data can often show that energy consumption is much higher than expected. This highlights the need to commission building operating systems to ensure that interactions between systems are fully functioning and optimised.

A key element of commissioning (or re-commissioning for existing buildings) is the use of energy management tools that help optimise energy performance. These systems have a series of controls and sensors that allow for energy managers to improve performance. These systems are needed for both new and existing buildings (see Chapter 5 for more information on building automated systems).

Building energy performance certificates

The energy performance of whole buildings needs to be assessed in a similar way to what is done for individual items of energy-consuming equipment. The key benefit of a building performance policy is that it can influence the market at a critical time, such as when the building is being leased or sold. Thus, it is applicable both to new and existing buildings. The primary intent is to generate market pressure to look for higher-performing buildings. The EU has led the world on the implementation on building performance certificates (Box 6.8).

Performance certificates can be derived in a variety of ways, including actual measured data and from a building characteristic evaluation or asset rating.[12] The building evaluation method usually involves simplified software rating tools. The credentials required of the auditor vary by programme, as does the entire scope of the programme, such as whether it is voluntary or mandatory. Key elements of any programme include reproducibility of ratings, and monitoring and evaluation.

Major differences in programme philosophy exist. Some programmes, such as the Residential Energy Services Network (RESNET) programme in the United States,[13] have chosen to require criteria for individuals conducting the energy audits that are more stringent than in the EU. The intent is to ensure that all performance ratings are of a very high quality. The negative perspective is that market entry is high, cost is high and market uptake is slow. A balance is required between rigour and accessibility, but repeatability of performance ratings is of considerable importance.

Building codes

Building codes have been widely pursued by many countries and this policy is considered highly likely to receive greater attention in the near term. Development and adoption of building codes has evolved dramatically in recent decades, a process that continues (Figure 6.10). Many developing countries are also working on building codes that are not included in this list. They can be both voluntary and mandatory.

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[12] There may also be concerns between measured energy consumption and predicted or simulated energy performance, but these issues go beyond the scope of this book.

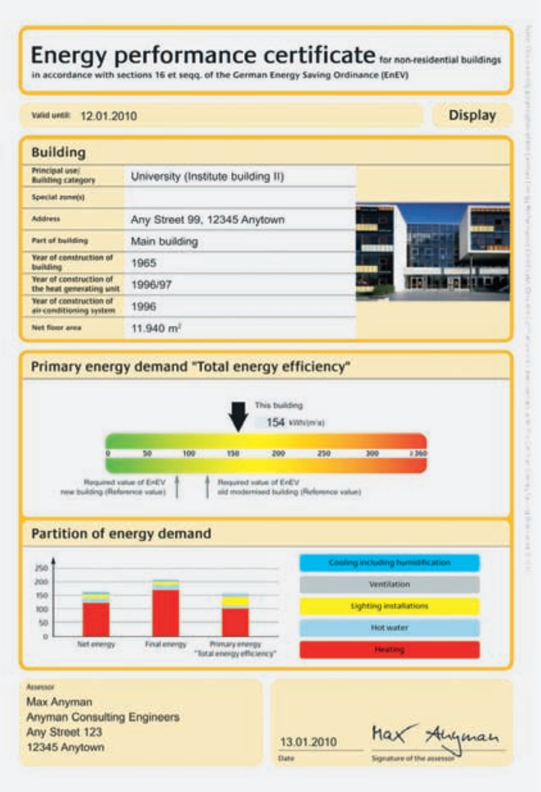
[13] The United States RESNET programme has a scale that benchmarks a building code compliant house in 2006 at 100 and a ZEB at 0. For the majority of the housing stock, the scores are well over 100 (RESNET, 2013).

Box 6.8 Whole-building certificates in the European Union

The EU has made significant progress in mandating a whole-building rating metric (Directive 2002/91/EC as amended by Directive 2010/31/EU). This is in the form of a rating or energy performance certificate based on a comprehensive calculation methodology, which is issued when the building is constructed, sold or rented out. The IEA Policy Pathway on Energy Performance Certification of Buildings highlights the EU approach together with other country examples (IEA, 2010b). Generally, these policies show the performance of the building on a relative ranking scale that highlights its performance compared to others. Most of the EU uses its historical grading of "A" to "G". However, there can be further distinctions, such as subcategories of "A1", "A2" or "A3", with "A1" having very low-energy consumption.

Initial results from examples within the EU have been positive. For example, Portugal showed a doubling in the number of certificates that met category "B" or higher performance (IEA, 2010b).[14] The German energy performance certificate is an example that is different from most of the EU and does not follow the "A" to "G" classifications (Figure 6.9).

Figure 6.9 German energy performance certificate, using a distinctive scale



Energy performance certificate for non-residential buildings
in accordance with sections 16 et seqq. of the German Energy Saving Ordinance (EnEV)

Valid until: 12.01.2010 | **Display**

Building

Principal use/ Building category	University (Institute building II)
Special zone(s)	
Address	Any Street 99, 12345 Anytown
Part of building	Main building
Year of construction of building	1965
Year of construction of the heat generating unit	1996/97
Year of construction of air-conditioning system	1996
Net floor area	11.940 m²

Primary energy demand "Total energy efficiency"

Partition of energy demand

Assessor
Max Anyman
Anyman Consulting Engineers
Any Street 123
12345 Anytown

13.01.2010
Date

Max Anyman
Signature of the assessor

Source: IEA, 2010b.

Key point *Building performance certificates and labels are effective ways to provide whole-building energy performance information to consumers.*

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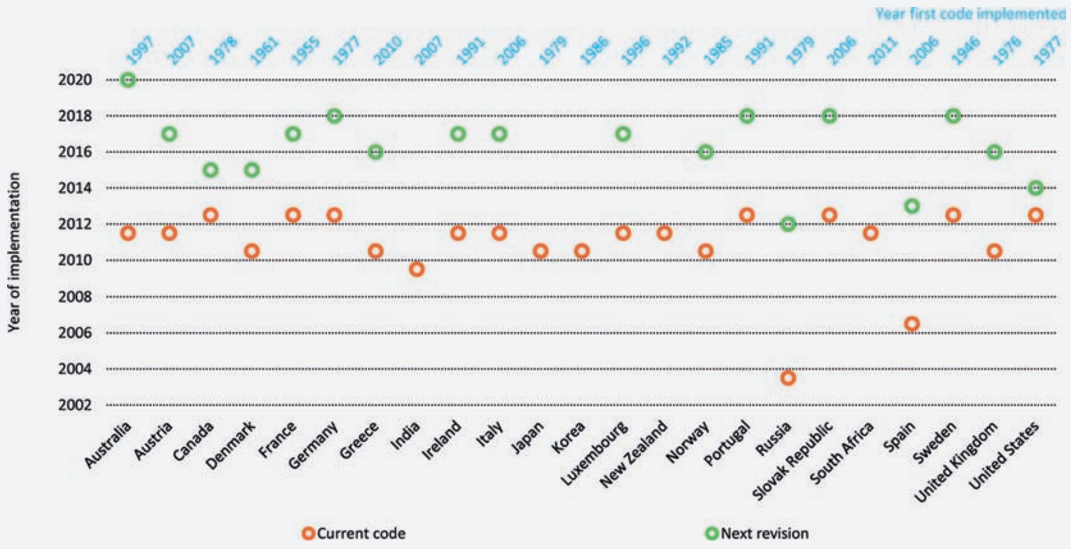
[14] Note that this initiative was combined with an education campaign so the certificates alone were not fully responsible for the increase.

Figure 6.10 History and future plans of building codes for selected countries



Note: the 2012 building code update in Russia has not yet been implemented.
Source: IEA, 2013.

Key point *Building codes represent an important policy instrument being pursued by many countries over many years.*

While it is widely accepted that building codes are the most effective policy instrument to influence new construction, there are limitations and concerns that need to be discussed. The majority of the world's building codes deal with the major end-uses of energy, including heating and cooling equipment, and the associated load resulting from the materials that are used to construct the building envelope. Furthermore, they sometimes include additional components, such as water heating and electric lighting. The basic focus of building codes is to ensure that a structure, with its core mechanical equipment, is built in accordance with intended design considerations that meet an expected average or typical energy consumption (TEC) metric. However, building codes do not consider the density, variations, preferences or behaviour of occupants. As a result, two identical, fully compliant building code structures can have large differences in energy consumption.

Building codes are predominantly focused on new construction; however, there has recently been growing interest in extending them to existing buildings, especially for major retrofits. In the EU, minimum requirements have to be set for the overall energy performance of existing buildings undergoing major renovation, in addition to setting performance requirements for retrofitted or replaced building elements that form part of the building envelope and that have a significant impact on buildings energy performance, as intended by Directive 2010/31/EU.

Generally, energy performance-based building codes allocate an allowable amount of energy per unit of floor area. Often, the performance-based energy budget is predicated upon a typical building configuration with prescriptive building characteristics. For example, the energy budget for a particular building may reflect a certain wall thickness with an associated amount of thermal resistance for a typically used insulation, a double glazed low-e window with vinyl framing, a condensing gas boiler, a conventional gas water heater and a specified lighting intensity.

There are advantages and disadvantages to performance-based building code programmes. The advantages include flexibility to be able to comply using a variety of approaches, which fosters creativity and construction efficiency. An additional benefit is that with increasingly stringent building codes, prescriptively specifying how someone will construct a building is less appropriate, especially when the variability associated with construction is considered. A more stringent building code can be formulated by increasing the requirements without having to specify every detail.

The negative perspective for performance-based approaches is that certain building components may not be upgraded because builders find them too expensive or too cumbersome to change, leading to technological development of some products remaining stagnant. For example, instead of investing in a high-performance building envelope, a builder may choose to specify the best possible heating, ventilation and air-conditioning system that they can. While the energy budget allocation may be satisfied, the occupant may be cold near inferior windows or doors and may raise the thermostat; thus, the building may consequently use more energy than expected. Furthermore, later replacement of the space heating and cooling equipment may not meet the high standard of the original premium equipment and efficiency may be diminished. Another example might be if someone uses renewable energy, such as solar thermal or photovoltaic cells, to meet their total energy budget. A subsequent owner may not replace the renewable energy system at the end of its life and the buildings become lower performing.

A preferred approach may be a combination of minimum prescriptive requirements for individual elements, along with total performance criteria that are more stringent than the culmination of all of the individual minimum criteria. This will ensure that a maximum level of efficiency is obtained overall, while ensuring that all components are improved to at least a minimum threshold.[15]

Climatic considerations

Climatic considerations are important when establishing building codes, as are regional and/or local building practices. Many countries have large differences in climate. Building codes will therefore need to have variations in criteria to address them. Product and technology suitability, and cost effectiveness, are highly dependent upon the climate. For example, wall or roof reflectivity may be highly important in a hot climate but not in a cold climate. Having highly insulating windows is much more important in a cold climate than in a hot climate, where shading of the window may be crucial. There are many detailed technological and economic analyses that need to be conducted before a new building code can be drafted, especially if it is mandatory.

Advanced technologies discussed in earlier chapters have significant technical and economic considerations relating to climate (Table 6.4). The complexity can exist not only in a regional and global context, but also within a specific country. Manufacturers are interested in developing products that have the greatest possible market, so climate is an important consideration for them. Policy makers also have a similar perspective. For example, to address the large global residential heating load, advanced building envelope technologies and heating equipment need to be marketed to the locations with colder weather and greatest populations. Milder weather locations will have lower energy savings and cost effectiveness is diminished because installed costs are the same but usage is much lower.

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[15] It should be mentioned that Article 4 of the EU Energy Performance of Buildings Directive, in combination with Articles 6, 7 and 8, allows this approach.

Table 6.4 Technology complexities with climate considerations

Technology	Cold	Climate mixed	Hot
Gas absorption heat pump for heating	High priority, most cost effective.	With cooling capability, maybe cost effective.	Less cost effective.
Solar cooling	Not recommended.	Harder to justify.	High priority, most cost effective.
Solar thermal: water and heat	Freeze protection, less resource.	Freeze protection, decent demand.	Low-cost options for water heating.
Heat pump water heater (air source)	Cold ground water, but cold ambient air.	High priority, decent ambient air and cold ground water.	Great ambient air temperatures but warmer ground water.
Windows	Highly insulating, most cost effective.	Harder to justify highly insulating, good for dynamic windows.	Low solar heat gain and dynamic windows.
Insulation	Higher levels justified.	Moderate levels justified.	Adequate to moderate levels justified.
Roofing	Insulation and air sealing are critical.	Insulation and air sealing are critical, reflectivity can help.	Reflectivity critical, insulation and air sealing important.

Note: this table is representative and does not present the extensive details that would be required for analysis by policy makers, but rather shows the complexity of climate.

Enforcement and compliance

Enforcement determines the true effectiveness of building codes and is a major concern. Building energy efficiency increases as the rigour of building code implementation increases. Varying levels of success in enforcement are reported, and there is usually some level of non-complying construction taking place.[16] There have been efforts to simplify building codes to increase compliance. A major source of non-compliance in many non-OECD countries is informal or unauthorized construction. Often inadequate infrastructure exists for permitted construction, representing a major barrier to enforcement. Infrastructure here includes elements such as education, human capacity, performance metrics and product availability.

Building components need to have performance metrics to show their level of efficiency. Often products such as space heating, cooling and water heating equipment have energy descriptors (*e.g.* annual fuel utilisation efficiency [AFUE], COP, energy factor), but not all building products do so. Does the insulation have a published thermal conductivity rating? Does the window have a documented U-value or solar heat gain value? Developing this infrastructure in non-OECD countries and improving it in OECD countries, along with harmonising test procedures for innovative products of the future, will lead to greater adoption of energy efficient systems.[17] More effort is needed on this issue in all countries but especially in fast-growing developing regions (Box 6.9).

Existing building efficiency improvement programmes

Programmes designed to upgrade buildings with a comprehensive or systems approach have existed for quite some time and vary in nature. For example, in the United States local and state jurisdictions administer a national weatherisation programme that has upgraded 6.4 million low-income homes over the last 33 years (WAP, 2013). Typical whole-house

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[16] One perspective is that with progressively more stringent building codes, the overall level of construction continues to improve even though full compliance may be lacking.

[17] See Chapter 3 on building envelopes for more details on building component infrastructure and testing considerations.

Box 6.9 Building code policy action in APEC

To ensure that building codes result in higher-performing buildings, it is essential to have an effective enforcement programme. APEC conducted phase II of the CEEDS project with a focus on building codes. The process was very similar to the phase I process discussed previously on building labels and standards. Key findings included a variety of suggestions to improve compliance. For example, it emphasised the need for improved compliance rather than enforcement, which meant the code became the responsibility of all parties, not just regulators. Specific elements included education, product availability, product ratings, clearer messages and the need for staged enforcement. It also suggested the development of a detailed roadmap focusing on building code compliance improvements (APEC EWG, 2011). So far, this has not been pursued but it should be the subject of greater international policy co-ordination, as discussed above.

improvements save about 20% of the utility bill per year (Khawaja, *et al.*, 2006). While these types of programme save energy, they will not be nearly enough to address the large energy consumption of the existing building stock. There has, however, been both interest in and the need to pursue deep energy upgrades or deep renovation. The concept of conducting in-depth building envelope upgrades and then reducing heat, cooling and ventilation equipment capacity is discussed in Chapter 3.

There has been some debate about whether fewer, but deeper retrofits should be pursued, compared to higher volumes of shallower performance retrofits. Cost analysis seems to point to deeper retrofits being the preferred option since they are more economically viable with a longer-term perspective (to 2050). This analysis also included possible energy reductions on the order of 80% to 85% (ECOFYS, 2010). This analysis is consistent with the assessment in Chapter 3 identifying the need to install optimal levels of insulation in accordance with life-cycle cost analysis, to avoid future upgrades potentially being cost prohibitive.[18]

A major initiative in Europe, “Renovate Europe”, is calling for a 60% to 90% reduction in existing building energy consumption, with an average improvement of 80%. The programme is seeking to increase the normal major building renovation rate of 1% per year today to 3% per year by 2020. Participating contributors include major global building material and equipment suppliers representing products such as insulation, windows, heating and cooling equipment, lighting, controls and sensors, and others. The overarching goal is to reduce the energy consumption of the building sector in 2005 by 80% by 2050. A key focus of the group is to mobilise policy makers to take action and to pursue policies that will accelerate deep energy renovations (EuroAce, 2013).

KfW Bankengruppe (KfW) in Germany has had a significant building renovation programme since 1990 for older buildings. Over a 20-year period, 61% of buildings in the former East Germany have been refurbished with EUR 61 billion of funding provided through 877 000 loans (KfW, 2013a). Recently, there has been a greater focus on energy efficiency retrofits. The bank has a formula that provides grant funds (up to 20% of the project cost with a maximum EUR 15 000 for the most efficient performance), and loan financing up to a maximum of EUR 75 000. To qualify for the deep retrofits that result in consumption approximately 45% less than a benchmark building, efficiency measures need to include significant envelope and heating equipment improvements. The programme also specifies lower levels of incentives for modest improvements (KfW, 2013b).

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[18] See Chapter 3 (Figure 3.9) for more information.

Zero-energy and very low-energy buildings

Zero-energy or very low-energy building policies focus on reducing the energy consumption of new buildings to very low levels or even to energy-producing buildings. Targeting new construction to meet these goals is critical to achieving the 2DS objective. There are many definitions for ZEB, including terms such as net zero energy, which generally refers to net annual site energy consumption. The term zero-carbon emission building is also used. Energy-producing buildings generate[19] more energy annually than they consume and can be termed "plus-energy" or "energy-plus" buildings (Box 6.10). The core objective of these programmes is to significantly reduce the energy consumption of the buildings by implementing advanced technologies. Any remaining load is served through on-site renewable energy such as photovoltaic cells and small wind systems. Other options could include the purchasing of "green" power from the grid. In urban areas, it could also include modern distributed energy systems using low-carbon waste heat or renewable sources.

When experts look at the potential for all buildings to achieve zero energy, a number of general conclusions can be drawn. Zero-energy single-family homes are technically viable, but their market viability will be highly dependent on the cost of new energy efficient products and materials, and the cost of photovoltaic (PV) and building-integrated photovoltaic (BIPV) systems. Market viability will also depend on energy prices and policies to promote the widespread adoption of zero-energy homes. However, upgrading existing homes to meet zero-energy criteria may be extremely costly due to the inefficiencies inherent in existing buildings. Large services sub-sector buildings in dense urban areas will also be challenging since the electricity loads are very high and unobstructed surface areas for effective PV use is limited. Therefore, purchasing "low-carbon" grid power may be a necessity.

Several countries have adopted ZEB goals and policies (Table 6.5). Many proactive EU countries will be implementing ZEB policies for all new construction around 2020, while the legal requirements under Directive 2010/31/EU mean all new buildings have to be nearly zero energy by 2019 for buildings occupied and owned by public authorities, and by 2021 for all new buildings. It is worth noting that the US DOE Building Technologies Program had a goal of achieving cost-effective market-viable zero-energy residential homes by 2020 and services sub-sector buildings by 2025. This goal was recently replaced with one to achieve 50% savings in the entire building sector by 2030.

Recommendations

To achieve the 2DS objectives, assertive policy implementation will be needed to move the buildings sector to a significantly more sustainable future (Table 6.6). Large-scale upgrades are essential, given the lengthy replacement period characteristic of the building stock. New construction under much more stringent building codes will need to be very low energy or zero energy. The process of deep renovation using whole-building integrated solutions will need to be accelerated, so that all existing buildings that are currently in service and will remain in service past 2050 can be upgraded.

The development of new technology will be needed, achieving both higher levels of performance and major cost reductions, and may include breakthrough materials and systems. This will require a comprehensive set of co-ordinated policies.

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[19] This is mostly expected from excess on-site electricity generation. There also is the concept of energy producing windows that contribute more energy (passive heating) annually than they lose (Arashteh *et al.*, 2006).

Multi-dimensional, integrated policies that address technologies relative to components and whole buildings should be implemented. These policies are applicable to the large array of highly effective yet under-utilised technologies, the introduction of existing technologies to new markets and the introduction of new technologies. While every recommendation may not be possible or applicable in every country, significant focus is needed in these areas to achieve the 2DS objective.

Table 6.5 Zero-energy goals/policies by country

Country	ZEB/Low-energy building goal
United Kingdom	Zero carbon: new housing and schools 2016; new public buildings 2018; new non-residential 2019.
Japan	Realise ZEB for all new public non-residential buildings by 2020, realise average ZEB of all new commercial buildings by 2030.
United States	New or major renovated Federal buildings zero fossil fuels by 2030 (EISA Section 433); Buildings Program goal is to reduce buildings sector by 50% by 2030.
Sweden	New residential ZEB by 2021. New services ZEB by 2021 (except education and hospitals ZEB by 2019).
Norway	New residential and services ZEB, 2020.
Canada	New residential and services ZEB, 2050.
Denmark	New residential, reduction compared to 2008 – 25% in 2010, 50% in 2014, 75% in 2020. New services, reduction compared to 2008 – 25% in 2010, 50% in 2015, 75% in 2020.
Spain	New residential except mobile homes ZEB by 2021. New services except warehouses, religious, and industrial ZEB by 2021.
Ireland	New residential CO_2-neutral by 2013.
Netherlands	New residential and services, 50% reduction compared to 2008 by 2015, proposal for ZEB by 2020.

Sources: IEA, 2013; ANRE, 2011; US DOE, 2013b.

Box 6.10 Building of tomorrow: Austria's biggest plus-energy office building

Achieving zero-energy status can be a challenge for large office buildings, yet Austria is in the process of upgrading an existing building to become the largest plus-energy office building (Figure 6.11). This project is part of the refurbishment of the Vienna University of Technology (Univercity 2015 www.univercity2015.at/en/) and is owned by the Bundesimmobiliengesellschaft m.b.H (BIG), who is also the building contractor. The project intends to demonstrate not only the technical but also the economic feasibility of plus-energy office buildings. Within this building, the plus-energy concept is fulfilled by optimising the power consumption of the whole building and by the installation of Austria's largest façade-integrated photovoltaic plant. Key features of the building were designed using a simulation software tool called "BUILDOPT_VIE"[20] and include:

- optimised building envelope with maximised potential for passive heating and cooling;
- exterior automated shade control integrated into the building instrumentation and control;

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[20] The tool was developed by Research Centre of Building Physics and Sound Protection, Vienna University of Technology, Austria. Software simulation tools are essential in designing energy efficient buildings but go beyond the scope of this book.

- highly efficient central ventilation systems with regenerative heat and moisture recovery (rotary heat exchangers), demand-based control of the ventilation system for higher air quality and less energy use;
- core night ventilation and thermal coupling to occupied spaces with motorised windows;
- floor radiant distribution (thermal-component activation) for highly efficient heating and cooling and a higher comfort;
- highest lighting optimisation (position, products, and daylight detection control);
- optimisation of energy management and intelligent control devices of building systems (*e.g.* low-energy motion detectors, high-efficiency control and motors, elevators);
- green IT (server, laptops, office PCs, network) (Haus der Zukunft, 2013).

Figure 6.11 Austria's largest plus-energy office building, to be completed by 2015

Source: figure courtesy of architects Kratochwil-Waldbauer-Zeinitzer, Schöberl & Pöll GmbH, in Haus der Zukunft, 2013.

Key point *This large office renovation will offer plus-energy performance, which is extremely challenging in an urban environment.*

Table 6.6 Technology and policy recommendations for immediate implementation

Whole building	R&D and field evaluation	Case studies	Awards of excellence	Financial incentives	Labelling	Standards	**Recommended actions/goals**
New construction	√	√	√	√	√	√	Building codes with supporting infrastructure and strive for net ZEB.
Existing buildings (deep renovation [DR])	√	√	√	√	√	√	Develop retrofit buildings codes, promote building ratings and incentives for DR.
Envelope							
Advanced facades		√	√	√	√	√	Integrated solutions with dynamic glass.
Insulation	√	√		√	√	√	Promote and incentives only for DR.
Reflective roofing		√	√	√	√	√	Promote in hot climates.
Air sealing					√	√	Add standards in whole-building programmes.
Windows	√	√	√	√	√	√	Develop affordable U-value $\leq$ 0.6 (W/m^{2}K).
Heating and cooling							
Electric resistance heating (all)						√	Ban for water and main heating source.
Gas heating						√	Mandate 95%+ efficiency standards.
Ground-source heat pumps (HP)				√	√	√	Promote and support for efficiency standards.
Cold climate (air) and gas thermal HPs	√	√	√	√	√	√	Develop cold climate electric solutions COP > 3.0; small gas thermal COP > 1.2.
Gas water heating				√	√	√	Promote instantaneous and condensing.
HP water heating		√	√	√	√	√	Promote in market, standards < 10 years.
Solar heating and cooling	√	√	√	√	√	√	Affordable solar thermal and innovative cooling for hot-climate developing countries.
Lighting, cooking and plug loads							
Incandescent lighting						√	Ban the sale of incandescent light bulbs.
Fluorescent lighting					√	√	Educate and mandate performance levels.
Solid-state lighting	√	√	√	√	√	√	Develop affordable high lm/W solutions.
Controls and sensors		√	√	√	√	√	Promote integrated systems.
Biomass cooking and heating	√	√		√			Develop low-cost alternatives with incentives.
Appliances, televisions, plug loads, etc.	√	√	√	√	√	√	Develop technology beyond standby improvements, standards and labelling.

Notes: W/m^{2}K = watts per square metre per kelvin; lm/W = lumens per watt.

Analytical Framework

This annex provides a brief overview of the *Energy Technology Perspectives (ETP)* model as well as the analytical framework for the development of the buildings analysis presented in this publication.

The *ETP* analysis and modelling aim to identify the most economical way for society to limit the increase in global average temperature to 2°C and examines how to achieve the deep emissions reduction required to at least halve global emissions by 2050.

Achieving the *ETP 2012* 2°C Scenario (2DS) does not depend on the appearance of breakthrough technologies. All technology options introduced in *ETP 2012* are already commercially available or at a stage of development that makes commercial-scale deployment possible within the scenario period. Costs for many of these technologies are expected to fall over time, making a low-carbon future economically feasible. To make the results more robust, the analysis pursues a portfolio of technologies within a framework of cost minimisation.

Many subtleties cannot be captured in a cost optimisation framework: political priorities, consumer preferences, feasible ramp-up rates, capital constraints and public acceptance. For the end-use sectors (buildings, industry and transport), doing a pure least-cost analysis is difficult and not always suitable. Long-term projections inevitably contain significant uncertainties.

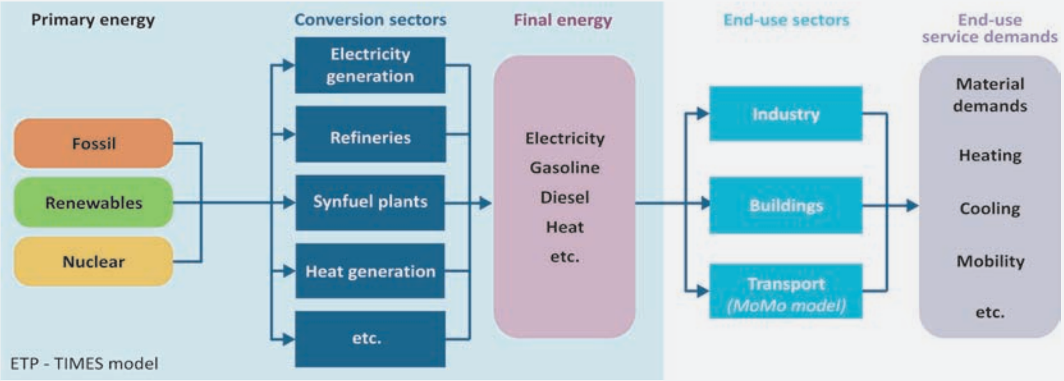
The *ETP* model, which is the primary analytical tool used in *ETP 2012*, combines analysis of the energy supply and demand, and it supports integration and manipulation of data from four soft-linked models: energy conversion, buildings, industry and transport.

It is possible to explore outcomes that reflect variables in energy supply (using the energy conversion model) and in the three sectors that have the largest demand, and hence the largest emissions. The following schematic illustrates the interplay of these elements in the processes by which primary energy is converted to the final energy that is useful to these demand-side sectors (Figure A.1).

The *ETP* buildings sector

The buildings sector includes both the residential and services sub-sectors. The residential sub-sector includes those activities related to private dwellings. It covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances. The services sub-sector includes activities related to trade, finance, real estate, public administration, health, food and lodging, education and commercial services. This is also referred to as the commercial and public service sector. It covers energy used for space heating, cooling and ventilation, water heating, lighting and in a number of other miscellaneous energy-using equipment such as commercial appliances and cooking devices, x-ray machines, office equipment and generators.

Figure A.1 The *ETP* model



Data and indicators: availability, gaps and challenges

The assumptions used in the buildings model are developed using energy indicators that build on available historical data on energy and service level trends. Those indicators are used to give an adequate picture of energy intensity levels for buildings or end-uses in a country and to assess the potential for improvement in energy efficiency.

However, detailed energy data availability currently constitutes the limiting factor for developing very detailed and therefore more meaningful indicators, including for IEA member countries.

Energy statistics at the IEA have been established around the concepts of energy security, including detailed data on stocks and trade, and energy balance. While an energy balance provides sectoral (residential and services) energy consumption by energy sources, detailed data on buildings energy consumption (by buildings types or end-use), buildings characteristics, and socio-economic information are currently not widely available. Therefore, other data sources must be used.

Energy balances do not provide any activity data, which constitute the essential denominator of any useful energy indicator. For instance, while a balance shows the residential sub-sector's overall consumption, a more meaningful indicator would be the heating consumption per square meter or the average consumption per type of appliance.

In 2009, the Ministers of IEA member countries agreed to a new annual questionnaire dedicated to energy efficiency. Since then, the IEA Secretariat has collected statistics on both end-uses energy consumption and activity on an annual basis. The data are then used to assemble indicators that constitute the basis for many studies and analyses, including the ones presented in this publication. This is certainly an important step forward, but there are still major issues regarding missing data and data quality for several IEA countries. Furthermore, the questionnaire is, at the moment, used for collecting data from IEA member countries only.

The IEA Secretariat is actively engaged in promoting the need for more detailed data in OECD and non-OECD countries through a series of workshops and training sessions as well as the preparation of two companion documents: *Manual on Statistics for Energy Efficiency Indicators* and *Manual on Development of Energy Efficiency Indicators*. However, for the time being, there is still a lack of both end-use consumption and activity data, and hence a need for using alternative sources.

As a consequence, the analysis presented in this publication builds on various sources of data collected through a network of contacts in countries, associations and industries. In cases where energy use and activity data are lacking, technology data can serve to estimate end-use energy consumption. Building stock and equipment vintage data can also help to determine efficiencies and potential improvements.

More work is needed to improve the quality of data and refine the analysis. In many cases, data are not available due to lack of structure, financial and human capacity, or interest and commitment in collecting the data. For energy policy makers to have the means to realise their ambitions, there is an urgent need to allocate the necessary resources for collecting more detailed data on both end-use consumption and activity. Good and reliable statistics are the basis for any sound energy policy; this is also true for energy efficiency policy and actions.

Key aggregate drivers used in the buildings model

Gross domestic product (GDP) and population are the two fundamental drivers of demand for energy services in the buildings sector (Table A.1 and Table A.2).

- **GDP:** this is assumed to grow at 3.6% per year between 2010 and 2030, and slow to 2.9% per year between 2030 and 2050. Overall, global GDP (at purchasing power parity) will be 3.6 times greater in 2050 than it was in 2010.
- **Population:** the world's population is expected to increase by 35% to 9.4 billion in 2050 (UN DESA, 2011), with growth rate highest in Asia and Africa.

These are kept constant across all scenarios as a means of providing a starting point for the analysis and facilitating the interpretation of the results.

Table A.1 GDP projections used in this publication

	2010	2020	2030	2040	2050	AAGR 2010-50
World	74 321	111 226	151 563	204 763	267 034	3.2%
OECD Americas	17 813	23 166	29 065	36 094	44 510	2.3%
OECD Europe	16 268	20 000	24 066	28 657	33 661	1.8%
OECD Asia and Oceania	6 903	8 681	10 069	11 477	12 751	1.5%
Non-OECD Europe and Eurasia	3 901	5 773	7 932	10 588	13 042	3.1%
China	10 520	22 293	34 233	49 398	63 697	4.6%
India	4 065	8 337	14 727	24 999	37 721	5.7%
Other developing Asia	4 818	7 869	10 858	15 110	21 524	3.8%
Latin America	4 509	6 620	8 750	11 393	14 721	3.0%
Africa	3 032	4 699	6 347	9 017	13 475	3.8%
Middle East	2 492	3 789	5 518	8 031	11 931	4.0%

Notes: AAGR = average annual growth rate. Numbers in USD 2010 at purchasing power parity.
Sources: IEA and OECD analysis.

Table A.2 Population projections used in this publication

	2010	2020	2030	2040	2050	AAGR 2010-50
World	7 006	7 782	8 457	9 016	9 448	0.8%
OECD Americas	475	519	556	587	611	0.6%
OECD Europe	547	567	580	585	584	0.2%
OECD Asia and Oceania	209	213	213	210	205	0.0%
Non-OECD Europe and Eurasia	332	333	328	321	313	- 0.1%
China	1 341	1 388	1 393	1 361	1 296	- 0.1%
India	1 225	1 387	1 523	1 627	1 692	0.8%
Other developing Asia	1 175	1 326	1 452	1 545	1 601	0.8%
Latin America	477	526	566	593	607	0.6%
Africa	1 022	1 278	1 562	1 870	2 192	1.9%
Middle East	204	245	283	317	348	1.3%

Source: UN DESA, 2011.

In addition to GDP and population, numerous factors have an impact on buildings energy consumption trends, building heating and cooling loads, the number and types of appliances owned and patterns of use. The other key aggregate parameters in the buildings sector are as follows:

- **Urbanisation:** today, slightly less than half of the world's population lives in urban areas (UN DESA, 2012). By 2050, 6.25 billion people, or 67% of the world's population, are expected to live in urban areas.
- **Household numbers:** the global number of households is projected to grow by 68% between 2010 and 2050. This is larger than population growth due to the continuing trend of fewer people per household. The recent trend towards larger floor areas per house is likely to continue, although this will be weak in many mature economies.
- **Residential sub-sector floor area:** decreasing number of persons per household, increased wealth and strong increase in consumption of new residential units in non-OECD countries will drive the 74% increase in residential floor area.
- **Services sub-sector floor area:** this will increase by 66% between 2010 and 2050.

Buildings model fundamentals

The buildings sector is modelled using a global simulation stock accounting model, split into residential and services sub-sectors and applied across 31 countries/regions (Table A.3).

The logic of the residential and services sub-sector is the same. As very few countries can provide energy consumption by type of buildings, the model is only specified by end-uses for each sub-sector (further development is ongoing to improve the disaggregation of the sub-sectors) (Table A.4).

Space heating demand is informed by detailed data on building stocks (including energy efficiency of different vintages) in OECD countries. Where these data are not available, the

Table A.3 Countries and regions in the *ETP* buildings model

Zone	OECD countries Country/region	Zone	Non-OECD countries Country/region
OECD Americas	Canada Chile Mexico United States	Non-OECD Europe and Eurasia	Russia Other non-OECD Europe and Eurasia members of the EU Other non-OECD Europe and Eurasia non-members of the EU
OECD Asia and Oceania	Korea Japan Israel Other OECD Asia and Oceania	Developing Asia	China India ASEAN Other developing Asia
OECD Europe	France Germany Italy United Kingdom Denmark Finland Iceland Norway Sweden Other OECD Europe members of the EU Other OECD Europe non-members of the EU	Latin America	Brazil Other Latin America
		Africa	South Africa Other Africa
		Middle East	Middle East

Table A.4 End-use, energy sources and data contained in the buildings model

End-uses	Technologies/energy	Key variables
Space heating	Coal	Urban population
Space cooling	Light fuel oil, kerosene, liquefied petroleum gas	Rural population
Water heating	Heavy fuel oil	Gross domestic product
Lighting	Diesel	Number of households
Residential cooking	Natural gas	Residential floor area
Residential appliances	Electricity	Services floor area
Service equipment	Commercial heat	Share of floor area heated
	Modern biomass	Share of floor area cooled
	Traditional biomass	System efficiency
	Solar	Fuel shares
	Heat pump	Useful energy intensity
	Hydrogen	Appliances penetration rate
	Geothermal	Appliances unit energy consumption
		CO_2 emission factors

model uses average stock efficiencies. For appliances, the model recognises that equipment penetration is driven by income per capita and historical regressions. Space cooling is projected using regional climatic conditions and income per capita.

Buildings floor area and residential households

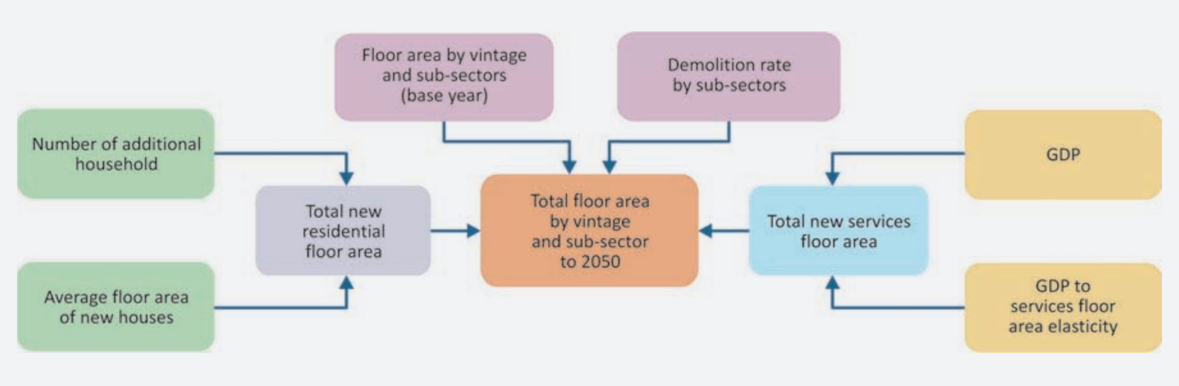
While population, urbanisation and GDP are readily available for all countries and regions analysed, the number of households and residential and services floor area, while available for most OECD countries from official sources, are more difficult to obtain for other countries. Where the information is not available, the model uses income, population and urbanisation data, as well as services value-added, to project floor space per capita and activity levels. For example, the services floor area for most non-OECD countries is based on an elasticity factor between services floor area and value-added observed in countries where this information is available, which is then applied to projected value-added to year 2050.

Based on this set of drivers, demand for individual energy services and the share of each energy technology needed to meet this demand are projected to 2050. Changes in energy service demand related to the building envelope are driven by assumptions on various retrofit and new-build technology packages that deliver set performance levels.

The buildings floor area in the base year is broken down in 5-year steps (vintages). Where vintage information is not available, estimates on the distribution of the stock, based on available historical population and household data are developed.

The evolution of the floor area to 2050 for the residential and services sub-sectors is based on different factors (Figure A.2). The stock accounting framework is applied to each country/region analysed, and a global figure is obtained by summing up all regions.

Figure A.2 Stock accounting framework for residential and services sub-sectors



As is the case for floor area, the number of households is available for OECD countries and for some non-OECD countries from official sources. Where not available, estimates are also based on available related information. For example, the number of households in India is developed based on population data (available from the United Nations) and the average people per household in urban and rural area (available from India National Sample Survey Organisation [NSSO]). For years where occupancy rates are not available, the numbers of households are extrapolated using the observed trend in population.

In the services sub-sector, floor area is the driver to develop the estimates of energy consumption for all end-uses. In the case of the residential sub-sector, floor area is the key driver for the development of energy consumption for space heating, space cooling and lighting, while appliances, cooking and water heating energy consumption are driven by the number of households.

Space heating and space cooling energy consumption

The details below related to the modelling of space heating energy consumption. The same logic and calculation methods are used for space cooling.

The starting point for estimating energy consumption for space heating is the total floor area per year of construction for each time period (vintage).

Each vintage, in each time period, has its specific useful energy consumption (expressed in megajoules [MJ] per year). This information is seldom available. As a result, the useful intensity by vintage (expressed in MJ per square metre [m^2] per year) is derived using available information (*e.g.* the typical useful intensity of new building stock in a single time period) and then applying an improvement rate for each vintage over that single time period. The model also takes into consideration the performance degradation of buildings between each time period as well as the improvement resulting from refurbishment of older units. These specifications allow the analysis of the impact of increasing the rate of refurbishments or mandating minimum efficiency improvements at time of retrofit.

The total useful energy consumption (MJ/year) of the sub-sector for each time period is then calculated as:

$$
\begin{aligned}
Energy_{useful} = \sum_{vintage} & Area_{vintage} * \%heated * Intensity_{vintage} \\
& * \left[\%retrofit_{vintage} * \left(1 - improvement_{vintage}\right) + \%demolish_{vintage} \right. \\
& \left. + \%remaining_{vintage} * \left(1 + degradation_{vintage}\right)\right]
\end{aligned}
$$

Where:

$Energy_{useful}$ = useful energy consumption in MJ/year in year *t*

$Area_{vintage}$ = floor area in vintage *x* in year *t*

%heated = share of total floor area heated (or cooled) in year *t*

$Intensity_{vintage}$ = average useful energy consumption per m^2 in vintage *x* in year *t*

$\%retrofit_{vintage}$ = share of floor area retrofitted in vintage *x* in year *t*

$Improvement_{vintage}$ = improvement factor in vintage *x* (*e.g.* renovated stock performs 20% better than average vintage stock in the same year)

$\%demolish_{vintage}$ = share of floor area demolished

$\%remaining_{vintage}$ = share of floor area not renovated or demolished

$Degradation_{vintage}$ = loss of efficiency between year *t*-1 and year *t*

Finally, the total final energy consumption for space heating (MJ/year) is then calculated as:

$$Energy_{total} = \sum_{fuel} \frac{Energy_{useful} * share_{fuel}}{Efficiency_{fuel}}$$

Where:

$Energy_{total}$ = final energy consumption for space heating (or cooling)

$Energy_{useful}$ = useful energy consumption in MJ/year in year *t*

$Share_{fuel}$ = share of fuel *x* used for space heating (or cooling)

$Efficiency_{fuel}$ = efficiency of the system (technology) using fuel *x*

The 6DS assumes that not much change will happen in system efficiency and fuel shares. The 2DS assumes that there is a global goal to be reached to achieve large reductions in emissions. This scenario assumes a greater share of “carbon free” energy sources, more improvements in system efficiency, faster improvement of building shell in terms of specific useful intensity and higher retrofit rate.

Residential appliances energy consumption

Energy consumption of appliances is specifically modelled for refrigerators, freezers, dishwashers, clothes washers, clothes dryers and televisions. Energy consumption for the category "other appliances" is based on growth in GDP per capita and expected increase in the share of appliances energy consumption of these appliances.

For the appliances modelled specifically, the projected stock of appliances takes into account the changes in GDP per capita, the increase in the number of households and the expected saturation rate by appliances.

The stock turnover model follows the same logic as for the floor area by vintage. The model assumes that about 2% of the stock is replaced each year (10% by step of 5-years). Different unit energy consumption (UEC) values are attributed to the "existing" and "new" stock of appliances.

The total energy consumption per type of appliances for each time period is calculated as:

$$Energy_{total} = \sum_{age}(Stock_{age} * UEC_{age}) * Households * Saturation$$

Where:

$Energy_{total}$ = final energy consumption for appliance *x* in year *t*

$Stock_{age}$ = Number of appliances in vintage *y* in year *t*

UEC_{age} = Unit energy consumption of appliance *x* in vintage *y* in year *t*

Saturation = share of houses owning appliance *x* (can be higher than 1 if there is more than one appliance *x* per household)

Households = total number of households

Other end-uses (water heating, cooking and lighting)

For water heating, lighting, residential cooking and other service equipment, the starting points are the specific useful energy consumption (per m^2 or per household), average efficiency of equipment and fuel shares.

The specific useful intensity is then assumed to improve through time (faster in the 2DS than in the 6DS).

Lighting energy consumption in each year is calculated as:

$$Energy_{total} = \sum_{type}(\frac{Energy_{useful} * Share_{type}}{Efficiency_{type}}) * Area$$

Where:

$Energy_{total}$ = final energy consumption for lighting

$Energy_{useful}$ = useful energy in MJ/year in year *t* required to light desired floor area

$Share_{type}$ = share of lighting type *x* used for lighting

$Efficiency_{type}$ = efficiency of the lighting type used

Area = floor area in year *t* that is lit

For water heating, cooking and other service equipment, energy consumption is calculated as follow:

$$Energy_{total} = \sum_{fuel} \left(\frac{Energy_{useful} * Share_{fuel}}{Efficiency_{fuel}}\right) * Activity$$

Where:

$Energy_{total}$ = final energy consumption of end-use activity

$Energy_{useful}$ = useful energy in MJ/year in year *t* required to perform desired end-use activity

$Share_{fuel}$ = share of fuel *x* used for end-use activity

$Efficiency_{fuel}$ = efficiency of system (technology) using fuel *x*

Activity = services floor area (used for other service equipment and services water heating) or number of households (used for residential water heating and cooking).

The rate of improvement of the specific useful energy, fuel share and system efficiency are IEA assumptions and were circulated to countries for validation.

Ensuring consistency between modelling results and available information

Energy consumption from the model is aggregated and the calculated base year (by sub-sector and by energy source) is compared to available information from IEA energy balance.

This comparison helps refine the model and the assumptions used. For example, if the model is overestimating natural gas use when compared to the balance, then the input used for gas boilers efficiency or the share of natural gas in space and water heating will be changed to better track the aggregate "known" results. The input that will be changed will be different from country to country. Data coming from official or semi-official sources will not, in most case, be adjusted. Adjustments will be made on the variables that are the "least certain" or are based on the most assumptions in a country.

Given the data situation for the buildings sector, and the numerous assumptions used for modelling buildings sub-sector energy consumption by end-use, it is more accurate to look at the trends than at the actual level of energy consumption. The trends in energy reveal important insights about the relative importance each end-use will play in the future, and where there are more opportunities to restrain the growth in energy consumption.

Key assumptions in the buildings scenarios

Existing, widely available and cost-effective technologies offer opportunities to significantly reduce energy use and emissions in buildings at low costs. In countries with CO_2-intensive electricity generation mixes, reducing electricity demand or moving to off-grid technologies may be a higher priority than reducing the direct use of fossil fuels, while in regions with high dependence on fossil fuels, reducing heating and cooling demand may be a priority. In this respect, the 2DS is based on large-scale deployment of technologies in the buildings sector with the greatest opportunities for cost-effective energy and CO_2 reductions (Table A.5).

Table A.5 Technology status for the buildings sector in the 6DS and 2DS

End-use	2010 Status	2050 Status (6DS)	2050 Status (2DS)	Comments
Building envelope	Useful energy consumption for space heating in residential sub-sector is over 100 MJ/m^2 in most OECD countries.	Useful energy consumption of the stock decreases by 10% over 2010 levels.	Useful energy in new houses is reduced to 25 MJ/m^2.	Improvements in envelopes from advanced technologies (insulation, air sealing, reflective surfaces and high-performance windows, etc. combined with proper ventilation) reduce the heating and cooling load and allow downsizing of heating and cooling equipment.
Space and water heating	Conventional technologies are widely used in residential and services buildings, with natural gas accounting for 30% of energy use for space and water heating.	Conventional technologies are still widely used. Heat pumps and solar provide approximately 5% of input energy.	Heat pumps provide 10% and solar energy and 13% of total input energy for space heating.	Use of heat pumps becomes common practice. Electric resistance heating is no longer the main source of heating, and minimum efficiency for gas equipment is over 95%. Affordable solar thermal is widely available, and large electric resistance water heaters are no longer produced. Instantaneous gas and heat pump water heaters are affordable and widely used.
Space cooling	Space cooling only accounts for 3% of total energy consumption in buildings.	Energy use more than doubles from 2010 level as more buildings have space cooling equipment.	Increased penetration of efficient air conditioners and solar cooling help reduce energy consumption by 30% over the 6DS.	Demand growth is reduced in hot climates through passive envelope technologies. More efficient systems are promoted and minimum efficiencies are regulated.
Lighting	Lighting intensity is 0.12 MJ/m^2 in the services sub-sector and 0.015 MJ/m^2 in the residential sub-sector.	Ban on incandescent lighting in several countries helps reduce lighting intensity by 53% in the residential sub-sector and 31% in the services sub-sector.	All buildings use solid-state lighting and optimise natural day lighting. Lighting intensity is reduced to 0.056 MJ/m^2 in services and 0.004 MJ/m^2 in residential.	Optimal daylight is harvested in new buildings and solid-state lighting is widely available and cost effective. Lighting regulations are widely implemented in most countries.
Cooking	About 70% of cooking energy use is biomass – mostly traditional biomass in non-OECD countries.	Use of biomass is reduced to 58%, most of it being a modern, more efficient form of biomass.	All biomass use is modern; increased use of electricity (displacing oil use). Cooking intensity is over 15% lower than in the 6DS.	Traditional inefficient biomass usage still exists but is very limited. Healthier solutions are implemented and biomass usage is better utilised in high-efficiency central applications.
Appliances and other equipment	Appliance intensity is 4.0 MJ per household. Fossil fuels account for about 45% of service equipment energy demand.	Little improvement in energy intensity or fuel mix compared to the base year.	Appliance intensity is 2.9 MJ per household. Fossil fuels account for about 32% of services equipment energy demand.	Efficient appliances reach saturation in most countries except for remaining rural populations in developing countries. Growth in electronics is slowing, and they are more efficient but also more widespread.

International Technology Collaboration and Building Related Organisations[1]

IEA Energy Technology Network

The multilateral technology initiatives (Implementing Agreements) supported by the IEA are a flexible and effective framework for IEA member and non-member countries, businesses, industries, international organisations and non-government organisations to research breakthrough technologies, to fill existing research gaps, to build pilot plants and to carry out deployment or demonstration programmes – in short to encourage technology-related activities that support energy security, economic growth and environmental protection.

There are eight core Implementing Agreements that are working on activities that are directly or indirectly related to buildings (listed below).

- Implementing Agreement for a Co-operative Programme on Efficient Electrical End-Use Equipment (4E IA) www.iea-4e.org.
- Implementing Agreement for a Programme of Research and Development on Energy in Buildings and Communities (EBC IA) www.iea-ebc.org.
- Implementing Agreement for a Programme of Research and Development on Heat Pumping Technologies (HPT IA) www.heatpumpcentre.org.
- Implementing Agreement for a Programme to Develop and Test Solar Heating and Cooling Systems (SHC IA) www.iea-shc.org.
- Implementing Agreement for a Programme of Research, Development and Demonstration on District Heating and Cooling, including the Integration of Combined Heat and Power (DHC IA) www.iea-dhc.org.
- Implementing Agreement for a Programme of Research and Development on Energy Conservation through Energy Storage (ECES IA) www.iea-eces.org.
- Implementing Agreement for Co-operation on Technologies and Programmes for Demand-Side Management (DSM IA) www.ieadsm.org.
- Implementing Agreement for a Co-operative Programme on Photovoltaic Power Systems (PVPS IA) www.iea-pvps.org.

For further information on the activities of IEA Implementing Agreements, see www.iea.org/techno/ia.asp.

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[1] The mention of specific organisations does not imply that they are endorsed or recommended by the IEA in preference to others of a similar nature that are not mentioned.

Government organisations

Most countries have a number of energy, development and statistic agencies that collect buildings energy use related data and undertake analysis related to energy efficiency in the buildings sector and or buildings related research. Most of these organisations work at the national level, but there are also state, regional and local organisations as well. Many countries also have government research organisations. Examples include the United States Department of Energy's Office of Energy Efficiency and Renewable Energy, China's Ministry of Housing and Urban-Rural Development and India's Bureau of Energy Efficiency, among many others. There are also many organisations that are closely affiliated with government programs that fall within the non-government organisation category.

Industry organisations

A variety of industry organisations that represent various manufacturing sectors, such as building materials (insulations, glass, windows, sealants, roofing, etc), heating, cooling and ventilation equipment, water heating (including solar thermal), lighting and appliances, also conduct buildings related analysis and promote the wider uptake of energy efficienct building technologies. In many cases, these organisations may be regionally based, or in some cases globally based. Examples include PU Europe, the European Alliance of Companies for Energy Efficiency in Buildings (EuroACE) and the American Chemical Council. These organisations usually have members that work in all regions of the world and have a broad perspective on the global buildings market.

Non-government organisations

There are many types of non-government organisations that work to promote and inform governments and the general public on the importance of greater buildings energy efficiency. Examples of these organisations include the American Council for an Energy Efficient Economy, the European Council for an Energy Efficient Economy, the Collaborative Labeling and Appliance Standards Program (CLASP) and the Global Building Performance Network (GBPN). There are also numerous standard setting organisations that product proper building design guidelines, building material ratings and overall performance specifications. Examples include the American Society of Heating, Refrigeration and Air-Conditioning, the International Standards Organisation, the National Fenestration Rating Council and the Australian Fenestration Council.

Abbreviations, Acronyms and Units of Measure

Abbreviations and acronyms

2DS	*ETP 2012* 2°C Scenario
EIA	Efficient Electrical End-Use Equipment Implementing Agreement
6DS	*ETP 2012* 6°C Scenario
AAGR	average annual growth rate
ACH	air changes per hour
AFUE	annual fuel utilisation efficiency
APEC	Asia-Pacific Economic Cooperation
APF	annual performance factor
ASEAN	Association of Southeast Asian Nations
ASHP	air-source heat pump
AST	active solar thermal
BAS	building automation system
BAT	best available technology
Bbiomax	maximum allowed value for Bbio coefficient
BCA	Building and Construction Authority (Singapore)
BEE	Bureau of Energy Efficiency (India)
BIPV	building-integrated photovoltaic
BREEF	Building Retrofit Energy Efficiency Financing (Singapore)
BREEAM	Building Research Establishment Environmental Assessment Method
CCFL	cold-cathode fluorescent lamp
CDM	Clean Development Mechanism
CEEDS	Cooperative Energy Efficiency Design for Sustainability
CEM	Clean Energy Ministerial
CLASP	Collaborative Labeling and Appliance Standards Program
CFL	compact fluorescent lamp
CO_2	carbon dioxide
COP	coefficient of performance

COP 15	Copenhagen Conference of the Parties
CRT	cathode ray tube
DHC	district heating and cooling
DOE	Department of Energy (United States)
DR	deep renovation
DSM	Demand-Side Management
ECBC	Energy Conservation Building Code (India)
EIFS	exterior insulation finishing system
EPBD	Energy Performance of Buildings Directive (European Union)
EPS	expanded polystyrene
ESCOs	energy service companies
ETICS	external thermal insulation composite system
ETP	*Energy Technology Perspectives*
EU	European Union (27)
GBC	Green Building Council (United States)
GDP	gross domestic product
GHG	greenhouse gas
GLS	general lighting service
GSHP	ground-source heat pump
HDD	heating degree-day
HP	heat pump
HPT	heat pump technology
HID	high-intensity discharge
HVAC	heating, ventilation and air-conditioning
IA	Implementing Agreement
IBP	Fraunhofer Institute of Building Physics (Germany)
ICF	insulated concrete forms
ICT	information and communication technology
IEA	International Energy Agency
IPEEC	International Partnership for Energy Efficiency Cooperation
ISE	Fraunhofer Institute of Solar Energy (Germany)
ISIC	International Standard Industrial Codes
ISO	International Organization for Standardization
JNNSM	Jawaharlal Nehru National Solar Mission (India)
KfW	KfW Bankengruppe (Germany)
LBNL	Lawrence Berkeley National Laboratory (United States)

LCD	liquid crystal display
LEED	Leadership in Energy and Environmental Design
LED	light-emitting diode
LFL	linear fluorescent lamp
Low-e	low-emissivity
LPG	liquefied petroleum gas
MEPS	minimum energy performance standard
NMEEE	National Mission on Enhanced Energy Efficiency (India)
NTU	Nanyang Technical University (Singapore)
NREL	National Renewable Energy Laboratory (United States)
NSSO	National Sample Survey Organisation (India)
OECD	Organisation for Economic Co-operation and Development
OLED	organic light-emitting diode
ORNL	Oak Ridge National Laboratory (United States)
OSB	oriented strand board
PCM	phase change material
PDP	plasma display panel
PEMFC	polymer electrolyte membrane fuel cell
PLED	polymer light-emitting diode
PPP	purchasing power parity
PV	photovoltaic (solar)
R&D	research and development
RDD&D	research, development, demonstration and deployment
RESNET	Residential Energy Services Network
RTU	roof top unit
SEAD	Super-efficient Equipment and Appliance Deployment
SENER	Secretariat of Energy, Mexico
SHC	solar heating and cooling
SHGC	solar heat gain coefficient
SIP	structurally insulated panel
SOFC	solid oxide fuel cell
SPF	seasonal performance factor
SSL	solid-state lighting
SWH	solar water heating programme (South Africa)
TEC	typical energy consumption
TES	thermal energy storage

TPES	total primary energy supply
UEC	unit energy consumption
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
VIP	vacuum insulated panel
WBCSD	World Business Council on Sustainable Development
WEO	*World Energy Outlook*
WUFI	Wärme und Feuchte Instationär
XPS	extruded polystrene
ZAF	South Africa
ZEB	zero-energy building

Units of measure

Btce	billion tonnes of coal equivalent
dm^2	square decimetre
EJ	exajoule (10^{18} joules)
g	gramme
GJ	gigajoule (10^9 joules)
Gt	gigatonne (10^9 tonnes)
GW	gigawatt (10^9 watts)
GW_e	gigawatt electrical capacity
GW_{th}	gigawatt thermal
kg	kilogramme (10^3 grammes)
kVA	kilovolt-ampere
kW	kilowatt (10^3 watts)
kW_e	kilowatt electrical capacity
kWh	kilowatt-hour (10^3 watt-hours)
kW_{th}	kilowatt thermal
lm	lumen
m	metre
m^2	square metre
mK	metre kelvin
m^2K	square metre kelvin
MJ	megajoule (10^6 joules)
mm	millimetres
Mt	megatonne (10^6 tonnes)

Mtoe	million tonnes of oil equivalent
MW_{th}	megawatt thermal
Pa	Pascal
PJ	petajoule (10^{15} joules)
TWh	terawatt-hour (10^{12} watt-hours)
TWh_{th}	terawatt-hour thermal
W	watt

Definitions, Regional and Country Groupings

Definitions

B

Biomass	Biomass is a biological material that can be used as fuel or for industrial production. It includes solid biomass (*e.g.* wood, plant and animal products), gases and liquids derived from biomass, industrial waste and municipal waste.
Biomass and waste	Biomass and waste includes solid biomass, gas and liquids derived from biomass, industrial waste and the renewable part of municipal waste. It includes both traditional and modern biomass.
Buildings	Buildings include the residential and services sub-sectors.
Building envelope	The building envelope represents the portion of a structure that is the primary thermal barrier that separates the interior from the exterior. This includes the main components including walls, roofs, windows and foundations. Other typical names include building shell, building enclosure and thermal fabric of the building.

C

Co-generation	Co-generation refers to the combined production of heat and power.
Coal	Coal includes both primary coal (including hard coal and brown coal) and derived fuels (including patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas-works gas, coke-oven gas, blast-furnace gas and oxygen steel furnace gas). Peat is also included.
Coefficient of performance (COP)	COP is the ratio of heat output to work supplied or energy input, generally applied to heat pumps as a measure of their efficiency.
Commercial heat	Refers to heat consumed by final end-users. It includes heat produced for sale only.
Cool roofs	Cool roofs reflect the sun's energy and are either white or cool coloured. White surfaces strongly reflect both visible sunlight (wavelengths 0.4 µm – 0.7 µm) and invisible near-infrared sunlight (0.7 µm – 2.5 µm) to attain high solar reflectance. "Cool-coloured" surfaces offer choice of colour by strongly reflecting only the near-infrared radiation. They reflect more sunlight than conventional colours, but less than white.
Cooling load	The cooling load represents the energy required to maintain interior conditions at a thermally comfortable temperature. While actual interior temperature set points vary significantly from building to building, designers use standard design conditions and expected climatic

		conditions along with building envelope characteristics to properly size mechanical equipment. This does not represent the energy to run mechanical equipment, which is based on equipment efficiency. Buildings that do not use any mechanical equipment to cool a building do not have a cooling load even though interior temperatures may exceed comfortable conditions.
D	Direct emissions	Direct emissions refer to emissions that are attributed directly to end-use equipment that is located on a building.
E	Energy intensity	A measure where energy is divided by a physical or economic denominator.
G	Geothermal energy	Energy available as heat emitted from within the earth's crust, usually in the form of hot water or steam. It is exploited at suitable sites for electricity generation using dry steam or high enthalpy brine after flashing as well as directly as heat for district heating, agriculture, etc.
	Gross domestic product (GDP)	GDP is the market value of all officially recognised and final goods and services produced within a country.
H	Heat	Heat is obtained from the combustion of fuels, nuclear reactors, geothermal reservoirs, capture of sunlight, exothermic chemical processes and heat pumps, which can extract it from ambient air and liquids. It may be used for domestic hot water, space heating or cooling, or industrial process heat. Most heat included in this category comes from the combustion of fuels in co-generation installations, although some small amounts are produced from geothermal source, electrically powered heat pumps and boilers.
	Heating degree day (HDD)	Refers to the total seasonal heating requirements to satisfy a desired temperature setting compared to the average daily temperature (either actual or historical average). Desired or set temperatures vary by preference and consumer behaviour, but design engineers usually follow a standard protocol by country or region. For example, if a desired temperature were 20°C and the average daily temperature were 5°C, there would be 15 HDD for that day. All days with a heating load are summed up to derive total HDDs for the season that have large variations based on climate.
	Heating load	The heating load represents the energy required to maintain interior conditions at a thermally comfortable temperature. While actual interior temperature set points vary significantly from building to building, designers use standard design conditions and expected climatic conditions along with building envelope characteristics to properly size mechanical equipment. This does not represent the energy to run mechanical equipment, which is based on equipment efficiency. The heating load can also be met through harvesting passive heating contributions.
I	Indirect emissions	Indirect emissions generally refer to emissions that are attributed to electricity generation at central power plant or at co-generation plant. They also can refer to emissions produced in power and industrial processes used for district heating and cooling networks.

M	Modern biomass	Modern biomass includes all biomass with the exception of traditional biomass.
N	Natural gas	It comprises gases, occurring in underground deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing hydrocarbons only in gaseous form, and "associated" gas produced in association with crude oil as well as methane recovered from coal mines (colliery gas).
O	Oil	Oil includes crude oil, condensates, natural gas liquids, refinery feedstocks and additives, other hydrocarbons (including emulsified oils, synthetic crude oil, mineral oils extracted from bituminous minerals such as oil share, bituminous sand and oils from coal liquefaction) and petroleum products (refinery gas, ethane, liquefied petroleum gases, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes and petroleum coke).
P	Purchasing power parity (PPP)	PPP is the rate of currency conversion that equalises the purchasing power of different currencies. It makes allowance for the differences in price levels and spending patterns between different countries.
R	Rebound effect	Rebound effect results in part from increased consumption of energy following the improvement in the efficiency of an energy-consuming product or service. For example, consumers may set thermostats to a higher, more comfortable temperature in response to savings gained from reduced annual heating expenses from a major building refurbishment, such as a more efficient boiler or better insulated windows and walls.
	Renewable	Renewable includes biomass and waste, geothermal, hydropower, solar photovoltaic, concentrating solar power, wind and marine (tide and wave) energy for electricity and heat generation.
	Residential sub-sector	The residential sub-sector includes those activities related to private dwellings. It covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances. It does not include energy use for personal transport, which is covered in the transportation sector.
S	Seasonal performance factor (SPF)	SPF is used to measure the efficiency of heat pumps with regards to operational performance over the season, where the seasonally averaged coefficient of performance (COP) is calculated as the ratio of energy output (delivered heat) over the total energy supplied during the season.
	Service equipment	Includes a wide variety of energy consuming equipment that is found in the services sub-sector, such as fork lifts, medical equipment, office equipment and cooking devices.
	Services sub-sector	The services sub-sector includes activities related to trade, finance, real estate, public administration, health, food and lodging, education and commercial services (International Standard Industrial Codes revision 4.0 33 to 99). This is also referred to as the commercial and public service sector. It covers energy used for space heating, cooling and ventilation, water heating, lighting and in a number of other

		miscellaneous energy-using equipment, such as commercial appliances and cooking devices, x-ray machines, office equipment and generators. Energy use for transportation or for commercial transport fleets is excluded from the services sub-sector.
T	Thermally-broken frame	A thermally-broken frame applies to metal window framing that has been used in many applications but is still needed in high structural applications, such as high-rise buildings with high wind loading. These frames have a low conductive strip of material that disrupts the heat flow through highly conductive materials while still maintaining structural integrity.
	Total final consumption (TFC)	TFC is the sum of consumption by the different end-use sectors. TFC is broken down into energy demand in the following sectors: industry (including manufacturing and mining), transport, buildings (including residential and services) and other (including agriculture and non-energy use). The final consumption of the transport sector includes international marine and aviation bunkers.
	Traditional biomass	Traditional biomass refers to the use of fuel wood, charcoal, animal dung and agricultural residues in stoves or heating devices with very low efficiencies.
U	U-value	It is a measure of the rate at which heat passes through a component or structure when a temperature difference is maintained across the material. Its measurement involves difficult concepts and techniques, and includes conduction, convection and radiation losses. R-value for all practical purposes is the inverse of the U-value. Lower U-values allow less heat loss than higher U-values.
	Useful energy	Useful energy is equal to the delivered (input) energy minus losses for boilers, furnaces, water heaters and other equipment. It is used to provide an estimate of service (*e.g.* thermal heat or lighting output) for a given activity or space in buildings.
V	Value-added	Value-added is an output approach of measuring GDP. It can be measured either gross or net, that is, before or after deducting consumption of fixed capital.

Regional and country groupings

ASEAN (Association of the Southeast Asian Nations)	Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.
China	refers to the People's Republic of China, including Hong Kong.
OECD	Includes OECD Americas, OECD Asia and Oceania and OECD Europe regional groupings.
OECD Americas	Canada, Chile, Mexico and the United States.
OECD Asia and Oceania	Includes OECD Asia, comprising Japan, Korea and Israel, and OECD Oceania comprising Australia and New Zealand.

OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.
European Union (27)	Austria, Belgium, Bulgaria, Cyprus,[2] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and United Kingdom.
Non-OECD	Includes Non-OECD Asia, non-OECD Europe and Eurasia, Middle East, Africa and non-OECD Latin America regional groupings.
Non-OECD Asia	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Chinese Taipei, Cook Islands, Democratic People's Republic of Korea, East Timor, Fiji, French Polynesia, Hong Kong, India, Indonesia, Kiribati, Laos, Macau, Malaysia, Maldives, Mongolia, Nepal, New Caledonia, Pakistan, Papua New Guinea, People's Republic of China, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu and Vietnam.
Non-OECD Europe and Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Former Yugoslav Republic of Macedonia, Republic of Moldova, Romania, Russian Federation, Serbia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan. For statistical reasons, this region also includes Cyprus,[3] Gibraltar and Malta.
Middle East	Bahrain, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen.
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.
Non-OECD Latin America	Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, British Virgin Islands, Cayman Islands, Brazil, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, Saint-Pierre et Miquelon, Saint Kitts and Nevis, Staint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay and Venezuela.
Other developing Asia	Non-OECD Asia regional grouping excluding China and India.

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[2] 1. Footnote by Turkey
The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus issue".
2. Footnote by all the European Union Member States of the OECD and the European Union
The Republic of Cyprus is recognized by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[3] *Ibid.*

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Annexes

Annex A · Analytical Framework

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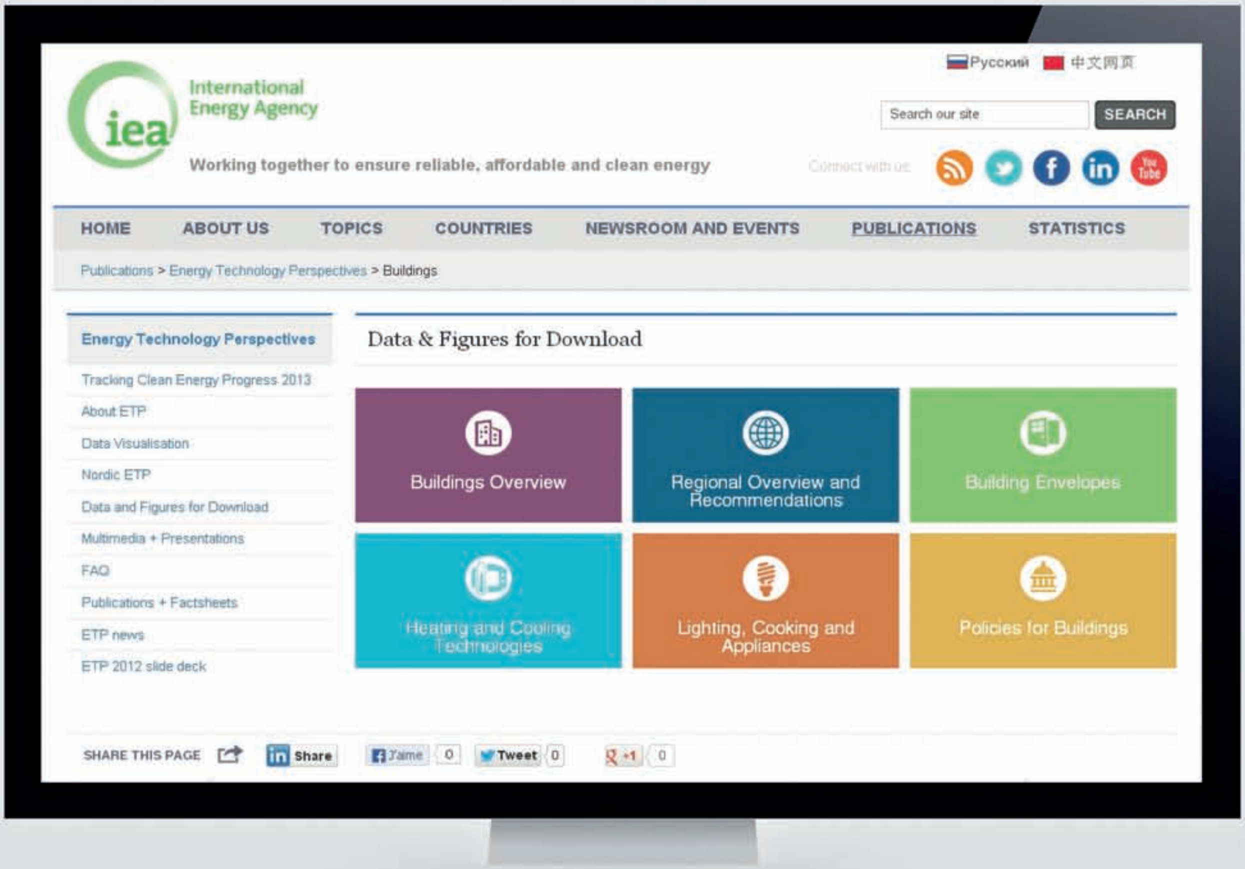

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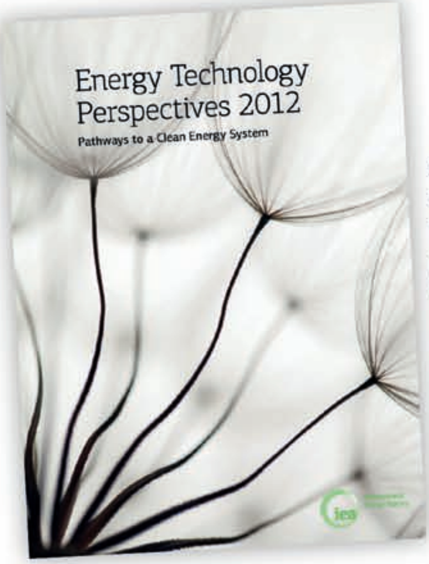

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Building Envelope Technology Roadmap (released late 2013). The *Technology Roadmaps* identify actions for governments, industry, financial partners and civil society that could advance technology developments described in the *ETP 2012 2DS*. As of June 2013, 18 global roadmaps have been published, covering a wide range of energy demand and supply technologies, including solar heating and cooling, geothermal heat and power, smart grids and energy efficient buildings: heating and cooling equipment.

The ***Policy Pathway on Building Energy Codes*** (released fall 2013) is an IEA-UNDP joint publication that provides policy makers the pathway to effective and successful implementation of building energy codes. The pathway includes four phases (plan, implement, monitor and evaluate) with a series of steps and actions for governments to follow. The choice and sequencing of those steps and actions will vary depending on current development of building energy codes in each country.

Tracking Clean Energy Progress 2013, released in April 2013, examines progress in the development and deployment of key clean energy technologies. Each technology and sector is tracked against interim 2020 targets in the *ETP 2012* 2DS, which lays out pathways to a sustainable energy system in 2050.

Nordic Energy Technology Perspectives, released in January 2013, assesses pathways and key challenges to a carbon-neutral energy system in the Nordic region. Other countries seeking to radically transform their energy system should take note.

For more information, please visit www.iea.org/etp

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