Chapter 4: Sustainable Buildings in the Urban Environment

The buildings sector will play an important role in achieving substantial energy and emissions reductions to 2050. This will need to be reconciled with rapid expansion of the global built environment and ownership of energy-consuming equipment, especially in developing countries. Urban areas offer a key opportunity to tackle building energy efficiency head-on and to realise low-carbon, integrated energy communities.

Key findings

- **Urban buildings accounted for roughly 62% of total buildings energy consumption in 2013, or nearly 3/4 of buildings energy use when traditional biomass and other biofuels are excluded.** They are expected to account for more than 70% of total buildings energy use by 2050 under both the 6DS and 2DS as the world continues to urbanise.
- **More than half of buildings sector floor area growth is expected in urban areas in developing countries.** Prescriptive policies on building energy codes for new buildings in urban areas will be critical to achieving buildings sector energy and emissions objectives to 2050.
- **Urban buildings energy consumption under the 6DS would grow by as much as 70% over 2013 levels, reaching 132 exajoules (EJ) in 2050.** Urban carbon dioxide (CO_2) emissions would increase from 7 gigatonnes of CO_2 equivalent ($GtCO_2$) in 2013 to nearly 12 $GtCO_2$ in 2050. Roughly 85% of urban buildings CO_2 emissions would come from upstream power generation in 2050 (compared to 75% today), showing the significant influence of continued growth in urban electricity demand.
- **Space heating and cooling continue to be a critical area of needed action in the buildings sector.** Space heating accounts for more than 1/3 of global buildings energy use and will continue to be the largest building end-use to 2050 in both the 6DS and 2DS. Space cooling, while a significantly smaller portion of energy demand in buildings today (roughly 5%), is the fastest growing end-use and could increase by as much as ten-fold in some regions if concerted effort is not made to improve building envelope efficiencies.
- **Cities have several key enabling characteristics to reduce space heating and cooling demand.** This includes local influence over building regulatory, planning and zoning functions as well the possibility to connect to efficient, low-carbon or zero-carbon district energy networks.
- **If aggressive building energy efficiency policies are pursued in line with the 2DS, urban buildings energy consumption could be reduced by 30% in 2050 compared to the 6DS.** Annual buildings sector CO_2 emissions (direct) would be reduced by over 50% compared to 6DS levels.
- **The greatest direct emissions savings in urban buildings under the 2DS are achieved in space heating and cooling (60%), followed by water heating (22%).** Efficient appliances and miscellaneous equipment account for roughly 40% of total (direct and indirect) emissions reductions and will help to decarbonise the power sector through lowered electricity demand.
- **High-efficiency new buildings, deep energy renovations of existing buildings and low-carbon, energy efficient heating and cooling technologies are the most important levers to reduce emissions from buildings in urban areas.** Use of efficient district heating and cooling networks can also play a role in achieving low-carbon and even carbon-neutral communities.
- **While zero-energy buildings (ZEBs) and near-zero energy buildings (nZEBs) are technically feasible in cities, challenges (*e.g.*, high urban densities and limited on-site renewable potential) may limit their achievement in urban areas.** Cost-effective building efficiency and design measures, paired with low-carbon, high-efficiency heating and cooling supplies, will therefore be critical to achieving near-zero and net-zero emission communities in cities.

Opportunities for policy action

- Local planning and policy design, including more compact urban development, can play an important role in meeting targets related to energy efficiency in buildings. This includes local enforcement of mandatory construction and building renovation codes as well as design of targeted energy efficiency initiatives to engage local consumers and building stakeholders.
- National policies have substantial leverage to enable effectiveness of urban sustainable energy planning through the setting of minimum performance standards for building codes, appliances and equipment. National land use planning frameworks, fiscal policies and capacity building programmes can also serve to enable local decision makers to pursue appropriate urban planning and energy efficiency measures.
- In emerging markets, new construction in cities offers a unique opportunity to address increasing energy demand through energy efficiency measures, building design and urban planning. National support to provide training and capacity tools to city authorities and building stakeholders is a key first step to enabling local building energy efficiency action.
- In mature economies, urban densification and deep energy renovation of existing buildings can reduce the energy footprint of the buildings sector. This will require appropriate financial and regulatory tools as well as market conditioning to enable widespread adoption of deep energy efficiency measures.
- Both national and local governments can support local energy efficiency action in buildings by promoting advanced building components and energy efficient technologies through appropriate pilot programmes and financial incentives to help establish local market demand. Packaging of efficiency measures is another way to increase awareness and adoption of energy efficient building technologies.
- With national support, city governments can lead on deep energy renovation in public buildings. Local energy efficiency programmes and incentives (*e.g.*, low-interest loans, tax rebates and zoning or planning exemptions) can also support deep energy renovations in the private sector over the coming decade to ensure that the process becomes widely available and is standard practice.
- The integration of modern district energy networks and energy efficient buildings can be a valuable opportunity to achieve cost-effective and efficient, low-carbon communities in dense urban areas. It will require greater coordination and financial support among stakeholders to create a long-term stable market environment that incentivises energy efficiency and that rewards flexibility.

This chapter outlines the rationale and strategic opportunities for energy efficiency action in urban buildings with respect to 2DS objectives for a sustainable, low-carbon buildings sector. Because of the high segmentation and diversity of the global buildings stock, the following sections examine the key energy technology and policy priorities for urban buildings as well as policy actions needed to realise the anticipated energy and emissions reductions to 2050 under the 2DS. A particular focus has been paid to space heating and cooling demand in urban buildings, as urban areas offer both opportunities and challenges to achieving deep energy efficiency gains in the buildings stock. This includes three detailed case studies in Sweden, Italy and China that explore various cost-effective, integrated technology options for meeting low-carbon, energy efficient heat demand. Finally, the chapter considers market conditions and policy recommendations that are needed to put cities and the global buildings sector on a 2DS pathway.

The global buildings sector consumed more than 120 EJ in 2013, or over 30% of total final energy consumption[1] for all sectors of the economy. Nearly three-quarters of that was consumed in the residential sub-sector alone[2]. Buildings also accounted for half of global electricity demand, with electricity consumption increasing by more than 500% in some regions since 1990. When upstream power generation is taken into account, the buildings sector represents slightly less than one-third of global CO_2 emissions.

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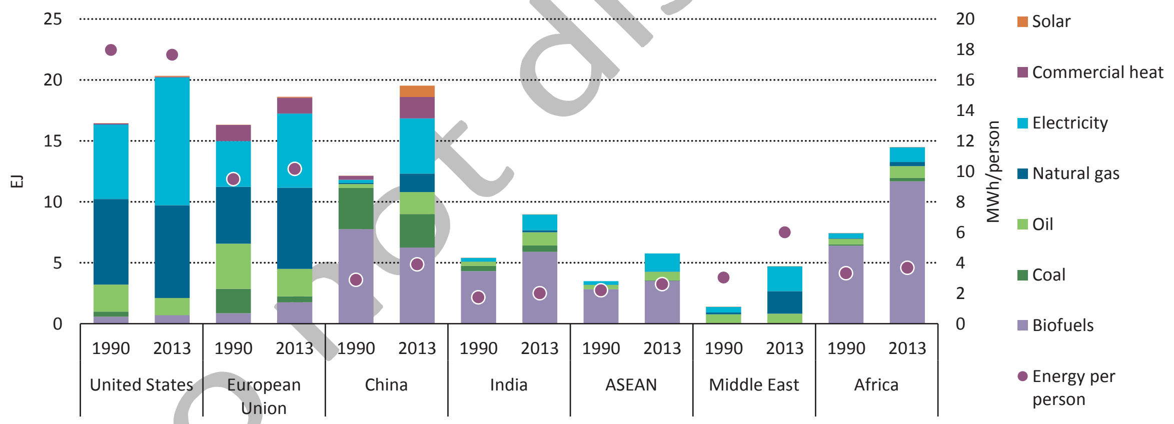
[1] Energy consumption hereto refers to final energy use, unless otherwise noted.

[2] See Chapter 1 on the Global Outlook for additional details on global buildings energy consumption.

Space heating and cooling demand continue to be a critical area of needed action in the buildings sector, where space heating currently accounts for more than one-third of global energy use in buildings and will continue to be the single largest energy consuming end-use to 2050 in both the 6DS and 2DS. Space cooling, while a significantly smaller portion (roughly 5%) of energy demand in buildings today, is the fastest growing end-use in buildings and could increase by as much as 800% to 2050 in some hot, rapidly emerging economies (*e.g.*, Mexico and India). Concerted effort is therefore needed to improve building envelope efficiencies and to reduce growing global demand for conditioned (mechanical) thermal comfort.

Globally, building energy performance (as measured by energy per floor area) has improved since 1990 – from an annual average of more than 200 kilowatt-hours (kWh) per square metre (m^2) in 1990 to roughly 160 kWh/m^2 in 2013 – as development and enforcement of building codes and energy efficiency policies have helped to offset growth in total energy consumption. However, the simultaneous effect of growing global wealth, which typically corresponds to demand for larger spaces (*i.e.* greater m^2 per person), smaller household[3] size (*i.e.* fewer persons per household) and increased demand for energy services and comfort, has offset many of those efficiency gains. As a result, overall buildings energy consumption on a per capita level has remained practically constant at five megawatt-hours (MWh) per person per annum since 1990. Some countries, such as the United States, Sweden and France, have been able to reduce energy consumption per person through aggressive building policies, but most countries have not decoupled buildings energy use from population growth (Figure 4.1). In many developing regions, and even in some developed countries, energy use per person has increased since 1990.

Figure 4.1 • Buildings energy consumption and intensity per person in select regions, 1990-2013



Note: ASEAN = Association of Southeast Asian Nations; China refers to the People's Republic of China.

Source: Population: UN DESA (2013), *World Population Prospects: The 2013 Revision, Medium-Fertility Variant*, United Nations Department of Economic and Social Affairs, Population Division, New York; calculations derived with IEA (2015a), "World energy balances", *IEA World Energy Statistics and Balances* (database).

Key point • Significant effort is still needed to decouple population growth and buildings energy use in most regions in order meet 2DS energy and emissions targets by 2050.

Urbanisation has also played a strong role in buildings energy trends since 1990. In developing countries, urbanisation is typically associated with increased access to and use of energy services, less use of biofuels (*e.g.*, traditional solid biomass and dung) for water heating and cooking, and increased use of electricity. Globally, traditional biomass and other biofuels consumption in the buildings sector decreased from roughly 1.4 MWh per person in 1990 to slightly above 1.3 MWh per person in 2013, while average electricity consumption per person increased by more than 65% to 1.5 MWh per person during the same period (Figure 4.2). In rapidly emerging economies,

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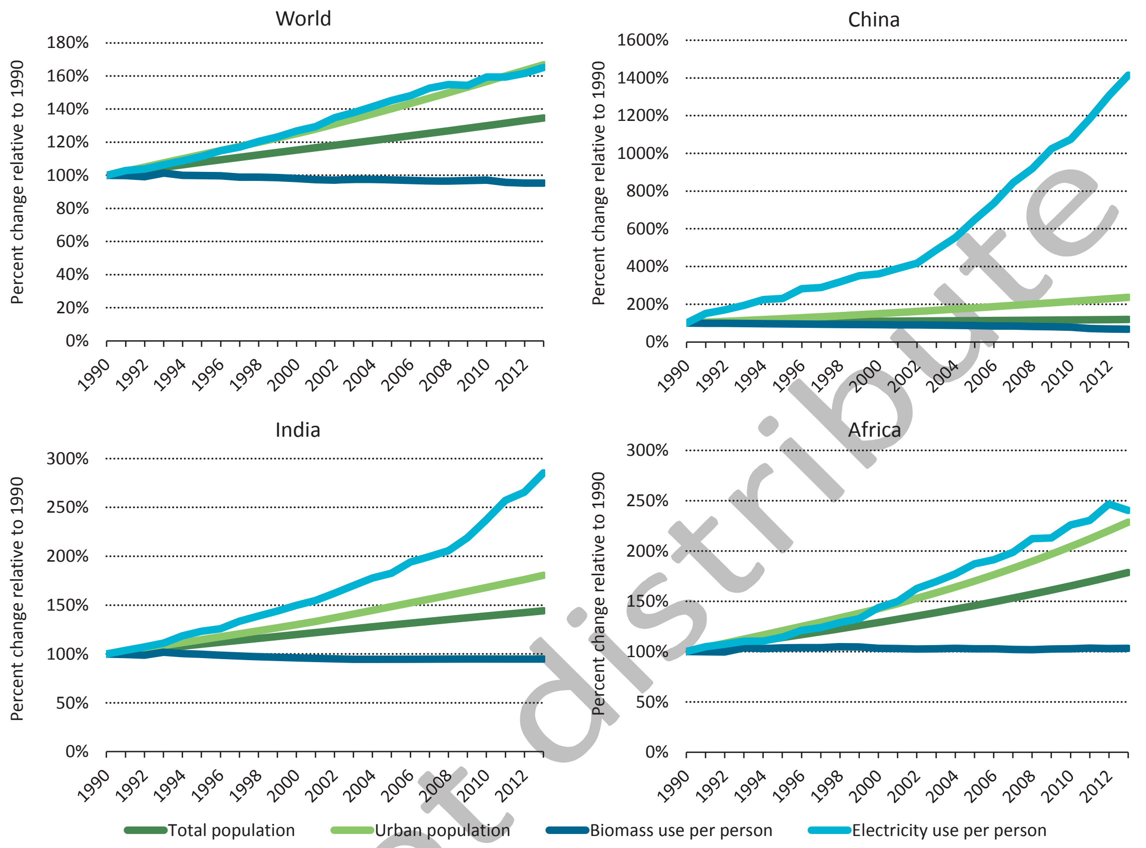
[3] The terms household and dwelling are used interchangeably in this chapter.

such as the People's Republic of China[4], India and Indonesia, electricity use per capita increased as much as three-fold (India) to fourteen-fold (China) since 1990, whilst annual biomass consumption per person decreased slightly in each country during the same period.

Figure 4.2 • Population, biomass and electricity use per person in buildings for select regions, 1990-2013



Note: The graph does not provide information on the relative contributions of various drivers to building energy use, but rather shows various trends for building energy use relative to population growth.

Source: Population: UN DESA (2013), *World Population Prospects: The 2013 Revision, Medium-Fertility Variant*, United Nations Department of Economic and Social Affairs, Population Division, New York; UN DESA (2014), *World Urbanisation Prospects: The 2014 Revision*, United Nations Department of Economic and Social Affairs, Population Division, New York calculations derived with IEA (2015a), "World energy balances", *IEA World Energy Statistics and Balances* (database).

Key point • Globally, electricity growth in the buildings sector has been strongly tied to urbanisation, as urbanisation in developing regions has contributed to increased wealth and greater access to electricity.

Several key energy policy measures can act together to decouple continued global population growth, increasing wealth and expected urbanisation trends with aggregated buildings energy consumption. These measures include: prescriptive and enforceable building codes for new construction, especially in rapidly emerging markets where there is a window of opportunity to address future buildings energy demand as new buildings are constructed; improved codes and/or mandatory energy performance standards for existing buildings when they undergo renovations; appliance standards and labelling; whole-building rating, labelling and disclosure programmes; educational programmes and capacity building; and improved data availability and quality to inform policy design and implementation (IPEEC, 2014; IEA, 2013a)[5].

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[4] The People's Republic of China is hereafter referred to as China.

[5] Further information can be found in the IEA Policy Pathways on *Energy Performance Certification of Buildings* (IEA, 2010a), *Monitoring, Verification and Enforcement* (IEA, 2010b) and *Modernising Building Energy Codes* (IEA, 2013c).

While many buildings sector energy policies and technology priorities are set on the national scale, cities will still play an important role in meeting 2DS objectives to 2050. As a policy bridge from national to local buildings stakeholders, municipal authorities play the important roles of implementing, monitoring and enforcing building energy policies. This includes in particular building construction codes and renovation standards, which are critical to addressing space heating and cooling energy use for thermal comfort in buildings.

Cities are also often at the forefront of building energy efficiency, with some cities going beyond national energy policy measures and implementing innovative policy responses and programmes in response to energy and sustainability objectives (Box 4.1). As the home to half the world's population, urban areas tend to be the first places to adopt new building technologies, from energy efficient lighting and appliances to advanced district heat networks with integrated renewable energy. Greater support of local energy efficiency action, including the right policy and market measures to value flexibility and innovation in urban buildings, can therefore help to maximise energy efficiency potential in the buildings sector.

Box 4.1 • C40 cities: leading by example

The C40 Cities Climate Leadership Group was established in 2005 as a global network of large cities taking action to address climate change by developing and implementing policies and programmes that lead to measurable reductions in greenhouse gas emissions and climate risks through knowledge sharing of effective energy efficiency, planning and urban development measures. The C40 network now consists of more than 75 megacities, representing more than 550 million people and roughly 25% of global gross domestic product (GDP), that have undertaken more than 8 000 actions since 2005 to reduce urban emissions and climate risks.

Among the various actions that C40 cities have implemented are several building performance measures to promote energy-efficient building designs and regulations that will facilitate an improved buildings market where energy efficiency is valued. In some cases, this has included policy measures to reduce energy consumption and emissions in municipal buildings, which account for an estimated one-third of C40 cities' buildings energy consumption. For instance, Paris, France has committed to reducing energy consumption and CO_2 emissions in municipal buildings by 30% by 2020, compared to 2004 levels, including deep renovations of 600 public schools to reach a target of 65 gigawatt-hours of energy savings per year. Buenos Aires, Argentina similarly initiated the Energy Efficiency in Public Buildings Programme to reduce energy consumption in public buildings by 20% between 2009 and 2015, and Dubai in the United Arab Emirates introduced a buildings renovation programme to refurbish 30 000 buildings by 2030, starting first with very high energy consuming government buildings.

Other cities have introduced broader public programmes to address energy efficiency across the entire local buildings stock, including both voluntary and mandatory building codes. For example, Jakarta, Indonesia initiated a green building code in 2012 that requires energy efficiency measures for both new and existing buildings of a certain size. Melbourne, Australia similarly implemented a series of both voluntary and mandatory building codes to support its target of being a carbon neutral city by 2020. This includes the 1 200 Buildings Program, which provides funding support to owners of commercial and non-residential buildings who commit to achieve at least a 38% reduction improvement in energy efficiency.

Not all cities have the same mayoral or municipal authorities, but the C40 network is helping cities to exchange information and share experiences that are supporting cities to lead on improving building energy efficiency. This includes the C40 Municipal Building Efficiency network that was launched in 2014 to identify technologies and energy efficiency financing mechanisms for public buildings. Similar networks were also created to address private building energy efficiency and district energy systems.

To date, more than 1 650 actions have been taken by C40 cities to address energy efficiency and emissions reduction in the buildings sector (C40-ARUP, 2014). More information can be found online at www.c40.org.

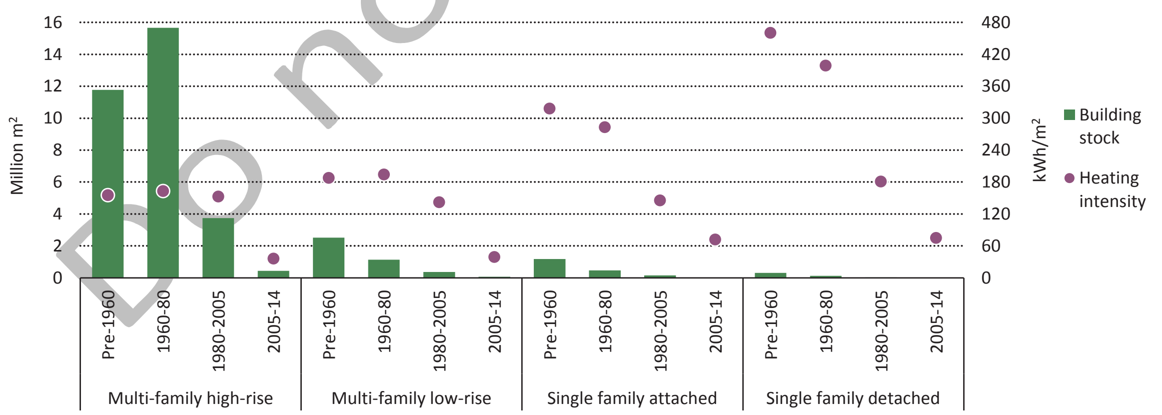
Urban building variability and segmentation for action

The global buildings sector is highly diverse, although several key buildings types exist in most urban areas. In the residential sub-sector, dense urban centres typically have multi-storey (*i.e.* greater than three storeys), multi-family buildings, while lower density urban areas and peri-urban (suburban) areas more often have multi-family low-rise and single family homes. Each can have very different performance in both heating and cooling conditions depending on local climate, building type, vintage and material choice, while core energy loads for refrigeration, water heating, cooking and cleaning are typically tied more closely to the number of occupants.

Commercial and services sub-sector building types can similarly have large differences in energy consumption and performance intensities depending on the building type and purpose. The food service industry, hospitality industry, hospitals, shopping centres and office buildings with large glass facades often have high energy intensities, whereas warehouses, libraries, schools and general office buildings often have more moderate intensities. Building design – for example, the choice of inoperable windows with mechanical heating, cooling and ventilation (HVAC) systems – and operations can also significantly impact building energy demand. Some modern buildings, even with advanced, energy efficient technologies, can actually have very high energy intensities due to design and operations when compared to older, more traditional buildings (IEA-TU, 2015).

Conducting more detailed analyses of building types and intensities, urban planners and policy makers can prioritise various building stock segmentations for policy intervention (*i.e.* identifying market segments for large energy savings potential and critical buildings of concern). For example, in Torino, Italy, there are a few buildings segments that represent very large portions of city's residential building stock and energy consumption (Figure 4.3)[6]. Multi-family, high-rise buildings constructed prior to 1980 account for more than 70% of total residential floor area and roughly 70% of total energy consumption for space heating[7]. They also have an average space heating energy intensity above 150 kWh/m². Addressing deep renovations and energy efficiency measures in these buildings would therefore offer substantial energy savings.

Figure 4.3 • Building stock segmentation and priority areas in Torino, Italy



Source: Delmastro, C. et al. (2016), "Scaling up the cost-optimal methodology for selecting long-term energy renovation policies at the urban scale," Energy Policy, forthcoming.

Key point • Data collection and analysis can help to identify key buildings market segmentations that can be used to prioritise policy action and programme development in support of large energy savings.

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[6] Residential buildings account for roughly 46% of the total number of buildings and more than one-third of total final energy consumption in Torino (Politecnico di Tornio, 2015).

[7] Space heating accounted for more than 70% of residential energy consumption in 2014 (Politecnico di Tornio, 2015).

Global urbanisation to 2050 is likely to have important implications on building stock variations and energy consumption patterns. In developed countries, migration from rural or suburban areas (typically single family homes) to denser urban areas (often attached or multi-family dwellings) could result in significant reductions in building energy consumption, as single family homes often have much higher energy footprints per household or per person than multi-family dwellings (Table 4.1). This is partly due to larger floor areas in single family homes as well as to greater exterior surface area per dwelling (often referred to as the shape factor), both of which play an important role in household space heating demand. Conversely, urban multi-family buildings can be more energy intensive for cooling loads (as they are denser with more people and equipment per unit of floor area) and can have greater internal heat gain than a single family house. However, as heating loads are generally far more intensive in cold regions than cooling loads in warmer regions, the net effect is that urbanisation (and urban densification) in many developed countries will have a positive effect on overall thermal loads and energy consumption for space heating and cooling.

Table 4.1 Typical urban and non-urban household characteristics and energy intensities, select countries

	United States		Sweden		China		India	
	Multi-family*	Single family*	Multi-family*	Single family*	Urban (average)	Rural (average)	Urban (average)	Rural (average)
Persons per household	1.9-2.3	2.5-2.8	1-2.3	1.6-2.6	2.8	3.9	4.6	4.9
Floor area per household (m^2)	79-102	101-231	45-84	146-250	75.5	144.2	54	54
Energy use (MWh/household)	14-22	20-31	11-14	19-30	6.6	15.9	7.9	9.2
Electricity use (MWh/household)	*6.4-7.2*	*9.1-13.5*	*2.0-4.6*	*4.7-23*[8]	*2.2*	*1.0*	*1.4*	*0.7*
Energy use (kWh/m^2)[9]	177-215	134-197	115-156	88-140	87.7	110.4	146.3	170.4
Energy use (MWh/person)	7-10	8-11	7-9.5	6.5-10	2.3	4.1	1.7	1.9

Notes: Energy intensities can vary significantly across residential building types, design and location and because of occupant behaviours. Typical energy consumption is reported as final energy. *Single family and multi-family households are not explicitly urban or rural, although multi-family residential buildings are more likely to be in urban areas than suburban or rural. Single family households in the United States and Sweden are also more likely to be suburban or rural than urban.

Source: United States: US DOE (2014), *Buildings Energy Data Book*, US Department of Energy, Washington, and US EIA (2009), *Residential Energy Consumption Survey*, US Energy Information Administration, Washington, elaborated by IEA; Sweden: SEA (2013a), *Energistatistik för flerbostadshus 2012*, Swedish Energy Agency, Eskilstuna, and SEA (2013b), *Energistatistik för småhus 2012*, Swedish Energy Agency, Eskilstuna, elaborated by IEA; China: TU (2014), *2014 Annual Report on China Building Energy Efficiency*, Tsinghua University Building Energy Research Center, Beijing, elaborated by IEA; India (2014): Government of India (2012), *Census of India 2011*, Ministry of Home Affairs, elaborated by IEA.

In emerging markets and developing countries, urbanisation is likely to have a mixed effect on energy consumption and intensities in buildings in the coming decades, due to the various effects of rural-to-urban migration on energy demand and fuel choice. Traditional biomass consumption in rural areas (and even some urban areas) is still very common in many developing countries, and while rural households may have limited or no access to modern energy services and

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[8] Note: Geothermal heat pumps are increasingly common in single family households in Sweden and can considerably increase household electricity consumption, as space heating is the largest end-use in residential buildings.

[9] Note: Total household energy use per m^2 does not accurately represent the effect of energy intensity differences in single and multi-family homes, as water heating, cooking, appliances and other plug-load energy uses are typically tied to household occupancy rather than floor area.

amenities (*e.g.*, electricity networks and appliance ownership), the overall energy intensity of biomass consumption (*e.g.*, for water heating and cooking) is nevertheless very high compared to the same activities performed using modern commercial fuels. Urbanisation, and increased access to energy networks and commercial fuels, is consequently likely to have an initial effect of reducing overall energy intensity of household energy demand as rural populations initially shift away from traditional biomass use.

At the same time, urbanisation, access to energy networks and the effect of increasing wealth will all drive household demand for additional energy services and activity. For instance, urban households often use more lighting (in terms of hourly usage and lumens per m^2) compared to rural households in developing countries, as energy costs are typically a much smaller fraction of urban household income. Space heating and cooling (in terms of set temperature) and hot water usage also typically increase with urbanisation in developing countries, as households have greater purchasing power and can afford greater comfort. Appliance ownership and usage similarly increase in urban areas. Urban household energy intensities – in terms of use of modern commercial fuels – therefore are usually significantly higher than in rural households.

The net effect of urbanisation in developing countries – accounting for changes in energy behaviour, household purchasing power and shifts from traditional biomass to modern commercial fuels – will have a critical impact on buildings sector energy use and intensities as household demand for services and comfort in emerging markets continues to approach levels similar to developed countries. While rural-to-urban policy development goes beyond core buildings issues, policies that target high-efficiency building construction, efficient consumer choices and energy behaviour can also help to meet related development objectives (*e.g.*, economic prosperity and improved health), as energy efficiency measures can have numerous multiple benefits to society[10].

Global urban buildings energy demand

In order to assess the contribution of urban buildings energy demand and efficiency potential, urban buildings energy consumption has been estimated across the residential and services sub-sectors and the major end-uses (space heating and cooling, water heating, lighting, cooking, appliances and other equipment). The high diversity and variability of the global buildings stock – along with the considerable need for improved data on building energy characteristics and performances across countries, regions and urban/non-urban divides – makes it difficult to assess accurately urban building energy consumption. Urban boundary definitions (*i.e.* what is considered urban, peri-urban and rural) also make it difficult to distinguish global urban building energy consumption, as country definitions vary considerably (see Chapter 3) and as building types and energy consumption patterns can vary significantly across different urban forms. A general modelling methodology was therefore developed to distribute energy consumption by end-use and fuel type to urban and non-urban buildings.[11]

Key urban building drivers

Historically, several factors have been the key drivers of energy demand in the buildings sector, including population, economic activity (as expressed by GDP), building sector size (*e.g.*, floor are and number of households), building energy policies and other factors, such as climate and

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[10] Additional information on the benefits of energy efficiency measures can be found in the IEA publication on *Capturing the Multiple Benefits of Energy Efficiency* (IEA, 2015c).

[11] Additional information on the assumptions and process used to estimate global urban building energy can be found in the methodology annex.

energy prices (IEA-IPEEC, 2015). The extent to which each driver contributes to buildings energy consumption differs from country to country, within countries, and across variations in social, economic, geographic and demographic characteristics.

The global buildings stock accounted for an estimated 210 billion m^2 in 2013, of which more than 80% was residential floor area across as many as 2 billion households. Urban buildings accounted for an estimated 126 million m^2 (or nearly 60% of global buildings floor area), including nearly 31 billion m^2 of floor area in the services sub-sector (83% of total services floor area) and 1.2 billion households (60% of the global total).

By 2050, urban buildings floor area (residential and services) is expected to double to 254 billion m^2, with more than 75% of expected growth coming from non-member countries of the Organisation of Economic Co-operation and Development (OECD) (Table 4.2). This is largely driven by urbanisation in non-OECD countries (with total urban population nearly doubling in those countries), and also because of expected increases in average dwelling size as household incomes in urban areas continue to rise. Services floor area in non-OECD countries likewise doubles between 2013 and 2050. In OECD member countries, urban floor area increases by 50% over 2013 levels. This is partly due to continued urbanisation as well as to continued growth of urban services activity (with services floor area in those countries growing 55% between 2013 and 2050).

Table 4.2 Drivers for energy consumption in urban buildings to 2050, OECD and non-OECD

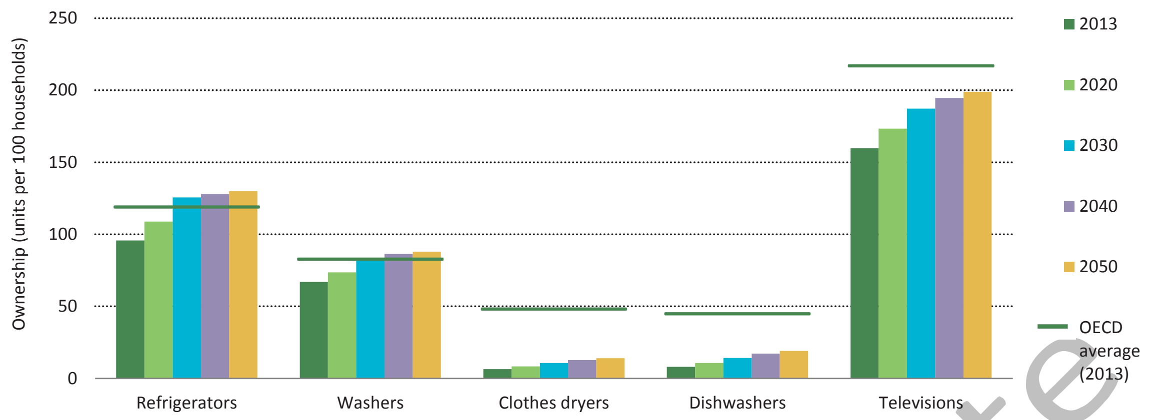
	OECD			**Non-OECD**		
	2013	**2030**	**2050**	**2013**	**2030**	**2050**
Urban population (billion)	1 009.4	1 139.5	1 237.1	2 754.5	3 871	5 041.7
Urban GDP (billion USD)	41 642	60 599	86 067	44 235	102 751	198 200
Households (million)	390.7	452.8	494.3	810	1 266.3	1 736.7
Occupancy (persons per household)	2.6	2.5	2.5	3.4	3.1	2.9
Average dwelling size (m^2)	152.5	165.7	179.2	82.1	91.5	95.1
Residential floor area (billion m^2)	40.9	51.2	59.6	54.4	98.3	141.9
Residential floor area per capita (m^2)	*58.7*	*66.3*	*71.7*	*24.1*	*29.5*	*32.8*
Services floor area (billion m^2)	18.7	23.8	29	12.1	17.6	23.3

Note: GDP expressed in 2014 USD at purchasing power parity (PPP); further description of buildings sector drivers for urban energy estimates can be found in the methodology annex.

Source: Population: UN DESA (2014), *World Urbanisation Prospects: The 2014 Revision,* United Nations Department of Economic and Social Affairs, Population Division, New York.

Urbanisation and increasing wealth in non-OECD countries will also contribute to a rapid growth in appliance ownership. In many developing countries, ownership levels for large appliances (*e.g.*, refrigerators and clothes washers) and other household plug-loads (*e.g.* computers and televisions) are still low, with significant potential for growth. For example, less than 8% of households in rural areas of India and only around 40% of urban households had a refrigerator in 2010 (Prayas, 2012). In China, less than 10% of urban households and practically no rural households owned a computer in 2000; by 2012, nearly 95% of urban households in China owned a computer, while still less than a quarter of rural households owned one (NBS, 2014). As household incomes continue to rise in non-OECD countries, especially in urban areas, appliance ownership levels are therefore likely to increase rapidly (Figure 4.4).

Figure 4.4 • Estimated urban ownership levels to 2050 in OECD non-member countries



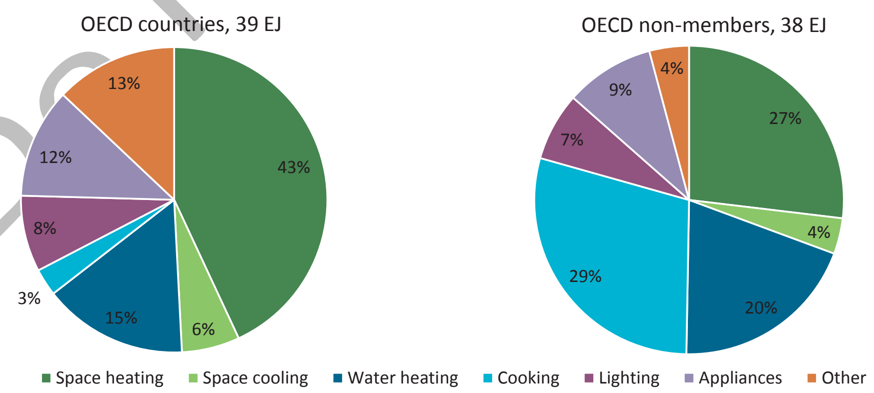
Note: Ownership levels vary considerably across non-OECD countries relative to household wealth (GDP per household).

Key point • Appliance sales to 2050 are expected to surge in urban areas in developing countries as household wealth and appliance ownership levels continue to increase.

Energy demand outlooks and opportunities to 2050

Total energy consumption in urban buildings accounted for an estimated 77 EJ in 2013, or slightly more than 60% of total buildings energy consumption that year. OECD non-member countries consumed nearly as much as OECD countries in urban areas, although there are stark differences in energy demand across the buildings end-uses (Figure 4.5). For instance, space heating energy use is roughly 60% greater in OECD countries, as OECD non-member countries are typically in far warmer climates with smaller heating loads. Conversely, water heating and cooking energy consumption is far more important in non-OECD regions, partly because of smaller space heating and (for the time being) smaller cooling loads and also because traditional biomass use, even in urban areas, is still considerable in many developing countries. When traditional biomass and other biofuels are excluded, global urban buildings accounted for nearly three-quarters of total buildings energy use in 2013.

Figure 4.5 • Urban building final energy estimates by end-use in OECD countries and non-members, 2013


OECD countries, 39 EJ

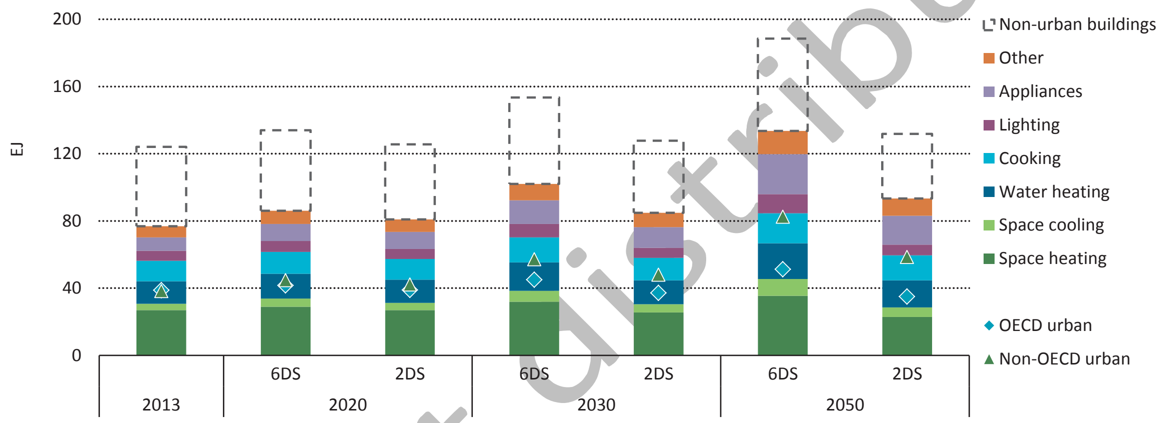
OECD non-members, 38 EJ

Key point • Globally, space heating demand in urban areas is the single-largest building end-use, while cooking and water heating are still a major share of energy demand in developing countries.

There are also stark contrasts in fuel shares and average urban building energy use per person across OECD and non-OECD regions, even as urban energy demand in developing countries continues to grow at a rapid pace. In OECD countries, electricity and natural gas accounted for more than 80% of urban buildings energy consumption in 2013, and average urban buildings energy use per person (including both the residential and services sub-sectors) was roughly 11 MWh per person. By contrast, electricity and natural gas use in non-OECD countries only accounted for 40% of urban buildings energy use, while biomass consumption was nearly 30%. Energy use per capita was still less than 5 MWh per person, although some of this can be explained by differences in building energy requirements (*e.g.*, less space heating needs).

Under the 6DS, total energy consumption in urban buildings reaches 132 EJ in 2050 (roughly 70% of total buildings energy consumption in 2050), meaning that 85% of expected energy growth in global buildings is likely to occur in urban areas. Urban buildings energy consumption in 2050 under the 6DS more than doubles over 2013 levels in non-OECD countries as demand for energy services and comfort continue to increase along with urban population growth. By contrast, urban buildings energy use in OECD member countries continues to increase marginally by less than 1% per year to 2050 under the 6DS (Figure 4.6).

Figure 4.6 • Urban buildings energy consumption and savings scenarios to 2050 by end-use



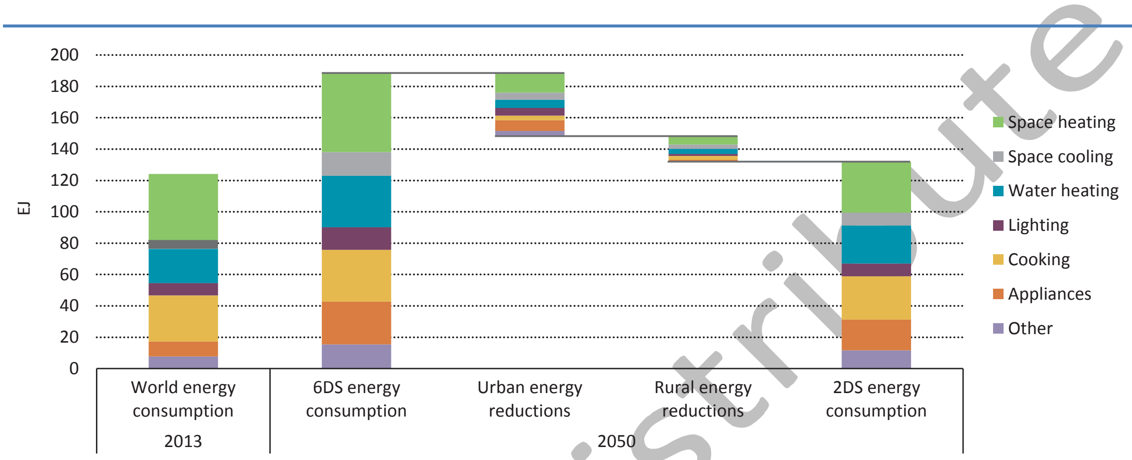
Key point • Urban buildings energy consumption could increase by as much as 70% over 2013 levels under the 6DS, with urban buildings energy demand more than doubling in non-OECD countries.

Growing household wealth, paired with continued growth in demand for comfort, contributes to significant growth in urban buildings space cooling energy consumption, which globally increases more than 2.5-fold over 2013 levels under the 6DS. In rapidly emerging, hot countries in non-OECD regions (*e.g.*, India, Indonesia and Mexico) urban space cooling demand increases as much as five- to ten-fold over 2013 levels by 2050. Global urban energy consumption for appliances and other small residential plug-loads (*e.g.*, computers and small electronic devices) similarly surges as household wealth and demand for energy services increases in non-OECD countries. Globally, urban appliances and other plug-load energy use grows by more than 180% over 2013 levels to 2050 in the 6DS, and nearly four-fold in non-OECD countries during the same period.

Under the 2DS, urban buildings energy consumption decreases by 30% compared to the 6DS, accounting for more than 70% of global buildings energy reductions to 2050 (Figure 4.7). Demand for energy services and comfort in developing countries continues to increase in both the 6DS and the 2DS, but prescriptive building codes for new construction along with energy efficiency and fuel switching measures help to meet that demand with lower overall energy consumption. As a result, total urban energy demand in non-OECD countries is 30% lower than the 6DS in 2050. In OECD countries, energy consumption is cut by a third in 2050 compared to the 6DS (or more than 10% lower compared to 2013), as deep energy renovations of existing buildings, paired with very low-energy new building construction and high-efficiency equipment purchases, reduce overall space heating and cooling demand.

Globally, urban space heating and space cooling demand under the 2DS are reduced by more than 35% compared to the 6DS, accounting for nearly 40% of total urban energy savings in 2050. Lighting and appliances energy use is reduced by 33% as a result of performance standards and increased uptake of high-efficiency products, and cooking is reduced by 15% through energy efficient equipment (*e.g.*, clean cook stoves) and greater shifts away from traditional biomass use (as energy efficiency savings allow for greater access to affordable electricity). Urban water heating energy use decreases by 25% in 2050 compared to the 6DS, due to both energy efficiency measures (*e.g.*, mandatory condensing boilers and increased sales of heat pump water heaters) and considerable growth of solar thermal collectors in both OECD and non-OECD countries.

Figure 4.7 • Global energy savings by end-use to 2050 (urban and non-urban buildings), 6DS to 2DS



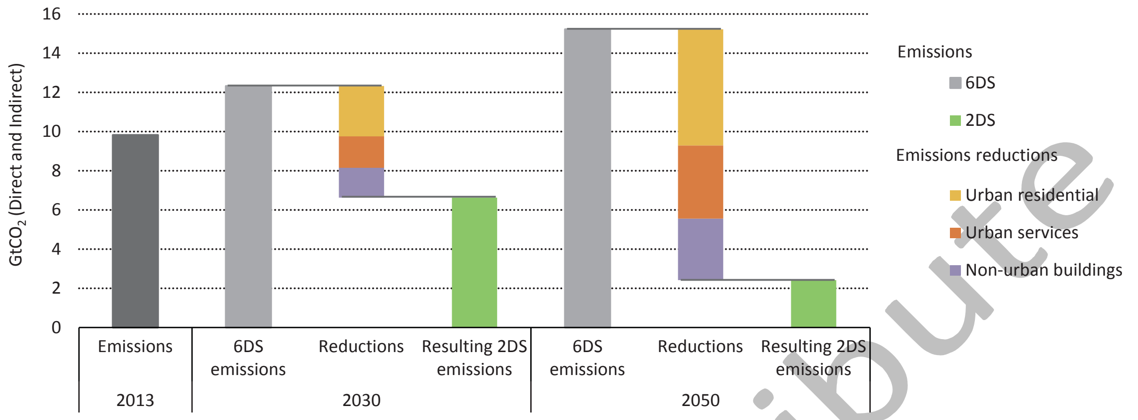
Key point • Urban buildings account for 70% of global buildings energy reductions in 2050, with space heating and cooling demand reductions accounting for roughly 40% of urban building energy savings.

Globally, total urban solar thermal consumption (for space heating and water heating) increases more than 650% over 2013 levels under the 2DS, while fossil fuel consumption (*i.e.* coal, oil and natural gas) in urban buildings decreases by 50% in 2050 compared to the 6DS. Overall electricity consumption in 2050 also decreases by 33% compared to the 6DS, both as a result of energy efficiency measures (*e.g.*, appliance and lighting standards) as well as the large uptake of efficient heat pump technologies for space heating, space cooling and water heating.

Urban building energy efficiency measures, including equipment efficiency and improvements in the thermal envelope of buildings, and fuel switching in the 2DS lead to an 85% reduction of total CO_2 emissions in urban buildings in 2050 compared to the 6DS. Direct emissions, from the combustion of fossil fuels, decrease by 50% in 2050 compared to the 6DS, while indirect emissions (from upstream generation of electricity and commercial heat) decrease by 93%. Nearly 60% of 2DS emissions reduction comes from the urban residential sub-sector, which also constitutes nearly half of total global buildings CO_2 emissions reduction to 2050. Overall, urban buildings (residential and services) account for more than three-quarters of total buildings sector emissions reduction to 2050 (Figure 4.8).

Urban buildings energy efficiency measures have considerable importance on global CO_2 emissions when the impact of buildings on power generation is considered. While the global buildings sector only constituted about 8% of (direct) energy sector related CO_2 emissions in 2013, more of half of global electricity and commercial heat went to buildings that year, making it responsible for roughly 7 $GtCO_2$ of upstream CO_2 emissions. Urban buildings are estimated to have accounted for nearly 80% of total buildings electricity and commercial heat consumption in 2013, and more than three-quarters of total global buildings electricity growth to 2050 is expected to come from urban residential and services buildings. Energy efficiency in urban areas therefore not only contributes to reducing overall buildings electricity and commercial heat demand but also plays an important role in supporting decarbonisation of the power sector, as improved efficiency and reduced buildings electricity and heat demand allow for an improved, more efficient, more resilient and lower carbon grid.

Figure 4.8 • CO_2 emissions reductions in urban buildings to 2050, 6DS to 2DS



Key point • Urban buildings CO_2 emissions decrease by 85% over 6DS levels in 2050 as a result of strong energy efficiency measures paired with decarbonisation of electricity and commercial heat production.

Energy efficiency and fuel switching in urban buildings can also contribute to improved living conditions (*e.g.*, improved thermal comfort) and better air quality in cities. While local pollution and quality of life are difficult to quantify within a global modelling framework, the continued use of fossil fuels and also traditional biomass consumption can have a considerable impact on local air quality. Many cities across the globe have identified local air quality as a major public health concern, and energy efficiency in buildings, paired with decline in buildings fossil fuel consumption, can contribute to reductions in local air pollution (Box 4.2).

Box 4.2 • Local air pollution and urban buildings in China

Air pollution in China's cities, notably from particulate matter (PM 10 and PM 2.5), is a serious issue that has been identified by the Chinese government as a priority area of concern. While industry and power generation (notably using coal) are the major sources of local air pollutants in most Chinese cities, the buildings sector is also largely responsible for local air quality, both because of direct consumption of coal and other fossil fuels and also because buildings in northern urban China consume considerable amounts of commercial heat from China's important district heating network, fuelled mostly by coal.

Buildings energy consumption and emissions have been highlighted as a key priority for the Chinese government, which recognised the important role of the buildings sector on air pollution prevention and control in its *Air Pollution Prevention and Control Act Plan* (State Council, 2013a). The plan put forward the goal of improving overall national air quality, including measures to proactively develop green buildings and district heat reform in urban China. Specifically, the plan considers detailed measures to: adopt green building standards in public buildings and indemnificatory housing (rent controlled or price controlled housing options provided by the government for low- and middle-income families); implement mandatory energy saving standards in new buildings; promote the utilisation of low-carbon, efficient technologies and equipment (*e.g.*, solar water heating, heat pumps, and building integrated solar photovoltaic); accelerate the push for heating metering and energy efficiency renovation in existing residential buildings in northern urban China; and accelerate the development and refurbishment of the district heat supply network.

Since 2013, the Chinese government has developed additional strategies in line with the *Air Pollution Prevention and Control Act Plan* and the broader *12th Five-Year Energy Development Plan* (State Council, 2013b), including the *Green Building Action Plan* (State Council, 2013c) and the 2014 *National Plan on New Urbanisation for 2014 to 2020* (State Council, 2014), which both set forth goals for reducing energy consumption and emissions from the buildings sector (IEA-TU, 2015).

Energy technology priorities, policies and benefits for urban buildings

The energy savings potential in urban buildings is enormous. While most building technologies and policies to achieve more efficient buildings are not unique to urban environments, there are numerous technology solutions that are available today that can significantly reduce urban buildings energy consumption. This includes advanced lighting solutions (*e.g.*, light emitting diodes [LEDs]), water heating technologies (*e.g.*, instantaneous condensing gas water heaters, heat pump water heaters and solar thermal collectors), and advanced building materials.[12]

One critical policy that has had broad success in most applications is the promotion and regulation of more efficient building equipment (*e.g.*, appliances, lighting and heating equipment) through labelling and minimum energy performance standards (MEPS). These are usually best pursued at a national level rather than at the city level, although there are examples of cities that have initiated their own policy programmes that support or mandate purchases of energy efficient equipment. For instance, the city of Cape Town in South Africa implemented mandatory lighting and appliances efficiency policies in 2014 in order to reduce growth in rapidly rising electricity demand (City of Cape Town, 2014).

The largest elements that impact energy consumption in most urban buildings are the construction and building operation practices that are highly linked to heating and cooling loads. Typically, key building construction policies, such as robust, enforceable and adaptable advanced building energy codes that can enable high levels of compliance[13], are set at the national level, but cities nonetheless enable several key components that allow for greater success than might be seen at a national scale or in non-urban areas. Local authorities often have building regulatory, planning and zoning functions, and they generally have the ability to achieve greater levels of education across buildings stakeholders to help administer effective building policies. From a national and global public policy perspective, engaging cities can therefore improve effectiveness of building construction policies due to their large economies of scale and the potential replicability of programmes.

Cities can also play a critical role in curtailing the current energy consumption of the world's existing building stock. Many cities are already leading in this area through energy efficiency measures in public buildings and through building technology and energy efficiency awareness programmes, which can be much more targeted than national energy policy outreach. However, significant effort is still needed to enable and pursue a long-term global strategy for deep energy renovation[14] in existing buildings (IEA, 2013a). National support of local policy action in this area will help to ensure that on-going building renovation measures in cities are not a missed opportunity for deep energy efficiency improvements.

There are a few key technologies for the buildings sector that may have limited opportunities when considering adoption in the urban built environment. In particular, solar thermal market

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[12] More information on building envelope technologies and research and development pathways for advanced building envelope components can be found in the IEA Technology Roadmap on *Energy Efficient Building Envelopes* (IEA, 2013b). Additional information on building technologies and policies can be found in the IEA's *Transition to Sustainable Buildings: Strategies and Opportunities to 2050* (IEA, 2013a).

[13] See IEA Policy Pathway on *Modernising Building Energy Codes* (IEA, 2013c) for more information.

[14] The Global Buildings Performance Network defines deep renovations as actions that achieve building performance levels that are not more than 60 kWh/m^2 per year for all building code loads (*i.e.* space heating and cooling, water heating and installed lighting) (GBPN, 2013).

adoption may be limited in certain urban environments as a result of building densities and space constraints. While solar thermal is a critical, low-carbon technology for achieving energy efficiency and emissions objectives in single-family residential buildings and in low-density building clusters, there can be insufficient roof area to provide enough heat to satisfy water heating or space heating demand in larger buildings (*e.g.*, multi-family residential buildings, hospitals and hotels). Building shading from the surrounding built environment in higher density urban areas can also be a constraint to solar technology applications. Integrated facade solar thermal systems are a promising option for both new construction and possibly for major building renovations in dense urban areas, but further development to make these systems cost effective and technically viable across various applications is still needed.

One particular area of policy interest in the global buildings sector is to improve data and understanding of actual building energy performance, which is needed to develop and refine both national and local buildings sector policy priorities. Data, and a more acute sense of local building energy needs and opportunities, are valuable tools that city and municipal authorities can use to shape policy decisions and prioritise energy efficiency efforts. It can also help cities to target the right stakeholders (*e.g.*, building operators and local construction companies) to increase adoption of energy efficient technologies.

Several cities are already leading in this area with mandatory (although typically non-binding) policies that require energy consumption and performance disclosure reporting (IMT, 2015). Some cities – for instance the city of Boulder, Colorado in the United States – are even taking this a step further and requiring certain building types to comply with local MEPS as part of the buildings rating and reporting scheme (City of Boulder, 2015). However, many cities do not have the resources or capacity to implement these types of programmes. National support of local action in this area would therefore be beneficial to both urban areas and national policy makers in improving understanding of buildings sector performance and establishing more effective, targeted buildings energy policies.

Despite the important role urban authorities can play in meeting buildings energy efficiency and emissions objectives, local policy makers and buildings actors do not always necessarily consider buildings actions with respect to CO_2 emissions reduction or energy efficiency design. Instead, urban policies often consider important buildings issues such as affordable housing, building safety, working conditions within the built environment and other issues related to social well-being and economic prosperity. Yet, energy efficiency measures in buildings can add essential local value, through job creation, lower energy bills, improved air quality and even improved quality of living (*e.g.*, through improved thermal comfort). As buildings sector investments and economic prosperity are closely linked, implementation of energy efficiency measures in the urban buildings sector can lead to important multiple benefits for local economies, while reducing total buildings energy consumption and CO_2 emissions at the same time (Box 4.3).

Box 4.3 • Building energy efficiency measures: multiple benefits for local communities

Energy efficiency has been the primary factor in driving down energy consumption in IEA countries over the last 25 years, with avoided expenditures in IEA countries resulting from energy efficiency investments over that period valued at USD 5.7 trillion to energy consumers (IEA, 2015d). Globally, significant investments in energy efficiency continue to rise, with energy efficiency now considered a “first fuel” in terms of effective tools for achieving energy conservation goals (IEA, 2015c). The economic, social and environmental benefits of energy efficiency investments are also increasingly recognised in policy decision making processes, alongside the conventional benefits of reduced energy demand and lower greenhouse gas emissions. This is in part due to the variety of policy issues that can be supported by energy efficiency.

Buildings present a significant opportunity for addressing multiple policy goals via energy efficiency improvements. Building energy efficiency investments can contribute to economic development by boosting productive GDP growth, creating net employment and reducing the amount of generation assets needed to meet peak demand (Washan et al., 2014; Mount and Benton, 2015). Investments in energy efficiency are also often pursued as a means of addressing energy affordability in urban areas, as making energy services less expensive and addressing energy poverty in cities can result in direct public health benefits (*e.g.*, fewer premature deaths and reductions in respiratory infections), which further improve the cost-benefit case for energy efficiency investment (Wilkson et al., 2009).

Evidence of health co-benefits can similarly be used to justify revenue sharing between public budgets, with empirical studies showing as much as 42% of building energy renovation costs being recouped through co-benefits on health budgets (Liddell, 2011). Energy efficiency improvements can also be seen as a business diversification activity for energy suppliers, offering new services to consumers while reducing the overall cost of services to citizens (*e.g.*, as an energy service company) (Hall et al., forthcoming).

The increased recognition of the multiple benefits of energy efficiency has resulted in a variety of approaches to their assessment within local policy decision-making. Several IEA member states (*e.g.*, Germany and the United Kingdom) already incorporate net employment benefits from building energy renovations in their policy assessment processes. For instance, the CO_2-Building Rehabilitation Programme (CBRP) programme in Germany can be seen as an example of an energy efficiency investment programme used as a means of economic stimulus, to create jobs and boost economic growth (Rosenow et al., 2013). The influence of energy efficiency on economic growth, however, is not regularly featured in policy assessments in most cities.

Health and well-being benefits are also increasingly connected with energy efficiency investments in buildings. There is considerable disparity, however, between practices of accounting for these impacts in policy assessments. For example, the “Warm Up New Zealand” programme, where health and well-being outcomes comprised the majority of recorded benefits, contrasts with policy assessment in the United Kingdom, where evidence of health and well-being benefits is provided but no attempt is made at quantifying them. No impact is consequently made then on the energy efficiency policy’s net present value in the United Kingdom.

As the appreciation of the multiple benefits of energy efficiency grows, addressing disparity between the levels of recognition shown by different cities and countries will help to add universal value to multiple benefits and allow integration in buildings energy policy. Part of the existing disparities across accounting methods are related to the different economic and social contexts of each city and country, which result in different relevance for some benefits and thus different accounting of them in policy decision making processes. The emerging nature of both the evidence and the methods of recognition of benefits of energy efficiency can also lead to substantially different valuation across cities and countries.

Continued efforts are needed to raise the value of local energy efficiency measures in meeting multiple policy objectives for local decision makers. Best case examples of where the benefits from energy efficiency policy have been recognised, and how they have been accounted for, can make an important contribution to justification of continued investment in energy efficiency in buildings. Retrospective (ex-post) evaluations can also to address disparities in recognition. More broadly, international cooperation and experience sharing across cities can help to encourage the incorporation of energy efficiency in local policy design, so that energy efficiency and emissions reduction become standard practices in local buildings markets.

Incorporating multiple benefits of energy efficiency into local planning and policy design and tapping into the enormous energy savings potential in urban buildings will require both support and direction from national policy frameworks. While many cities are already acting on important energy-related buildings issues, there are still often key barriers to achieving the potential scale of urban sustainable energy actions in the buildings sector. These frequently include jurisdictional rights and boundaries (*i.e.* lack of authority to implement certain policies), financial constraints (*e.g.*, lack of capacity to raise or leverage funds for energy efficiency programmes) and other capacity related issues (*e.g.*, institutional knowledge of advanced building technologies).

National policies have substantial leverage to enable local decision makers to pursue appropriate urban planning and energy efficiency measures. This includes the use of national land use planning frameworks, fiscal policies (*e.g.*, tax incentives, grants and subsidies, housing loans and third-party financing[15]) and capacity building programmes to provide direction (in the same way as national setting of MEPS for building codes, appliances and equipment) and empower local planning and policy design. By providing strong support to cities, national governments can help deliver sustainable energy transitions, including the use of adaptive measures and targets, in urban buildings, while also achieving national energy and climate policy targets (see Chapter 7).

Reducing urban building heating and cooling energy demand

Space heating and cooling currently account for around 40% of global buildings energy consumption and are a critical area of needed action in the buildings sector. Several key factors influence building thermal demand, including local climate, urban form and design, building orientation and shape profile, technology and material choices, and occupant behaviour. While variations in thermal energy demand across the global buildings stock may not be completely understood, policy support and building energy codes are needed everywhere to transform the buildings market and achieve an efficient, low-energy buildings sector.

Reducing heating and cooling demand in buildings has been well documented across most mature markets using widely available, cost effective building envelope technologies and energy efficient heating and cooling equipment. This is generally easier to achieve in new construction, although deep energy renovations in existing buildings in cold climates have nevertheless achieved heating performance loads of around 40 kWh/m^2 to 60 kWh/m^2 using cost effective technologies. Other building deep renovation projects have shown that it is technically possible to achieve very low heating loads in the range 15 kWh/m^2 to 25 kWh/m^2 range (more typical of nZEBs or *passive haus* standards). However, these performance levels are not always cost effective, and more research and development, market conditioning and product promotion is needed to advance this field (IEA, 2013b).

New construction, especially in emerging markets, provides important opportunities to reduce heating and cooling loads, including proper building orientation to the sun and designing the shape profile of the building to reduce thermal loads. It is widely accepted that building codes are the most effective policy instrument to influence new construction, although the effectiveness of building energy codes depends on the level of compliance, which typically requires monitoring, verification and enforcement of the codes and standards. Urban areas, through permitting and local enforcement of mandatory construction and building renovation codes, therefore can play a critical role in achieving improved thermal demand in new buildings.

Cities can also help to transform building construction markets through local policy support and urban planning authorities (*e.g.*, zoning and permitting) to guide them towards high performance, energy efficient buildings. This includes working with local stakeholders to optimise building design that takes into account prevailing climatic conditions, greater passive design (including passive ventilation and heating contributions) and advanced facades that harvest natural daylight while reducing cooling loads. Local demonstration projects, including deep energy renovations in

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[15] Additional information on fiscal tools for building energy efficiency can be found in the Buildings Performance Institute Europe (BPIE) report on *Energy Efficiency Policies in Buildings – the Use of Financial Instruments at Member State Level* (BPIE, 2012).

public buildings, can also be used as education tools and market drivers to encourage uptake of energy efficient technologies and building practices in cities.

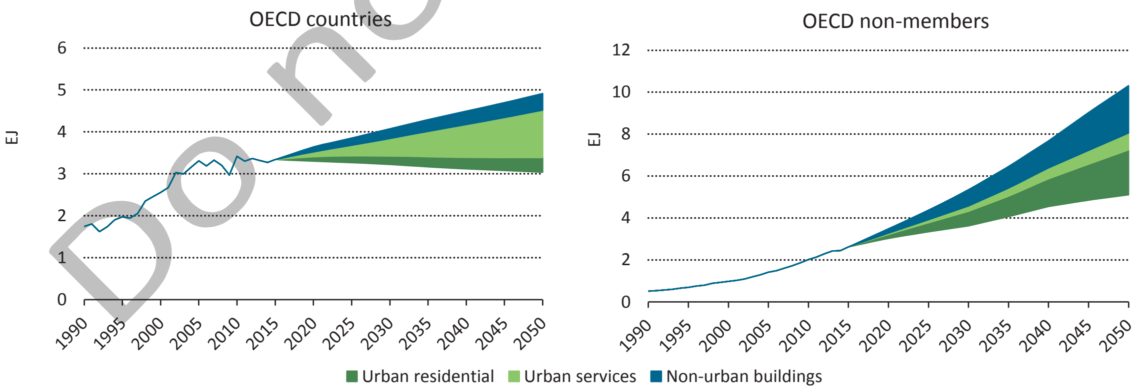
Another important role that urban areas can play in achieving low heating and cooling energy demand in buildings is through raising awareness with local consumers and building operators to address energy efficiency technology and behaviour in buildings. Consumer choices, behaviour and building operation can lead to significant energy consumption differences in any region of the world. For instance, in China, studies have shown that occupant behaviour and building operations can vary energy consumption by as much as two- to six-fold in residential households and between two- and ten-fold in office buildings (Zhang, S. et al., 2010). The needed policy effort to achieve reduced urban building thermal energy demand therefore goes beyond construction and should include the operation of buildings, including advanced energy management tools and overall education and training for building operators and occupants.

Growing cooling demand in urban buildings

Global buildings cooling demand is increasing rapidly, especially in hot, humid climates in emerging markets. Dense urban environments with large, multi-storey buildings – including the increasing choice of glass facades in commercial and services buildings – are ripe for growth in space cooling demand in most developing regions. Cities can also be significantly hotter than surrounding areas due to urban heat island effects (LBNL, 2013).

Without concerted effort to reduce cooling energy demand in buildings through energy efficient envelopes and cooling equipment, global buildings cooling energy consumption will continue to grow rapidly to 2050, especially in non-OECD countries, where more than 80% of expected space cooling growth is expected to occur (Figure 4.8). Urban areas, where the greatest growth in household demand for energy services and comfort will happen, are responsible for nearly 70% of expected global growth in cooling demand under the 6DS and likewise account for 65% of global cooling energy savings under the 2DS.

Figure 4.9 • Cooling energy demand and savings to 2050 (6DS to 2DS), OECD countries and non-members



Key point • Building envelope and energy efficiency improvements would lead to an 80% reduction in global urban buildings cooling consumption in 2050 under the 2DS.

Unlike OECD countries, where a significant share of space cooling loads and savings potential comes from the services sub-sector (due to higher use of mechanical HVAC systems in commercial and services buildings, relative to lesser need for space cooling in many OECD residential buildings), residential buildings space cooling energy consumption in non-OECD countries is likely to increase dramatically as household demand for thermal comfort increases in hot climates. It will consequently be critical to address new residential buildings construction –

with more than 900 million new households expected by 2050 in urban areas in non-OECD countries – through prescriptive building codes that reduce thermal demand intensities using a wide array of building envelope technologies. Globally, similar actions are also needed to address thermal loads in services buildings, starting first with aggressive building codes for new construction as well as deep renovation programmes for existing services buildings.

The first priority in building design and policy development should be to reduce the need for cooling from a passive heat rejection perspective[16] (IEA, 2013b). Reflective surfaces, including cool roofs and low-emissivity (low-e) glass windows with spectrally selective coatings tailored to reject the sun's energy, building orientation and exterior shading are critical elements that should be addressed in both new construction and building renovations in hot climates. Natural and night-time ventilation strategies can also be applied in some hot climates, and reflective roadways and pavements (*i.e.* high albedo effect) can help to reduce average urban temperatures that in turn reduce air conditioning loads in buildings (LBNL, 2013).

Efficient cooling equipment is also of importance, although it should be a secondary priority after building design. Advanced chillers exist in many markets, and geothermal systems can offer high performances for large individual buildings or possibly for district cooling networks. District cooling can also take advantage of urban building densities and economies of scale to achieve high operating efficiencies using numerous sources to produce thermal energy (usually via chilled water). This can include the use of "free cooling"[17] sources (*e.g.*, rivers, streams and other geothermal sources), renewable energy sources and even off-peak and seasonal cooling generation (*e.g.*, through ice storage) that can help level out electricity demand and lower space cooling costs[18]. For example, the city of Chicago in the United States has the world's longest district cooling network that delivers chilled water to more than 4.4 million m^2 of building space using five interconnected plants based on ice-storage technology (Enwave, 2015). Beyond the energy saving benefits provided by the large scale, flexible chilled water production process, the district cooling network also provides numerous benefits to buildings served, including lower capital costs, nearly 60% less fresh water used each year (as a result of no chillers or cooling towers on site) and reduced mechanical space (often on the roof, where solar systems or green roofs could been installed). The district cooling network also provides benefits to the local utility grid, by reducing electricity demand in buildings during peak cooling periods.

Efficient building envelope technologies

Globally, there is increasing general knowledge about the importance of insulation in buildings, even if continued work is needed to improve knowledge of the right levels of insulation and to achieve better installation practices. By contrast, the important role of windows and air sealing in efficient building envelopes still needs to be elevated in buildings policy development and construction practices, especially in developing countries.

In most urban areas, multi-family residential buildings are a major building type with significant thermal loads. While these buildings often have much lower heat load requirements than single

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[16] A key strategy to reduce cooling demand in buildings is to address heat gained from the sun, where the use of innovative technologies and building envelope design can actually avoid the need for interior conditioning.

[17] "Free cooling" is a term used to associate the use of "free" or available natural resources to provide partial or full cooling to buildings. Free cooling can also be used in cooling assisted applications (*i.e.* in support of normal cooling processes) to improve overall district cooling efficiencies.

[18] The use of (*e.g.*, from rivers and the ocean) can also provide higher operating performances. For instance, the Climespace Bercy district cooling network in Paris, France uses free cooling from the Seine River to augment the net operating efficiencies of its cooling production plant. Since free cooling was applied in 2009, the average coefficient of performance (COP) of the plant chillers increased by more than 30% (IEA, 2014).

family buildings (as exterior surface represents a smaller portion of each apartment), glazing area (*i.e.* windows) within the thermal envelope represents a much greater portion (*i.e.* greater window-to-wall ratio). For example, typical window-to-wall ratios for single family buildings may be 12% to 15%, whereas in some apartments the ratio might be as high as 60% or more. Installing better windows can therefore have a dramatic impact on heating and cooling demand, especially in emerging markets where the majority of installed windows are not efficient (*i.e.* low thermal performance) (Box 4.4).

Box 4.4 • Energy efficient building envelope technologies

The IEA released a technology roadmap on *Energy Efficient Building Envelopes* in 2013 looking at critical and emerging technologies that improve the thermal load in buildings (IEA, 2013b). The Roadmap also detailed the investment, policies, regulations and actions necessary to advance and popularise these technologies in both new and existing structures.

Globally, one critical technology to improve window performance and building energy demand is low-e glass coatings. Low-e coatings act as a radiant barrier that reduce heat loss in winter and heat gain in summer. They also have varying optical properties that allow either low or high solar heat gain, tailored to heating or cooling dominated climates. Low-e coatings reduce heat loss through windows by around 33% to 40%, and can reduce heat gained from the sun by over 50%.

Another important window technology is dynamic solar control, including exterior shading and dynamic glass, which can provide significant benefits for most countries. In warm to hot climates, dynamic solar control can offer dramatic cooling load reductions beyond those provided by low e glazing. Dynamic solar controls can also offer increased passive heating contributions when designed and operated correctly in colder climates.

In most mature economies, double-glazed windows with low-e glass are standard building products with large market shares. Many mature economies are now also pursuing triple-glazed windows (two surfaces of low-e glass). However, much effort is needed to bring these technologies to emerging markets, and it is imperative that the world “leap-frog” the transition from single-glazed clear glass windows to at least double-glazed low-e windows (and eventually triple-glazed low-e windows in cold northern zones).

Globally, more effort is also needed to implement air sealing in buildings so that air leakage (*i.e.* infiltration and exfiltration) is reduced, particularly as it can reduce heating, cooling and ventilation energy consumption by as much as 30%. Large variations exist between building practices and building stocks across the globe, but air sealing should generally be considered a high priority for both new construction and existing buildings everywhere. Air leakage may not be a critical requirement for moderate climates that do not require the use of heating and cooling systems, but globally, and especially in developing countries with huge potential for space cooling demand, it should be considered a high priority for any building that will have a space conditioning system installed.

Urban areas are a natural place to develop both knowledge and demand for efficient building envelope technologies, since cities offer large demand for building products and are often the first places to adopt building technologies when they are introduced to the market. Major focus first needs to be on investments for local and/or regional manufacturing of efficient building envelope products in order to enable commodity-based material pricing. National and urban policy makers, along with building code officials, should also place much greater effort in improving construction practices and technology choices in cities in order to create the right market conditions and critical demand to bring efficient building envelope technologies to cost-effective scales.

Challenges and opportunities for urban buildings renovation

Building renovation, especially in developed countries with cold climates, is a critical priority for meeting 2DS objectives in the global buildings sector. While modest energy savings are often pursued via individual component replacements (*e.g.*, window replacement or modest levels of added insulation) or through energy management activities, these types of periodic refurbishments without deep energy efficiency measures represent a missed opportunity to achieve major energy savings at cost-effective investments. A more assertive effort is needed to pursue deep energy renovations to drastically reduce space heating and cooling demand across the world's existing buildings stock.

Despite increasing recognition of the importance of deep energy renovations in the world's existing buildings stock, there has been practically no progress – locally, nationally or globally – in establishing policies that have enabled widespread implementation of deep energy renovation. Often, building envelope technology measures are "available and market ready" because of new building construction policies and market drivers, and the result is that public support has been limited for additional market conditioning and incentives for building renovations. However, the renovation market is much more challenging, due to high variability of existing building conditions, multiple approaches to efficiency improvements and other external barriers, such as historical preservation or building association restrictions. As a result, high transactional costs for deep energy renovations currently exist in most markets, and financing institutes typically do not readily trust the parameters associated with existing building energy savings measures.[19]

In order for cities to capture large reductions in building energy consumption, public policy needs to support deep energy renovations with a long-term perspective, as it could take 10 to 15 years in most markets for deep energy renovation measures to become fully viable at competitive prices. Very high performance building envelope components can be supported through a variety of incentives to help establish a market for better and more cost effective products, typically within a decade. These market conditioning tools can then be used to implement mandatory energy efficiency measures or performance levels across existing building stocks when they undergo refurbishments or other major changes (IEA, 2013b). However, financial incentives for broad sweeping energy renovations are needed first to enable systems level approaches to deep building energy renovations, and many urban areas do not have the capacity to support these types of incentives without additional regional or national support.

There is some promising work on scaling up deep building energy renovations, both on the national and urban scale, to move this important agenda ahead (Box 4.5). Packaging of energy efficiency measures is another promising way to increase awareness and adoption of deep renovation measures in buildings. By packaging together short-term measures (*e.g.*, with payback periods of maybe two to ten years) with measures that have longer payback periods (*e.g.*, facade renovation), policy makers and building stakeholders can improve overall payback periods and encourage greater uptake of deep energy efficiency gains during planned building renovations.

Box 4.5 • Energiesprong and adaptation for urban buildings in the city of London

Energiesprong (or energy leap in Dutch) is an innovative buildings refurbishment programme that was created in the Netherlands by Platform31 with support from the Dutch government. In short, Energiesprong convened various building stakeholders (*e.g.*, housing associations, builders and financers)

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[19] See focus of the Investor Confidence Project to improve financing for building renovation, www.eeperformance.org.

to organise a large-scale refurbishment proposition (initially 111 000 homes in Holland), which then achieves deep energy renovations (in this case, net-zero energy performance[20] for building heating, hot water, lighting and appliances) within ten days using off-site pre-fabrication and with a 30-year energy performance warranty from the builder (Energiesprong, 2014). By working with buildings stakeholders and bundling deep energy renovations across a critical buildings stock, Energiesprong has enabled a financial and regulatory environment that lowers investment risks for financers and eliminates upfront investment costs for consumers, who see no increase in their monthly energy bills (which are instead paid to an energy service provider rather than to a traditional energy utility).[21]

Currently, the Greater London Authority is undertaking a detailed assessment of Energiesprong to establish the extent to which the programme could be transferrable to the metropolitan area of London. The assessment will consider the four key pillars of Energiesprong (notably, energy performance guarantee, delivery timescales, and affordability and attractiveness) within the urban framework to establish the financial envelope for delivering net-zero energy renovations in London, including any planning, financial and regulatory issues, constraints or opportunities. The assessment will also look at how Energiesprong (currently working with public housing) can be delivered across other tenures (including notably private rented and owner-occupied housing).

The Greater London Authority is also engaging with key organisations and supply chains in the United Kingdom to consider how Energiesprong could be delivered successfully in the capital. The initial assessment is expected by the end of 2015. Additionally, the Greater London Authority is working with the Carbon Neutral Cities Alliance to do an initial, high-level assessment of the transferability of Energiesprong within the urban environment to other international cities.

One particular area that cities can support to enable deep energy renovations in urban buildings is through whole building energy performance evaluation and disclosure. Many cities are already pursuing voluntary and even mandatory energy performance disclosure policies that function as a macro-level metric of building energy performance, which can be used both to target poorly performing buildings in cities and to encourage additional private financing for energy efficiency measures by demonstrating the impact and return on deep energy renovation investments.

Energy performance certificates can be derived in a variety of ways, including actual measured data and using a building characteristic evaluation or asset rating. The building evaluation method usually involves simplified software rating tools, and credentials required of the auditor vary by programme. For instance, the Residential Energy Services Network (RESNET) programme in the United States requires energy auditors to meet criteria that are more stringent than mandatory certificates elsewhere, such as the energy performance scheme that is widely used in the European Union. The intent of the RESNET programme is to ensure that all performance ratings are of a very high quality; a drawback, however, is that market entry and programme costs are high, while market uptake is slow. A balance between rigour and accessibility is therefore needed to encourage greater uptake of this useful tool, which urban areas can help to propagate while also improving understanding of local building energy performances and market segmentations.

Opportunities for (n)ZEB buildings in urban areas

There are many types of zero-energy, near-zero energy and net-zero energy building programmes, goals and definitions for buildings that use very low energy and that have either on-site renewable energy resources (*e.g.*, photovoltaic or solar thermal collectors) or are connected

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[20] Net-zero refers to building energy consumption that is not higher than the energy produced by that building.

[21] More information about Energiesprong can be found at http://energiesprong.nl/.

to an external source of “clean” or “green” energy.[22] The fundamental objective of these programmes is to pursue the construction of buildings that need as little energy as possible to ensure a substantial reduction in a building’s carbon footprint, although the balance between investments in building energy efficiency (with diminishing marginal energy savings) relative to increasing construction or refurbishment costs has not necessarily been considered, as many ZEB and nZEB buildings have been demonstration or showcase buildings (often in single family homes in non-urban areas).

The concept of ZEBs and nZEBs has grown considerably over the past 20 years, and the cost effectiveness of construction is increasingly viable, although typically in single family and low-rise buildings in non-urban or peri-urban areas. In many parts of the world, where there are low to moderate energy prices, more effort is needed to make ZEBs and nZEBs fully market viable without policy intervention. This is particularly true of urban ZEB and nZEB construction, where costs and opportunities for multi-family and large commercial buildings in dense urban environments are less evident than in non-urban settings. While there do exist urban building demonstrations of low energy and zero-energy buildings (and even an energy positive[23] large-scale public building demonstration in Austria [IEA, 2013a]), these projects tend to be on buildings with large disposable areas that are not common in most dense urban building sites.

Solar resources in urban areas for meeting ZEB and nZEB energy objectives can also be hindered by lack of adequate roof area and by shading from adjacent buildings. While vertical surfaces are an option for meeting energy demand requirements, they also have reduced energy production potential due to multiple factors, including limited space, poor angle orientation and the need to maintain adequate daylight into buildings. Integrated technology solutions can offer improved renewable energy supply, but even then, total potential solar thermal heat and electricity production in a dense urban environment may not fully satisfy energy demand for some building types (see Chapter 6).

In many urban areas, zero energy communities may be a more realistic goal for achieving a low- or zero-emission buildings sector. When ZEBs and nZEBs are not feasible, either due to technical limits or cost constraints, integrated energy solutions (*e.g.*, low-energy buildings with advanced district heat and carbon-neutral power generation) can be a viable option to meet urban energy and emissions objectives through cost-effective investments. Integrated energy systems can also allow for greater flexibility, including increased use of variable renewable sources, and can provide overall improved local energy system efficiency.

Integration of energy efficient buildings and district heat

The analysis presented in this section is intended to provide analytical support to both national and local policy makers through an initial assessment of building energy efficiency measures and efficient heat options as a guide in choosing technology solutions to reduce the energy intensity of urban buildings. Typically, these types of integrated analyses are conducted on a local or even network level, but broader assessments such as those described here can provide a first order of useful assessment for policy makers.

Many of the world’s largest cities today are located in cold regions and have large heating demand in buildings. Increasing the uptake of deep energy efficiency measures to reduce space heating and cooling demand in buildings is essential to meeting 2DS objectives, as is providing low-carbon heating and cooling solutions in urban areas. Local planning and policy design can

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[22] See *Building Energy Performance Metrics: Supporting Energy Efficiency Progress in Major Economies* (IEA-IPEEC, 2015) for more details regarding variations and needs for improved metrics for zero-energy and low energy buildings.

[23] Energy positive buildings refer to buildings that have more on-site renewable energy supply than energy demand.

play an important role in meeting those targets, especially through enforcement of mandatory construction and building renovation codes and through support for efficient, low-carbon heat supply options, including advanced district heat networks.

Worldwide, district heating has only a small fraction of the total buildings heat market (roughly 11% of global space heating and water heating energy consumption in 2013), while in some countries and regions, district heat networks are quite extensive. For example, there are over 6 000 district heating systems in Europe, and nearly 140 million European Union citizens live in a city with at least one district heat system (Euroheat and Power, 2015). In China, the district heat network in northern urban China accounted for more than 178 000 kilometres in 2013, covering more than 90% of floor area in that region.

District heat networks do not necessarily make sense for all urban environments, and specific cost assessments of energy technology options across local building stocks relative to potential heat sources, urban buildings density, climatic conditions and energy pricing are some of the key areas that should be considered as part of policy strategies for urban buildings. However, there is considerable demonstrated evidence in many dense, cold urban environments that district heat can be highly efficient and cost-effective, given the right market policies and urban or district planning strategies (IEA, 2014). This can be especially true if policy and planning assessments capture the indirect advantages of district heat networks, including their capacity to pursue numerous integrated technologies solutions (*e.g.*, co-generation, industrial waste heat, heat pumps, solar thermal energy and off-peak or seasonal thermal storage) due to economies of scale and their access to various energy sources.

Historically, programmatic activity for district energy networks have been pursued independent of renovations and investments in energy efficiency in buildings. However, integrated analysis of the technical, economic, policy and business cases of integrated buildings policy is needed (*e.g.*, the choice to expand or upgrade district heat networks, promote more efficient stand-alone technologies or mandate deep energy renovations in buildings) in order to minimise investments in energy performance and carbon emissions abatement across the energy economy.

Currently, there exist a few projects and research programmes (*e.g.*, the European Union *Stratego* project[24]) that are looking at the role of different energy efficiency options to achieve cost-effective pathways to meeting thermal comfort in buildings while also meeting broader energy and emissions targets to 2050. The work in this area is aimed at supporting more effective design of energy policies targeting efficient, low-carbon buildings, including technology and policy options to reduce heating and cooling demand in the urban built environment. Further work in this area is needed, including greater assessment of the effects of policies, climatic variations and varying energy prices on achieving a lower carbon footprint across the buildings sector and broader energy economy.

The conclusions of the analysis presented in this section show that there is an opportunity to provide low-carbon, clean district heat to urban areas when paired with effective building energy efficiency measures. For many existing building types in cold climates, pursuing deep energy renovations beyond the 50 kWh/m^2 to 70kWh/m^2 range is technically feasible but not necessarily cost effective, given options to meet remaining heat demand through high efficiency equipment (*e.g.*, heat pumps) or clean district heat.[25] These building renovation measures can also complement improved district heat efficiencies (*e.g.* through lower distribution temperatures)

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[24] The *Stratego* project seeks to assess multi-level actions for enhancing heating and cooling plans across the European Union and to bring the gap between European Union policy, national objectives and actions taken at the regional and local levels. More information can be found at http://stratego-project.eu/.

[25] For new buildings and even many existing single-family or low-rise buildings, even lower (*e.g.*, nZEB or ZEB) performance levels are technically achievable and cost effective.

and can be planned strategically with district heat network expansion to meet additional building demand without increasing supply capacity. The key to proper buildings and district heat integration is that the entire effort be properly planned, coordinated and implemented over a long enough period to engage stakeholders and allow for capital investment planning.

Modernising existing district energy networks

Globally, there are many old district heat networks that have large piping losses with inefficient heat production systems. For older systems reaching lifetime maturity, alternative approaches (*e.g.*, deep building energy renovations with efficient, distributed heat generation) may make more sense in terms of needed investments or energy and emissions reductions. In many networks, however, there is an opportunity to plan strategic investments in line with a more efficient buildings sector to achieve efficient, high-performance heat generation with net energy and emissions reductions across both buildings and heat and power generation. When planned strategically, those integrated energy efficiency measures can even lower life-cycle costs for both buildings and district heat networks.

Modern, advanced and integrated district heat systems, including 4th generation low temperature (*i.e.* less than 50-55°C) district heating systems with renewable and waste heat sources, are possible, and international collaboration through the IEA's Energy Technology Network[26] is assessing the technical potential and economic viability of these advanced district networks across different conditions and technical solutions. Continued effort in this area, along with modernisation of existing district heating networks to improve generation efficiencies and reduce system losses, will play an important role in meeting 2DS objectives for low-carbon heat in buildings (Box 4.6).

Box 4.6 • Advanced district heating solutions for energy efficient, low-carbon communities

The IEA hosts two international initiatives that address the development and deployment of cost-effective district heating and cooling (DHC) and combined heat and power (CHP) technologies in support of an efficient, low-carbon energy sector. This includes the IEA CHP/DHC Collaborative[27], established in 2007 as an international cooperation of government agencies, industry and non-governmental organisations assessing DHC and CHP technologies and related market issues and policies, and the IEA Implementing Agreement on District Heating and Cooling including Combined Heat and Power (DHC/CHP IA). The IEA DHC/CHP IA is an international research collaborative founded in 1983 that considers the design, performance and operation of distribution systems and consumer installation to make DHC and CHP powerful tools for energy conservation and reduced environmental impact[28].

The DHC/CHP IA work programme currently has two research projects related to technical assessments of district heat for urban buildings, including a project on transforming district heating systems from high to low temperatures and a project looking at optimising urban form for district energy to reduce greenhouse gas emissions and energy consumption. A similar project, Annex TS1, is currently assessing holistic and innovative approaches to communal, low temperature heat supply using district heating in order to connect demand (buildings) and generation in support of a 100% renewable energy based community.

Several examples of advanced, low-temperature district heating systems already exist in innovative energy systems implemented in communities across several countries participating in the DHC/CHP IA. This includes projects such as the Drake Landing solar community in Alberta, Canada, which provides space heating needs for 54 residential buildings using 90% solar thermal energy, short-term and season energy storage, low-temperature district heat and energy efficient homes. Similar projects exist in Germany,

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[26] More information on the IEA's Energy Technology Initiatives can be found at http://www.iea.org/techinitiatives/.

[27] More information on the IEA CHP/DHC Collaborative can be found at https://www.iea.org/chp.

[28] More information on the IEA DHC/CHP IA as well as past and current projects can be found at www.iea-dhc.org.

Denmark, Norway and the United Kingdom, where low-temperature district heat for both existing buildings and new low-energy buildings in cold climates is being used to achieve low-carbon and even zero-carbon communities using combinations of renewable energy (*e.g.*, solar thermal and geothermal), heat pumps and efficient heat generation (*e.g.*, biofuel boilers and high-efficiency CHP).

To date, examples of advanced, low-temperature district heating solutions for low-carbon and zero-carbon integrated energy systems have typically been small-scale (in terms of connected buildings and network size) projects. Further research and demonstration of opportunities for advanced, low-temperature district heat solutions in existing district heat networks are needed to bring these technologies to market and to reinforce the economic feasibility and long-term value of advanced, integrated district heating solutions. Policy support and financial incentives are also needed to facilitate investments in modernisation and improvement of the world's existing inefficient district heat networks (IEA, 2014). This includes continued support of research activities and demonstration projects that can be used to design sustainable business models that reward innovation and flexibility for low-carbon, efficient, integrated energy systems.

District heat and buildings strategies in Stockholm, Sweden

The city of Stockholm, Sweden had an urban population of 897 700 inhabitants in 2013, with a total metropolitan population of nearly 2.2 million people. The Stockholm municipality has a relatively old buildings stock compared to the rest of Sweden and one of the highest population densities in the country, with roughly 4 800 persons per square kilometre (SCB, 2015). Space heating is the single largest energy load in Swedish buildings (roughly 55% of total final demand), and Stockholm city has a typical heating period from 15 September to 15 May.

The largest portion of the buildings stock in Stockholm (roughly 80%) is multi-family residential buildings with an average of four to five storeys. Nearly two-thirds of existing residential buildings in Stockholm were built before the 1960s, and multi-family residential buildings built before 1960 account for more than half of total residential floor area. The typical space heating intensity of those multi-family, pre-1960s buildings is above 130 kWh/m^2, whereas buildings built after the 1960s tend to have energy intensities between 90 kWh/m^2 and 110 kWh/m^2. Single family buildings in Stockholm, while a much smaller share of residential floor area (roughly 20%), typically have lower energy intensities between 70 kWh/m^2 and 110 kWh/m^2. This is largely due to use of heat pumps for space heating in roughly 50% of single family households (SEA, 2013b).

Nearly 80% of total existing buildings in Stockholm are connected to the district heat network, including roughly 85% of total residential buildings and nearly 95% of multi-family residential buildings. While energy efficiency measures are needed to lower heating energy demand in buildings across Stockholm, those measures will have an important impact on the district heat network as building energy demand diminishes, especially as options for expanding to new customers within the existing system boundaries are limited. It will therefore be important to plan energy efficiency investments strategically through a system-level approach in order to avoid costly or unnecessary investments in buildings or the district heat network.

Building envelope efficiency potential

The residential buildings stock in Stockholm was divided into 18 common building types through national and municipal statistics on building characteristics (*e.g.*, age and construction type). Heating energy intensities for the different residential stocks were also gathered from building energy certificates, which are required for all new and sold buildings in Stockholm (and then every 10 years for multi-family buildings). Using this information, three building renovation packages were considered for each of the building classes, for a total of 54 building renovation packages. This includes building envelope measures (*e.g.*, insulation, window replacement and air sealing) and other energy efficiency improvements, such as heat recovery from ventilation and upgrade of equipment (*e.g.* electrical motors in circulation pumps). The renovation packages were considered with respect to the Swedish "national strategy proposed for energy renovation of buildings" (SEA and SNBHBP, 2013), and real investment data from renovation programmes initiated by the Swedish Energy Agency were used as part of the cost analysis.

Based on the assessment of the renovation packages across the 18 residential building types, it was determined that energy efficiency measures (from a building perspective only) would be cost effective until the 50 kWh/m^2 to 70 kWh/m^2 range for most building types. However, those savings (roughly 50-60% over the existing average residential space heating intensity) would have considerable effect on the district heat network, as options for expanding district heating to new connections (in-fill) in Stockholm are small. The network could be expanded to surrounding areas with lower heat densities (*e.g.*, suburbs with single family homes), but the costs for these types of expansions are typically much higher than adding additional connections within the existing network (due to infrastructure costs and increased distribution losses from lower heat densities).

Integrated energy assessment

The district heat system in Stockholm is the largest district heating and cooling network in Sweden (roughly 1 330 kilometres of network length) and is an older, complex system operated by six district heat companies across several major networks with some interconnections between operators. Stockholm has increasingly phased out fossil fuel use for district heat production over the last two decades, and fossil fuels (mostly coal and oil, depending on winter temperatures) now account for less than 15% of district heat generation. Approximately 60% of district heat is now produced using biomass and municipal solid waste, while another 25% is produced using heat pumps (Fortum, 2014).

As building energy efficiency measures will have an important influence on district heat investment strategies, a series of assessments were made looking at nine possible scenarios for residential building efficiency measures with respect to district heat pathways in Stockholm (Table 4.3). These scenarios – ranging from minimal investments in buildings and district heat to aggressive building renovation schemes (*e.g.*, greater than 60% stock improvement) and carbon-neutral district heat investments[29] – considered the effects of building energy efficiency measures on district heat investments to 2050.

Table 4.3 Building energy efficiency and district heating pathway scenarios for Turin

		Buildings stock renovation pathways		
		Standard rate 1% renovation, 15% stock efficiency improvement	**Moderate rate** 2% renovation, ~35% stock efficiency improvement	**Advanced rate** 3% renovation, 60% stock efficiency improvement
District heat pathways	**Standard rate** Only planned network maintenance investments	BAU	A	B
	Moderate rate Increased low-carbon investments	C	D	E
	Aggressive rate Strong investments for a carbon neutral network	F	G	H

Note: BAU = business-as-usual; further information on the above scenarios can be found in the methodological annex for this chapter.

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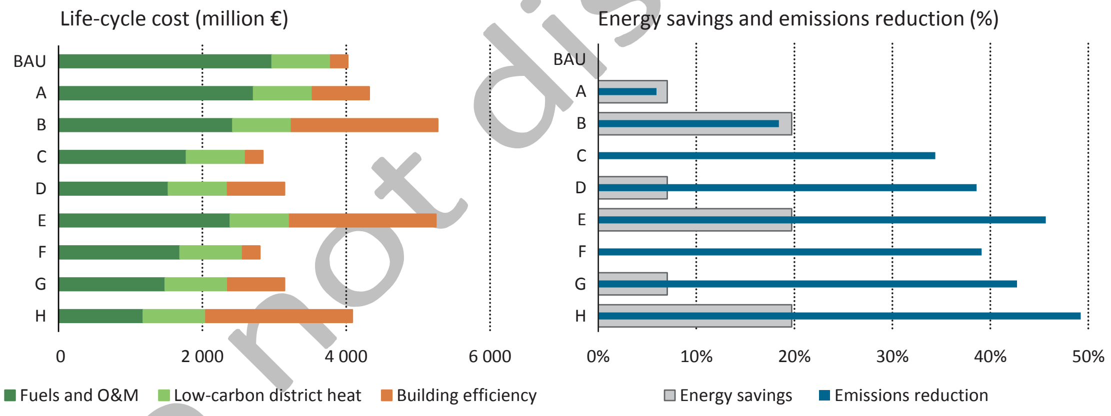
[29] The scenarios considered in this analysis assumed a carbon tax in support of low-carbon investments in buildings and the district heat network. Further information on the assumptions and methodologies applied in the case study can be found in the methodology annex for this chapter.

The nine scenarios for Stockholm were considered from a discounted life-cycle cost perspective (*i.e.* investments in district heat and energy efficiency measures in buildings, energy costs and any operations and maintenance costs) with respect to energy savings and CO_2 emissions reduction potential. The conclusions indicate that energy saving measures in buildings without any intervention in the district heat network would not reduce the total life-cycle costs from a systems perspective, as capital and operational costs in the district heat network would offset savings from buildings energy demand reductions (Figure 4.10). Conversely, investments in low-carbon or carbon-neutral investments in the district heat network (*e.g.*, additional waste heat recovery and solar thermal integration with seasonal storage) would allow for important emissions savings with few buildings stock renovations, given the sheer number of buildings that rely on district heat in Stockholm. Energy and emissions reductions are naturally greater when moderate building efficiency measures are paired with district heat investments.

In terms of meeting energy and emissions targets with respect to total life-cycle costs, moderate building renovations with an aggressive district heating pathway would lead to the greatest energy savings and emissions reduction relative to a business-as-usual scenario. In this combination (scenario G), average residential building energy intensity is lowered to 85 kWh/m^2 and energy consumption and CO_2 emissions (buildings and district heat) are lowered by 7% and 43%, respectively. More aggressive building measures with carbon neutral district heat would lead to greater energy and emissions reductions, but life-cycle costs would be higher as district heat capacity investments would not be fully utilised.

Figure 4.10 • Costs and energy and emissions savings to 2050 for integrated buildings in Stockholm



Key point • Moderate building efficiency measures paired with carbon neutral district heat investments in Stockholm would lead to the greatest, most cost-effective energy and emissions reductions in 2050.

Conclusions and recommendations for further work

Deep energy savings and emissions reductions across the buildings stock and district heat network are possible in Stockholm if energy efficiency measures and district heat investments are planned strategically to 2050. Further energy and emissions reductions are possible with more aggressive building measures (*e.g.*, scenario H), but long-term strategic planning for district heat investments would be critical to achieve lower capacity in base load production in the longer term with more flexibility in short- to medium-term capacity as buildings are renovated.

Further analysis on the influence of energy price variations (including in particular carbon taxes and the availability and cost of waste heat recovery for district heat production) is needed to improve understanding of the cost-effective targets for building and district heat investments to 2050. Continued assessment of building technology cost curves would also improve understanding of how deeply residential buildings could be renovated relative to district heat investments as building energy efficiency measures become more common (and therefore possibly less expensive). Finally, additional research on the impact of lower heat densities (from reduced buildings sector heating demand) on network distribution losses would help to improve understanding of necessary district heat investments to 2050.

Energy conservation and low-carbon district heat in Turin, Italy

Turin, Italy is a city of roughly 910 000 inhabitants in north-western Italy, with a total urban metropolitan population of roughly 1.7 million people. The region has a temperate, continental climate with moderately cold, dry winters (*i.e.* between -2°C and 5°C in January) that contrast with the Mediterranean climate along the coast of Italy. The heating period in Turin typically lasts from 15 October to 15 April.

The city of Turin (excluding surrounding the metropolitan area) has roughly 36 500 residential buildings, accounting for roughly 47% of buildings in Turin, that cover approximately 50 million m^2 of floor area (150 million cubic metres of volume) with an average space heating energy intensity of 170 kWh/m^2. Residential buildings that are connected to the district heat network (roughly 35% of residential buildings volume) have a lower heating energy intensity of approximately 110 kWh/m^2, which is largely due to shape factor as most residential buildings connected to the network are multi-family buildings.

Energy conservation through more efficient building envelopes will be essential to meeting objectives to lower space heating energy consumption across Turin's buildings stock. Single family households have some of the worst performances for space heating energy intensity (see Figure 4.3), although these buildings only account for about 5% of total residential floor area and less than 10% of total residential space heating energy consumption. Targeting deep energy renovations in Turin's multi-family residential buildings – as the largest share of residential floor area and total residential space heating energy consumption – will therefore be key to reducing space heating energy demand. More efficient multi-family residential buildings will also help to reduce the important effect of residential heat curve loads on Turin's district heat network.

Building envelope efficiency potential

The residential buildings stock in Turin has been broken down into 36 reference building classes through geospatial analysis and statistical data (Corgnati et al., 2013; Mutani et al., 2014; Delmastro et al., 2015). More than 80% of residential buildings in Turin were constructed prior to the 1980s, before there were regulations on building energy consumption, and nearly half of the residential stock is comprised of multi-residential, apartment block housing (*i.e.* greater than four storeys), which account for more than 80% of total residential building volume. Low-rise, multi-residential buildings account for another 19% of the housing stock (11% of volume), and another 21% of residential buildings are single family attached housing (5% of volume). The remainder is single family detached housing (1% of volume).

Four building renovation packages (which consider a combination of building envelope and equipment measures) were simulated for each of the 36 reference building classes in Turin. An additional 25 renovation packages were stimulated for both multi-family high-rise buildings built before the 1970s (the largest portion of the residential building stock) and single family detached houses built before the 1980s (the most energy intense portion of the residential building stock), for a total of 194 potential building efficiency packages (TABULA, 2012; Guala, 2013; Fausone, 2013). These renovation packages were then assessed for energy reduction potential (in terms of building heating energy intensity [kWh/m^2] and energy consumption) relative to total life-cycle costs (*i.e.* efficiency investments and any building or equipment operation and maintenance costs relative to savings on energy). The analysis concluded that the cost-optimal range for building energy efficiency measures across the various Turin residential buildings stock types was typically in the range of 45 kWh/m^2 to 75 kWh/m^2. Energy efficiency measures beyond those levels of renovation, while technically feasible, generally came at higher costs with much lower or no return on investment.

Integrated energy assessment

Turin has the largest district heating network in Italy, serving roughly 570 000 inhabitants (or nearly 60 million cubic meters of building volume) (IREN, 2015). District heat is currently produced using gas-based CHP and gas boilers along with a small (12 500 cubic metres) daily storage system. Roughly 35% of residential buildings volume in Turin is connected to the heat network, and 93% of the connections are in the residential sector. Energy saving measures in Turin's residential stock would therefore have an impact on district heat production, costs and investment strategies.

To explore the effects of building energy efficiency measures on district heat and to improve understanding of potential, cost-effective pathways forward for building energy conservation relative to district heat supply options, a series of assessments were made looking at nine possible scenarios for residential buildings and district heat in Turin (Table 4.4). These scenarios – ranging from minimal investments in buildings and district heat to aggressive building renovation schemes (*e.g.*, greater than 50% stock energy performance improvement) and carbon-neutral district heat investments – were considered from a discounted life-cycle cost perspective (*i.e.* investments in district heat and energy efficiency measures in buildings, energy costs and any operations and maintenance costs) with respect to energy savings and CO_2 emissions reduction potential. Opportunities (and costs) for district heat expansion relative to building energy efficiency measures were also considered in some of the scenarios, and a carbon tax was assumed in support of low-carbon investments in buildings and the district heat network.[30]

Table 4.4 Building energy efficiency and district heating pathway scenarios for Turin

		Buildings stock renovation pathways		
		Standard rate 1% renovation, <10% stock efficiency improvement	**Moderate rate** 2% renovation, 30% stock efficiency improvement	**Advanced rate** 3% renovation, 55% stock efficiency improvement
District heat pathways	**Standard rate** Little expansion, few investments	BAU	A	B
	Moderate rate Slight expansion, low-carbon investments	C	D*	E
	Aggressive rate Moderate expansion, carbon neutral investments	F	G*	H*

Note: BAU = business-as-usual; * indicates further expansion of the district heat network at or below previous heat output capacity due to building envelope energy efficiency renovation packages; further information on the above scenarios can be found in the methodological annex for this chapter.

The conclusions of the scenario analyses found that energy saving measures in buildings without any intervention in the district heat network would not reduce the total life-cycle costs from a

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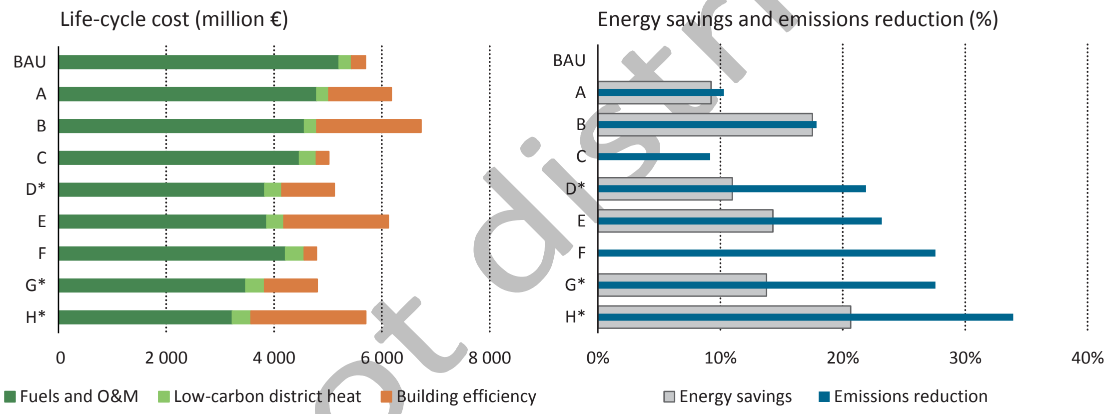
[30] Further information on the assumptions and methodologies applied in the case study can be found in the methodology annex for this chapter.

systems perspective, even with lower renovation rates, due to capital and production costs with continued gas-based district heat production in an increasing carbon-constrained world (Figure 4.11). Investments in low-carbon or carbon-neutral investments in the district heat network (*e.g.*, waste heat recovery and solar thermal integration with seasonal storage) would allow for important emissions savings in practically any configuration with buildings stock renovations, although energy and emissions reductions are naturally greater with more aggressive building energy efficiency measures.

In terms of meeting energy and emissions targets with respect to total life-cycle costs, combinations of moderate to advanced building renovations with an aggressive district heating pathway would lead to the greatest savings relative to a business-as-usual scenario. This is due largely to two reasons. First, that energy savings in buildings heat demand would allow for increased use of smaller scale heat production plants and greater use of low-grade heat from renewable sources or waste heat. Second, the reduced building energy demand would allow for expansion of the district heat network at or below previous heat output capacity, thereby lowering the cost of district heat production and further reducing energy consumptions and CO_2 emissions from buildings that were not previously connected to the network in Turin.

Figure 4.11 • Costs and energy and emissions savings to 2050 for integrated buildings in Turin



Note: BAU = business-as-usual; * indicates further expansion of the district heat network at or below previous heat output capacity due to building envelope energy efficiency renovation packages.

Key point • Moderate to advanced building stock renovations with an aggressive, carbon-neutral district heat pathway would allow for the greatest energy and emissions savings below BAU life-cycle costs.

Conclusions and recommendations for further work

The results of the Turin analysis illustrate that deep energy reductions and emissions savings are possible through combinations of building energy efficiency measures integrated with low-carbon and carbon-neutral district heat investments. The potential energy, emissions and life-cycle cost savings would depend on the extent to which aggressive energy efficiency measures and district heat investments are pursued. This would depend on Turin's energy and emissions reduction targets to 2050, and the analysis described here underscores that these actions can be achieved at or below business-as-usual life-cycle costs.

A strategic long-term vision will be necessary for Turin's buildings stock and district heat network in order to encourage the effective planning and implementation of building renovation measures and district heat network investments. This is especially true for Turin's district heat network, as predictability of heat demand and load curves are critical to district heat capacity and operation investments.

Future analysis in this area should consider the influence of energy price variations on decision making structures across the buildings market and district heat network. Consideration of various discount rates, financial incentives and market conditions relative to investment decisions and energy and emissions reductions would similarly improve the understanding of the range of suitable options and interventions in Turin's buildings and district heat network. Finally, future work could consider not only space heating demand but also other energy related demands in buildings (including the services sub-sector, not assessed here) and the various technical and operational solutions that would meet overall energy and emissions objectives for Turin.

Industrial waste heat recovery in Qianxi, China

The district heat network in China covers 90% of floor area in north urban China, or roughly 11 billion m^2, making it the largest and fastest growing district heat network in the world (Euroheat and Power, 2015). Heating in northern China is a major portion of total Chinese buildings energy consumption, accounting for roughly 181 million tonnes of coal equivalent (tce) in 2013 (or roughly ¼ of total primary energy consumption by buildings in China). The average space heating intensity of buildings connected to the district heat network in northern China was around 130 kWh/m^2 in 2013, and while energy consumption per unit of floor area has decreased over the past decade as new, more efficient buildings are constructed, the substantial growth in total floor area continues to drive increases in heat demand (in absolute terms) (IEA-TU, 2015).

District heat in north urban China is predominantly fuelled by coal, which accounts for more than 80% of commercial heat production in China. Coal-fired boilers and CHP (mostly coal) accounted for 48% and 42% of primary energy used for commercial heat production in 2013. Gas-fired boilers accounted for another 8%, with the remaining 2% coming from various sources (*e.g.*, small-scale CHP and heat pumps) (TU, 2014). Without assertive effort to improve the intensity of buildings heat demand and also to improve the energy efficiency of heat generation, total primary energy consumption for heating in northern China could reach as much as 250 million tce by 2030, when total heated floor area is expected to reach 15 billion m^2 (TU, 2015). This would place heavy pressure on energy supply chains in China as well as on the environment, due to China's heavy use of coal.

To reduce the intensity of heat demand in buildings, energy-efficient buildings have been promoted heavily over the last two decades, including policies and programmes to renovate existing buildings stock in northern China through insulation and envelope improvements (IEA-TU, 2015). Typical annual heat demand in many buildings in north urban China consequently ranges from 60 kWh/m^2 to 100 kWh/m^2, and further work on renovating existing building stock was announced under the 2013 *Green Building Action Plan* (MOHURD, 2014).

The Chinese government has also identified the critical need to improve the efficiency of district heat supply (*e.g.*, through high-efficiency CHP and waste heat utilisation). Low-grade heat recovery is a particularly promising area for energy efficiency gains, as power generation and industrial plants in China release large amounts of heat into the atmosphere each year. Low-grade waste heat released during the winter heating period is estimated at approximately 90 million tce per year, which if recovered could replace most of the existing coal-fired boilers in the district heat network, while even satisfying new demand in the future (Fang et al., 2013).

Qianxi industrial waste heat recovery

Qianxi county is an administrative district of roughly 390 000 persons in the eastern part of Tangshan city. District heat, using coal-fired boilers, has historically been the main source for space heating in the downtown area of Qianxi, whose winter heating period lasts from roughly 15 November to 15 March each year, with an average temperature of -7.8°C in January. Heated floor area in Qianxi is currently around 3.2 million m^2, with a current peak heating load of around 45 watts (W) per m^2. By 2020, total heated floor area is expected to reach nearly 6.9 million m^2, and as high as 10.8 million m^2 by 2030. Consequently, annual district heat demand could increase from 145 megawatts (MW) today to as much as 310 MW in 2020 and nearly 490 MW in 2030 if assertive efficiency measures are not taken for new building additions. Even if all new building construction meets the expected new Standard for Energy Consumption in Buildings[31], district heat demand would still increase to as much as 274 MW in 2020 and 378 MW in 2030.

Rapid growth of buildings floor area and expected growth in district heat demand pose a central challenge to meeting energy and environment objectives in Qianxi, including restrictions on future coal combustion. A demonstration project was therefore developed in 2014 to recover waste heat from two nearby steel plants (J and W), with the aim of recycling three types of industrial waste heat for the district heat network: the cooling water of the blast furnace, the flushing water of blast furnace slag and the mixed steam from basic oxygen furnaces and rolling heating furnaces. Using this heat recovery, the heating power potential was estimated at 217.5 MW, which could serve the basic district heat load to 2030.

Most of the first stage of the demonstration project at plant W was completed in January 2015. First, long pipelines were constructed to connect the heat recovery sources in the two steel plants and the existing district heating network in downtown Qianxi. A new heating station was also established beside the W steel plant, and heat exchangers were installed to recover the heat of the flushing water and mixed steam at the W plant. In the second and third stages, absorption heat pumps and absorption heat transformers will be installed at the J steel plant and then within the district heat network substations to lower return water temperatures and improve system efficiencies.

The Qianxi project was developed as part of a public-private partnership between the local government, which owns a 5% stake in the project and which serves as an intermediary between the local industries and citizens, and the J and W steel plants. The district heating company services the district heat network with the franchise right rented from the local government, and the waste heat recovered from the steel mills is purchased at 4.5 Chinese Yuan (RMB) per gigajoule. Local buildings then pay a heat price is 23 RMB/m^2.

The total investment for the first phase of the demonstration project was approximately 283 million RMB, which included: 170 million RMB for transportation pipelines, 45 million RMB for pipelines inside the plants, 30 million RMB for heat recovery devices and 20 million RMB for the new heating station. The second and third phases would cost an additional 51 million RMB and 110 million RMB, respectively, with an expected annual district heat production cost reduction of nearly 30 million RMB in 2016, leading to an annual cost reduction of 63 million RMB in 2030. The completed projected is therefore expected to have a payback period (static) of roughly 7 years across the entire three phases (Table 4.5).

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[31] See section on "Standard for Energy Consumption in Buildings" in the IEA-Tsinghua University report on *Building Energy Use in China: Transforming Construction and Influencing Consumption to 2050* (IEA-TU, 2015).

Table 4.5 Integrated network investments (million RMB, cumulative) and payback period (years)

	2016	2020	2030
Long-distance transportation pipeline	170	170	170
Devices and pipelines in plants	113	113	128
Heat station	*20*	*20*	*20*
Pipes inside the steel plant	*45*	*45*	*55*
Heat exchangers	*30*	*30*	*35*
Absorption heat pumps	*18*	*18*	*18*
Advanced heating substations	-	46	146
Total	**283**	**334**	**444**
Annual cost reduction (million RMB per year)	**28**	**41**	**63**
Static payback period (years)	**10.1**	**8.1**	**7.0**

Note: Investments in equipment retrofits in substations are estimated at 0.3 RMB/W (heating power), mainly for the installation of absorption heat transformers.

Source: TU, 2015, Feasibility Study

Performance of the integrated system

The actual heat recovery efficiency of heat exchangers has been calculated since the installation at plant W in January 2015. The blast furnace slag is able to provide 105.5 MW of heat, including 90.5 MW for the district heat network and 15 MW for factory heating. Another 44 MW from steam could be captured, and when the absorption heat pumps at the network substations are included, the integrated system is expected to provide 165 MW for the 2015-2016 heating period. In future stages of the project, when capacity at plant J is added and additional absorption heat transformers are installed in the network substations, the heating power could reach 225 MW.

Compared with the traditional coal boiler system, the integrated district heat and industrial waste heat recovery system reduces coal consumption by nearly 42 000 tce, leading to a potential energy savings potential through waste heat recovery of nearly 84 000 tce in 2030. In terms of local pollutant improvements from replacement of the traditional coal boilers, this means a reduction of nearly 355 tonnes of sulphur dioxide (SO_2) and 310 tonnes of nitrogen oxides (NO_x) in 2016, leading to an estimated reduction of 715 tonnes of SO_2 and 620 tonnes of NO_x in 2030.

The new integrated system does use more electricity[32], but the net effect is still a large reduction in energy consumption and emissions, with positive return on the investments in an acceptable period of less than 10 years (Figure 4.12). Since most of the delivery pipes and recovery equipment were invested in the first stage, the economics benefit from energy savings will improve over time as more waste heat is recovered and the system efficiencies improve.

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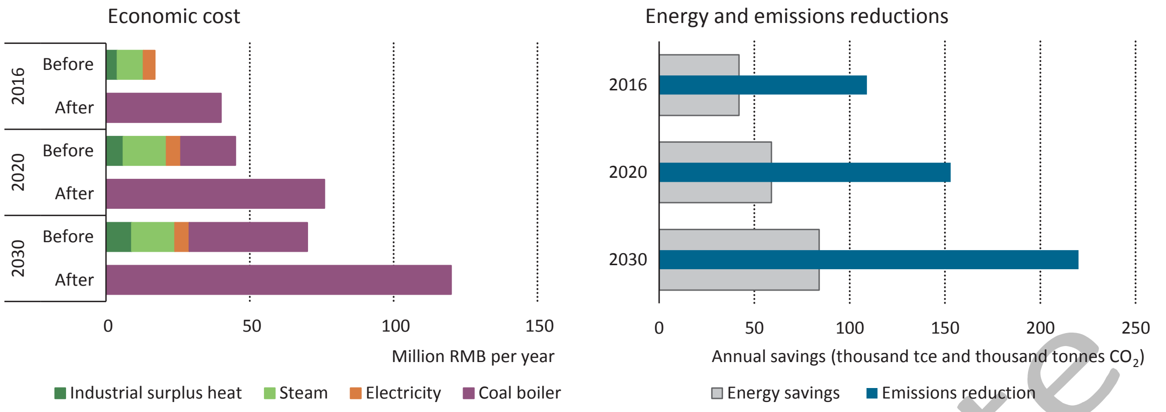
[32] The heat from mixed steam has traditionally been used to generate electricity in the steel mills, with a thermal efficiency of around 18%. Under the new integrated system, the steam is recovered for district heat, and electricity is therefore purchased from the grid to compensate the difference.

Figure 4.12 • Heat generation costs and energy and CO_2 emissions savings from waste heat recovery



Note: Steam and electricity purchases cost roughly 32.5 RMB per gigajoule and 0.65 RMB per kWh, respectively.

Source: TU, 2015, Feasibility Study

Key point • The Qianxi integrated district heat project demonstrates the energy, emissions and economic benefits of waste heat recovery potential in China for meeting buildings sector heat demand.

Conclusions and waste heat recovery potential for district heat in China

The Qianxi district heat project demonstrates the capacity for industrial waste heat recovery in district heating networks using cost-effective, integrated measures with reasonable payback periods (*i.e.* less than ten years) and considerable energy and emissions savings. Both the industrial (steel) companies and the district heat networks achieve improved profits because of the synergies provided by waste heat recovery, and the social benefits (*e.g.*, reductions in local pollutants and stable district heat costs) are considerable.

The Qianxi project also demonstrates the potential for industrial waste heat recovery in other parts of urban China with access to waste heat. Chinese crude steel production in 2013 was 779 million tonnes, with more than 60% of production in northern china where there also is a considerable potential for waste heat recovery for district heat consumption (NBS, 2014). For instance, Hebei, Shandong and Liaoning – where there are large district heat networks – have annual crude steel productions of 188 million tonnes, 61 million tonnes and 60 million tonnes, respectively.

Altogether, the potential heating power from waste heat recovery from the steel plants in northern China is estimated at 12.6 gigawatts. If urban areas with access to this heat were to apply integrated district heat with waste heat recovery systems similar to the Qianxi demonstration project, steel plants alone in northern China could meet the heat demand for as much as 631 million m^2 (assuming an average peak heating load of $40W/m^2$), saving as much as 5.3 million tce in traditional coal boilers. If other types of waste heat recovery (*e.g.*, other industrial waste heat and sewage) were recovered, the potential impact on energy and emissions savings could be even greater.

Investment synergies for low-carbon heating

The integration of modern district energy networks and renovated, energy efficient buildings in dense cold climate cities will require greater coordination and financial support to align appropriate clean energy, low-carbon solutions. The overwhelming majority of district heat networks today continue to have a business operation and investments approach that is driven by core economics (*i.e.* heat sales). Under this business model and market structure, building energy efficiency improvements are not necessarily advantageous to district heat operators.

However, integrated, advanced district heating can provide low- or zero-carbon heat to buildings in urban environments in support of energy and sustainability objectives, while still producing important revenue streams for district energy providers. This is especially true in most urban areas with existing district heat networks, where it will take as much as 30 to 40 years to fully renovate the existing building stock, even with extremely aggressive public policy to pursue deep energy renovation.

The challenge to transform district heating networks over time and to meet a more efficient buildings stock is not insurmountable, but will require engagement of district energy providers. If given the right incentives and market conditions, district energy networks can be the drivers of this process by taking a longer term, proactive position where they help serve as energy service providers or as system integrators. Long-term stability of policy strategy that incentivises energy efficiency, flexibility and innovation, and that enables fair market conditions to reward those choices, is needed to encourage uptake of integrated buildings energy efficiency and clean district heat (IEA, 2014). This includes policy and financial measures to reduce the risks of upfront investments in these types of projects.[33]

Recommended actions for the near term

The buildings sector – accounting for slightly less than one-third of final energy consumption and global CO_2 emissions when upstream power generation is taken into account – will play a vital role in any long-term strategy to shift the global energy economy to a sustainable, cost-effective and efficient 2DS pathway. Because of the long life of most buildings and many types of building equipment, urgent action is needed now to put the buildings sector on the right pathway to achieving energy efficiency and sustainability objectives. Urban areas, as home to more than half the world's population today and where nearly 65% of expected buildings sector floor area growth will occur, will play a critical role in meeting 2DS targets in the buildings sector and in the broader energy economy.

Key policy actions in the buildings sector can deliver significant energy savings and emissions reduction by stimulating widespread deployment of efficient energy technologies, including efficient building envelopes and advanced and renewable heating and cooling equipment. Prescriptive policies for low-energy new buildings construction are a necessary first step for all countries, and improved capacity building is needed in many countries to ensure that building codes compliance is standard practice. Deep building renovation measures for existing stock are also needed in many regions, including in particular OECD countries, where the bulk of buildings to 2050 are already constructed today.

Urban areas, through regulatory, planning and zoning functions, can play an important role in achieving building construction and renovation objectives. This includes local enforcement of mandatory construction and building renovation codes, working with local stakeholders to establish the right market conditions and policy frameworks to achieve energy efficiency potential, and supporting development of efficient and low-carbon energy communities through integrated energy technology solutions. Energy efficiency measures in buildings can also deliver numerous multiple benefits for local communities, including job creation, improved air quality, more affordable energy and improved access to stable, efficient energy networks.

Globally, continued efforts are needed to achieve high market penetrations of efficient building technologies, including high-efficiency appliances, lighting and equipment in buildings through

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[33] Further information on how policy and market regulations can help mitigate market failures in support of efficient, low-carbon heat supply can be found in the IEA report on *Linking Heat and Electricity Systems: Co-Generation and District Heating and Cooling Solutions for a Clean Energy Future* (IEA, 2014).

MEPS and product regulations. While most building technologies and policies are not exclusive to urban areas, cities can nevertheless play an important role in meeting objectives related to energy efficiency in buildings through local initiatives and awareness programmes, energy performance rating and reporting schemes, and through engagement with local buildings stakeholders to ensure that efficient products are available and used as standard practice.

The integration of modern district energy networks and energy efficient buildings is an important opportunity in dense urban areas, especially in cold climate cities where there are cost-effective, technically feasible integrated solutions that can put the buildings sector and local energy network on a sustainable and efficient 2DS pathway. This will require greater coordination of stakeholders and strategic policy development, including financial support to create a long-term stable market environment that incentivises energy efficiency and flexibility.

Further research of district heat modernisation and the effects of deep efficiency improvements in buildings is needed, including greater assessment of the effects of energy efficiency policies, climatic variations and varying energy prices on achieving a lower carbon footprint across the buildings sector and broader energy economy. This includes additional assessment of the market and regulatory barriers on both the local and national levels that either encourage or hinder the pursuit of more optimised, integrated sustainable local energy systems.

Opportunities for policy action

National policies have a substantial leverage to enable effectiveness of urban sustainable energy planning, especially through fiscal policies (*e.g.*, tax incentives, housing loans and third party financing), national land use planning frameworks and capacity building programmes that can enable local decision makers to pursue appropriate urban planning and energy efficiency measures. Greater support of local energy efficiency actions is needed from national governments to encourage widespread deployment of cost-effective energy efficiency measures in the buildings sector. This includes building the right policy and market conditions for energy efficiency action, promoting advanced building components through appropriate pilot and demonstration programmes, and in the short- to medium-term providing financial incentives to help establish market demand.

With national support, city governments can lead on the critical tasks of achieving high building codes compliance for new construction and a global uptake of deep energy renovation in existing buildings. This includes deep renovations in public and municipal buildings as well as creating incentives and local energy efficiency programmes that support deep energy renovations in the private sector. Action in this area is critical over the coming decade to ensure that the process becomes widely available and is standard practice.

Support for local energy efficiency action responsive to specific urban needs and market conditions is needed to make advanced, integrated district heating and cooling solutions with energy efficient buildings a reality. National policy design and support that enables flexibility and innovativeness is one critical item that can help move this area along, as can continued financial incentives and programme support (*e.g.*, partial or total loan financing mechanisms) to demonstrate the potential for coordinated building efficiency and district energy integration.

Last, data, and a more acute sense of building energy needs and opportunities, are valuable tools that both national and local governments can use to shape policy decisions and prioritise energy efficiency efforts. Data can also play a critical role in targeting the right stakeholders on both the local and national scale to increase adoption of energy efficiency. Greater effort to improve global understanding of buildings sector energy performance and efficiency therefore should be a priority across all countries to ensure the right measures to put the buildings sector on an efficient, sustainable and cost-effective 2DS pathway.

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