Achieving Zero-Carbon Buildings:

Electric, Efficient and Flexible

Executive Summary | February 2025 | Version 1.0

Energy
Transitions
Commission

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. The ETC is chaired by Lord Adair Turner who works with the ETC team, led by Faustine Delasalle (Vice-Chair), Ita Kettleborough (Director), and Mike Hemsley (Deputy Director).

The ETC's, *Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible*, was developed by the Commissioners with the support of the ETC Secretariat, provided by Systemiq. This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this publication but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse this briefing paper.

In addition to this report and accompanying executive summary, we will also be publishing Infographics and Toolkits, outlining how to decarbonise the energy used to operate commercial and residential buildings, reduce embodied carbon from new buildings, and accelerate the buildings energy transition.

The ETC team would like to thank the ETC members, member experts and the ETC's broader network of external experts for their active participation in the development of this report.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organisations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2°C. Many of the key actions to achieve these goals are clear and can be pursued without delay.

This report should be cited as: **ETC (2025), *Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible.***

Learn more at:

www.energy-transitions.org
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Executive Summary

The use of energy and materials in constructing and operating buildings results in ~12 $GtCO_2$ a year, or a third of all global emissions.[1] Any strategy to achieve net-zero emissions by mid-century must therefore include dramatic reductions in those from the buildings sector.

This ETC report on building decarbonisation assesses the emissions reduction potential across all types of buildings and considers carefully how the challenge differs by region. In particular:

- It considers both the emissions resulting from the operation of buildings (i.e. the energy from fossil fuels used for heating, cooling, cooking, lighting, and appliances), and the embodied emissions which result from constructing, maintaining and demolishing buildings.
- It assesses the relative importance of actions to decarbonise building materials and energy supply (e.g., switching from gas boilers to electric heat pumps), and actions to reduce the demand for energy and materials (e.g., via improved building design and insulation, and changes in consumer behaviour).
- It assesses the implications of building decarbonisation for both total electricity demand and peak electricity demand, and the potential for investments and choices at the building/household level to reduce electricity system costs by shifting demand away from peak periods.

The main report addresses the different types of building and energy use in 13 chapters as shown in the table of contents.

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[1] IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.* Global emissions includes those from the energy, buildings, industry and transport sectors.

Table of contents and mapping to chapters in the main report

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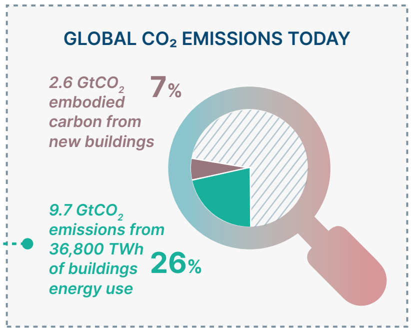
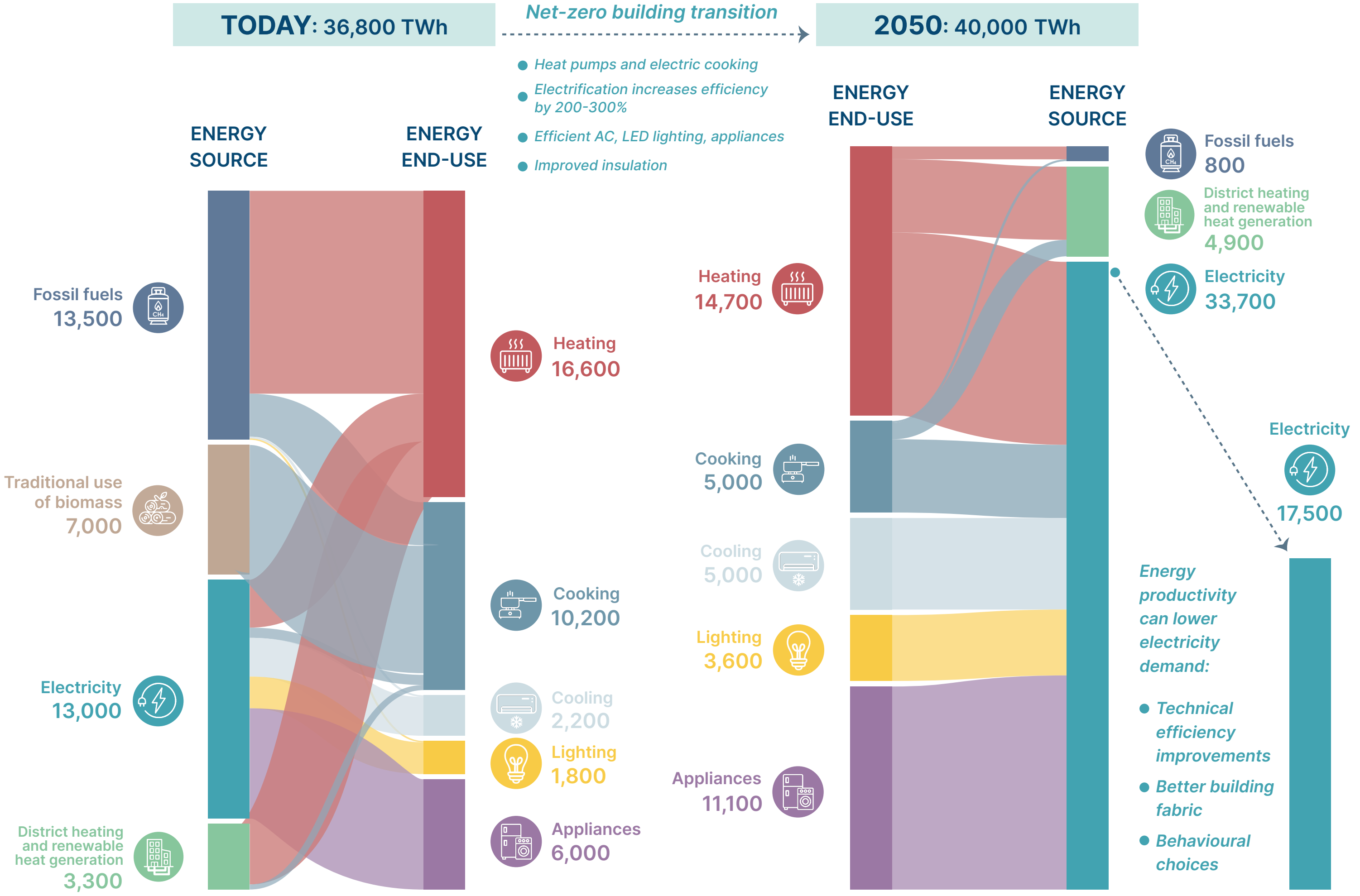
DECARBONISING THE ENERGY USED IN RESIDENTIAL AND COMMERCIAL BUILDINGS



Achieving zero-carbon buildings: Electric, efficient and flexible

ANNUAL FINAL ENERGY CONSUMPTION USED IN BUILDINGS

TWh



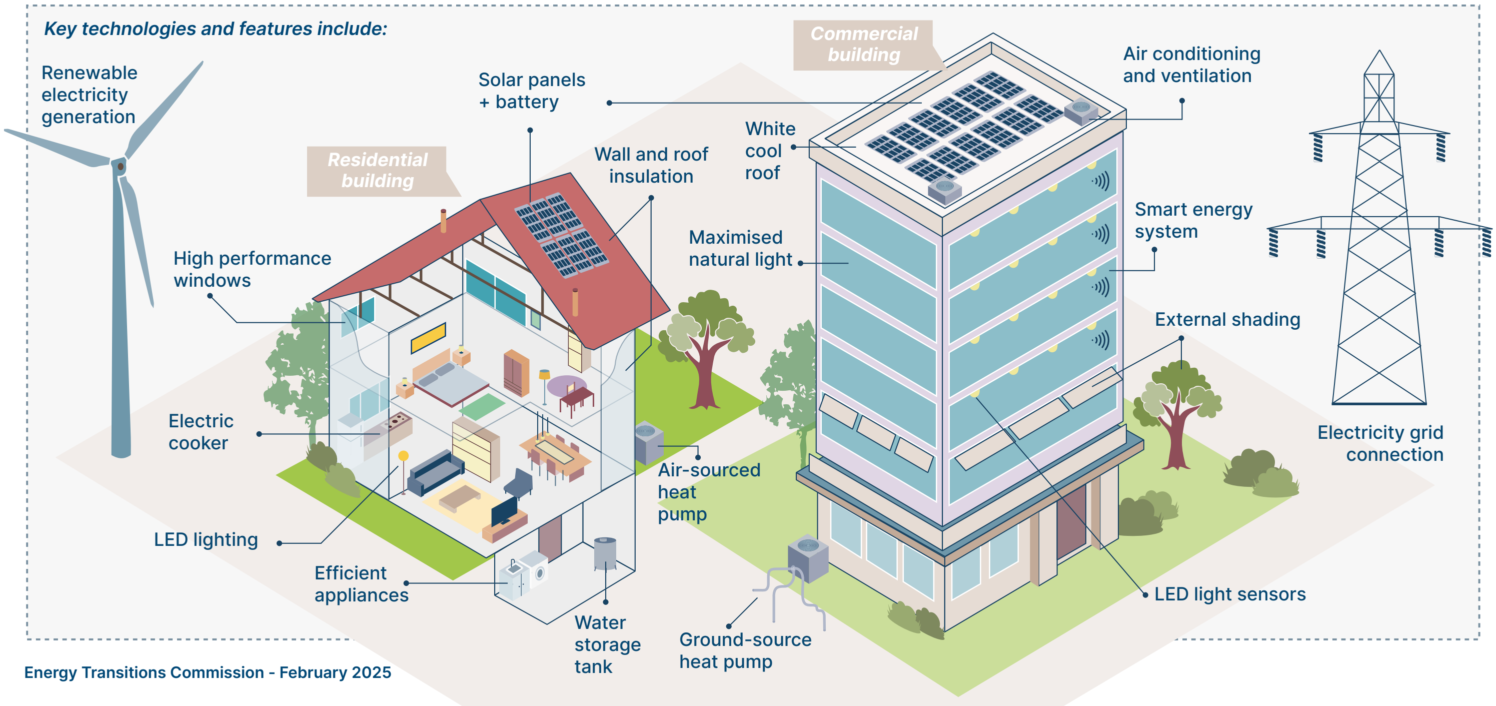
- Heat pumps and electric cooking
- Electrification increases efficiency by 200-300%
- Efficient AC, LED lighting, appliances
- Improved insulation

Energy productivity can lower electricity demand:

- *Technical efficiency improvements*
- *Better building fabric*
- *Behavioural choices*

Electric, efficient and flexible buildings: What will it look like?

Key technologies and features include:



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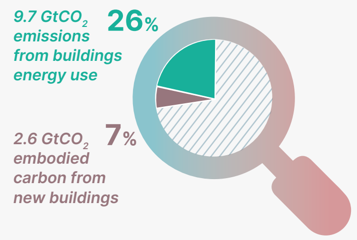
REDUCING EMBODIED CARBON FROM NEW BUILDING CONSTRUCTION

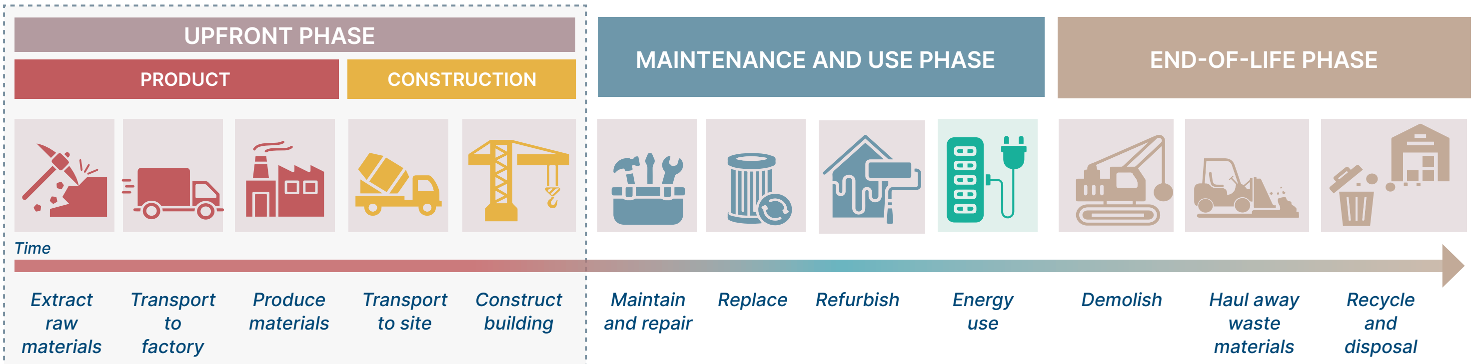
GLOBAL CO_2 EMISSIONS TODAY



Embodied carbon: what is it?

STAGES OF A BUILDING LIFECYCLE

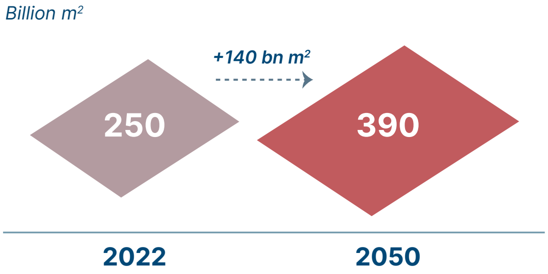
Type of building emissions: ▨ *Embodied* ▨ *Operational (heating, cooling, cooking, lighting, appliances)*



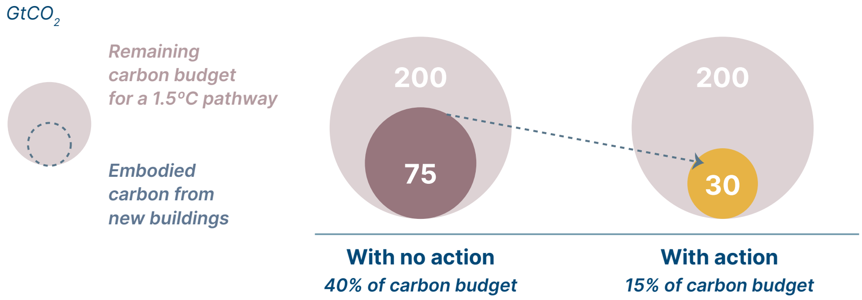
Priority: Reduce use of high-carbon steel, cement and concrete

Reducing emissions from the construction of new buildings is critical

GLOBAL FLOOR AREA IS SET TO EXPAND BY 50%

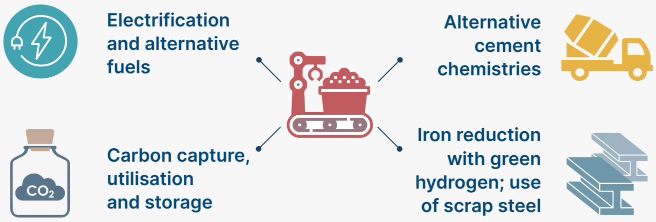


WITH NO ACTION, NEW FLOOR AREA COULD PRODUCE 75 $GtCO_2$



What action is needed?

DECARBONISE STEEL AND CEMENT/CONCRETE



Electrification and alternative fuels

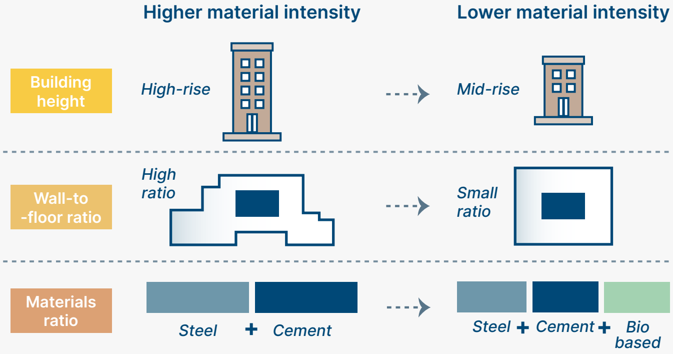
Alternative cement chemistries

Carbon capture, utilisation and storage

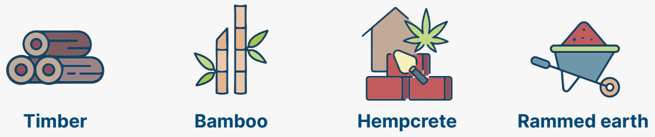
Iron reduction with green hydrogen; use of scrap steel

BUILD LESS & BE MORE EFFICIENT IN CONSTRUCTION

USE LESS CEMENT, CONCRETE AND STEEL



USE ALTERNATIVE, LOW-CARBON MATERIALS



3 conditions for bio-based materials to have lower whole-life carbon:

① **Sustainably sourced**: *Harvested at the right time and replanted*

② **Store carbon** *while in building*

③ **Dealt with properly at end-of-life**: *Recycled or burnt with carbon capture*

1. The scale of the challenge: Building energy use and emissions

Buildings accounted for 12.3 GtCO$_2$ in 2022, resulting from [Exhibit 1]:[2]

- **Emissions from the operation of buildings: 9.8 GtCO$_2$ or 26% of global emissions.** The direct use of fossil fuels, which includes the use of gas and oil for heating and TUOB for cooking in low-income countries, accounts for 3 GtCO$_2$ (8%). The indirect use of fossil fuels for electricity used in buildings accounts for 6.8 GtCO$_2$ (18%). Operational emissions are produced by the world's total stock of buildings, around 250 billion m^2.[3]

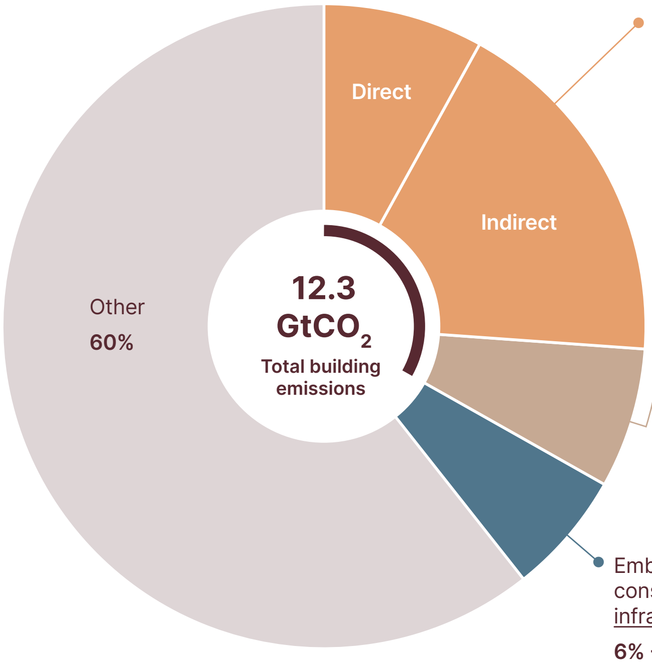
- **Emissions from the construction of new buildings: 2.5 GtCO$_2$ or 7% of global emissions.** These emissions are referred to as **embodied carbon** and arise from the production of materials - predominantly steel and cement/concrete - and the use of fossil fuels in transportation and construction. Embodied emissions come from the additions to the global building stock in a given year, around 5 billion m^2.[4]

Exhibit 1

Buildings account for 33% of global emissions; around three-quarters of this from the energy used to operate buildings, a quarter is from the annual construction of new buildings

Global emissions by sector, 2022

GtCO$_2$



Emissions from buildings operational energy use

Generated from:
~250 bn m^2 - the current stock of global buildings

26% - 9.7 GtCO$_2$

Embodied carbon from new building construction

Generated from:
~5 bn m^2 a year - the annual additions to global building stock (~2% per year growth)

7% - 2.6 GtCO$_2$

Embodied carbon from construction of new infrastructure

6% - 2.3 GtCO$_2$

***Direct use** of fossil fuels in buildings (e.g., gas and oil boilers and stoves)*

***Indirect use** of fossil fuels used to generate electricity to power, heat and cool buildings*

***Embodied emissions** arise from the production of materials (e.g., cement, steel, and aluminium) and the energy used to construct buildings*

NOTE: This shows annual carbon flows as opposed to stock. Infrastructure includes roads, pipes, airports, railways.

SOURCE: IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.*

[2] IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.*
[3] IEA (2023), *World Energy Outlook 2023.*
[4] Ibid.

Operational energy

Energy is used in buildings for five end-uses [Exhibit 2]:[5]

- **Heating** is the biggest source of operational emissions in buildings, accounting for 45% of final energy use in buildings and 80% of direct fossil fuel use.

- **Cooking** accounts for a further 15% of direct fossil fuel use. However, cooking is largely driven by TUOB in lower-income countries.[6] TUOB is highly inefficient (as little as 10% of energy used is converted to useful heat), meaning cooking is the second largest component of final energy demand in the building sector (~30%).

- **Cooling, lighting and appliances** are already over 95% electrified, thus the majority of emissions result from the indirect use of fossil fuels to generate electricity. Appliances account for ~15% of final energy demand, which equates to 8% of total global emissions. Cooling and lighting each account for ~5% of final energy demand and 2–3% of global emissions. However, cooling is set to the be the fastest growing source of energy demand from buildings over the coming decades, with major implications for sector emissions if clean electrification does not keep pace and if refrigerant leakage is not managed.

These global averages mask significant variation across countries and building types:

- Some parts of the world, such as Africa, have no or very little heating needs, while others, such as parts of Canada and the Nordic countries, have very low cooling needs. Many countries, including China, the US, and parts of Europe, have seasonal heating and cooling needs.

- Residential buildings account for 60% of operational emissions, despite comprising 80% of global floor space.[7]

- Commercial buildings – a diverse group of buildings, including offices, hotels, restaurants, hospitals and schools – make up 20% of global floor space but produce 40% of operational emissions.

Overall, 35% of total energy use in buildings is electrified, meaning that as the power sector is decarbonised, operational emissions will fall in turn.

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[5] IEA (2022), *World Energy Outlook 2022.*

[6] TUOB refers to the use of solid biomass (e.g., wood, wood waste, and charcoal) with basic technologies (e.g., open fires and basic stoves).

[7] IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action*; IEA (2023), *World Energy Outlook 2023.*

Embodied emissions

Global floor area is set to increase 55% by 2050, from 250 billion m^2 to 390 billion m^2, which will drive significant demand for steel, cement, and concrete.[8] If there were no change in today's global average embodied carbon intensity (0.5 $GtCO_2$ per billion m^2), constructing this additional 140 billion m^2 would generate ~75 $GtCO_2$.

Embodied emissions arise from a wide variety of processes, materials, and machinery used to construct buildings. Estimates for embodied emissions in specific buildings or categories of building are subject to greater uncertainty than those for operational emissions. This reflects wide variation in the way buildings are built, the materials used, and the lack of a consistent measurement framework.

Most embodied emissions derive not from activities conducted at the building site, but from the production of the materials used - and 95% of these emissions result from the production of iron/steel and cement/concrete.[9]

As will be discussed in Section 9, the two most important levers to reduce embodied emissions are therefore decarbonising the production of steel and cement/concrete, and building in ways that use less of these materials.

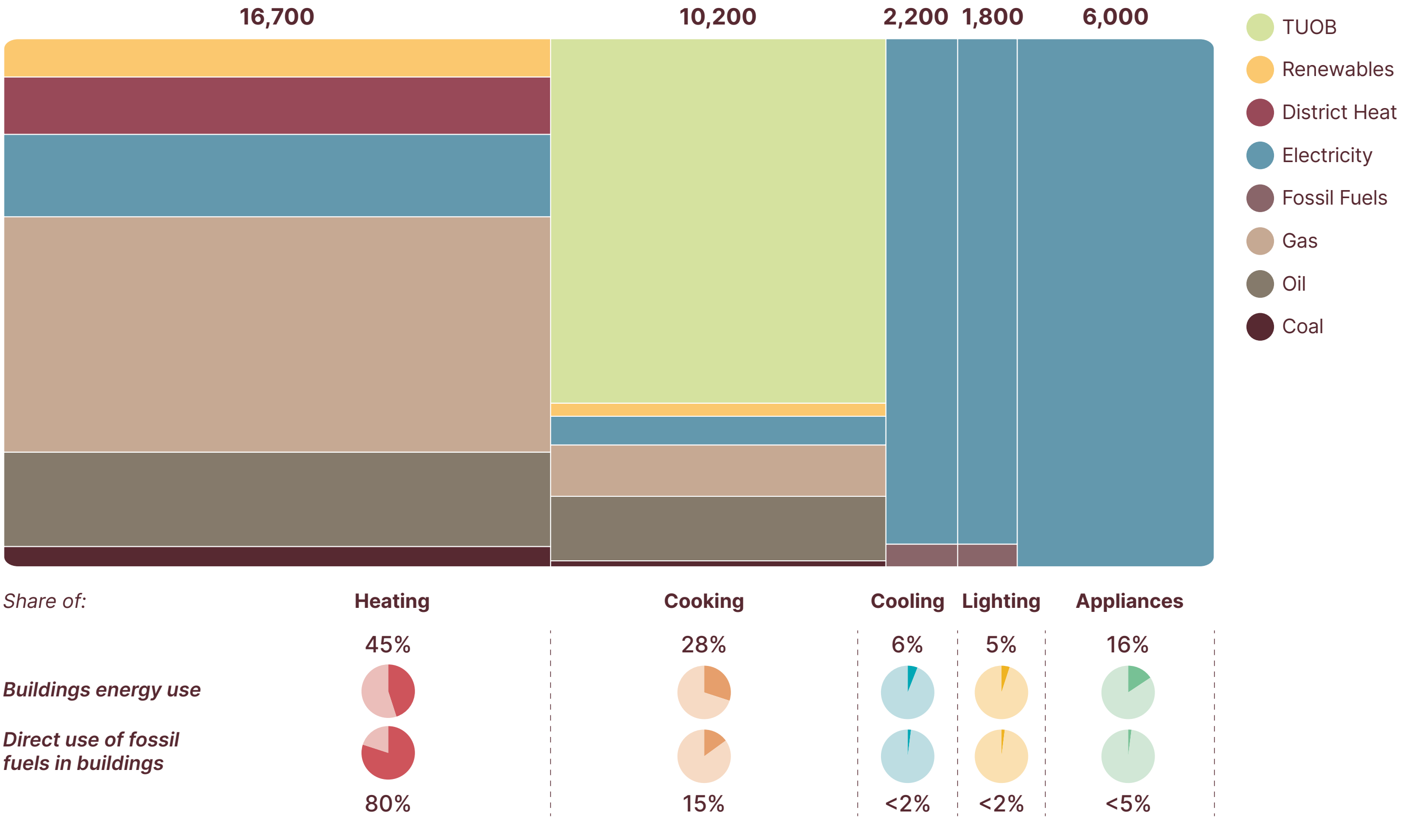
Exhibit 2

The direct use of fossil fuels in buildings accounts for ~40% of energy use, followed by electricity at 35%, and the traditional use of biomass for cooking at 20%

Global buildings operational energy use by end-use and fuel, 2022

TWh

Total buildings energy use ~37,000 TWh



NOTE: Shares of building energy by end-use from 2021 applied to 2022 actuals. Heating includes both space and water heating. TUOB = traditional use of biomass.

SOURCE: Systemiq analysis for the ETC; IEA (2022), *World Economic Outlook 2021*; IEA (2023), *World Economic Outlook 2022*.

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[8] IEA (2023), *World Energy Outlook 2023*.

[9] WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

2. Overall conclusions: Supply- and demand-side levers to reduce operational and embodied emissions

Both the emissions from energy used to operate buildings and embodied emissions can be reduced with either "supply-side" or "demand-side" levers.

- For operational emissions, "supply-side" means changing the energy input used for heating and cooking from fossil fuels or TUOB to electricity, while also decarbonising electricity generation. "Demand-side" means actions which enable people to enjoy the same level of heating, cooling, lighting and appliance output while using less energy.

- For embodied emissions, "supply-side" primarily means decarbonising the production of the key materials used, while "demand-side" primarily means designing buildings in ways that reduce the quantity of materials required.

Both operational and embodied emissions could be reduced to close to zero by mid-century using a combination of supply- and demand-side levers. For each, demand-side levers have a particularly important role to play in reducing cumulative emissions in the period before full supply-side decarbonisation can be achieved, which is critical to limiting the increase in global temperatures as close to 1.5ºC as possible.

Feasible reductions in operational energy use and emissions

As Exhibit 2 shows, total building operational energy use is currently around 37,000 TWh, of which 13,800 is the direct use of fossil fuels, 12,800 TWh is electricity, and 7,000 TWh is TUOB in cooking.[10] And as Exhibit 1 shows, this energy use results in 3 $GtCO_2$ from the burning of fossil fuels and TUOB for heating and cooking, and 6.8 $GtCO_2$ from the combustion of fossil fuels (and a small amount of biomass) to generate electricity.

Exhibit 3 shows a technically feasible scenario for the evolution of building operational energy demand between now and 2050. If neither the mix of energy sources nor the efficiency of their end-uses change, population and income growth could result in a 55% increase in energy consumption for buildings, approximately 57,500 TWh by 2050. And if the carbon intensity of electricity generation were also unchanged, this would imply and equal 55% increase in emissions.

But a combination of electrification, improved energy productivity, and the decarbonisation of electricity generation can reduce emissions to close to zero by mid-century:

- Electrification will account for the largest share of this reduction due to its inherent efficiency advantage:

    - Residential heat should be almost entirely electrified, significantly reducing the required energy input to achieve any level of heating comfort, given the superior efficiency of heat pumps vs. gas boilers which is explained in Section 3.

    - Electricity will also eventually replace the hugely inefficient use of traditional biomass as a cooking fuel in low-income countries. Although it is important to note that during the transition to this endpoint, there will initially be a significant shift from TUOB to fossil fuels. This is discussed in Section 5.

- In addition, there are major opportunities to improve the technical efficiency of electrical technologies, whether used in the applications which are already entirely electrified (cooling, lighting, and appliances) or in newly electrified heating or cooking.

- And three other categories of energy productivity improvement could reduce the amount of energy required to deliver any given standard of living. Better building design and construction, particularly improved insulation, could cut energy requirements in 2050 by 3,600 TWh. Improvements to existing buildings, particularly in high-income countries, could deliver a further 1,700 TWh reduction. And changes in consumer behaviour, such as setting thermostats at optimal cooling/heating levels could, in this scenario, deliver a further 1,500 TWh reduction.

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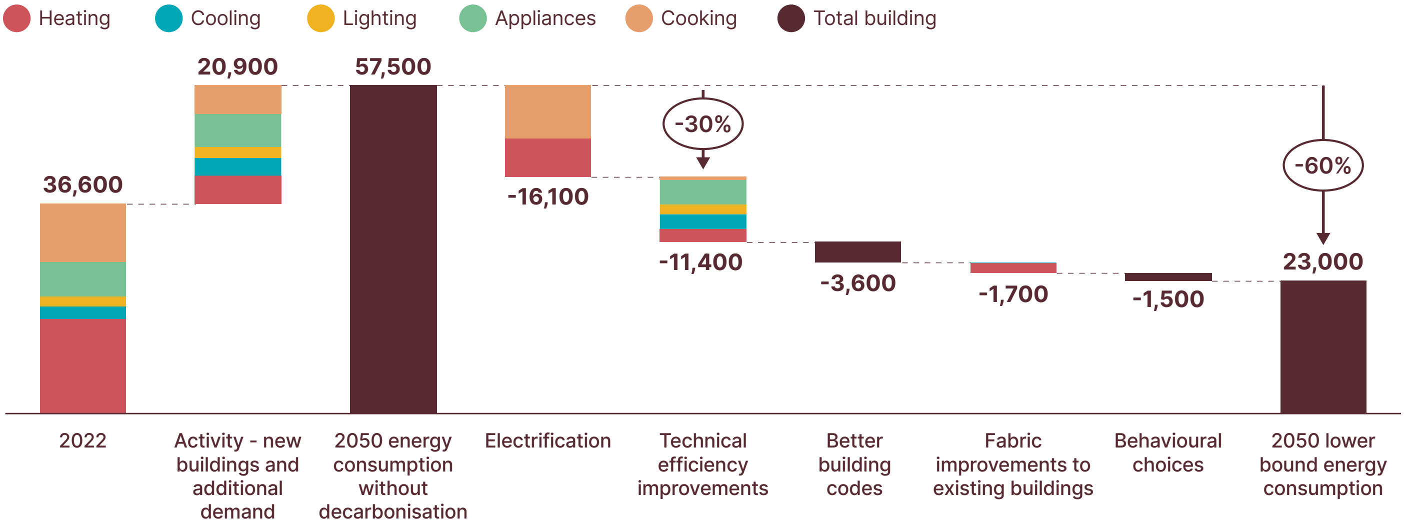
[10] Systemiq analysis for the ETC; IEA (2021), *World Economic Outlook 2021*; IEA (2022), *World Economic Outlook 2022*.

Exhibit 3

Electrification, technical efficiency gains, and improving building fabric could reduce final energy demand by 60%

Impact of energy productivity on final energy demand in 2050 – residential + commercial buildings
TWh



NOTE: The increase in activity to 2050 includes both an increase in fossil fuel energy use (e.g., new fossil fuel boilers and cookers largely in lower-income countries) and new electric heating and cooking appliances, largely in high-income countries and China. The electrification lever then refers to the transition of the existing stock of fossil fuel heating and cooling to clean technologies.

SOURCE: Systemiq analysis for the ETC; IEA (2023), *World Energy Outlook 2023*; IEA (2021), *Net Zero by 2050*.

The significance of these energy productivity levers is, however, greater than their relative size in Exhibit 3 might suggest for three reasons:

- First, because as Section 8 will discuss, they could significantly reduce total electricity demand in 2050, making it easier to build new renewable generation capacity and grids fast enough to meet growing demand.
- Second, and crucially, because these levers could significantly reduce peak electricity demand which is a major driver of total electricity system costs.
- Third, because reductions of electricity demand will translate into big emissions reductions in the decades before complete electricity decarbonisation has been achieved.

All of the levers together could, in principle, reduce total building energy use to ~23,200 TWh by 2050, of which 18,600 TWh would be electricity, with a small and declining role for fossil fuels, plus some modern biomass applications. The final additional lever to achieve zero emissions from buildings is therefore the decarbonisation of electricity generation.

Feasible reductions in embodied emissions

As Exhibit 1 showed, embodied emissions arising from the construction of buildings amount to 2.6 $GtCO_2$ per year, with another 2.2 $GtCO_2$ resulting from the construction of infrastructure.[11] The vast majority of these emissions result from the production of the materials used in construction, in particular steel and cement/concrete.

Decarbonisation of the production of steel, cement/concrete, aluminium, glass, and bricks is therefore essential and the work of the Mission Possible Partnership shows that near total decarbonisation could, in principle, be achieved by mid-century. If combined with the electrification of construction-related transport and other activity, and the decarbonisation of electricity supply, this would result in zero embodied emissions in new buildings built after 2050.

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[11] IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.*

But there are significant opportunities to reduce the actual quantity of cement/concrete, steel, and other materials used per m² of building construction, and these should also be pursued as aggressively as possible for two reasons:

- First, because they will play a crucial role in reducing emissions in the period before the full decarbonisation of material production. Exhibit 4 shows a scenario in which these demand-side measures account for a sixth of the reduction in total cumulative emissions (from now to 2050) even if material production is rapidly decarbonised to achieve net-zero by 2050. But if the decarbonisation of material supply is delayed, demand-side levers which reduce the quantity of materials would become even more important.
- Second, because many of the measures taken to reduce material use would be cost-effective, reducing costs for building owners and occupiers. They would also reduce total global demand for key raw materials such as iron ore and limestone.

Achieving the demand-side potential

For both operational and embodied emissions, demand-side levers are crucially important alongside the supply-side actions, such as electrification, the decarbonisation of material production, and the decarbonisation of electricity generation.

There are, however, multiple barriers which could make it difficult to achieve the full scale of the energy productivity and material efficiency improvements indicated in Exhibits 3 and 4. In particular, the ability to enforce effective building codes varies greatly across the world and can only gradually be improved.

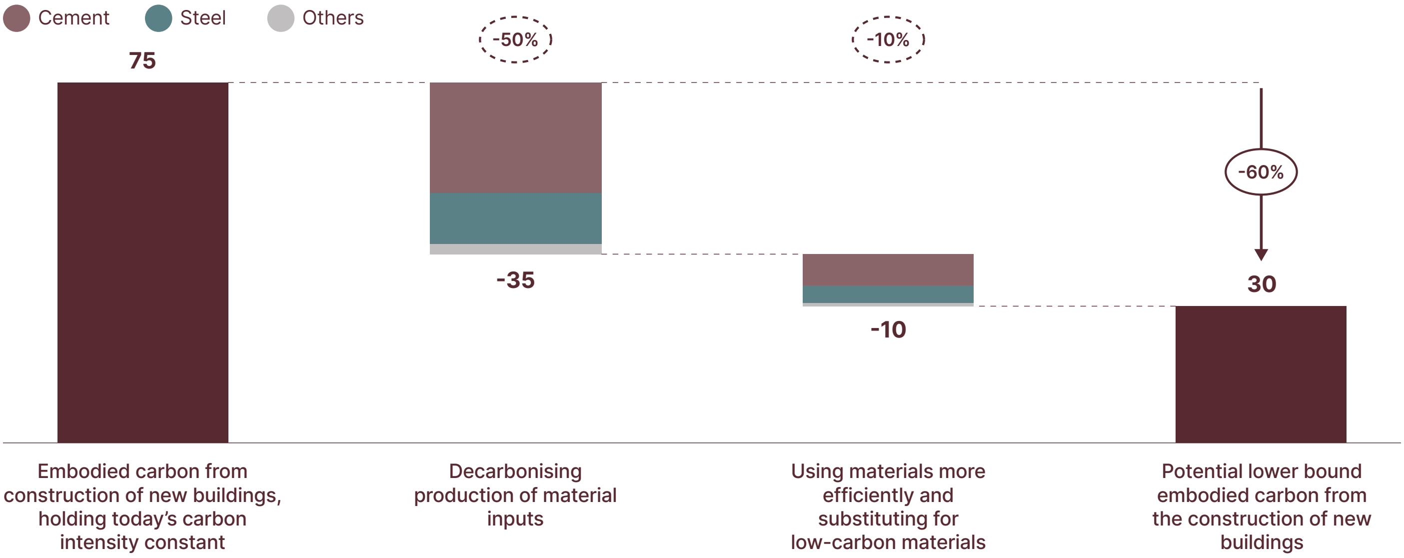
The scenarios presented in Exhibits 3 and 4 should therefore be taken as indicative of the size of the prize that could be available with forceful and effective policy design and implementation. In reality, only some proportion of this potential will be achieved.

The decarbonisation of buildings will imply a big increase in electricity use. National strategies must therefore assume that much larger and fully decarbonised power systems will be at the core of any path to a net-zero emissions economy.

Exhibit 4

The total embodied carbon from building 140 billion m² by 2050 could be reduced by 60% with action to decarbonise material inputs and with material efficiency and substitution

Potential reduction of embodied carbon from the construction of new floor space, cumulative emissions 2023–50
GtCO₂e



SOURCE: Systemiq analysis for ETC; MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.

3. The heating decarbonisation challenge: How electrification and cost-effective insulation can displace fossil fuels

Emissions today	Energy use today	Energy use in 2050	
		Baseline with electrification	*+ energy productivity*[12]
4.1 GtCO₂ *10% of global emissions*	16,700 TWh	14,000–15,000 TWh	8,000–13,000 TWh *But relies on strong policy action*

Space and water heating accounts for 45% of total energy use in buildings, but 80% of direct fossil use.[13] While household and businesses across the world need to heat water, space heating is concentrated in northern latitude countries with significant winter heating needs [Exhibit 5]. The most important decarbonisation challenge for the buildings sector is how to decarbonise space heating in these colder countries.

Achieving this requires both:

- Replacing the direct use of fossil fuels in buildings with clean heating technologies, primarily electricity and primarily with heat pumps, which have a significant efficiency advantage.
- Reducing household and commercial energy demand for space heating, particularly peak energy demand, via improved insulation and smart energy management systems.

Replacing fossil fuels with clean heating technologies – primarily electric

There are multiple clean heating technologies which could be deployed and multiple types of new and existing residential and commercial buildings (e.g., apartments, terraced and detached houses, restaurants and offices). Technologies, options for improved insulation, and the ease with which they can be deployed vary greatly between buildings. But despite this huge variety of individual circumstances, it is clear that:

- Electrification should dominate the decarbonisation of building heating with some variant of electric heat pump deployed wherever possible.
- Heat pumps are a viable option in most buildings – claims that they cannot work in existing buildings without very extensive insulation are overstated.
- Heat pumps are already cost competitive vs. fossil fuels in many countries; but in others, the high cost of electricity compared to gas is an impediment to rapid progress.

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[12] Technical efficiency improvements to heat pumps, better new buildings, fabric retrofits to existing buildings, and behavioural choices.

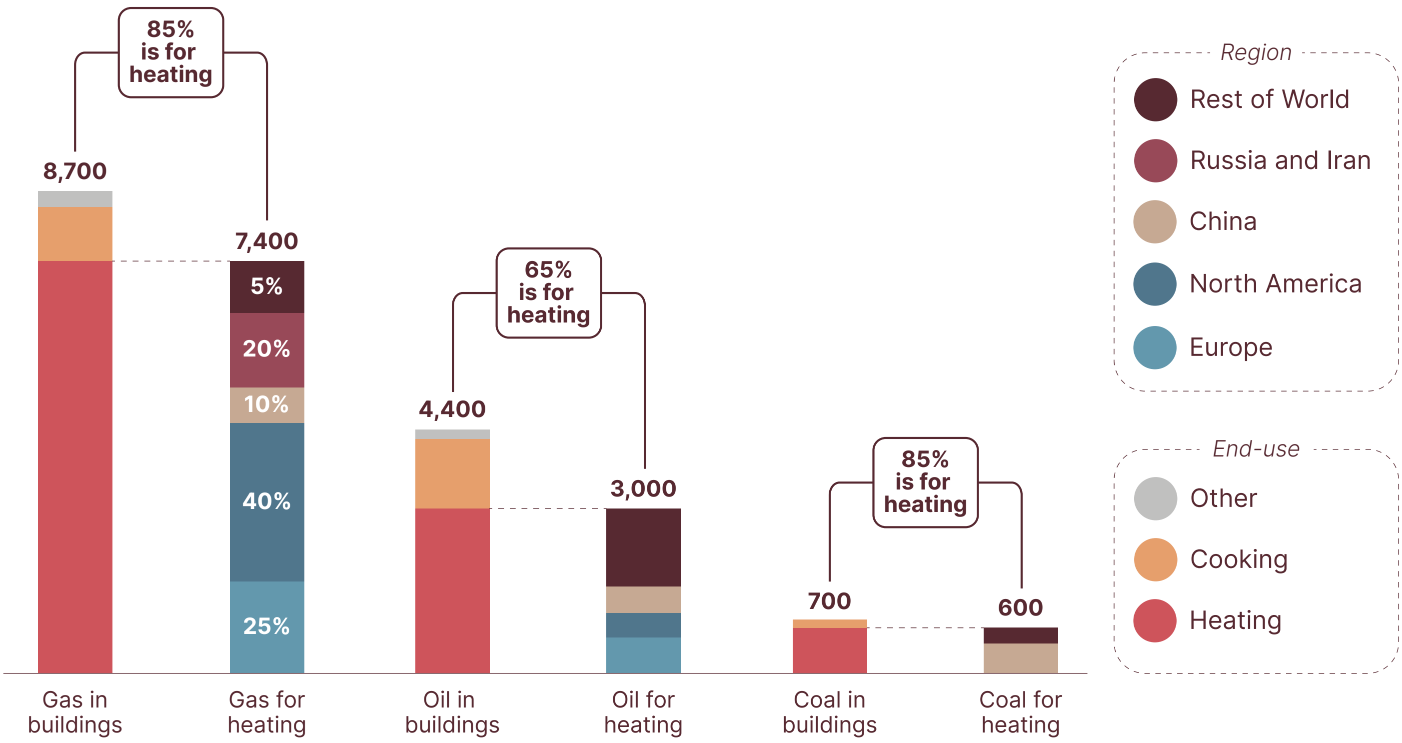
[13] IEA (2022), *World Energy Outlook 2022.*

Exhibit 5

The pace of heating decarbonisation is predominately a question of how fast gas and oil use in Europe, North America and China can be electrified

Fossil fuel use in buildings by end-use and region, 2022
TWh

Total fossil fuel energy use for heating = ~11,000 TWh



NOTE: Heating includes both space and water heating. Other includes building cooling, lighting and appliances. Russia and Iran are included in Rest of World for oil and coal.

SOURCE: Systemiq analysis for the ETC; IEA (2022), *World Economic Outlook 2021*; IEA (2023), *World Economic Outlook 2022*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center (2018), *Annual Report of Building Energy in China*.

Multiple heat pump variants as the dominant solution

There are multiple variants of heat pumps – including air-to-air, air-to-water, ground-to-water, and a number of networked options – but all enjoy a significant efficiency advantage over other heating technologies, delivering multiple kWh of heat into a building per kWh of electricity [Exhibit 6]. The Annex to the main report explains the fundamental technology and the variants.

This fundamental advantage means that heat pumps should be deployed wherever feasible, with the optimal specific variant of heat pump technology reflecting local conditions. Air-to-air systems are likely to dominate in countries which also have significant cooling needs, since reversible heat pumps can be deployed to provide both heating in winter and cooling in summer. Air-to-water heat pumps will dominate in countries which already have "wet" home heating systems (i.e. the circulation of hot water via radiators). Ground-source heat pumps are inherently very efficient and should be deployed wherever possible, especially in new builds.

There is a huge untapped potential for heat networks, which deliver heat to multiple buildings from the same heat source, to be deployed. These range from networked ground-source heat pumps serving blocks of flats, to large-scale district heat networks serving hundreds or thousands of buildings using a combination of heat pumps with secondary heat sources or geothermal heat.[14] These are significantly more efficient and can be very cost-effective in urban areas.

Alongside the deployment of heat pumps as the dominant solution, other technologies should play niche or complementary roles:

- Electric resistive heating, which generates heat by passing an electric current through a resistor, will play a dominant role in water heating across the world, and a supplementary role in space heating where heat pumps are unsuitable, unfinanceable, or where households would rather incur higher running costs to avoid the changes to their home which heat pump installation would require. Extensive use of resistive heating will, however, significantly increase both overall and peak electricity demand, and policy should therefore strongly favour the installation of heat pumps.

- Solar thermal systems are an efficient and cost-effective solution for water heating in locations with strong solar radiation, but they cannot deliver space heating.

- Biobased fuels can play a useful role in specific circumstances. Bio-methane could be used in countries with large bio-resources, and the direct burning of sustainably produced biomass (whether in district heating systems or in individual household wood burning stoves) can play some role but has adverse local air quality effects via particulate matter and nitrogen dioxide. As a result, it will be subject to increasingly tight regulations which will limit its application.

- Hydrogen is not a viable alternative to replace gas heating in individual homes: it is much less efficient (e.g., green hydrogen would require 5–6 times more electricity than heat pumps), would still require substantial retrofit to boilers and the gas network, and would likely not be scalable until the mid-2030s. It may, however, play a role in district heating systems, located close to green hydrogen production and where supply pipelines can be guaranteed.

Heat pumps myths, realities and technological progress

Despite the inherent technological advantage of heat pumps, the deployment is in some countries, such as the UK, held back by misinformation about their capabilities. In particular, it is important to counter two myths.

- **"Heat pumps don't work in cold climates":** It is true that the efficiency of air-to-air or air-to-water heat pumps declines as air temperature declines, but the impact at all but the most extreme temperatures is sufficiently small that it does not undermine the case for air-based heat pumps in almost all climates. Refrigerants remain liquid at very low temperatures (e.g., below −30°C), meaning they can extract heat even in sub-zero temperatures. Ground-source heat pumps are unaffected by air temperature. As a result, Norway and Finland – which have average January temperatures of around −8°C – have the highest number of heat pumps per 100 households in the world, at more than 40.[15]

- **"Heat pumps won't work in old buildings without very extensive expensive retrofit":** Given the lower temperatures at which heat pumps typically operate, it is often asserted that they cannot deliver sufficient warmth to offset rapid heat loss from poorly insulated buildings. However, this argument has been hugely overstated, as long as radiators and heat pumps are properly sized. In addition, high-temperature heat pumps, which can reach temperatures of around 65°C, are increasingly available on the market.

Rather than these two issues, the crucial challenges relating to heat pumps are:

- The space availability within the house to install a hot water cylinder, the need for larger radiators in air-to-water systems, and the space available outside the house for the heat extraction unit.

- Their cost competitiveness versus fossil fuel-based heating systems and how this varies for different households.

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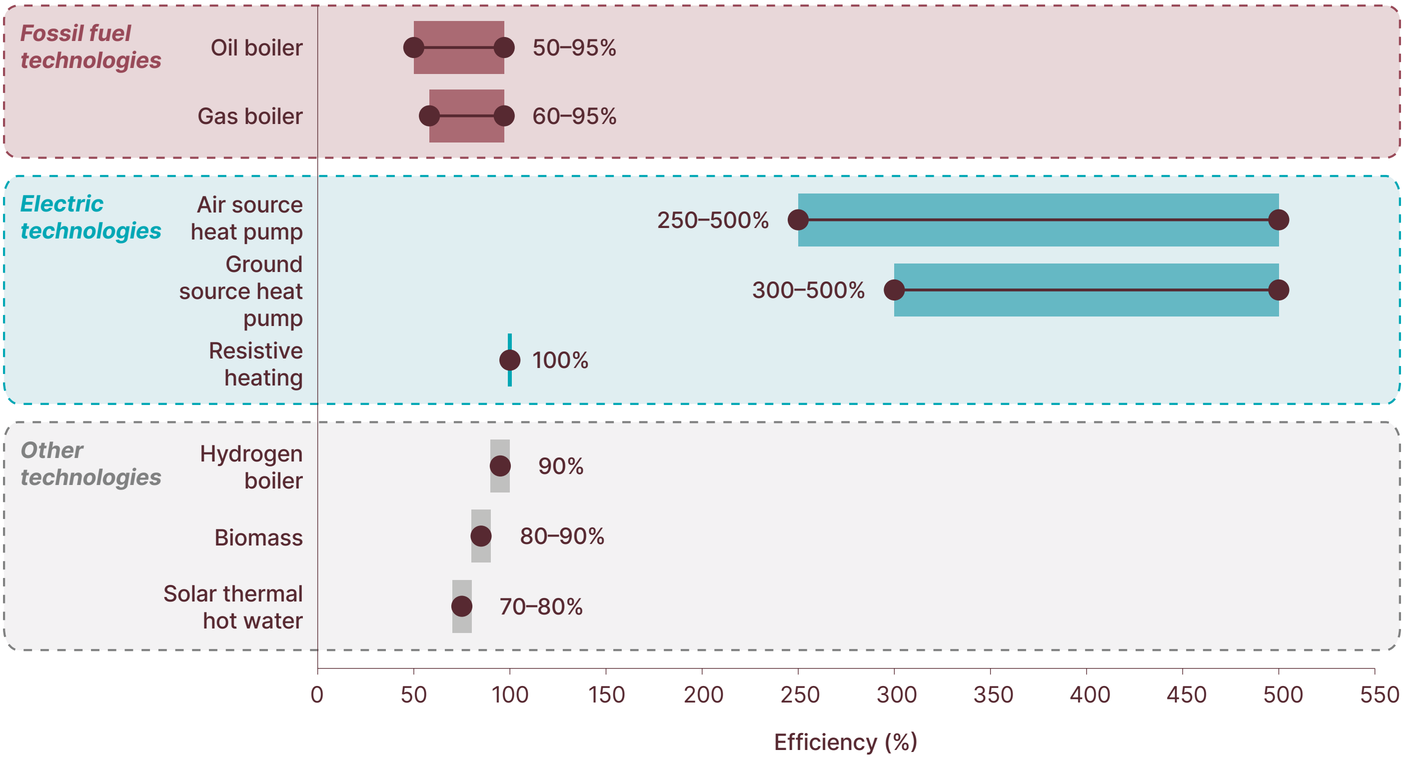
[14] Networked ground-source heat pumps use shared ground arrays which circulate low-temperature heat (e.g., around 20°C) to individual heat pumps in homes, which then upgrade the heat to around 50–65°C.

[15] Carbon Brief (2024), *18 misleading myths about heat pumps.*

Exhibit 6

Heat pumps are 3–5 times more efficient than gas boilers, while resistive heating converts 100% of electric energy to heat

Efficiency (primary energy to final energy) of space heating technologies
%



NOTE: The efficiency of heat pumps depends on the differential between the outside temperature and desired indoor temperature than technical efficiency, resulting in a huge range of possible efficiencies. The efficiency of solar thermal water heating is less than 100% due to losses while storing and distributing hot water around a building.

SOURCE: Systemiq analysis for the ETC; IEA (2022), *Future of Heat Pumps*; IRENA (2022), *Heat Pump Market and Costs*; IEA (2023), *Energy Efficiency Database*.

Cost competitiveness of heat pumps - electricity/gas price ratio vital

The relative cost efficiency of clean heating technologies depends on:

- **Upfront costs:** The upfront cost of an air-to-air heat pump plus an electric water heater is generally slightly more expensive than a gas boiler (€4,000–5,000 compared to around €3,000), but is cost competitive already in many countries [Exhibit 7]. Air-to-water heat pumps typically cost around 2–3 times more to install, although there are some countries where they are cheaper (e.g., Sweden and Denmark).[16] Resistive heating is by far the cheapest technology to install.

- **Running costs:** Given the inherent efficiency of heat pumps, operating costs would be around one third to one fifth of gas boilers if electricity prices were the same per kWh as for gas; but this efficiency benefit is offset by the higher cost of electricity relative to gas in many countries today.

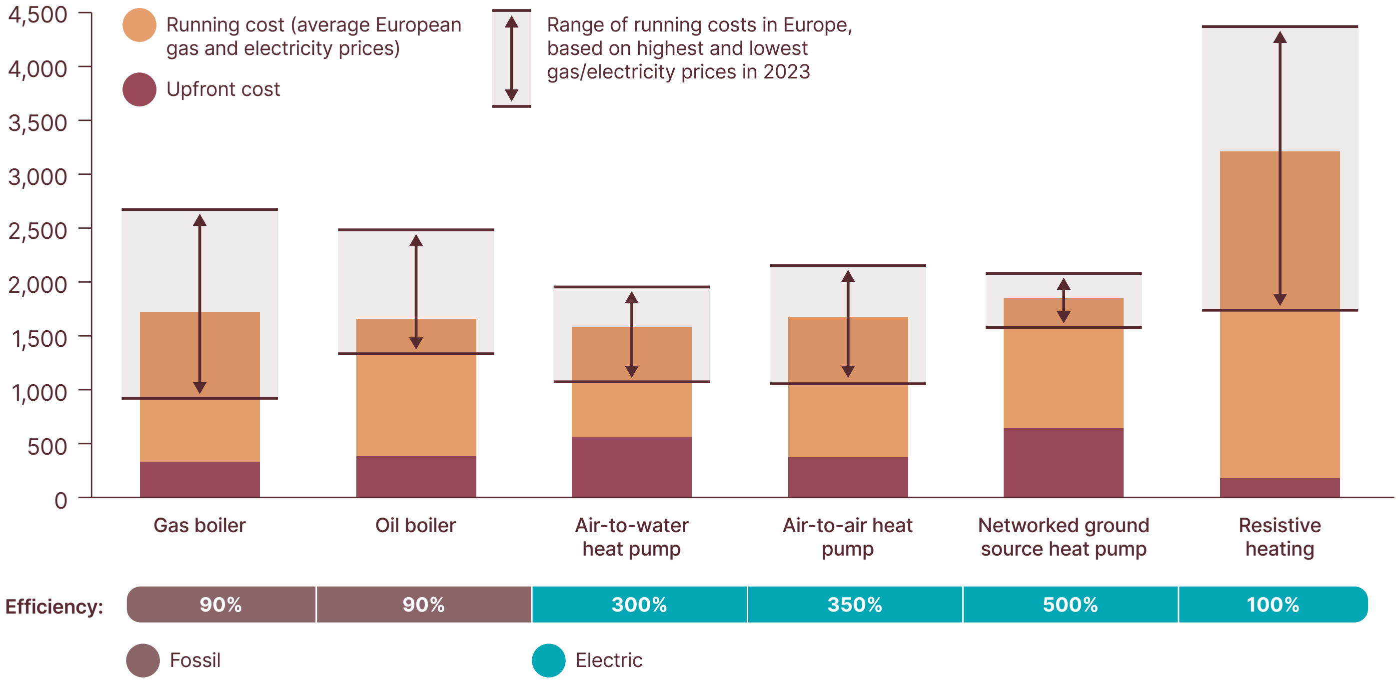
- **The cost of capital:** The interest rate at which a household or business can access funds to invest in new clean solutions, which varies greatly between specific households. This implies that public policies to reduce the cost of finance for low–income households have an important role to play.

These three together determine the **total cost of ownership (TCO)**, and Exhibit 7 shows that, on average across Europe, the TCO of fossil fuel boilers, air-to-air heat pumps, and air-to-water heat pumps are very similar.

Exhibit 7

The competitiveness of electric heating technologies depends on the relative cost of gas and electricity prices

Equivalent annual cost of ownership (technology, installation and running costs) – Europe
€ per year



NOTE: Assumes an average heat demand of 11,500 kWh a year per household, based on an average across the US and select European countries. Average, min and max running costs are based on 2023 retail prices. Assumes 5% discount rate. Excludes subsidies and maintenance costs. Networked ground source heat pumps – we assume a €50 a month standing charge fee for the shared ground arrays.

SOURCE: Systemiq analysis for the ETC; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024].

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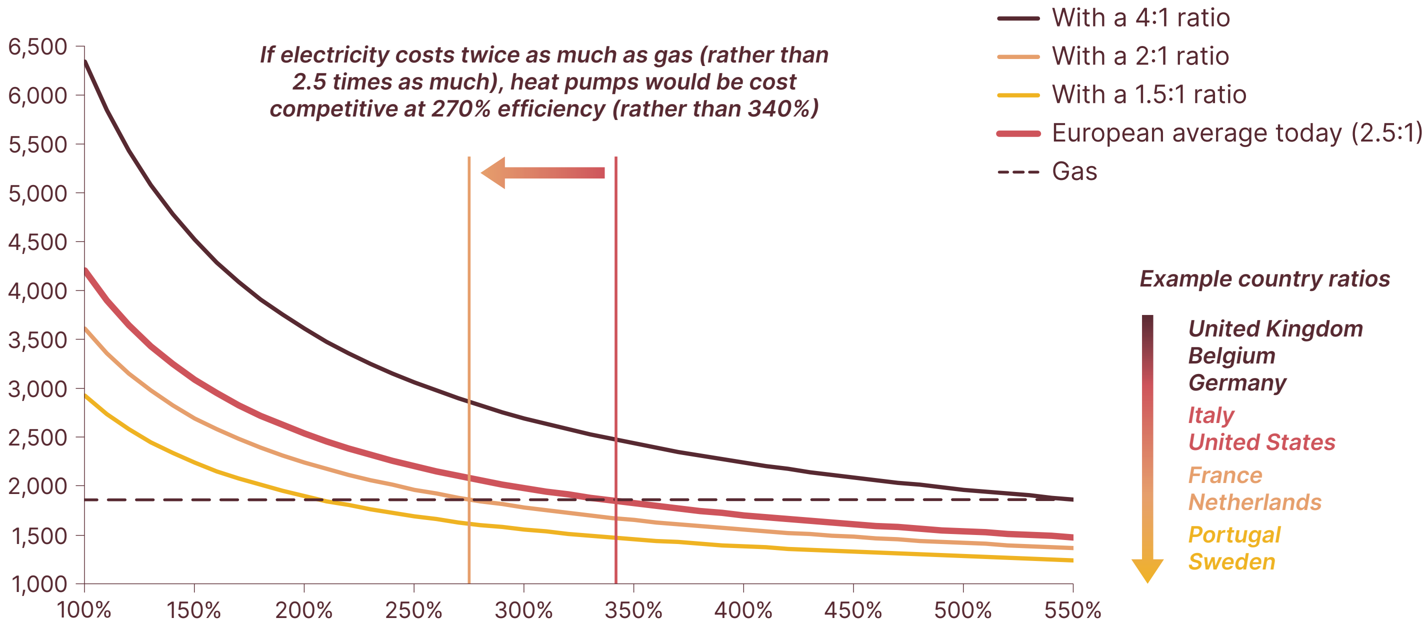
[16] Systemiq analysis for the ETC; IEA (2022), *The Future of Heat Pumps.*

Exhibit 8

The smaller the differential between gas and electricity prices, the lower the efficiency that a heat pump needs to achieve for cost parity with gas boilers

Equivalent annual costs (technology, installation and running costs) at different electricity to gas price ratios
€ per year



NOTE: Assumes an average heat demand of 11,500 kWh a year per household, based on an average across the US and select European countries. Fuel prices reflect averages from 2023. Assumes a discount rate of 5%.

SOURCE: Systemiq analysis for the ETC; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024].

However, the precise relative economics in specific countries depends on the ratio of the electricity to gas price, together with the heat pump efficiency attainable. Exhibit 8 shows that at a 2.5 price ratio (the average ratio across Europe in 2023), heat pumps would have to operate with an average Coefficient of Performance (COP) of over 3.4 to be cost competitive with gas boilers; if the price ratio was 2.0, heat pumps with a COP above 2.7 would be competitive.

Policies which decouple consumer electricity prices from gas prices and which enable electricity prices to reflect the falling cost of renewables are therefore vital to ensure that households gain maximum benefit from heat pump deployment. Over time, however, the relative cost advantage of heat pumps will improve as attainable efficiencies continue to increase, and as scale deployment makes possible significant reductions in upfront cost. It is notable, for instance, that air-to-air AC systems cost significantly less than air-to-air heat pumps used for space heating in some markets, despite the fact that they are technologically close to identical.

The mix of technologies: huge variety of individual circumstance but indicative national visions important

Given the huge variety of individual circumstances, and the potential for future changes in technological possibility and cost, it is not possible – nor necessary – to predict the precise future mix of technologies. But it is important that national and local strategies define a broad sense of direction, including an indication of which technologies are most likely to prove optimal in specific local contexts. Such a vision can help develop supply chains and skills to meet future demand and inform household choices.

In the main report, we present an indication for the UK and France of the possible mix of technologies which are likely to play the greatest role in different types and ownership of residential homes.

Reducing heating energy demand

If building heating were electrified, predominantly using heat pumps and with a complementary role for resistive heating, our analysis suggests that electricity demand for heating would rise from today's 2,600 TWh to 10,000 TWh by mid-century. This increase could be reduced to around 8,000 TWh with improvements to the efficiency of heat pumps from around 300% today to 400–500%. Public policy should favour heat pumps over electric resistive heating, and should support further innovation in heat pump technology.

In addition, however, there are two actions which can reduce the amount of energy required for heating while maintaining the same level of comfort:

- Installing smart energy management systems, which can optimise energy use according to actual need and can typically reduce energy consumption by 10–15%. In residential buildings, these can enable households to heat specific rooms, control heating remotely, and better control thermostats. In commercial buildings, these can be much more sophisticated, optimising energy use according to the weather and occupancy. The costs of these systems vary significantly, but in general are a no-regrets investment which can quickly pay back their cost through lower energy bills.
- Improving building design and insulation levels to reduce energy losses and enable buildings to retain heat. Possible actions to achieve this "passive heating" include:
  - Designing the orientation of new buildings to maximise solar exposure during the winter months.
  - Reducing heat losses via the building envelope, through better insulation of walls, floors, lofts, and windows.
  - Increasing the thermal mass of the building by using materials which can absorb heat and then slowly release it, thus increasing "thermal inertia".

When deployed in the construction of new buildings, investments in high-level insulation will almost always be cost-effective, delivering average energy consumption savings of 15–30%, and delivering high rates of return on investment [Exhibit 9]. And if the additional costs borne by developers were reflected in higher prices paid by households or businesses which will enjoy lower operational costs, free market incentives would ensure that this potential for energy efficiency improvement was seized. But imperfect information, and in the commercial sector, the complex relationships between building developers, owners, tenants, and sub-tenants mean that this will not always occur. Regulations requiring all new buildings to be built to high insulation standards are therefore a priority, but are not yet in place even in many of the high-income countries where heating needs are concentrated.

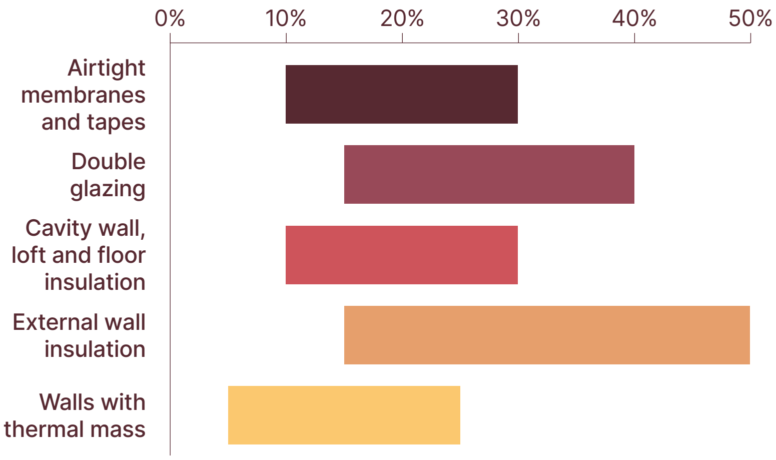
In high-income countries, moreover, much of the mid-century housing stock already exists today, and the economics of retrofitting existing buildings to very high insulation standards are less favourable than for new buildings [Exhibit 10]:

- If not already implemented, lower-cost retrofits focused on draught proofing, loft insulation and windows will almost always deliver a good return – although affording the upfront costs can be challenging.
- And retrofitting very inefficient properties is critical to ensuring that the costs of electric heating are manageable for low-income households living in poorer quality housing. This should therefore be a government priority.
- But for the average home, deep retrofit seeking to attain similar standards to a new-built home will, in many cases, not deliver a good rate of return and is not a prerequisite for installation of heat pumps.

Exhibit 9

Passive techniques in new buildings can reduce heating energy consumption by 15–30% on average

Impact on annual heating energy consumption of passive heating techniques
%



	Expected average cost to developer	Rate of return
Airtight membranes and tapes	Low $500–2,000	High 20%
Double glazing	Medium $2,500–5,000	Medium 5%
Cavity wall, loft and floor insulation	Medium $500–1,500	Medium 5%
External wall insulation	High $1,000–5,000	High 30%
Walls with thermal mass	High $2,500–10,000	Low <5%

NOTE: IRR analysis assumes a discount rate of 5%. Based on an average single-family house of 100 m². Rate of return = Assessment of developer costs and household energy bill savings in Europe.

SOURCE: Systemiq analysis for the ETC; Energy Saving Trust (2024); Checkatrade (2024); The Eco Experts (2024); Department of Energy and Climate Change (2014), *National Energy Efficiency Data-Framework*; Kattenberg, L., et al. (2023), *The Efficacy of Energy Efficiency: Measuring the Returns to Home Insulation*; Adan, H., Fuerst, F. (2016), *Do energy efficiency measures really reduce household energy consumption? A difference-in-difference analysis*; Hamilton, I., et al. (2013), *Energy Efficiency in the British Housing stock*; Tuohy et al. (2005), *Thermal mass, insulation and ventilation in sustainable housing - An investigation across climate and occupancy and ventilation in sustainable housing - An investigation across climate and occupancy*.

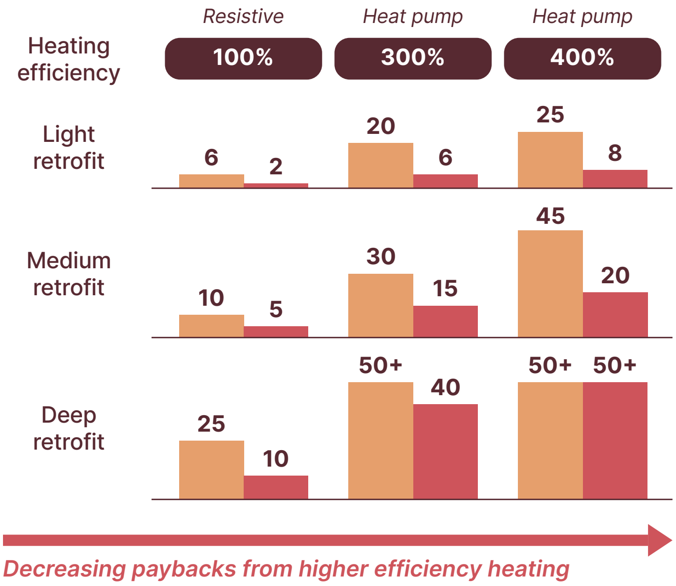
Exhibit 10

There is a clear opportunity for light and medium insulation in inefficient buildings – but without government support, the average household is unlikely to invest in deep insulation

Illustrative cost and energy savings for different insulation options

	Light	Medium	Deep
	Draught proofing, loft insulation	*Including cavity wall, internal wall, or floor insulation, or double glazing*	*A whole package of interventions, including light + medium + more structural changes (e.g., external wall insulation)*
% reduction in energy consumption	€1,000	€5,000	€25,000
Average property	5%	15%	30%
Very inefficient property	15%	30%	60%

Years to payback investment – based on average European energy prices Number of years



NOTE: Assumes an average heat demand of 11,500 kWh a year per household. Uses 2023 energy prices. Assumes energy reductions of 15% for light retrofit and 25% for deep retrofit. Assumes a discount rate of 5%, assessed over a 25 year period.

SOURCE: Systemiq analysis for the ETC; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024].

Reducing peak load electricity requirements

In today's fossil fuel building heating systems, heat supply can respond rapidly to demand, with gas drawn from storage to meet peak needs. And in fossil-dominated electricity systems, electricity supply can be ramped up rapidly to meet electric heating needs, switching on gas turbines as needed.

But in tomorrow's renewable energy system, based primarily on variable sun and wind, renewable supply cannot respond to demand. As a result, significant investment in backup capacity or storage will be required at the system level.[17] There is, however, significant untapped potential to flex building-level demand in response to changes in supply, without major changes in behaviour change or a reduction in living standards. This can be achieved through better insulation, water storage tanks, smart systems, and rooftop solar PV plus batteries. Section 8 discusses the range of ways in which these tools can reduce peak electricity demand both in countries which have high heating needs and those where cooling needs dominate.

Key actions

- **Policymakers** in high-income countries must set out timelines to ban fossil fuel heating:
    - New buildings: Banning installation from 2025.
    - Existing buildings: Banning the sale of new fossil fuel boilers from 2035.
- **Policymakers, local government, energy companies and technology companies** must develop street-by-street strategies for replacing fossil fuel boilers by:
    - Gaining a deep understanding of local housing stock to identify the most likely technologies.
    - Identifying gaps in local supply chains and skills.
    - Identifying how granular segments of the gas grid can be switched off.
- **Policymakers** should ensure electrification is the lowest cost solution. Rebalancing gas and electricity prices will be key, through:
    - Appropriate power market design that enables a rapid integration of lower-cost renewables.
    - Taking a measured and gradual approach to removing levies on electricity; these could be shifted to gas or to general taxation.
- **National and local policymakers** must commit to retrofitting the least efficient energy properties by 2035 by providing:
    - Grants and subsidies to low-income households and investing in social housing improvements.
    - Low-cost finance to enable all households to afford the upfront costs.
    - Clear guidance on low-cost insulation measures that can be safely and easily undertaken by homeowners and providing free independent advice.
- **Financial institutions** must develop new products to enable households to access low-cost finance for clean heating technologies and fabric improvements, for example, mortgage top-ups.

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[17] Forthcoming Q1 2025. See also ETC (2021), *Making Clean Electrification Possible.*

4. The access to affordable cooling challenge: Managing rising demand in a warming climate with passive cooling and efficient air conditioning

Emissions today	Energy use today	Energy use in 2050	
		Baseline with electrification	***+ energy productivity***[18]
1 $GtCO_2$ *3% of global emissions*[19]	2,200 TWh	5,000 TWh *But could be higher with greater climate change*	1,200 TWh *But relies on strong policy action*

As Exhibit 2 showed, cooling accounts for 2,200 TWh of energy demand, which is about 6% of total building operational energy use.[20] Despite the fact that more people live in countries with cooling needs than heating needs, this is far less than the 12,500 TWh used for space heating. This reflects the fact that many people in hot countries are unable to afford cooling technologies, but also that cooling is already almost entirely electrified.[21] This illustrates the huge potential to reduce heating energy use by applying the same heat pump technology already used in AC.

But without strong action to improve energy efficiency, cooling electricity demand could more than double by mid-century to around 5,000 TWh as a result of:[22]

- Rising populations and incomes, which will mean that many more people will need and be able to access space cooling.
- Climate change, which is expected to result in an additional 0.7 billion people living in hot climates, but with the potential for still bigger increases if global warming is not limited by rapid emissions reductions.[23] In general, demand for cooling tends to be systematically underestimated.

The challenge is therefore how to ensure that the supply of decarbonised electricity can grow in line with rising demand for cooling services.

Comfort levels in hot countries depend on two factors – temperature and humidity. Two main technologies can be used to reduce room temperature:

- **Air conditioning:** ACs move heat from inside a room and expel this outside, using in reverse the same heat pump technology which can be used to increase room temperatures. They are by far the most common cooling technology, with around 2 billion units in operation across residential and commercial buildings; this could increase to 5-6 billion by 2050.[24] They usually simultaneously reduce temperature and humidity.
- **Evaporative cooling** forces hot air in the room through wet cooling pads, which cause the water to evaporate, absorbing heat in the process. Cold air is then circulated back into the room. Because they contribute to humidity, they are only suitable in dry climates.

Where these space cooling technologies are unaffordable, fans and dehumidifiers can help people to deal with the impacts of hot and humid climates.

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[18] Technical efficiency improvements to AC, better new buildings, fabric retrofits to existing buildings, and behavioural choices.

[19] The 1 $GtCO_2$ emissions relates just to fossil fuel use to generate electricity. We estimate that an additional ~1 $GtCO_2e$ of emissions relates from refrigerant leakage and venting from AC.

[20] IEA (2022), *World Energy Outlook 2022.*

[21] Cooling technologies refers to those which are able to lower the temperature of a room (i.e. an AC or evaporate cooling). It does not refer to fans or dehumidifiers, which are important to deal with the impacts of hot and/or humid climates.

[22] IEA (2023), *World Energy Outlook 2023.*

[23] IEA (2019), *Helping a warming world to keep cool.*

[24] IEA, Space Cooling, available at www.iea.org/energy-system/buildings/space-cooling. [Accessed 24/09/2024].

Managing growing electricity demand

The growth of demand for cooling services is inevitable and should be welcomed since it will improve living standards for many low-income people living in hot climates. But the implications for electricity demand, and in particular for peak electricity demand, can be managed in three ways:

1. Improving the efficiency of the stock of ACs. There is a huge variation in the efficiency of ACs on the market today, both within and across countries, meaning there is significant potential to realise efficiency gains just through minimum efficiency standards and labelling. Continued technological advancements will drive further improvements, including variable speed motors which allow an AC to scale up and down (rather than just on and off), and a transition to refrigerants which are able to transfer more heat for the same electrical input. Realising these efficiency improvements for new AC units and encouraging the replacement of old units by the latest most efficient models, could in principle reduce 2050 electricity demand for AC from 5000 TWh to 2500 TWh [Exhibit 11].

2. "Passive cooling" via better building design and urban planning, which can reduce cooling energy needs by minimising heat gain and maximising natural ventilation, through optimal choices with respect to:

- **Orientation** of a building's longest sides against the direction of the sun to minimise solar gain.
- **Material and colour choice:** Painting roofs and walls white to reduce how much heat is absorbed, using bright and reflective coatings to reflect sunlight and reduce solar gain, and using ceramics and tiles which have a high thermal resistance.
- **Building envelope and design:** Key choices include a low window-to-wall ratio (as windows lead to more solar gain) and using shading structures such as awnings, trellises and porticos. Natural ventilation, including vents, solar chimneys, and optimising building shape to maximise natural airflow is also key.
- **Urban design** to provide natural shade and ventilation through tree planting and optimal street layout.

The potential impact of these levers will vary by specific circumstance, but reasonable estimates suggest that improved design and construction can often reduce building cooling needs by 25 to 40%.[25] Many of the possible actions, such as painting roofs, are also relatively low cost, even for existing buildings. And just as with heating, the cost for more extensive design and construction improvements are much lower when new buildings are built "right first time" than when seeking to retrofit existing buildings.

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[25] Ahmed et al. (2023), *The impact of window orientation, glazing, and window-to-wall ratio on the heating and cooling energy of an office building: The case of hot and semi-arid climate*; Song et al. (2021), *A review on conventional passive cooling methods applicable to arid and warm climates considering economic cost and efficiency analysis in resource-based cities.*

But unlike in high-income economies, where heating needs dominate, a large share of the mid-century building stock in lower-income economies with cooling needs will be newly built over the next 30 years. Between now and 2050, global floor area is expected to increase from 250 billion m² to 390 billion m².[26]

Codes and regulations which require high levels of energy efficiency in new building are therefore even more important with respect to cooling than heating, but also very challenging given that many lower-income countries lack the government capacity to effective enforcement. We estimate that, in principle, implementing more ambitious building codes across the whole world could reduce global electricity needs for cooling by around 20%, but it is inherently difficult to judge how much of this potential will in fact be achieved.

3. Behavioural choices on the use of AC: at present, typical temperature settings for AC systems vary greatly across the world – from around 24-26°C in many buildings in China or India, to 20°C or below in some parts of the US or Singapore.[27] As a result, typical household AC electricity consumption (among households which have AC) varies from around 4,000 TWh per year in Texas, to around 700 TWh per year in Hyderabad, India or Guangzhou, China. Electricity demand for cooling could therefore grow far more rapidly than our base case assumes if households in lower-income countries chose to adopt and could afford to adopt American levels of cooling. Conversely, cooling needs could be reduced by changes and temperature choices, which some European countries and China are seeking to influence by regulation.[28]

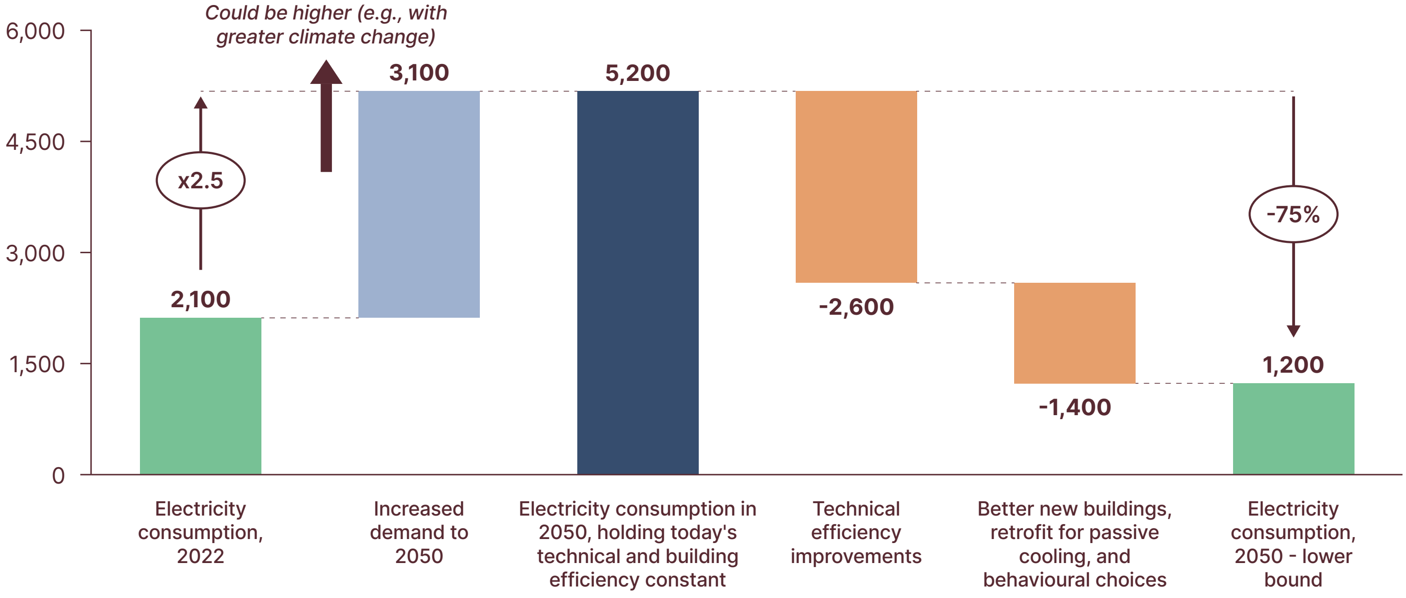
Exhibit 11 shows the potential combined impact of these three levers. If all were strongly and effectively used, it would be possible to deliver cooling services to an increasing share of a growing global population while reducing cooling electricity demand from today's 2,200 TWh to, in principle, 1,200 TWh by 2050. The biggest impact is achieved by increases in the technical efficiency of AC. The reductions shown on Exhibit 11 should, however, be treated as simply defining the scale of the opportunity which governments and industry should ideally pursue. The actually achieved reduction is likely to be significantly less.

Exhibit 11

Improving the technical efficiency of AC and deploying passive cooling techniques in new buildings could more than offset the increase in electricity demand - but relies on strong policies

Global electricity consumption from cooling, 2020 to 2050

Annual TWh



SOURCE: Systemiq analysis for the ETC; IEA (2021), *Net Zero by 2050*.

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[26] IEA (2023), *World Energy Outlook 2023.*

[27] UE EIA (2020), *Residential Energy Consumption Survey*; Odyssee-mure (2023), *Sectoral profile – households*; Lawrence Berkeley National Laboratory (2004), *A Tale of Five Cities: The China Residential Energy Consumption Survey*; Guo et al. (2022), *Extreme temperatures and residential electricity consumption: Evidence from Chinese households*; Energy Informatics (2022), *Investigation on air conditioning load patterns and electricity consumption of typical residential buildings in tropical wet and dry climate in India.*

[28] For example, in Belgium, public buildings have a heating limit of 19°C and an AC limit of 27°C and Beijing's "energy-saving police" check that AC in commercial buildings (e.g., offices, hotels, malls) is not set below 26°C.

Refrigerant leakage

The other challenge relating to growing demand for cooling is reducing the amount of refrigerant in the atmosphere from AC. Currently, around 2–5% of refrigerant in heat pumps and air conditioners leaks every year, and 90% is vented at end-of-life.[29] There are many different types of refrigerants, which work at different pressures and temperatures, and have different global warming potentials (GWP).[30] The Kigali Amendment to the Montreal Protocol in 2016 was an international agreement to phase out the use of HFCs in high-income countries by 2036 and in the rest of the world by 2047. Kigali is driving an industry transition towards using natural refrigerants, such as propane, which have a much lower GWP.

We estimate that emissions from refrigerant leakage and venting from AC and heat pumps could be almost 1 $GtCO_2e$ in 2030, rising to 2 $GtCO_2e$ in 2050; this is equivalent to 15% of today's annual emissions from buildings.[31] However, emissions in 2050 could be halved by:

- Drastically reducing how much refrigerant is vented at end-of-life with regulations and incentives for proper disposal of refrigerant.
- Reducing how much refrigerant leaks every year through skills certifications to improve the quality of installations and maintenance.
- A faster transition to lower-GWP refrigerants through tighter international regulation and R&D support to rapidly lower the costs of using alternative refrigerants safely.

Key actions

- **Policymakers** must implement ambitious building codes to ensure new buildings are built to high energy efficiency standards and deploy a wide range of passive cooling techniques.
- **National and local government, urban planners and developers** should collaborate to develop clear guidance and street-by-street approaches to deploy passive cooling techniques in existing buildings, for example whole-neighbourhood tree planting and painting roofs white.
- **Policymakers** should set minimum energy performance standards for AC and introduce labelling regulations that clearly set out the implications for running costs.
- **Companies and governments** should set limits on thermostats for AC in public and commercial buildings to reasonable levels (e.g., no less than 24°C).[32]
- **Policymakers** should implement regulations, incentives and skills accreditation schemes for the proper disposal of refrigerant from AC and heat pumps.

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[29] BSRIA (2020), *BSRIA's view on refrigerant trends in AC and Heat Pump segments*; Carbon Containment Lab (2022), *Managing Refrigerants in a Warmer World.*

[30] GWP measures a refrigerant's global warming impact relative to the same quantity of carbon dioxide over a 100-year period.

[31] We assume an average of 4.5 kg of refrigerant in a typical unit, that these assets last 15 years, and make reasonable assumptions about how the share of different refrigerants in in-use AC will change over time.

[32] IEA (2021), *Net Zero by 2050.*

5. Cooking: Eliminating the traditional use of biomass in low-income countries

Emissions today	Energy use today	Energy use in 2050	
		Baseline with electrification	*+ energy productivity*[33]
0.7 $GtCO_2$[34] *3% of global emissions*	10,200 TWh	~5,000 TWh	~4,500 TWh *But relies on strong policy action*

Cooking accounts for 15% of direct fossil fuel use in buildings.[35] But fossil fuels actually only account for 20% of cooking energy use. Instead, around a third of the global population, or 2.3 billion people, still cook with the traditional use of biomass (TUOB) - the use of solid biomass (e.g., wood, wood waste, and charcoal) with basic technologies (e.g., open fires and basic stoves).[36] TUOB is incredibly inefficient (as little as 10% of energy used is converted to useful heat) and has severe air quality and health impacts [Exhibit 12].

The energy transition for cooking is not just about transitioning to technologies which do not run on fossil fuels, but to ones that are clean from an air quality, health and safety perspective. Electric cooking meets both definitions of "clean" and is already an important energy source for cooking in high-income countries.

High-income countries should entirely electrify cooking by 2040, and China by 2050. In most countries, electric cookers do not cost materially more than a gas cooker (e.g., ~€500 for a 4-hob cooker), are 30–50% more efficient, and much safer.[37]

But progress towards electrification will be much slower in lower-income countries, given the higher cost of electricity relative to other fuel sources, and in some cases a lack of electricity supply and reliable grid infrastructure. Where cooking currently depends primarily on coal or TUOB, the transition will likely follow several stages:

- A crucial interim solution in the 2030s is to install improved cookstoves (e.g., insulated combustion chamber), which are much more efficient, safer, and emit less emissions (including particulate emissions harmful to human health).
- By 2040, strong policy will be required to ensure a transition to cleaner cooking fuels. Liquefied Petroleum Gas (LPG), is likely to be by far the dominant fuel, despite still having emissions of 0.2–0.25 $kgCO_2$ per kWh.[38] This is because the cost of electric cooking will be prohibitive in most lower-income countries, as well as unreliable access to electricity. In the last decade, 70% of those who gained access did so through LPG.[39]
- Alternatively, modern forms of bioenergy such as bioethanol and biomethane can be used. If produced sustainably, these also contribute to reducing emissions. However, purchasing biogas stoves can cost up to six times the monthly income for low-income households in Sub-Saharan Africa, and guaranteeing sustainable supply that does not contribute to detrimental land-use is uncertain.[40]
- By 2050, higher incomes and improved access to electricity should enable the vast majority of the world's population to transition away from fossil fuel cooking.

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[33] Technical efficiency improvements to cookers and behavioural choices.

[34] Emissions for cooking do not include those from the traditional use of biomass, in line with common carbon accounting for bioenergy which assumes lifecycle CO_2 emissions are zero. This means the ratio of emissions to energy use for cooking in this document is significantly different to other energy uses.

[35] IEA (2022), *World Energy Outlook 2022.*

[36] IEA (2023), *A Vision for Clean Cooking Access for All.*

[37] An induction hob is a type of electric hob that uses electromagnetic energy to directly heat cookware, as opposed to the entire hob; this makes them more efficient.

[38] LPG is produced during oil refining or extracted from oil and gas reservoirs.

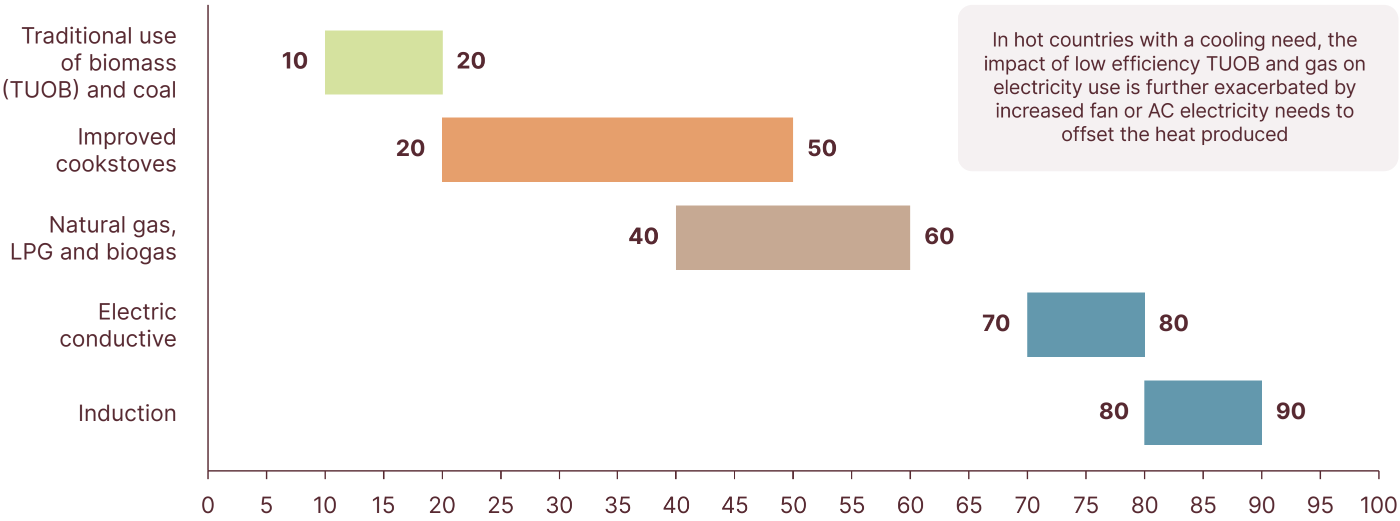
[39] IEA (2023), *A Vision for Clean Cooking Access for All.*

[40] Ibid.

Exhibit 12

High-carbon cooking fuels are also the least efficient; electric induction hobs are by far the most efficient cooking technology

Energy efficiency of cooking fuels and technologies
%



In hot countries with a cooling need, the impact of low efficiency TUOB and gas on electricity use is further exacerbated by increased fan or AC electricity needs to offset the heat produced

NOTE: LPG = Liquefied petroleum gas.

SOURCE: Systemiq analysis for the ETC; IEA (2023), *A Vision for Clean Cooking Access for All*.

Key actions

Policymakers should:

- Set clear targets for expanding clean cooking access.
- Run education and awareness campaigns, including community advocacy groups, training households and salespeople, and cooking classes to demonstrate new technologies. Education of young people, including social media, is key to changing norms in the next generation.
- Provide subsidies, grants and low-cost finance, along with international development finance, to lower the upfront costs and ongoing fuel costs while markets and supply is scaling up.
- Implement minimum health and efficient standards for cooking technologies, especially improved cookstoves.

6. Appliances & Lighting: Big opportunity to improve technical efficiency

Emissions today	Energy use today	Energy use in 2050	
		Baseline with electrification	*+ energy productivity*[41]
Appliances: 4.1 $GtCO_2$ Lighting: 0.7 $GtCO_2$ *13% of global emissions in total*	Appliances: 6,000 TWh Lighting: 1,800 TWh	Appliances: ~11,000 TWh Lighting: ~3,500 TWh	Appliances: ~6,500 TWh Lighting: ~1,500 TWh *But relies on strong policy action*

Appliances and lighting are already nearly 100% electrified.[42] However, almost 10% of the world's population do not currently have access to lighting and many rural households in low-income countries still rely on kerosene lamps due to a lack of access to electricity.[43] 20% of the global population do not have access to refrigerators and 25% don't have a mobile phone.[44] Expanding access to safe, electric lighting and to appliances will deliver significant improvements to comfort, access to information, health and productivity.

Without any action to improve efficiency, electricity demand for household appliances and lighting could double, from 7,800 TWh today to over 14,500 TWh.[45] A combination of rising incomes and falling consumer costs are enabling more households to afford appliances. At the same time, energy demand will also increase as households use appliances more frequently and choose larger and more energy-intensive models. However, there is significant potential to almost completely offset the increase in energy demand, without impacting access and living standards.

Appliances

Improving the technical efficiency of appliances could offset 70% of the increase in electricity demand [Exhibit 14]:

- The efficiency of appliances tends to increase over time as manufacturers innovate, compete on quality and look to cut their own costs. Key improvements to date have been reducing excess heat, increasing motor efficiency, and improving insulation in fridge freezers.
- Regulation has been crucial to accelerated improvements in energy efficiency. Analysis of global minimum energy performance standards and labelling regulations suggests that they have increased the underlying rate of technological improvement 2–3 times, resulting in energy savings of 10–30% over 15–20 years in most countries.[46]
- Accelerating the stock turnover of older, less efficient appliances through financial incentives should be targeted at large, energy-consuming white goods, especially fridges and freezers which use refrigerants that have a high global warming potential. This must be accompanied by investment in recycling and reuse facilities, with retailers obliged to offer trade-in schemes.

Lighting

If all lighting demand in 2050 could be delivered with LED light bulbs, electricity requirements could be even lower than they are today, at 1,600 TWh [Exhibit 15]. LED light bulbs are able to produce light without heat and are over 80% more efficient than traditional incandescent lighting, they run for 30–50 times longer, and have significantly lower lifetime costs. The cost of LED lights has fallen dramatically and they are now virtually cost competitive with incandescent bulbs in most countries; government bulk procurement policies have been a proven success at lowering retail costs (e.g., in India).

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[41] Technical efficiency improvements to appliances, shifting to LED lighting, and behavioural choices.

[42] Appliances refer to anything that households plug into electrical sockets, including kitchen appliances (e.g., fridges, microwaves, kettles, and rice cookers), household appliances (e.g., dishwashers, washing machines, vacuum cleaners) and digital equipment (e.g., laptops, TVs, mobile phones).

[43] CLASP (2024), *Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience.*

[44] CLASP (2024), *Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience.*

[45] IEA (2022), *World Energy Outlook 2022.*

[46] IEA/4E TCP (2021), *Annual energy reduction in new-product energy consumption from EES&L programmes.*

Today, around 50% of new lighting sales are LED.[47] With well-designed policies such as bans on the sale of incandescent lighting, and minimum energy performance standards and labelling, it is possible for LEDs to account for 100% of the market by 2030. Combined with further expected improvements in the efficiency of LED bulbs (~30%), this could more than offset the increase in electricity demand for lighting.

Key actions

Policymakers should:

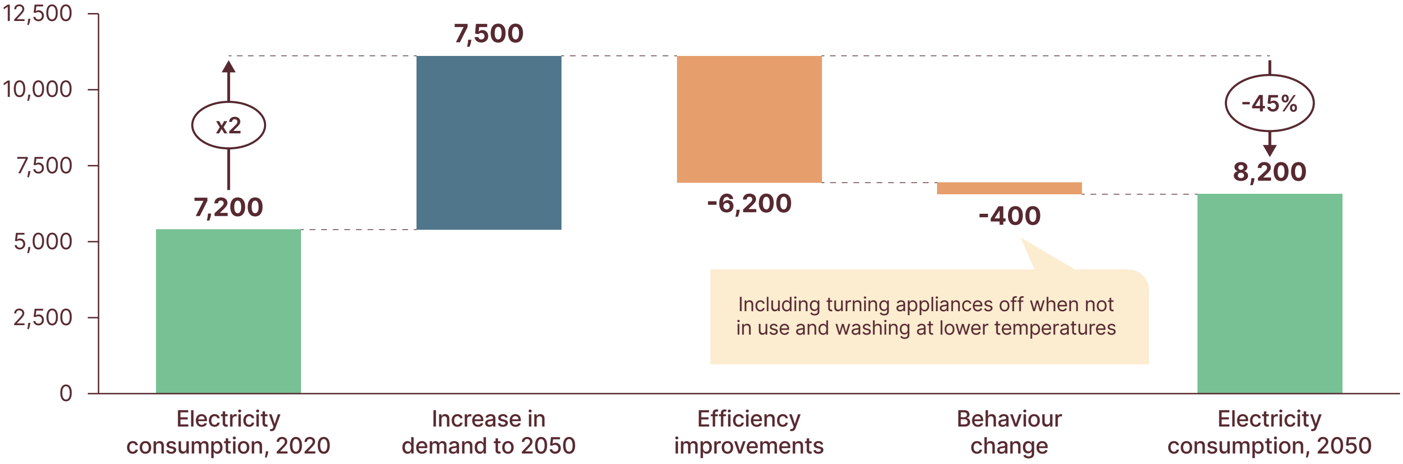
- Implement minimum energy performance standards for lighting and a wide variety of appliances, increasing their stringency over time.
- Introduce regulations for energy performance labelling.
- Introduce obligations for retailers to collect older and inefficient appliances for recycling.
- Bulk procurement of LED lighting and small appliances to help lower consumer prices.
- International collaboration to stop dumping of poor quality and inefficient products in lower-income countries, including regional harmonisation of standards and voluntary private sector commitments.
- Continue to drive further improvements in efficiency with targeted R&D support (e.g., financial incentives, prizes), focusing for example on developing smart appliances which work effectively within smart building systems to provide demand-side flexibility.

Exhibit 13

Improving the technical efficiency of appliances and switching to LED bulbs could offset 80% of rising electricity demand

Global electricity consumption by appliances and lighting, 2020 to 2050

Annual TWh



SOURCE: Systemiq analysis for ETC; IEA (2023), *Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030*; IEA (2023), *Lighting efficacy by technology in the Net Zero Scenario, 2010-2030*; IEA (2021), *Net Zero by 2050.*

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[47] IEA (2023), *Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030.*

7. Commercial buildings: Creating strong demand signals for low-carbon, efficient and flexible buildings

Commercial buildings account for 20% of the global build stock by area but for 40% of building operational energy use. This reflects several important differences from residential buildings [Exhibit 14]:[48]

- Lighting and appliance energy needs are much higher in commercial buildings, given higher floor space, energy consuming appliances such as computers, and the need for ventilation. This means that electricity is already a much more important fuel, providing 35–50% of commercial building energy in the US and EU, compared to around 25% in residential buildings.

- Space and water heating needs are less important on average, accounting for around 30–40% of energy compared to over 60% in residential buildings; although needs are much higher for hotels and sports facilities.

- Cooling needs are on average higher, which reflects the fact that many commercial buildings are air-conditioned even in countries where AC is not common for residential buildings.

Precise patterns of energy use differ significantly between specific commercial buildings types, as shown in Exhibit 15. But the key conclusions set out above for heating and cooling in the residential sector also apply to the commercial building sector:

- The key priority in space heating is to replace gas and oil boilers with heat pump electric systems.

- Improvements in the efficiency of AC systems (and other appliances) have major potential to reduce future electricity demand.

- And there are major opportunities to reduce energy use for space heating and cooling via better building design and construction which delivers passive heating/cooling.

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[48] US Energy Information Administration (2018), *2018 Commecial Buildings Energy Consumption Survey*; EIA (2023), *Annual household site end-use consumption, 2020*; Eurostat (2023), *Energy consumption in households*; Building Performance Institute Europe (2015), *Europe's Buildings Under the Microscope.*

However, specific features of commercial buildings, and in particular, large office buildings, create additional opportunities for increased energy efficiency. In particular, there is a large opportunity to:

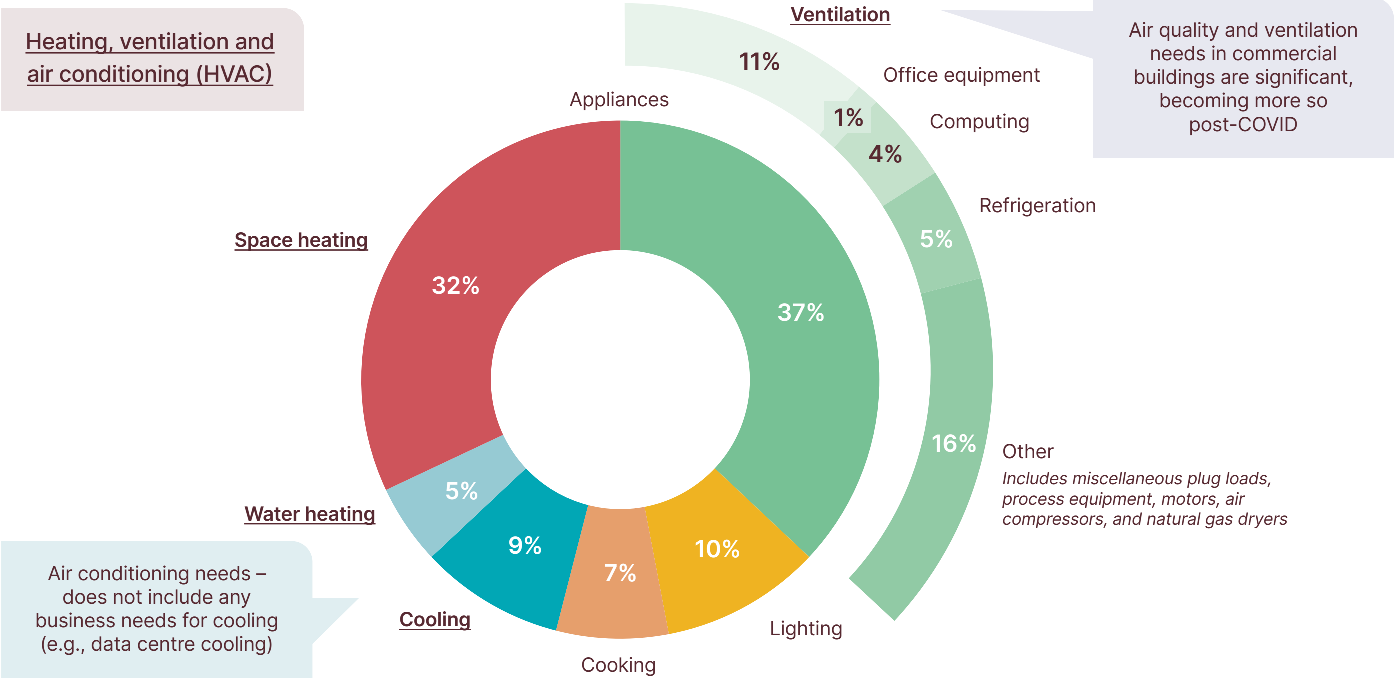
- Install combined heating and cooling systems, which are able to simultaneously heat and cool different parts of a building, with the potential to reduce energy consumption in some buildings by 30–40%.[49]
- Install building management systems which combines sensors, smart thermostats and predictive AI to flex energy consumption according to occupancy, the weather and energy prices. These can deliver energy savings of 10–20% without disruptive fabric improvements.[50]

In addition, there is a range of insulation techniques which are more applicable to large commercial buildings than to residential buildings, including low-emissivity glass and electrochemical glass which can control the balance of light vs. heat entering or leaving a building.

Exhibit 14

Heating, cooling and ventilation accounts for ~60% of commercial building energy use

Commercial buildings energy consumption by end-use in the US
% of energy consumption



Air quality and ventilation needs in commercial buildings are significant, becoming more so post-COVID

Air conditioning needs – does not include any business needs for cooling (e.g., data centre cooling)

NOTE: Space heating and water heating refer to ambient space heating needs and hot water needs for human occupants.

SOURCE: Systemiq analysis for the ETC; US Energy Information Administration (2018), *Commercial Buildings Energy Consumption Survey 2018*.

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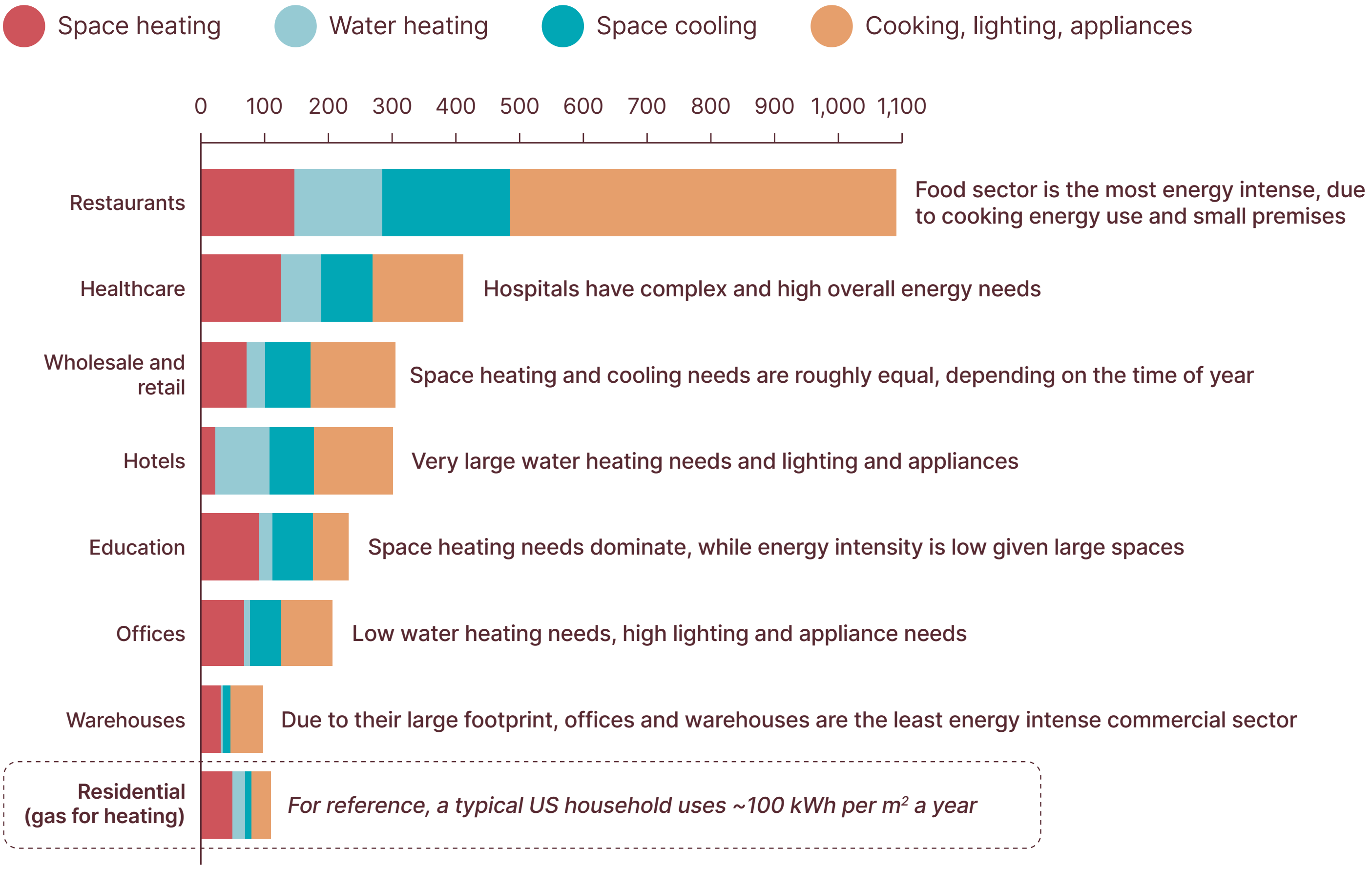
[49] Trane Technologies (2022), *Electrifying buildings with VRF technology*.
[50] Schneider Electric, *Non-residential buildings: high efficiency potential, low-retrofit cost*.

Exhibit 15

Energy needs vary significantly across different types of commercial building meaning there is no one-size-fits-all decarbonisation pathway

Energy intensity by subsector and energy end-use in the US, 2018
kWh per m^2 per year



SOURCE: US Energy Information Administration (2018), *Commercial Buildings Energy Consumption Survey 2018*.

The new build and retrofit opportunity

As in the residential sector, the greatest opportunity to improve energy efficiency is to ensure that new commercial buildings are built to very high standards. The economics of commercial building retrofit reflects a balance of considerations which will vary greatly by individual circumstance:

- On the one hand, there will be many commercial buildings where the installation of sophisticated energy management systems is more important than fabric improvements. This reflects the lower relative importance of heating and cooling systems compared to lighting and appliances.

- On the other hand, it is a feature of many commercial buildings that they undergo periodic substantive retrofit for reasons unrelated to energy efficiency (e.g., renovation for new tenants), and this creates an opportunity to simultaneously improve insulation.

Actions to seize the opportunity

The huge variety of commercial building types and major differences in national circumstance mean that specific actions to seize the energy efficiency opportunity will vary by country. But our report sets out three overall conclusions:

1. **Ambition:** There is a strong case for high-income countries to set earlier targets for the transition away from fossil fuel heating in commercial buildings than residential. This could involve immediate bans on the installation of gas or oil boilers in new commercial buildings, and by 2030 in existing buildings.

2. **Regulation:** There is a clear opportunity for more ambitious and better designed regulation to increase the energy efficiency of new commercial buildings and to require energy efficiency improvements at points of retrofit. This requires addressing the deficiencies of many existing building regulations which are often not based on quantitative measures of building energy performance (e.g., energy use per m^2).

3. **Voluntary action:** Alongside strong regulation, voluntary commitments and market incentives can play a greater role in commercial buildings than in residential. This reflects the facts that:

   - There are cost savings and revenue streams associated with more efficient and flexible buildings.

   - Commercial building owners need to de-risk their assets against future carbon and energy regulation; the expectation of future regulation or carbon pricing can therefore drive voluntary action today.

   - Some major commercial businesses, investors and building owners will have their own net-zero and financed emissions commitments.

Key actions

- **Policymakers** should:

  - Set ambitious targets for reductions in energy use intensity, differentiated by different types of commercial buildings, and mandate that all commercial buildings must have an energy performance certificates every five years.

  - Ensure data is reported to national authorities and identify the priority lowest-performing buildings to renovate.

  - Regulate that rented buildings must have a minimum Energy Performance Certificate (EPC) rating.

- **The low-carbon building certification market** must ensure certifications cover whole building emissions, including operational and embodied, set out clear minimum requirements for energy use intensity which measure performance using actual carbon and energy data, and provide transparency through publicly available targets, metrics and assessments.

- **The real estate and construction sectors** must set science-based targets to reduce whole life carbon emissions in new and retrofit buildings, and invest in collecting data, skills and knowledge sharing.

- **Businesses with large scope 1 and 2 emissions** (e.g., major hotel, restaurant and retail chains, professional services) should commit to reduce energy use intensity and emissions in their buildings.

- **Financial institutions** must focus on developing a clear understanding of how to price and assess value and risk. Lenders should develop clear lending criteria tied to minimum EPC standards and offer favourable rates for better performance. Investors and fund managers should set out clear plans to reduce financed emissions.

8. Buildings in a clean energy system: Managing total and peak electricity demand via efficiency and flexibility

As we electrify space and water heating and cooling, we will move from a world where energy for buildings is provided by a variety of fuels, to a system which is almost entirely electric (though with a small role for biomass, in particular in some district heating systems).

This electrification will, itself, moderate the growth of final energy consumed to operate buildings. As shown in Exhibit 3, if the mix of energy sources and the efficiency with which they are used remained unchanged, population and income growth would result in an increase in total building operational energy use from 36,700 TWh today, to around 57,000 TWh by 2050. Electrification alone would reduce this by 16,000 TWh via:

- The almost complete electrification of space heating, primarily in high-income countries. This will predominately be through heat pumps, which are able to deliver multiple kWh of heat for every kWh of electricity, but also with a role for resistive heating, which is capped at 100% efficiency.
- The eventual electrification of cooking in low-income countries, eliminating hugely inefficient TUOB, though with an important intermediate step to firstly improve health and air quality, which in many countries will involve increased use of LPG.

Exhibit 16 shows the potential consequences for electricity demand which could rise from today's 12,800 TWh, to reach 35,500 TWh if there were no improvements in energy efficiency. Peak electricity requirements could increase by an even greater percent, given that demand for heating and cooling services is concentrated in particular times of day or seasons of the year.

All of this electricity and peak electricity must be provided in a zero-carbon fashion. This will require large investments in zero-carbon generation, in grids, and in the storage or flexible generation capacity required to meet peak needs in a zero-carbon fashion.

It is therefore essential to identify and grasp opportunities to both:

- Reduce future total electricity demand from buildings.
- Reduce, in particular, future peak electricity demand.

Reducing total future electricity demand from buildings

Future electricity demand can be reduced via three energy productivity levers already described in this Executive Summary:

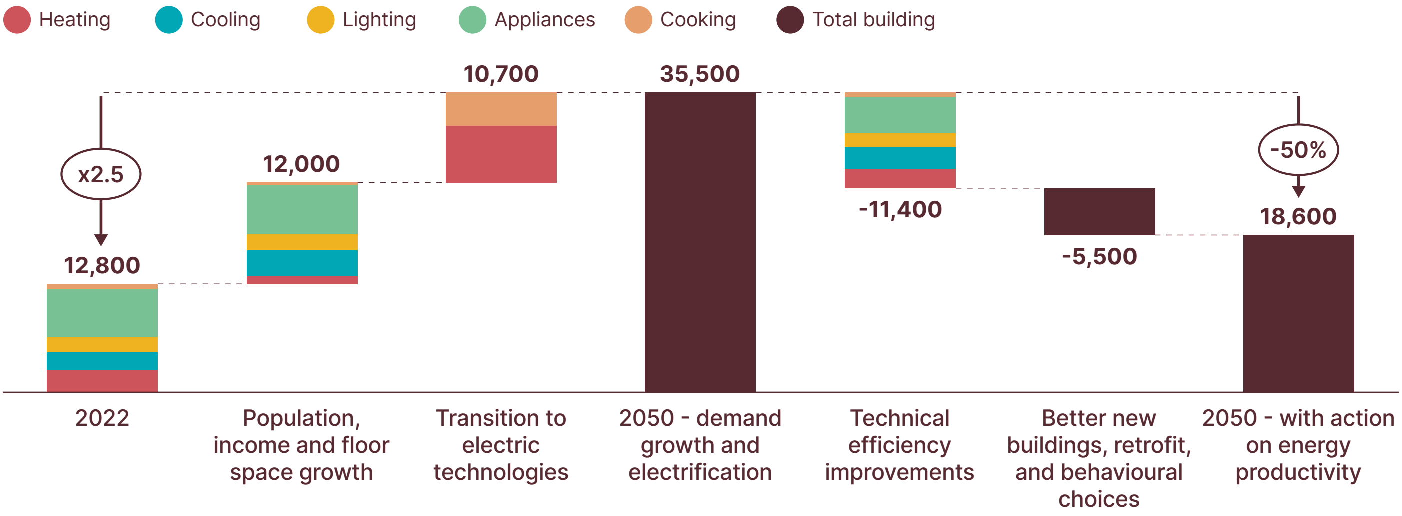
- **Improving the technical efficiency** of heat pumps, AC, other appliances and lighting and cooking technologies. Technically feasible improvements could reduce annual electricity demand in 2050 by a third – 11,400 TWh – and policies to seize this opportunity should be a priority. This could include, support for technical innovation, regulation to enforce minimum energy performance standards for all new equipment, and policies which encourage accelerated replacement of old equipment.
- **Improving building energy efficiency** via smart systems and improved insulation. As discussed already, there is major potential in new buildings in particular, but also in existing buildings, which together could reduce annual electricity demand in 2050 by a further 4,000 TWh. The importance of these measures would, however, be even more important if progress in improving the technical efficiency of heating and cooling systems was less than Exhibit 16 suggests might be possible.
- **Behavioural choices,** in particular, in relation to optimal thermostat settings, which could result in a reduction in demand of 1,500 TWh if heating settings were somewhat lower and cooling a bit higher in some of the highest consumption countries. Conversely, a significant further increase in demand could occur if consumers in lower-income economies adopted the cooling temperature choices of the US or Singapore.

It is important to pursue all of these energy efficiency improvements. But even if all the efficiency potential indicated on Exhibit 16 was achieved, electricity use in buildings would still grow from 12,800 TWh today to 18,500 TWh by mid-century. Reasonable projections for the actual result should assume a somewhat higher level, given uncertainty about how much of the energy improvement potential can in fact be grasped. While pursuing energy efficiency improvements, governments must therefore also plan for very significant increases in total electricity demand from building, alongside other drivers of rising electricity demand in road transport and industry.

Exhibit 16

Global electricity demand could more than double by 2050 from 13,000 TWh to over 35,000 TWh – but strong action on energy efficiency could cut this in half to ~19,000 TWh

Electricity demand in 2050 and impact of efficiency levers – residential + commercial
TWh



NOTE: The transition to electric technologies just considers the transition of individual fossil fuel boilers to heat pumps or resistive heating; additional electricity will also be required to power district heat networks.

SOURCE: Systemiq analysis for the ETC; IEA (2023), *World Energy Outlook 2023*; IEA (2021), *Net Zero by 2050*.

Reducing peak electricity demand via action at building level

Even if total electricity demand growth could be moderated via the efficiency improvements described above, electrification of heating together with rising cooling demand, will create a major challenge for electricity systems as a result of the combination of:

- The fact that demand for heating and cooling services varies by time of day and by season. The pattern varies by climate, with cooling demands in hot countries primarily varying on an hourly basis across day and night, while heating demands in colder countries typically display both daily and seasonal variation, as illustrated for the UK in Exhibit 17.
- The variable nature of wind and solar supply, which will play a dominant role in the decarbonisation of electricity generation.
- The fact that transmission and distribution grid investment requirements are driven by peak electricity demand, not average demand.

The first two factors make it more complex and expensive to balance power supply and demand in renewables-dominated systems, than in systems with large fossil fuel generation capacity. Alongside our work on buildings, the ETC is therefore currently conducting a major analysis of the balancing and grid build challenges in decarbonised electricity systems. Our report on this will be published in Q2 2025.

In that report, and in Chapter 8 of the main buildings report, we explain the different types of challenge created by seasonal and daily variations in electricity demand and renewable supply. The seasonal challenges need to be solved primarily via investments within the power generation and grid system, which our forthcoming report on power systems will describe.

But four actions at the building/household level can play a major role in managing the daily balance challenge, by shifting demand for grid-supplied electricity away from peak periods:

- **Improvements in building installation** which, alongside reducing total electricity demand, can make it easier to shift electricity use away from peak periods while still delivering the heating and cooling services desired. Exhibit 18 shows how many degrees of heat typical houses in different countries lose over a five hour period, ranging from 3°C in poorly insulated UK homes, to just 0.9°C in efficiently insulated Norwegian ones. The smaller the heat loss over time, the greater the potential to “preheat” or “pre-cool” a building using electricity when it is most abundantly available, while still enjoying heating or cooling at the desired time.

- **Smart systems** of the sort described in Sections 3, 4 and 7, can reduce both final and peak energy demand. They range from relatively simple measures potentially applicable in almost all homes (e.g., remotely controlled and room specific thermostats), to highly sophisticated commercial systems combining multiple sensors and controls, real-time analysis of weather and price patterns, and integrated heating and cooling systems.

- **Rooftop solar PV combined with storage batteries:** These do not reduce total final energy use, but by providing it at the building level, they reduce peak demand for grid supplied electricity. The cost effectiveness of these systems is improving rapidly due to collapsing costs of both solar PV panels and batteries; as a result, solar PV plus batteries (whether at the building level or at large scale within the grid) is likely to play a very significant role in energy systems in all countries with large solar resources.

- **Energy storage at building level:** As well as batteries, this can include hot water cylinders and other forms of thermal storage.

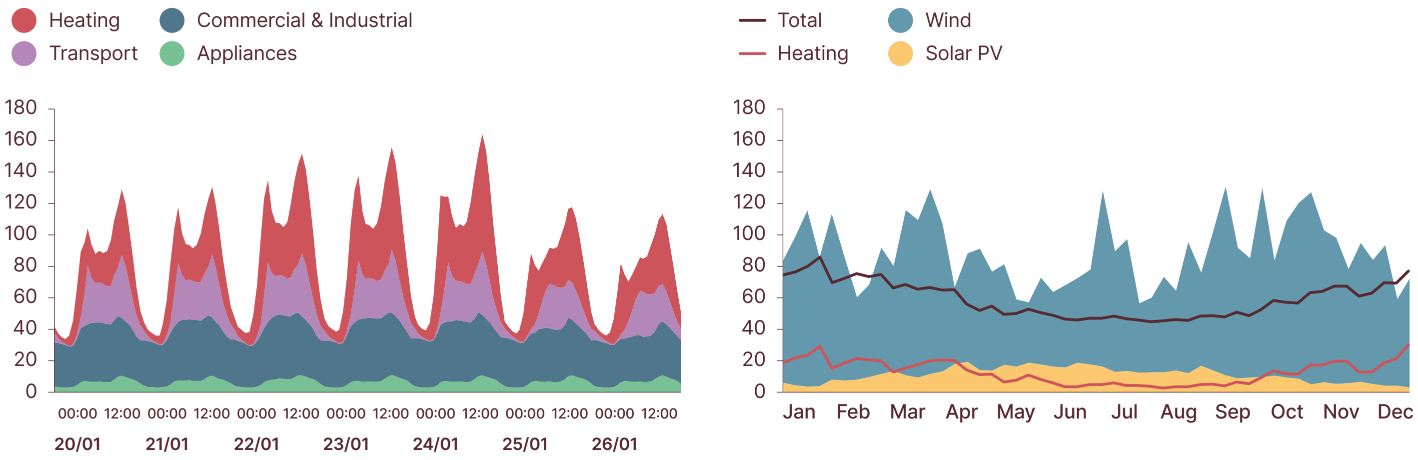
Deployed together, these technologies have the potential to significantly reduce peak electricity demands and should therefore be strongly encouraged by government policies. This could entail low-cost financing for insulation and consumer awareness of the benefits of solar PV, batteries, and smart systems. They must also encourage the development of time-of-use retail electricity price systems to create incentives for consumers (whether residential or commercial) to shift electricity demand away from peak periods. The ETC’s forthcoming report on future power systems will explore this issue in more detail.

Key actions

- **Policymakers** should commit to retrofitting the least efficient energy properties by 2035 by providing:
    - Grants and subsidies to low-income households and investing in social housing improvements.
    - Low-cost finance to enable all households to afford the upfront costs.
    - Clear guidance on low-cost insulation measures that can be safely and easily done by homeowners and provide free independent advice.
- **Policymakers** must set minimum energy performance standards for heat pumps, AC, household appliances and lighting and introduce labelling regulations that clearly set out the implications for running costs.
- **Policymakers** must implement ambitious building codes all over the world, with stringent requirements on kWh per m².
- **National and local governments, energy companies and network system operators** should run consumer campaigns, highlighting the benefits of smart systems, solar and water storage.
- **Energy companies** must roll out smart metres to all customers and develop dynamic time-of-use tariffs.

Exhibit 17

Heating needs peak in the evening and during the winter months in Northern latitude countries, while solar generation peaks in the middle of the day and during summer



Projected hourly electricity demand, United Kingdom, a week in January 2050
GW

Projected weekly electricity demand and renewable supply, United Kingdom, 2050
GW, averages over a week

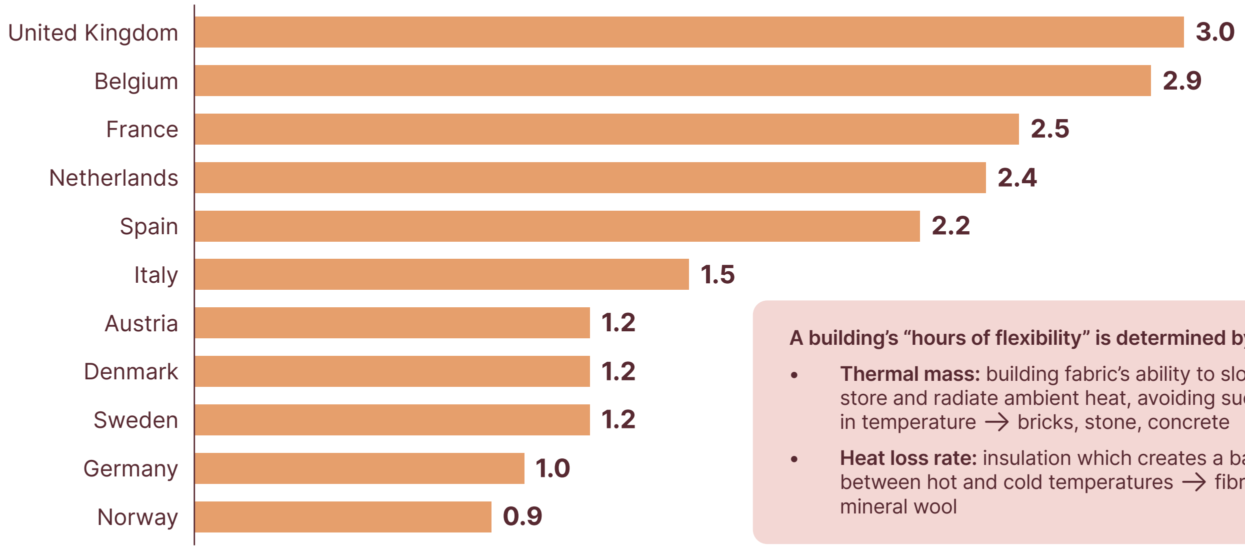
NOTE: Scenario assumes installed capacity of 75 GW of solar, 60 GW of onshore wind, and 100 GW of offshore wind, and minimum weather years out of the past 30 years (2010). Assumes a highly electrified economy, across residential, commercial and industrial sectors; excludes electricity load from storge and electrolysers; does not assume significant demand-side flexibility. Projections (LHS) for 20/02/2050–26/02/2050.

SOURCE: Systemiq analysis for the ETC; NESO (2022), *Future Energy Scenarios 2022*.

Exhibit 18

Homes vary significantly in terms of their ability to retain heat, with big implications for the ability of households to "pre-heat" their homes ahead of peak needs

Home temperature loss after 5 hours
°C



A building's "hours of flexibility" is determined by its:

- **Thermal mass:** building fabric's ability to slowly absorb, store and radiate ambient heat, avoiding sudden spikes in temperature → bricks, stone, concrete
- **Heat loss rate:** insulation which creates a barrier between hot and cold temperatures → fibreglass, foam, mineral wool

NOTE: Tested in 2019/20 with a temperature of 20°C inside and 0°C outside.

SOURCE: Tado, available at www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours?. [Accessed 01/08/2024].

9. Embodied emissions: Decarbonising material production and building better

Embodied emissions, which result from the construction or retrofit of buildings, amount to 2.6 $GtCO_2$ per year today. In addition, about 2.2 $GtCO_2$ a year is generated from the construction of wider infrastructure, such as roads, bridges, airports, pipelines, railways and ports. The total global floor area of buildings is projected to increase 55% by 2050, from 250 billion m^2 to 390 billion m^2.[51] If the carbon intensity of construction remained constant, the building of this additional 140 billion m^2 would result in 75 $GtCO_2$ of cumulative emissions between now and 2050. This would use up 40% of the remaining carbon budget that scientists estimate gives the world a 50% chance of limiting warming to 1.5°C.[52] It is therefore essential to reduce these cumulative emissions as fast as possible.

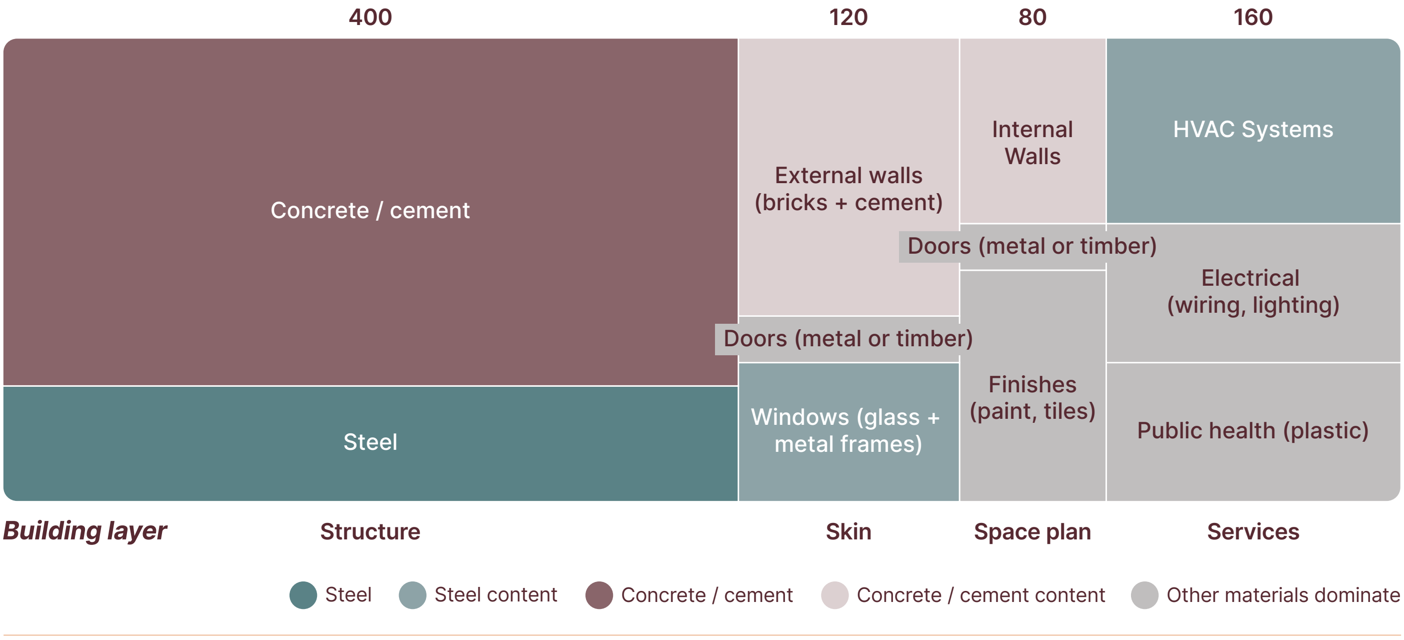
Around 70% of embodied emissions arise from upfront construction, with close to 30% accounted for by retrofitting and extension, and a small 1–2% resulting from end-of-life demolition and related activities.[53] Of the upfront emissions, over 90% result from the production of steel and cement/concrete; others result primarily from production of other materials, such as aluminium, glass, and bricks [Exhibit 19].

Exhibit 19

Steel, cement and concrete drive embodied carbon across all building layers; a building's structure accounts for half of total upfront emissions

Estimated upfront embodied carbon by building layer - Europe

$kgCO_2e$ per m^2



SOURCE: Systemiq analysis for the ETC; Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*; ArchDaily (2021), *How to Approach Embodied Carbon Reduction within an Architectural Project*.

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[51] IEA (2023), *World Energy Outlook 2023.*
[52] Forster et. Al (2024), *Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence.*
[53] WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today.*

Reducing embodied emissions requires action to:

- Decarbonise the production of key building materials.
- Reduce the use of carbon-intensive materials in new building construction and improve other aspects of construction efficiency.
- Reduce the use of materials in retrofit/extension.

Decarbonising material production

The MPP has set out feasible pathways to decarbonise the production of concrete, steel, aluminium and plastics by 2050.[54] Exhibit 20 shows the mix of levers to achieve this decarbonisation for concrete and steel, and suggests that 75–80% of the projected reductions will be achieved by decarbonising the production of the material.

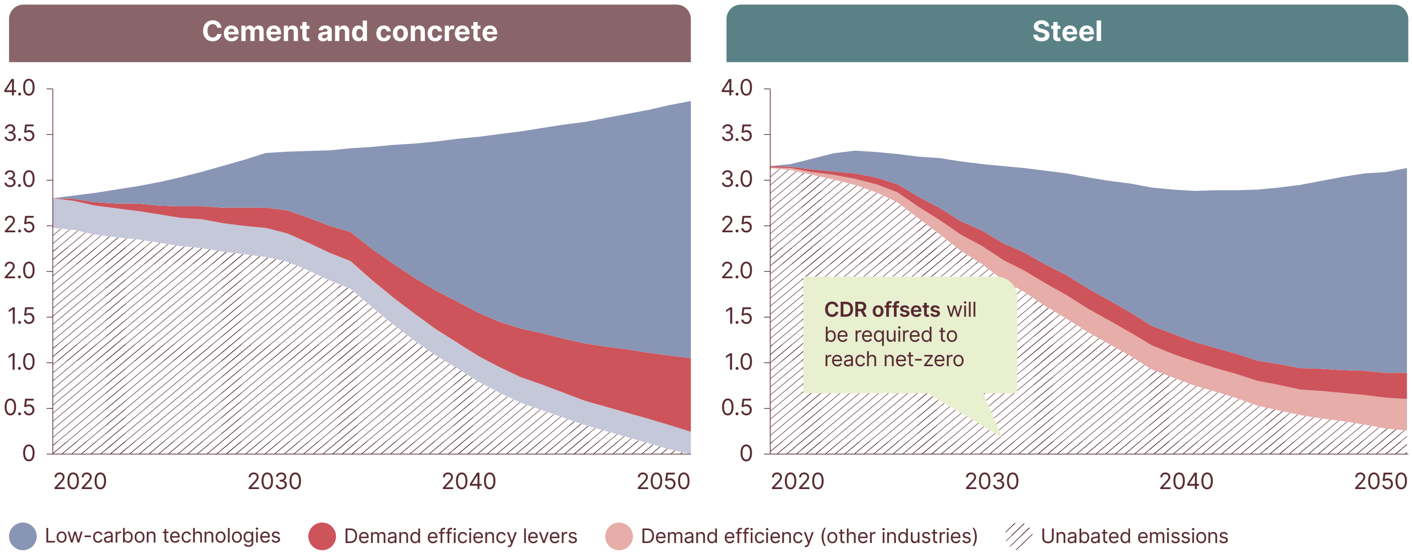
This decarbonisation is made possible by several different technologies including:

- For cement, the use of electricity or biofuels for high-temperature heat supply, the application of CCUS, and measures which reduce clinker use per tonne of cement.
- For steel, multiple technologies for primary iron production which replace coking coal as the reduction agent with syngas (CO plus H_2), pure H_2, or combined with CCS if H_2 is derived from natural gas.
- For aluminium, using low-carbon power could reduce emissions 70% by 2035.[55]
- For glass, fuel switching to electricity, biogas and hydrogen could reduce emissions by 75% by 2050.[56]

Exhibit 20

Addressing process and production emissions will have the biggest impact on embodied carbon, but reducing material demand is also critical to achieve net-zero by 2050

1.5°C aligned pathways to net-zero
$GtCO_2$ per year



NOTE: Demand efficiency refers to strategies which reduce the demand for high-carbon cement, concrete and steel, for example through building design strategies which reduce material efficiency, substituting for lower-carbon materials such as timber and hempcrete, and building less.

SOURCE: Systemiq analysis for the ETC; MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.

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[54] MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*; MPP (2022), *Making Net Zero Aluminium Possible.*
[55] MPP (2022), *Making Net Zero Aluminium Possible.*
[56] Glass for Europe (2020), *Flat Glass in Climate-Neutral Europe, 2050.*

Together, these actions could cut annual material production emissions close to net-zero by 2050. But it is important to recognise that:

- Particularly, for concrete and steel, this decarbonisation will entail accepting a "green cost premium" and will not therefore occur without public policy measures such as carbon pricing or production standard regulation, which make it economic to produce these materials in a zero carbon fashion.[57]

- Even if annual material production admissions could be reduced to net-zero by 2050, cumulative emissions between now and 2050 would amount to 40 $GtCO_2$ as shown earlier in Exhibit 4. This reflects the fact that it will take time to replace existing capital stock with new technologies.

To reduce cumulative emissions, it is therefore essential to also identify and pursue opportunities to reduce the use of carbon-intensive materials.

Demand efficiency in new building: lowering material intensity, low-carbon materials and building less

There are three main areas of opportunity to reduce material and other inputs to new building:

- **Build smarter:** Different building design choices, innovative construction techniques, and the use of lower carbon-intensive materials could reduce cumulative cement and concrete demand by 15–30% and steel demand by 15% to 2050.[58]

    - **Reducing material intensity:** The nature and scale of the opportunity varies greatly by individual circumstance, but options include: siting buildings in areas where ground elevation and soil conditions require relatively smaller foundations; maximising floor efficiency (i.e. how much of gross construction area is useable by tenants); minimising wall-to-floor ratios; and placing heavier equipment on lower floors. New technologies and designs can also lower concrete and steel use and reduce the cost and complexity of on-site construction, while delivering the same strength, for example via "manufactured reinforcement systems".[59]

    - **Material substitution:** This entails using alternative materials whose production entails lower – and in some cases zero or negative – emissions. These materials could be:

        - **Bio-based** materials, such as timber, bamboo and hempcrete, whose growth involves carbon capture and which are able to store their sequestered carbon throughout their use in buildings. As long as they are dealt with properly at end-of-life and are replanted, they can have significantly better whole-life carbon impacts than steel and cement. However, ensuring the sustainable supply and end-of-life treatment of bio-materials is challenging and without stronger regulations, there is a risk that whole-life carbon impacts can actually be worse. These materials cannot be used in all cases or construction projects (e.g., timber is currently only suitable for low- to mid-rise buildings), but where applicable can typically offer similar stability, safety and durability. There are, however, limits to the sustainable supply of biomass (at least in the short-term) and it is not therefore prudent to assume these materials can deliver a more than small (e.g., up to 10%) reduction in concrete use by 2050.[60]

        - **Innovative non bio-based materials** (such as mixtures of carbon fibre and ground stone). The economics of the different materials proposed are not yet clear, but it is possible that some variants of new material could play important future roles.

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[57] ITA (2024), *Business and finance call on governments to unlock demand for low-carbon products and accelerate industrial projects worth $1 trillion*, available at: https://ita.missionpossiblepartnership.org/news/entry/business-and-finance-call-on-governments-to-unlock-demand-for-low-carbon-products-and-accelerate-industrial-projects-worth-1-trillion/. [Accessed 20/11/2024].
[58] MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.
[59] Unipart, Construction Technologies, available at www.unipart.com/construction-technologies/manufactured-reinforcement-systems/. [Accessed 20/11/2024].
[60] ETC (2021), *Bioresources within a net-zero economy*.

- **Build less:** Changes in policy and urban planning could, in principle, reduce cumulative demand for building materials by 10% or more. In particular, there are opportunities to:
  - **Reduce overbuilding and vacancy rates in China,** which accounts for around 50% of global steel consumption and 60% of cement/concrete consumption, and where a high reliance on building construction to stimulate the economy has resulted in very high vacancy rates.[61] Around 40% of China's urban households own two or more apartments, and over 20% of all apartments are not occupied.[62]
  - **Extend building lifetimes,** which should be a priority in parts of Asia, where poor urban planning during rapid urbanisation has resulted in inadequate and inflexible buildings, and high demolition rates.
  - **Urban planning to develop more compact cities.** A recent Systemiq report, *Efficient and Balanced Space Use*, suggests that capitalising on the potential to "infill" new building in existing settlements and promoting multi-unit dwellings could avoid 40% of emissions from new building in the EU.[63]
  - In addition, there could in theory be an opportunity to reduce per capita floor use, which varies between 55 m² per capita in US, to 17 m² in Asia.[64] This would, however, have implications for living standards and our summary figures on Exhibit 4 do not assume that a reduction can be achieved.
- **Build efficient:** Options include modular construction, where parts of a building are made in a factory, shipped to site, and put together like big building blocks; digital tools to reduce waste in the design of buildings (e.g., digital twinning and 3D printing); and drones to handle materials. In total, we estimate that these have the potential to reduce global cumulative demand for cement and concrete by 1%, and by 5% for steel.[65] However, impacts for individual construction projects could be more significant.

As Exhibit 4 showed, these demand-side actions could together further reduce cumulative embodied emissions between now and 2050 from around 40 $GtCO_2$ to 30 $GtCO_2$. They would, however, be even more important if the decarbonisation of concrete and steel production occurred at a slower pace than indicated in Exhibit 20.

Optimal approaches to building retrofit

Close to 30% of embodied emissions over a building's lifecycle result from the multiple forms of retrofit/extension/partial rebuild.[66] These emissions, like those for upfront construction, will be reduced by the decarbonisation of material production. In addition, there will, in many cases, be significant opportunity to reduce material and energy use in retrofit.

But the optimal approach varies greatly by specific circumstance given a complex trade-off between:

- The potential for deep retrofit to reduce operational admissions.
- The high embodied emissions which might in some cases result.

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[61] World Steel Association, *Apparent steel use 2022*, available at www.worldsteel.org/data/annual-production-steel-data/?ind=C_asu_fsp_pub/CHN/IND. [Accessed 28/10/2024]; International Energy Agency, *Cement*, available at https://www.iea.org/reports/cement. [Accessed 28/10/2024].
[62] ETC and RMI (2020), *Achieving a green recovery for China*.
[63] Systemiq (2022), *Efficient and balanced space use: shaping vibrant neighbourhoods and boosting climate progress in Europe*.
[64] UN Environment Programme (2024), *Global Resources Outlook 2024*.
[65] MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.
[66] WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

In addition, measures of the scale of embodied emissions resulting from different types of retrofit are currently highly imperfect.

The implications are that:

- It is vital to drive both the decarbonisation of operational energy use (via electrification and grid decarbonisation) and the decarbonisation of construction material production.
- Achieving energy efficiency improvements should be a high priority for retrofits of the least efficient buildings, and for buildings in countries which have low levels of building efficiency or high levels of grid carbon intensity.
- High-quality measures of both embodied emissions incurred in retrofits and of operational emissions, can drive optimal trade-offs between retrofit emissions and operational emissions.

Policies and industry actions to drive down embodied emissions

As described above, there are in theory very large opportunities to reduce carbon emissions embodied in building construction, in particular in the upfront construction phase. But in most countries, there is less policy focus on embodied carbon than on operational emissions, and less industry focus on reducing them.

Increased momentum has, however, been gained as a result of the COP28 *Buildings Breakthrough* commitment (supported by 28 governments) and the World Green Buildings Council's Net Zero Carbon Buildings Commitment (signed by 176 companies).[67] Both of these aim to reduce embodied emissions in new buildings and major renovations by 40% by 2030.

Four categories of action are now required to reinforce this momentum:

- **Carbon pricing on construction materials.** While there are in theory multiple opportunities to reduce embodied carbon emissions, the nature of the opportunity varies greatly by type of building, and the optimal trade-off between reducing emissions and bodied vs. operational emissions is complex. As a result, there are limits to how far regulation can require specific types of decarbonisation actions, and a strong case for using the indirect lever of carbon prices to create widely dispersed incentives to reduce emissions. Such carbon prices would simultaneously create incentives to:
    - Decarbonise the production of construction materials (steel, cement, aluminium, bricks and glass).
    - Identify and implement demand-side efficiency improvements.
    - Develop new innovations in construction material and technique.
- **Better measurement of embodied emissions.** To support tighter regulation and increased voluntary action on embodied carbon, higher quality data is crucial. A first step could be for regulation to require all new construction and large renovations to complete lifecycle carbon assessments, with data collected by national authorities as part of planning permission. Industry and policymakers should work together to translate leading guidance and frameworks for embodied carbon to all countries and ensure harmonisation and comparability across countries.[68]
- **Regulation of embodied carbon.** Better data will enable regulation to begin setting minimum requirements for lifecycle emissions, being careful to sufficiently differentiate across different building types. Such regulation could focus either, as in France on specific embodied carbon limits (kgCO_2 per m^2), alongside operational energy efficiency limits (kWh per m^2); or as in Denmark, on whole-life carbon minimum requirements, allowing developers to make their own trade-offs between embodied and operational emissions.[69] Regulation could also mandate maximum carbon intensities for material inputs that are produced or imported, including minimum recycled content.
- **Voluntary industry action,** which could include:
    - Commitments from large developers and from commercial businesses whose buildings account for a large share of their scope 1 and 2 emissions (e.g., hotel and retail chains, professional services), to build low-embodied carbon new buildings.
    - Commitments from banks and asset managers to include estimates of embodied emissions in measures of "financed emissions" and to reduce these emissions.

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[67] WGBC (2023), *The Commitment*; BBP (2023), *Member Climate Commitment*; SBTI (2023), *Buildings Sector Science Based Targets Guidance.*

[68] For example, see the World Business Council for Sustainable Development (2024), *Built Environment Market Transformation Action Agenda*, and RICS (2023), *Whole life carbon assessment for the built environment: 2nd edition.*

[69] Ministère de la transition écologique (2018), *RE2020: Eco-construire pour le confort de tous*; Ministry of Interior and Housing (2021), *National Strategy for sustainable construction.*

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CRITICAL ACTIONS TO ACCELERATE THE BUILDINGS ENERGY TRANSITION

🔥 Heating ❄ Cooling 🍳 Cooking 💡 Lighting 🧺 Appliances 🏗 Embodied carbon

KEY ACTORS

■ Leading actors □ Supporting actors

Set out a clear vision for the building energy transition, supported by local delivery plans

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
🔥	*Ban fossil fuel boilers in new builds from 2025, and their sale from 2035 in high income countries + China*	■				
❄ 🔥	*Develop street-by-street decarbonisation plans and city-wide passive cooling programmes (e.g., planting trees and white roofs)*	■	■	□	■	□
🏗	*Commitments to reduce whole-life carbon emissions in buildings that are built, financed, and owned*	■	■	■		■

Underpin incentives for, and trust in, clean and electric technologies

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
🔥 🍳 🏗	*Carbon pricing (e.g., on high-carbon construction materials)*	■				
🔥 ❄ 🍳 💡 🧺	*Ensure consumers benefit from low-cost renewable electricity generation (e.g., rebalancing gas and electricity prices)*	■			□	
🏗 🔥 🍳	*Investment in innovation, skills and supply chains to drive down costs and improve efficiency*	■	■	□	■	
🔥 ❄	*Ban the use of refrigerants with high global warming potential*	■			■	
🔥 ❄	*Provide advice on clean technologies + insulation + smart and flexible technologies (e.g., solar, batteries, smart systems)*	■		□	■	

Create strong frameworks and standards for measuring and reducing whole-life carbon of new buildings

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
🔥 ❄ 🏗	*Regulations and certifications to set ambitious limits for operational energy efficiency (kWh / m²) and use actual, not modelled, data*	■				
🏗	*Develop frameworks to measure whole-life carbon, mandate assessments, and set ambitious embodied carbon limits*	■	■			
🏗	*Upskill on how to design lower carbon buildings (e.g., capabilities to use low-carbon materials, material efficient construction)*	□	■			

Manage new and peaky electricity demand with flexible and efficient buildings

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
🔥 ❄ 🍳 💡 🧺	*Minimum energy performance standards for AC, heat pumps, appliances and lighting*	■				
🔥 ❄	*Commitments to retrofitting the least energy efficient buildings by 2035 with low-cost finance and guidance*	■			□	■
🔥 ❄ 🍳 💡 🧺	*Rollout of smart meters and introduction of time-of-use tariffs*	■			■	■

Deliver a fair and just transition for households

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
🔥 ❄ 🍳 💡 🧺	*Low-cost finance and new financial products for retrofits, heat pumps, clean cooking and efficient AC*	■		■	□	
🔥 🍳	*Early planning for location-specific and co-ordinated gas grid phase down*	■		□	■	
🔥 ❄	*Investments in improving the energy efficiency of social housing and implement minimum standards for rental properties*	■		□		■

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