Achieving Zero-Carbon Buildings:
Electric, Efficient and Flexible

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 partners with Bloomberg New Energy Finance (BNEF) for leading market information. All BNEF data has been sourced from *about.bnef.com*.

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
www.linkedin.com/company/energy-transitions-commission
www.twitter.com/ETC_energy
www.youtube.com/@ETC_energy

The Energy Transitions Commission is hosted by SYSTEMIQ Ltd.

Front cover and Report design: Geist* Studio.

ETC Commissioners

Mr. Marco Alvera,
Co-founder and Chief Executive Officer – TES

Mr. Bradley Andrews,
Chief Executive Officer – SLR Consulting

Mr. Benoit Bazin,
Chairman and Chief Executive Officer – Saint Gobain

Mr. Ahmad Butt,
Executive Chairman – Deep Science Ventures

Dr. Zhao Changwen,
President, Center for International Knowledge on Development (CIKD), China – Center for International Knowledge on Development (CIKD)

Ms. Jamie Choi,
Chief Executive Officer – Tara Climate Foundation

Mr. John Creyts,
Chief Executive Officer – Rocky Mountain Institute

Mr. Spencer Dale,
Chief Economist – bp

Mr. Bradley Davey,
Executive Vice-President, Head of Corporate Business Optimization – ArcelorMittal

Ms. Faustine Delasalle,
Chief Executive Officer – MPP

Mr. Agustin Delgado,
Chief Innovation and Sustainability Officer – Iberdrola

Dr. Vibha Dhawan,
Director General – The Energy & Resources Institute

Dr. Julio Friedman,
Chief Scientist – Carbon Direct

Mr. Matthew Gorman,
Director of Carbon Strategy and Sustainability – Heathrow Airport

Mr. Craig Hanson,
Managing Director and Executive Vice President for Programs – World Resources Institute

Mr. Seb Henbest,
Group Head of Climate Transition – HSBC

Mr. Alex Hewitt,
Co- founder and Chairman – CWP Global

Dr. Thomas Hohne-Sparborth,
Head of Sustainability Research (at Lombard Odier Investment Managers) – Lombard Odier

Dr. Jennifer Holmgren,
Chief Executive Officer – LanzaTech

Ms. Naoko Ishii,
Director, Center for Global Commons and Professor, Institute for Future Initiatives – Center for Global Commons

Dr. Mallika Ishwaran,
Chief Economist – Shell plc

Mr. Greg Jackson,
Founder and Chief Executive Officer – Octopus Energy

Mr. Timothy Jarratt,
Group Executive, Market Development and Strategy – Ausgrid

Mr. Zou Ji,
Chief Executive Officer and President of Energy Foundation China – EF China

Mr. Shaun Kingsbury,
Chief Investment Officer – Just Climate

Mr. Zheng Li,
Executive Vice President – Institute of Climate Change and Sustainable Development, Tsinghua University

Mr. Zhenguo Li,
President – LONGi

Mr. Martin Lindqvist,
President and Chief Executive Officer – SSAB

Mr. Bruce Lourie,
President of the Ivey Foundation – The Transition Accelerator

Mr. Johan Lundén,
Senior Vice President, Project and Product Strategy Office – Volvo

Mr. Rajiv Mangal,
Vice President Safety, Health & Sustainability – Tata Steel

Ms. Laura Mason,
Chief Executive Officer – L&G

Mr. Nicholas Mazzei,
Vice President Sustainability - Europe – DP World

Ms. Maria Mendiluce,
Chief Executive Officer – We Mean Business Coalition

Ms. Dervilla Mitchell,
Director – Arup

Mr. Jon Moore,
Chief Executive Officer – BloombergNEF

Mr. Simon Morrish,
Founder and Chief Executive Officer – X-links

Ms. Paige Marie Morse,
Enterprise Director, Sustainability – AspenTech

Mr. Carl Moxley,
Group Climate Director – L&G

Mr. Jelle Nederstigt
President – Worley

Mrs. Damilola Ogunbiyi,
Chief Executive Officer – SEforAll

Mr. KD Park,
President – Korea Zinc Ltd

Ms. Nandita Parshad
Managing Director, Sustainable Infrastructure Group – EBRD

Mr. Alistair Phillips-Davies,
Chief Executive Officer – SSE

Mr. Andreas Regnell,
Senior Vice President, Head of Strategic Development – Vattenfall

Mr. Menno Sanderse,
Head of Strategy and Investor Relations – Rio Tinto

Mr. Ian Simm,
Founder and Chief Executive Officer – Impax Asset Management

Mr. Sumant Sinha,
Chairman, Founder and Chief Executive Officer – ReNew

Ms. Anna Skarbek,
Director, Climate Works Australia – Climate Works Centre

Mr. Steve Smith,
Interim Chief Strategy and Regulation Officer and President, National Grid Partners – National Grid

Ms. Marijn Steegstra,
Head of Client Coverage NL & Energy Transition, Europe and Africa – Rabobank

Lord Nicholas Stern,
IG Patel Professor of Economics and Government – Grantham Institute – LSE

Ms. Marina Taib,
Senior Vice President, Corporate Strategy – Petronas

Mr. Greg De Temmerman,
Deputy CEO and Chief Science Officer – Quadrature Climate Foundation

Mr. Chacko Thomas,
Group Chief Sustainability Officer – Tata Sons (Sustainability Group)

Mr. Simon Thompson,
Senior Advisor, Rothschild & Co – Rothschild

Mr. Nigel Topping,
Former UN Climate Change High-Level Champion – UK Climate Change Committee

Dr. Robert Trezona,
Founding Partner – Kiko Ventures

Mr. Jean-Pascal Tricoire,
Chairman – Schneider Electric

Ms. Laurence Tubiana,
Chief Executive Officer – European Climate Foundation

Mr. Fabby Tumiwa,
Executive Director – IESR

Mr. Adair Turner,
Chair – Energy Transitions Commission

Senator Timothy E. Wirth,
Vice Chair – United Nations Foundation

Mr. Lei Zhang,
Chief Executive Officer – Envision Group

Major ETC reports and working papers

To download all ETC reports, papers, explainers and factsheets visit www.energy-transitions.org

Global Reports

Mission Possible (2018) outlines pathways to reach net-zero emissions from the harder-to-abate sectors in heavy industry (cement, steel, plastics) and heavy-duty transport (trucking, shipping, aviation).

Making Mission Possible (2020) shows that a net-zero global economy is technically and economically possible by mid-century and will require a profound transformation of the global energy system.

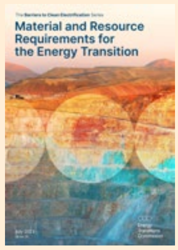
Mission Possible Series

Making Mission Possible Series (2021-2022) outlines how to scale up clean energy provision to achieve a net-zero emissions economy by mid-century.

Barriers to Clean Electrification Series

Barriers to Clean Electrification Series (2022–2024) recommends actions to overcome key obstacles to clean electrification scale-up, including planning and permitting, supply chains and power grids.

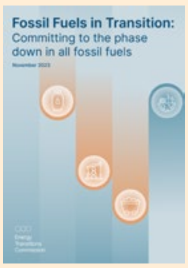
Financing the Transition (2023–2024) quantifies the finance needed to achieve a net-zero global economy and identifies policies needed to unleash investment on the scale required.



Material and Resource Requirements for the Energy Transition (2023) dives into the natural resources and materials required to meet the needs of the transition by mid-century, and recommends actions to expand supply rapidly and sustainably.

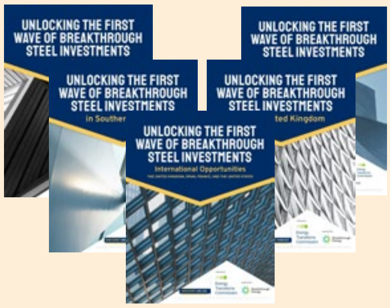
COP-focused

Keeping 1.5° Alive Series (2021–2022) COP special reports outlining actions and agreements required in the 2020s to keep 1.5°C within reach.



Fossil Fuels in Transition (2023) describes the technically and economically feasible phase-down of coal, oil and gas that is required to limit global warming to well below 2°C as outlined in the Paris Agreement.

Nationally Determined Contributions (2024) calls for industry and government collaboration to raise ambition in the next round of Nationally Determined Contributions by COP30 to limit the impact of climate change.



Sectoral and cross-sectoral focuses

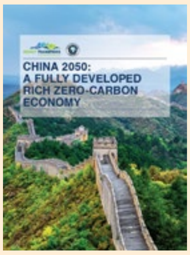
Sectoral focuses provided detailed decarbonisation analyses on six of the harder-to-abate sectors after the publication of the **Mission Possible** report (2019).

As a core partner of the MPP, the ETC also completes analysis to support a range of sectorial decarbonisation initiatives:

MPP Sector Transition Strategies (2022-2023) a series of reports that guide the decarbonisation of seven of the hardest-to-abate sectors. Of these, four are from the materials industries: aluminium, chemicals, concrete, and steel, and three are from the mobility and transport sectors – aviation, shipping, and trucking.

Unlocking the First Wave of Breakthrough Steel Investments (2023) This ETC series of reports looks at how to scale up near-zero emissions primary (ore-based) steelmaking this decade within specific regional contexts: the UK, Southern Europe, France and USA.

Geographical focuses



China 2050: A Fully Developed Rich Zero-carbon Economy (2019) analyses China's energy sources, technologies and policy interventions required to reach net-zero carbon emissions by 2050.

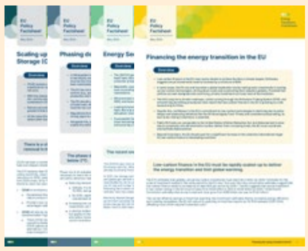
A series of reports on the Indian power system, outlining decarbonisation roadmaps for India's electricity supply and heavy industry.

Canada's Building Heating Decarbonization - Jurisdictional Scan (2024) provides an in-depth look at how governments across Canada and the globe are using policy to transition building heating away from fossil fuels.

Setting up industrial regions for net zero (2021-2023) explore the state of play in Australia, and identifies opportunities for transitioning to net-zero emissions in five hard-to-abate supply chains.

Pathways to Net-Zero for the US Energy Transition (2022-2023) examines the trendlines, challenges, and opportunities for meeting the US net-zero objective.

A Path Across the Rift (2023) reviews an analysis of African energy transitions and pinpoints critical questions we need to answer to foster science-based policymaking to enable decisions informed by clear and objective country-specific analysis.



EU Factsheets (2024) cover the phase down of fossil fuels, carbon capture, utilisation and storage (CCUS), financing the transition, and energy security, to bring a facts-based perspective to the EU debates around energy.

Glossary

Active heating and cooling: The use of mechanical heating and cooling technologies, such as boilers, heat pumps, and AC.

Carbon budgets: The maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other GHG reductions. The remaining carbon budget indicates how much CO_2 could still be emitted while keeping warming below a specific temperature level. Carbon Budgets provide directional insight only and remain highly uncertain. They relate only to anthropogenic emissions or emissions from natural sources arising because of human activity (e.g., land use change), and already allow for the significant carbon sequestration which naturally occurs in forests and oceans.

Carbon capture and use or storage (CCUS): We use the term "carbon capture" to refer to the process of capturing CO_2 on the back of energy and industrial processes. Unless specified otherwise, we do not include direct air capture (DAC) when using this term. The term "carbon capture and storage" refers to the combination of carbon capture with underground carbon storage; while "carbon capture and use" refers to the use of carbon in carbon-based products in which CO_2 is sequestered over the long term (e.g., in concrete, aggregates, carbon fibre). Carbon-based products that only delay emissions in the short-term (e.g., synfuels) are excluded when using this terminology. Carbon capture projects should aim to achieve capture rates of above 90%.

Carbon emissions/CO_2 emissions: We use these terms interchangeably to describe anthropogenic emissions of carbon dioxide in the atmosphere.

Carbon price: A government-imposed pricing mechanism, the two main types being either a tax on products and services based on their carbon intensity, or a quota system setting a cap on permissible emissions in the country or region and allowing companies to trade the right to emit carbon (i.e. as allowances). This should be distinguished from some companies' use of what are sometimes called "internal" or "shadow" carbon prices, which are not prices or levies, but individual project screening values.

Coefficient of performance (CoP): A measure of a heat pump or AC's efficiency. It is calculated as the temperature difference between the heat source and the heat sink and therefore demonstrates the efficiency of a heat pump at a moment in time, for example given the temperature outside and the desired inside temperature. A heat pump's CoP expresses efficiency as a multiple, rather than a percentage; a CoP of 3 can be interpreted as efficiency of 300%. Heat pump efficiencies are typically averaged over a season, to show the seasonal coefficient of performance (sCoP) for average winter conditions.

Cost of capital: A measure of the risk associated with investments; it expresses the expected financial return, or the minimum required rate, for investing in a company or a project.

Direct use of fossil fuels: The use of technologies that use/burn fossil fuels or biomass in a building (e.g., a gas or oil boiler, a gas stove, or the traditional use of biomass for cooking).

Embodied carbon emissions: Lifecycle carbon emissions from the production of building materials, such as cement, concrete and steel, and the use of fossil fuels in machinery and transport in construction, maintenance and demolition of a building.

Energy productivity: Energy use per unit of GDP.

Final energy demand: All energy supplied to the final consumer for all energy uses.

Global Warming Potential (GWP): Global warming potential is a measure of the contribution to warming from one ton of refrigerant, relative to the warming induced by one tonne of carbon dioxide.

Greenhouse gases (GHGs): Gases that trap heat in the atmosphere. Global GHG emission contributions by gas – CO_2 (76%), methane (16%), nitrous oxide (6%) and fluorinated gases (2%).

"Green" hydrogen: Refers to fuels produced using electricity from low-carbon sources (i.e. variable renewables such as wind and solar).

Heat network: Heat sourced or generated at centralised locations and distributed to individual buildings (e.g., via hot water). They range community heating (e.g., one block of flats or a street), to larger-scale district heating (e.g., cities and towns). There are many different types of heat networks, including those generating heat using fossil fuels, large-scale heat pumps, or utilising low-temperature heat from existing sources such as waste industrial or transport heat. The term also includes networked heat pumps, which use a centralised heat source (such as the ground) and transfer this low-grade heat to individual heat pumps, to be upgraded. Heat networks are generally much more efficient than individual technologies.

Heat pump: A clean heating technology which extracts heat from the air, water or the ground, and transfers that heat inside to where it is needed, either via hot water or hot air. They are the same technology as an air conditioner, but work in reverse. They utilise the refrigeration cycle, which involves compressing and then expanding a refrigerant, causing it to change state via condensation and evaporation.

Indirect use of fossil fuels: The use of fossil fuels to generate electricity.

Levelised cost of electricity (LCOE): A measure of the average net present cost of electricity generation for a generating plant over its lifetime.

The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity-generating plant divided by a discounted sum of the actual energy amounts delivered.

Liquified Petroleum Gas (LPG): Is a hydrocarbon gas that exists in a liquefied form supplied in two main forms, propane (C3H8) and butane (C4H10). LPG has a low boiling temperature and is typically stored in pressurised steel vessels.

Minimum energy performance standard (MEPS): Regulations which set a minimum standard for a technology's energy efficiency.

Negative emissions (or "net negative" emissions): Is used for the case where the combination of all sector CO_2 emissions plus carbon removals results in an absolute negative (and thus a reduction in the stock of atmospheric CO_2).

Net-zero carbon emissions / Net-zero carbon / Net-zero: We use these terms interchangeably to describe the situation in which the energy and industrial system as a whole or a specific economic sector releases no CO_2 emissions – either because it doesn't produce any or because it captures the CO_2 it produces to use or store. In this situation, the use of offsets from other sectors ("real net-zero") should be extremely limited and used only to compensate for residual emissions from imperfect levels of carbon capture, unavoidable end-of-life emissions, or remaining emissions from the agriculture sector.

Operational emissions: The emissions relating from the direct and indirect use of energy use to operate buildings (i.e. for heating, cooling, cooking, lighting and appliances).

Passive heating and cooling: Techniques and material choices which rely on natural elements such as the sun, and a building's envelope and fabric to maintain a comfortable indoor temperature and therefore reduce the use of mechanical, or "active", heating systems. These techniques can have a significant impact on improving comfort and lowering energy bills.

Peak energy demand: Increases in energy consumption by buildings over a day (e.g., heating demand in the morning and evening, cooling demand in the middle of the day and night), and over a year (e.g., heating demand in colder months, cooling demand in hotter or humid months).

Process emissions: CO_2 and other GHG emissions generated as consequence of a chemical reaction other than combustion occurring during an industrial process.

Refrigerants: Fluids which are capable to changing state between a liquid and gas at low temperatures due to very low boiling points. In other words, they are able to absorb and let go of heat energy quickly. There are many different types of refrigerants, which work at different pressures and temperatures.

Scope 1 emissions: Emissions from sources that an organisation owns or controls directly – for example from burning fuel in its own fleet of vehicles.

Scope 2 emissions: Emissions that a company causes indirectly and come from where the energy it purchases and uses is produced. For example, emissions caused when generating the electricity used in the company's office buildings.

Scope 3 emissions: Emissions that are not produced by the company itself and are not the result of activities from assets owned or controlled by them, but by those that it's indirectly responsible for up and down its value chain. An example of this is buying, using and disposing of products from suppliers. Scope 3 emissions include all sources not within the scope 1 and 2 boundaries.

Seasonal energy efficiency rating (SEER): Assesses the energy efficiency of an AC and is measured by the cooling output during a typical cooling-season divided by the total electric energy input during the same period.

Sequestration: Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide.

Sustainable biomass: In this report, the term 'sustainable biomass' is used to describe biomass that is produced without triggering any destructive land use change (in particular deforestation), is grown and harvested in a way that is mindful of ecological considerations (such as biodiversity and soil health), and has a lifecycle carbon footprint that considers the opportunity cost of the land as well as the timing of carbon sequestration and carbon release specific to each form of bio-feedstock and use.

Traditional Use of Biomass (TUOB): The use of solid biomass - including wood, wood waste, charcoal, agricultural residues and other bio-sourced fuels, such as animal dung - with basic technologies. It is primarily used for cooking in buildings, with three-stone fire or basic improved cookstoves, often with no or poorly operating chimneys.

Whole life carbon / emissions: The combined total of embodied and operational emissions over the whole life cycle of a building (i.e. material production, construction, use and maintenance, and end-of-life). Life cycle assessments (LCAs) should take into account the greenhouse gas impacts across land use change (if applicable), growth, harvesting, transportation, conversion, and use of bioresources.

Contents

How to navigate this report

Mapping by chapter number

Construction | Operation

BUILDING LIFECYCLE

Stakeholder navigation

This report serves as a comprehensive analysis of every aspect of the building energy transition, which involves a wide variety of different actors. This table suggests the most relevant sections for different groups of stakeholders in different regions (i.e. those with and without heating needs). There are implications for policymakers throughout the report.

Key actors	Priority sections	
	...In northern latitude countries	...In the rest of the world
Developers and construction companies	• 2.3: Passive heating • 2.4: Clean heating tech in new builds • 3.2.2: Passive cooling • 8: Buildings in clean energy system • 11–13: Reducing embodied carbon	• 3.2.2: Passive cooling • 8: Buildings in clean energy system • 11–13: Reducing embodied carbon
Energy and technology companies	• 2–6: Heating, cooling, cooking, appliances, lighting • 8: Buildings in clean energy system • 9: Reducing refrigerant leakage	• 3–6: Cooling, cooking, appliances, lighting • 8: Buildings in clean energy system • 9: Reducing refrigerant leakage
Financial institutions	• 2–4: Heating, cooling, cooking • 7: Commercial buildings • 11–13: Reducing embodied carbon	• 3–4: Cooling, cooking • 7: Commercial buildings • 11–13: Reducing embodied carbon
Commercial businesses and professional building owners	• 7: Commercial buildings • 2–6: Heating, cooling, cooking, appliances, lighting • 8: Buildings in clean energy system • 11–13: Reducing embodied carbon	• 7: Commercial buildings • 3–6: Cooling, cooking, appliances, lighting • 8: Buildings in clean energy system • 11–13: Reducing embodied carbon
Residential households	• 2–6: Heating, cooling, cooking, appliances, lighting • 8.3: Demand-side flexibility	• 3–6: Cooling, cooking, appliances, lighting • 8.3: Demand-side flexibility

Introduction: Coverage, report structure and summary conclusions

At COP21 in Paris, and again at COP26 in Glasgow, the vast majority of the world's nations agreed that it is essential to limit global warming to well below 2°C, and ideally to 1.5°C, with limited overshoot. Recent extreme weather events across the world have illustrated the vital importance of meeting those objectives. But we are running out of time to achieve them.

To limit global warming even to well below 2°C (e.g., to 1.7°C) will require CO_2 emissions resulting from the use of energy to fall to around net-zero by mid-century. This will require switching to the use of non-fossil fuel energy sources, together with a limited but vital role for carbon capture and storage (CCUS) in offsetting the small residual use of fossil fuels. Much of the work of the Energy Transitions Commission (ETC) has therefore been devoted to identifying how to achieve this decarbonisation of energy supply.[1] Through the work of the Mission Possible Partnership, the ETC has also described how to decarbonise the hard-to-abate, heavy emitting sectors, such as steel, cement and concrete, shipping and aviation.

This is the first ETC report looking in-depth at the global buildings sector, which makes up a third of global emissions, and 10% of direct fossil fuel energy use.[2,3] Its coverage includes:

- **Both "operational" and "embodied" emissions.** Operational energy is used in buildings for space and water heating, space cooling, cooking, lighting and multiple forms of appliances. Operational emissions result if fossil fuels are used directly in end applications, or indirectly to produce electricity. Embodied carbon results from the emissions generated from producing and transporting building materials (predominately steel, cement and concrete) and the use of fossil fuels in constructing, maintaining and demolishing buildings.

- **Both supply-side and demand-side levers.** Energy supply-side levers include switching from gas boilers to electric heat pumps for residential heating, which will reduce emissions if accompanied by power sector decarbonisation. Demand-side measures increase "energy productivity" by reducing the amount of energy needed to deliver end energy services, and thus human welfare (e.g., via improved building insulation). It is important to note, however, that the key supply-side lever of electrification also improves energy productivity: the theme that "electrification is efficiency" is a key message of this report.

- **The impact of building electrification on the overall electricity system.** Electrifying building heating and cooking will increase not only overall electricity demand, but peak electricity demand. Meanwhile, using variable renewables to decarbonise electricity supply means that a large share of electricity supply will not be dispatchable. It is therefore essential to identify and implement actions which can achieve time-specific power supply/demand balance in future electricity systems. These include many actions – such as improved insulation, decentralised storage and demand-side flexibility – which can be deployed at the building level, rather than within the electricity supply system.

The latter aspects of this report will feed into two other ETC workstreams:

- Our work on power sector transformation, which is looking at all the generation, storage, demand-side flexibility and grid investments which will be needed to balance supply and demand in zero-carbon power systems across different regions of the world. Our report from this work stream will be published in Q2 2025.

- Overall analysis of opportunities to improve "energy productivity" in all sectors of the economy, which will be published in Q1 2025. Box A describes the focus of this analysis and the different categories of energy productivity improvement which it will consider.

1 ETC (2024), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels*; ETC (2021), *Making Clean Electrification Possible*; ETC (2022), *Mind the Gap: How carbon dioxide removals must complement deep decarbonisation to keep 1.5°C alive*; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: vital but limited.*
2 Systemiq analysis for the ETC; BNEF (2023), *New Energy Outlook 2022*; IEA (2022), *World Energy Outlook 2022.*
3 We have previously evidenced the potential to electrify building heating in our 2021 *Making Clean Electrification Possible report*, the global investment required to decarbonise buildings in our 2023 *Financing the Transition report*, and developed scenarios for the decline of direct fossil fuel use in buildings in our 2023 Fossil Fuels in Transition report. The MPP has also developed detailed sector transition strategies to decarbonise cement and concrete, steel and aluminium. While buildings is a key source of demand for these materials, these strategies are broader than just the buildings sector.

Box A **The ETC's wider work on energy productivity**

Much of the work of the ETC has been devoted to identifying how to achieve decarbonisation of energy supply.[4] But emissions could also be reduced by using energy more efficiently; and even if all energy supply were decarbonised, greater energy efficiency would still play a critical role in reducing the total cost of energy inputs required. Improving overall "energy productivity", i.e. the amount of energy required to deliver any given level of GDP and human welfare, is therefore an important objective.

Over the last 10 years, global primary energy productivity has increased by 1.7% per annum, but with global GDP growing at 2.7%, overall energy demand has continued to grow.[5] But at COP28, nations agreed to double the rate of energy productivity improvements, achieving a global average of 4.1% per annum by 2030.[6]

To identify how this could be achieved, and to assess the long-term potential for energy efficiency improvement beyond 2030, it is essential to take a detailed sector-by-sector approach. The ETC is therefore conducting that sector-by-sector analysis and will produce an overall report supported by sector-specific appendices in Q1 2025.

The report will cover opportunities to improve energy productivity in:

- The **building sector**, drawing on the analysis and conclusions set out in this report.
- The **road transport sector**, where electrification will be a key driver of improvement, but where there are also opportunities to improve the technical efficiency (kWh of energy input per km travelled) of both internal combustion engines and electric vehicles.
- The **heavy industry sectors**, such as steel, cement and chemicals, where supply-side decarbonisation (e.g., switching from cooking coal to hydrogen as the reduction agent in iron production) could be accompanied by efficiency improvements in many process steps.
- The **aviation and shipping sectors**, where switching to new fuels such as sustainable aviation fuel (SAF) and ammonia might, in fact, reduce measured primary energy efficiency (because of significant conversion losses), but where there are significant opportunities to improve energy efficiency in-use (e.g., reducing the amount of jet fuel used per passenger km).

The analysis will consider the drivers of measured energy productivity at both the "primary" and "final" energy level, and will assess opportunities for three different types of energy productivity improvement:

- **Technical energy efficiency**, which measures the input of energy required to deliver a desired energy service. In buildings, this opportunity covers both:
    - The efficiency with which heating equipment converts a kWh of energy input into a kWh of heat delivered into a building.
    - The number of kWh which need to be delivered to maintain a specific temperature level, which depends on the efficiency of insulation.
- **Service efficiency,** which measures the potential for people to enjoy the same standard of living while using less energy-intensive services (e.g., using public transport rather than private cars), or products (e.g., increasing utilisation of existing buildings rather than building new ones).
- **Material efficiency,** where efficiency can be improved by delivering a given quantity of products with reduced material inputs (e.g., fewer kg of steel or cement used to construct a building).

4 ETC (2024), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels.*
5 IEA, *Energy Efficiency*, available at www.iea.org/energy-system/energy-efficiency-and-demand/energy-efficiency. [Accessed 26/11/2024].
6 COP28, Global Renewables and Energy Efficiency Pledge.

Structure of this report

The global building stock varies hugely by category (e.g., residential and multiple variants of commercial building), age, design, quality of construction, and typical unit size. Optimal approaches to decarbonisation must therefore be tailored to specific circumstance. Optimal approaches also sometimes involve complex trade-offs between the technical efficiency of heating/cooling equipment and the optimal level of insulation, and between operational and embodied carbon emissions. And some important policy levers – in particular the various forms of building regulation – are simultaneously relevant to both operational and embodied emissions.

As a result, there is no perfect way to structure a report on building decarbonisation. Our report structure therefore combines a mix of focus by building type, application type and key topic, and involves some unavoidable duplication of messages between chapters.

It covers in turn:

- **Chapter 1:** Current energy use and resulting emissions by building type and application.
- **Section A: Decarbonising the energy used to operate buildings**
    - Chapters 2–3 assess opportunities to reduce the emissions resulting from **space heating and cooling** in new and existing buildings (focusing mainly on residential). They consider the potential to electrify heating, to reduce energy input requirement via "passive" heating and cooling (e.g., via improved insulation), and to improve the technical efficiency of the key heat pump/AC technology.[7]
    - Chapters 4–6 investigate opportunities to reduce emissions from **cooking, lighting and appliances**.
    - Chapter 7 explores operational energy use in **commercial buildings**. Most of the relevant technologies apply also to the residential sector and are therefore already described in Chapters 2–6, but this chapter highlights specific features of their application to commercial buildings.
    - Chapter 8 explains how to manage **refrigerant leakage and venting** from heat pumps and ACs.
    - Chapter 9 explores the **system-wide implications of electrified buildings**. It assesses opportunities to create efficient and flexible buildings which can play a key role in managing electricity demand in a renewable energy system.
- **Section B: Reducing embodied emissions from the next generation of new buildings**
    - Chapter 10 describes the nature and scale of **embodied carbon emissions**, with the production of cement/concrete and steel playing a dominant role.
    - Chapter 11 assesses both (i) the potential to **decarbonise material production**, drawing on the work of the MPP, and (ii) the potential to **reduce the amount of material required in construction** of new buildings via improved building techniques and alternative materials.
    - Chapter 12 assesses optimal approaches to the **retrofit of existing buildings**, which can entail a trade-off between reducing operational vs. embodied emissions.
    - Chapter 13 sets out the **policy and industry actions** required to drive reduction in embodied emissions. It highlights the important role that carbon pricing should play.
- **Section C: Summary of the actions required from policymakers, industry, financial institutions.**

7 Active heating/cooling systems refer to the use of mechanical equipment to regulate indoor temperatures (e.g., heat pumps, AC). Passive solutions rely on natural elements such as the sun and a building's envelope to maintain a comfortable indoor temperature.

Summary conclusions

Each chapter of this report sets out our conclusions on the specific challenges considered, the public policy and industry actions required to drive decarbonisation, and potential implications for electricity demand and fossil fuel use.

The Executive Summary presents a condensed version of the chapter-by-chapter conclusions, and assesses the overall potential for reducing both operational and embodied energy via either supply-side or demand-side levers.

Our key conclusions related to operational energy use include:

1. **The solution to decarbonising residential and commercial heating will be predominately electric, and predominately heat pumps** – but there is no one-size-fits-all technology, with the optimal solution depending on building characteristics and household preferences. Heat networks (e.g., networked ground source heat pumps and district heating solutions) should be deployed where possible, since these can deliver significant efficiency gains and enable entire streets to be decarbonised and segments of the gas grid switched off.

2. **A whole-building approach is required to create zero-carbon ready buildings.** This involves consideration and optimisation across three types of technology: 1) installation of clean heating technologies which can be powered by clean electricity, 2) improvements to the building envelope and 3) consideration of a suite of smart and flexible technologies (e.g., smart system, solar and batteries). Insulating the least efficient homes must be a government priority, and combined with heat electrification can lower energy bills and improve comfort levels. However, for the average home, deep retrofit is not a pre-requisite for installing a heat pump, as long as radiators and systems are appropriately sized.

3. **Hydrogen should not be used for home heating in new or existing buildings.** It is much less efficient (e.g., green hydrogen for heating would require 5–6 more electricity than heat pumps) and would still require substantial retrofit to boilers and the gas network. It may, however, play a niche role in some specific locations (e.g., close to clean hydrogen production).

4. **Demand for cooling is set to more than double by 2050,** as a result of rising incomes and climate change. Demand could, however, be even greater if rising incomes drive significant behaviour change in parts of the world which are currently more conservative in their use. This will have significant benefits for health, wellbeing and productivity, but will create huge demands for electricity requirements that need to be managed.

5. **Deploying passive cooling techniques (e.g., white roofs and external shading) in buildings could reduce global demand for cooling by around 25%,** with even greater benefits for the 40% of the global population living in hot countries that may still not have access to AC in 2050. Many of these are low-cost, such as external shading and painting roofs white, and can reduce cooling energy demand in individual buildings by up to 50%.

6. **The risk of emissions relating to refrigerant leakage and venting from ACs and heat pumps is very large but can be managed.** Emissions from refrigerant leakage and venting in 2050 could be equivalent to 15% of today's total building emissions, but could be cut in half with regulations and incentives for proper disposal of refrigerant at end-of-life, skills certifications to improve the quality of installations and maintenance, and with a faster transition to lower-GWP refrigerants.

7. **For cooking, it is essential to phase out the traditional use of biomass (TUOB) as rapidly as possible,** eliminating its extremely harmful health effects and emissions. Intermediate fuels such as liquid petroleum gas (LPG) will play a role during the transition but the eventual solution should see cooking electrified across the world.

8. **Final demand for buildings could increase from 36,600 TWh to 57,500 TWh under business as usual.** But it would be theoretically possible to limit this to ~23,200 TWh via a combination of:

   - Electrification, which directly reduces final energy consumption because heat pumps are 3–4 times more efficient than fossil fuel boilers and electric cooking can be over 5 times more efficient than the traditional use of biomass.

   - Technical efficiency improvements in heating (e.g., from a COP of 3 to 4–5), cooking (e.g., moving to induction hobs), cooling equipment (where the average AC sold today is far less efficient than best available technology), household appliances, and moving all lighting to LED bulbs. These improvements could reduce required energy supply by around 25%.

   - Building new buildings to higher standards and incorporating passive heating and cooling techniques – where reducing operational energy per m^2 beyond current regulated standards by 25% may only add 1–5% to construction costs – and retrofitting existing buildings.

- Improving demand efficiency through the installation of smart systems which can reduce unnecessary energy use (e.g., sensors in commercial buildings, controlling thermostats remotely), and different behavioural choices (e.g., setting cooling thermostats slightly higher).

This illustrates the scale of the opportunity which should be pursued, even if in practice, only a proportion of the total opportunity if likely to be achieved.

9. **Electrification is efficiency, but as we move to a building energy which is almost wholly electric, the total demand for electricity will increase significantly.** Annual electricity requirements for buildings in 2050 could be 2.5–3 times higher than today, increasing from 12,800 TWh to around 35,000 TWh; but in principle this could be lowered to around 18,500 TWh with strong action on energy productivity. Pursuing this energy productivity potential must therefore be a priority, but public policy must also ensure rapid growth in clean electricity supply.

10. **Electricity demand for buildings will create peaky demand for grids, but there is huge untapped potential for demand-side flexibility.** Insulation can have a significant impact on a building's thermal inertia and peak heating needs; all buildings should aim to have 2–4 hours flexibility. Water storage tanks are a low-cost, no regrets solution for households with sufficient space to shift water heating outside of peak times. Smart systems are also a no-regrets solution, which can also support gradual behaviour change. Solar panels and batteries installed at building-level would be a huge benefit to the grid in countries with a big cooling need, and will become increasingly economic as costs decline.

11. **It is technically and economically feasible to almost entirely eliminate the direct use of gas and oil in buildings by 2050, with falls of around 15–20% possible by 2030.** Coal use can be entirely eliminated by 2040.

Our key conclusions related to embodied carbon are:

12. **Global floor area is set to expand by ~50% by 2050,** and if buildings continued to be built at today's embodied carbon intensity, this could result in **~75 $GtCO_2$ cumulative emissions between now and 2050.** This could be reduced to ~40 $GtCO_2$ by feasible actions to decarbonise the production of cement/concrete, steel and other building materials, as described in the MPP's sector transition strategies.

13. A further reduction to ~30 $GtCO_2$ could be achieved **via improvements in building design and construction technique and the elimination of wasteful overbuilding relative to demand, particularly in China.** Feasible measures include light-weighting construction techniques and building design considerations to use less material input, and using lower-carbon materials such as timber; some bio-based materials such as hempcrete can even have negative emissions if dealt with correctly at end-of-life. These demand-side levers will become even more important if the decarbonisation of material production occurs slower than indicated in the MPP scenarios.

14. **Key policy, industry and finance actions:**

    - Set out a clear national vision for the building energy transition, with targets for heat pump deployment and clear bans on fossil fuel heating and cooking, supported by local street-by-street delivery plans.

    - Underpin incentives for, and trust in, clean, electric technologies by creating early demand for low-carbon technologies, rebalancing gas and electricity prices, and providing time-limited subsidies for deployment.

    - Create strong frameworks and standards for measuring and reducing whole-life carbon of new buildings, particularly around embodied carbon.

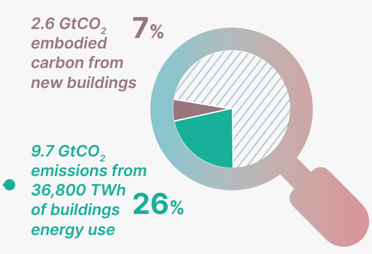
    - Manage new and peaky electricity demand with flexible and efficient buildings with time-of-use tariffs, minimum energy performance standards and labelling regulations, financial incentives for insulation, and encouraging the uptake of smart systems, rooftop solar PV and batteries.

    - Introduce carbon prices or equivalent regulation to drive the decarbonisation of material production, and create incentives for the more efficient use of carbon-intensive construction materials.

    - Deliver a fair transition for households, with targeted support for low-income households, investment in social housing, clear regulations on the energy efficiency of rented properties, and education and awareness of low-cost passive heating and insulation improvements.

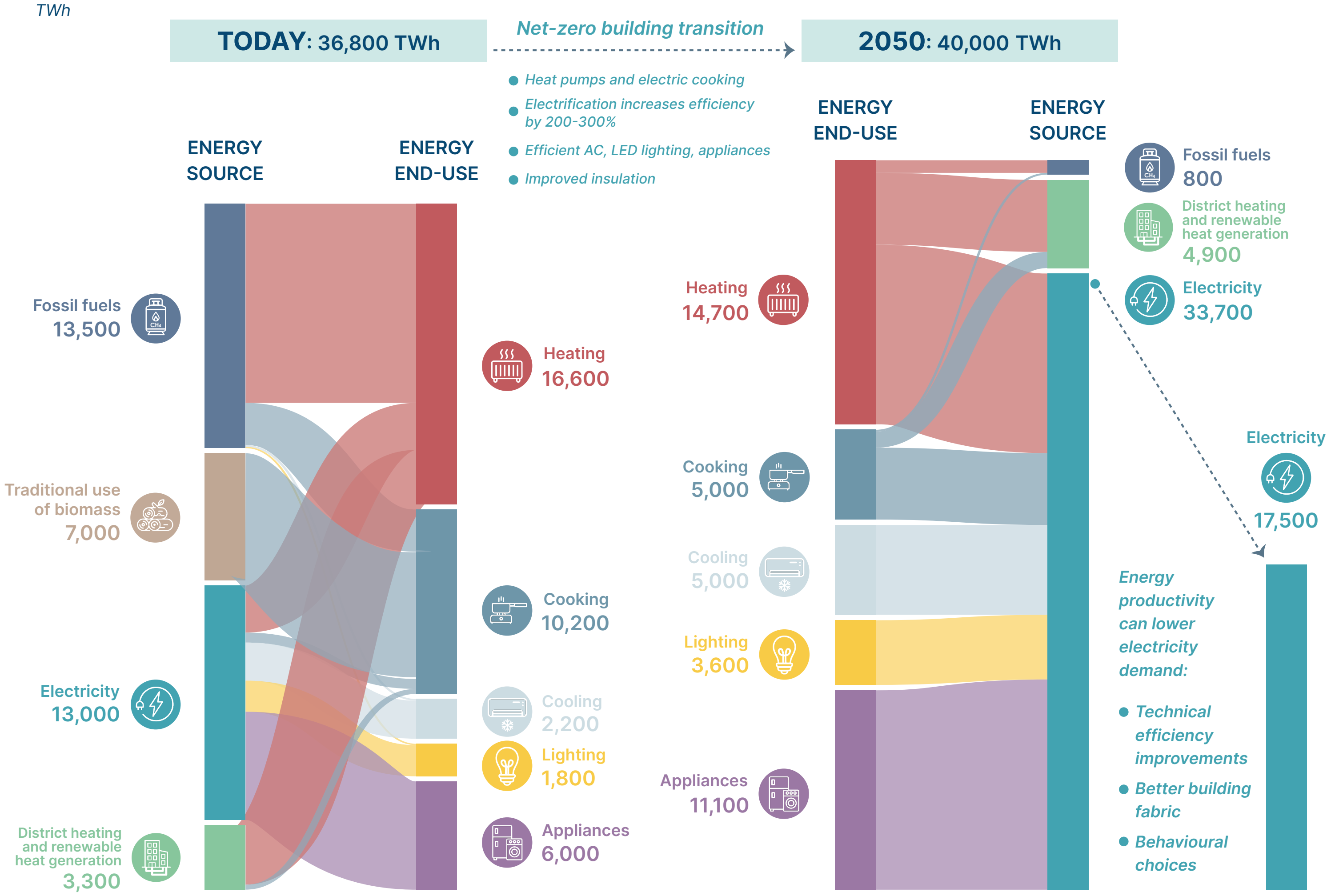
Energy Transitions Commission

DECARBONISING THE ENERGY USED IN RESIDENTIAL AND COMMERCIAL BUILDINGS

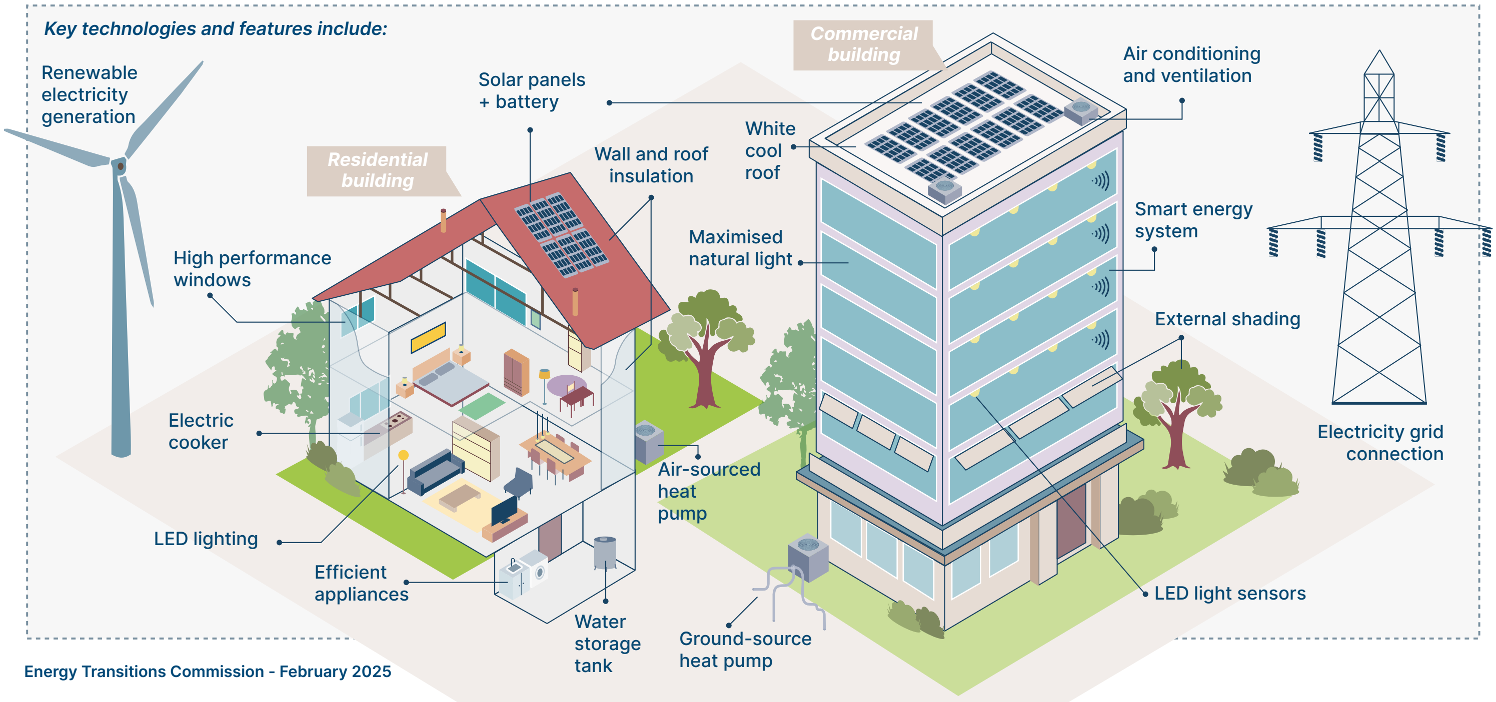


Achieving zero-carbon buildings: Electric, efficient and flexible

ANNUAL FINAL ENERGY CONSUMPTION USED IN BUILDINGS



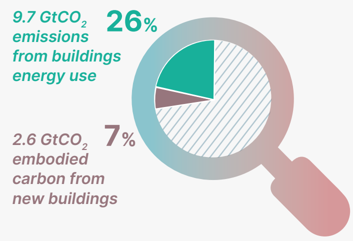
Electric, efficient and flexible buildings: What will it look like?



Energy Transitions Commission

REDUCING EMBODIED CARBON FROM NEW BUILDING CONSTRUCTION

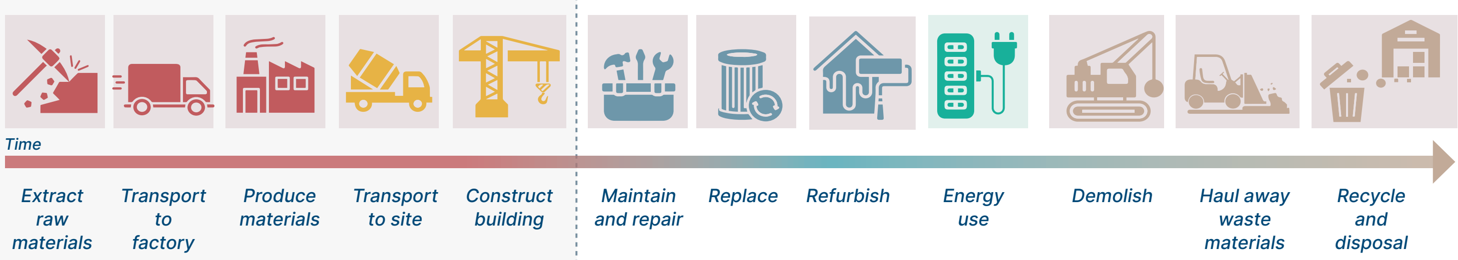
GLOBAL CO_2 EMISSIONS TODAY



Embodied carbon: what is it?

STAGES OF A BUILDING LIFECYCLE

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

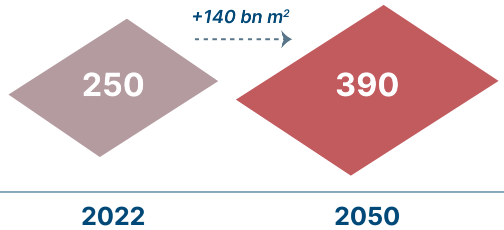


Priority: Reduce use of high-carbon steel, cement and concrete

Reducing emissions from the construction of new buildings is critical

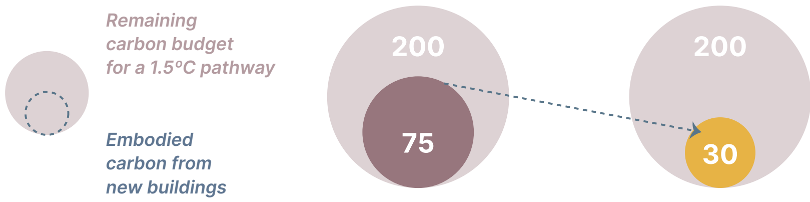
GLOBAL FLOOR AREA IS SET TO EXPAND BY 50%

Billion m²



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

$GtCO_2$



With no action
40% of carbon budget

With action
15% of carbon budget

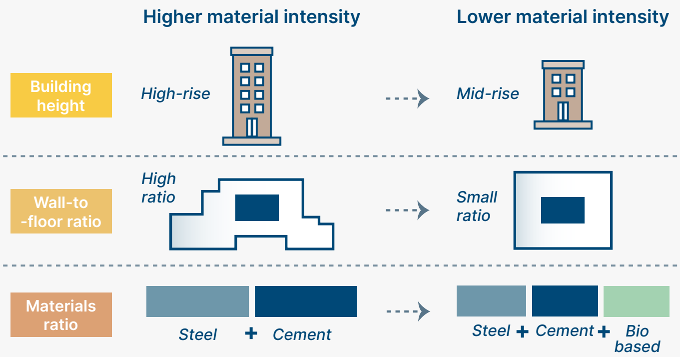
What action is needed?

DECARBONISE STEEL AND CEMENT/CONCRETE

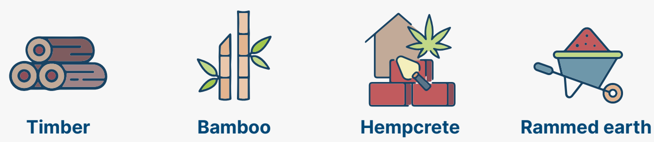
- Electrification and alternative fuels
- Carbon capture, utilisation and storage
- Alternative cement chemistries
- Iron reduction with green hydrogen; use of scrap steel

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*

The building decarbonisation challenge

1

Buildings account for 33% of global annual emissions, 12.3 $GtCO_2$ [Exhibit 1.1], and 10% of direct fossil fuel use, ~14,000 TWh.[8,9] This arises from:

- Emissions from the **operation of buildings**, which account for 26% of global emissions, or 9.8 $GtCO_2$. The direct use of fossil fuels accounts for 3 $GtCO_2$ (8%), predominately the use of gas and oil for heating. 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.[10]

- Emissions from the **construction of new buildings**, which account for 7% of global emissions, or 2.5 $GtCO_2$. These emissions are referred to as **embodied carbon**, and arise from the production of materials – predominately steel, cement and concrete - and the use of fossil fuels in transportation and construction. Embodied emissions relate to the additions to the global building stock in a given year, around 5 billion m^2.

A further 6% of annual emissions are the embodied carbon from new infrastructure, such as roads and bridges, railways, industrial facilities, ports, and pipelines.[11] Together with buildings, this makes up the world's "built environment". This report will predominantly focus on buildings – both residential and commercial – but will discuss some issues relating to the embodied carbon resulting from infrastructure construction in Section B.

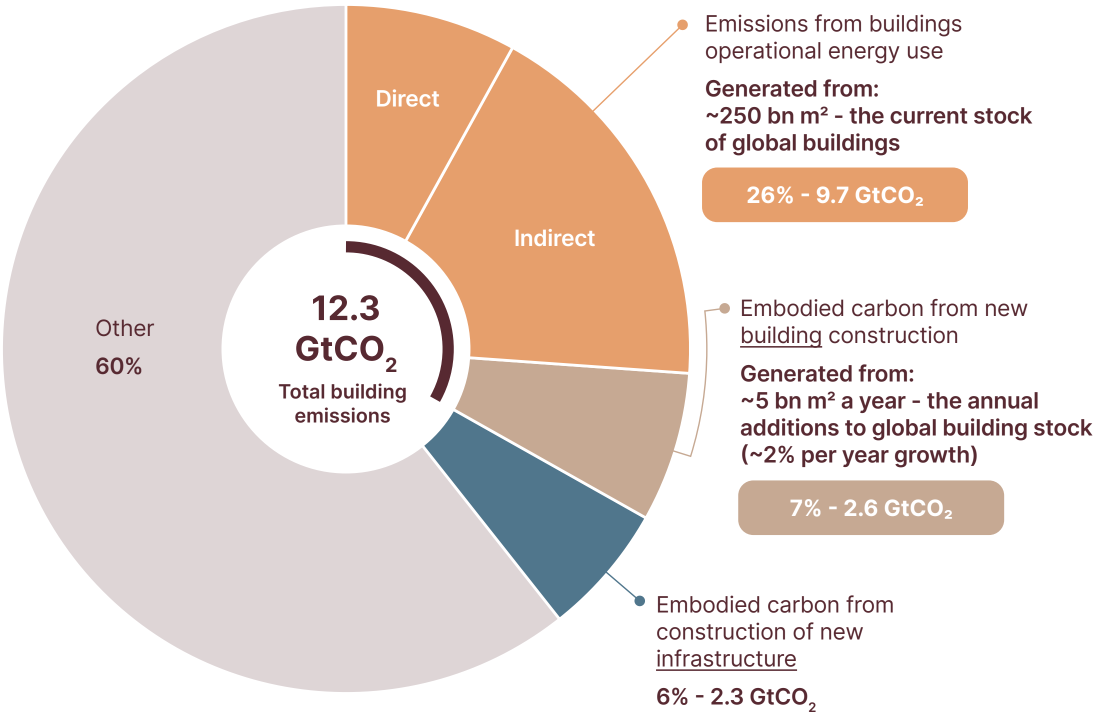
8 IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.*
9 IEA (2022), *World Energy Outlook 2022.*
10 IEA (2023), *World Energy Outlook 2023.*
11 IEA (2023), *The energy efficiency policy package: key catalyst for building decarbonisation and climate action.*

Exhibit 1.1

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

Global emissions by sector, 2022

$GtCO_2$



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.*

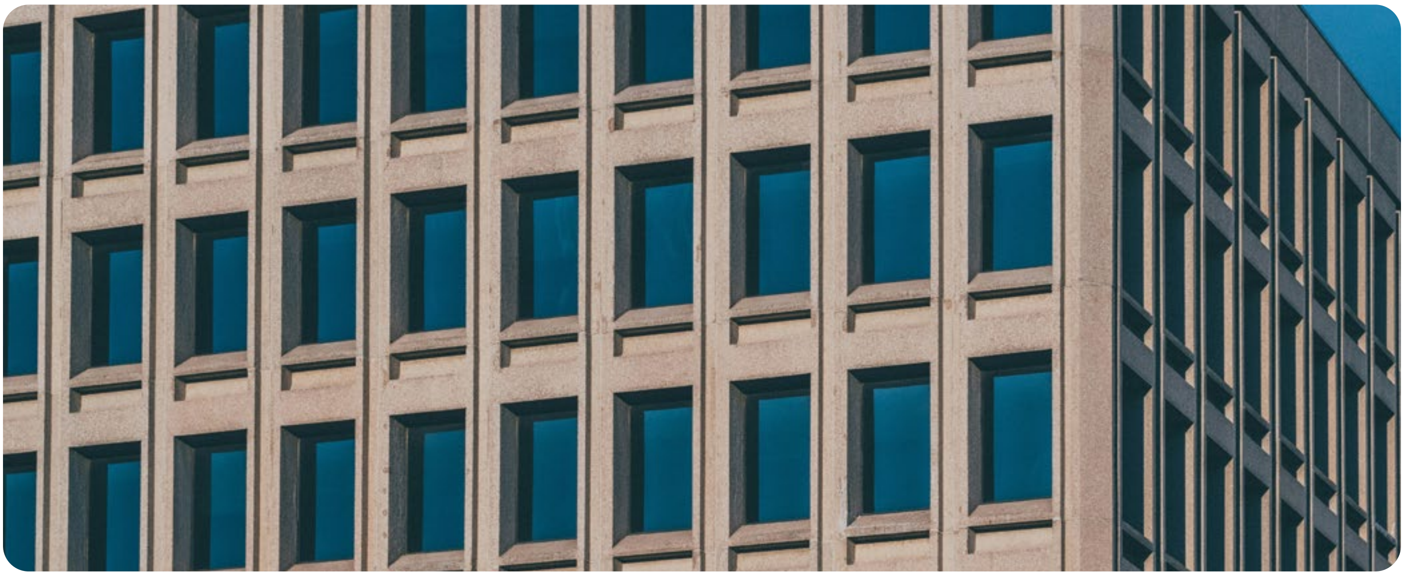
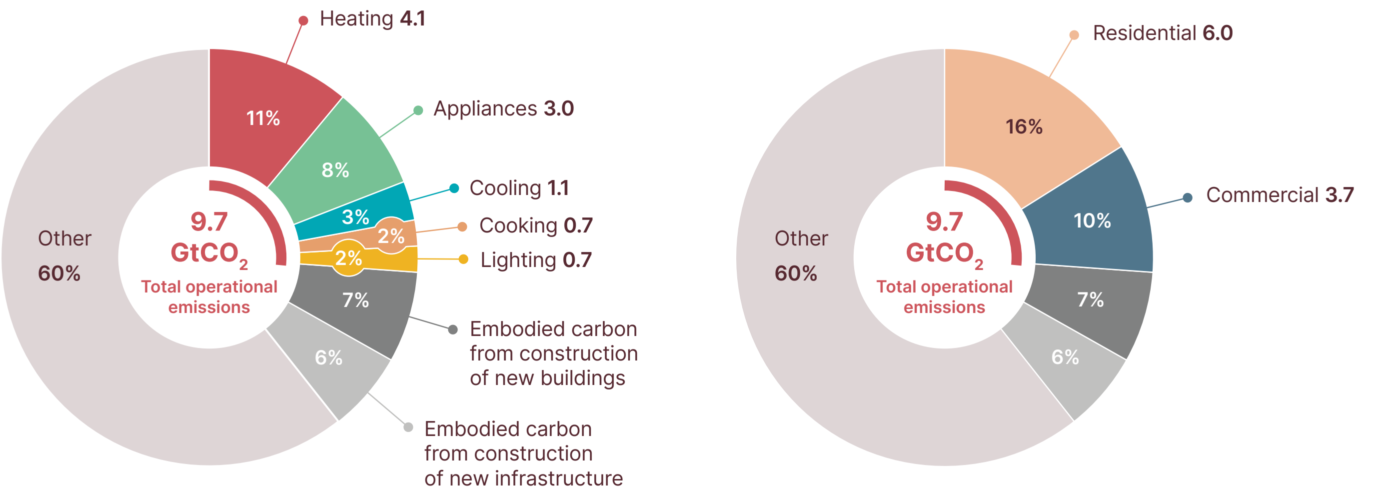


Exhibit 1.2

Heating and appliances are the biggest sources of operational emissions, while residential buildings account for 16% of global emissions, compared to 10% from commercial

Global operational emissions by end-use, 2022
$GtCO_2$

Global operational emissions by building type, 2022
$GtCO_2$



NOTE: This shows annual carbon flows in a given year. 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 total emissions for cooking could be larger.

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

1.1 Emissions from the energy used to operate buildings

Energy is used in buildings for five end uses: heating, cooling, cooking, lighting and powering appliances (e.g., refrigerators, TVs, and dishwashers) [Exhibit 1.3].

- Heating is the biggest source of operational emissions (11% of global emissions), accounting for 45% of final energy use in buildings and 80% of direct fossil fuel use [Exhibit 1.2].
- Cooking accounts for a further 15% of direct fossil fuel use, but is largely fuelled by the traditional use of biomass (TUOB) in lower-income countries.[12] TUOB is incredibly inefficient (as little as 10% of energy used is converted to useful heat), meaning cooking is the second largest component of final energy demand (~30%).
- Cooling, lighting and appliances are over 95% electrified, with emissions resulting from the indirect use of fossil fuels to generate electricity. Appliances account for ~15% of final energy demand, and are the second largest source of operational emissions from buildings and are responsible for 8% of all sector global emissions. Cooling and lighting each account for ~5% of final energy demand and 2–3% of global emissions; however, as we will explore in this report, cooling is set to the be the fastest growing source of buildings energy demand over the coming decades, with implications for emissions if clean electrification does not keep pace and if refrigerant leakage is not managed.

These global averages mask significant variation across countries; 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 both seasonal heating and cooling needs.

12 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).

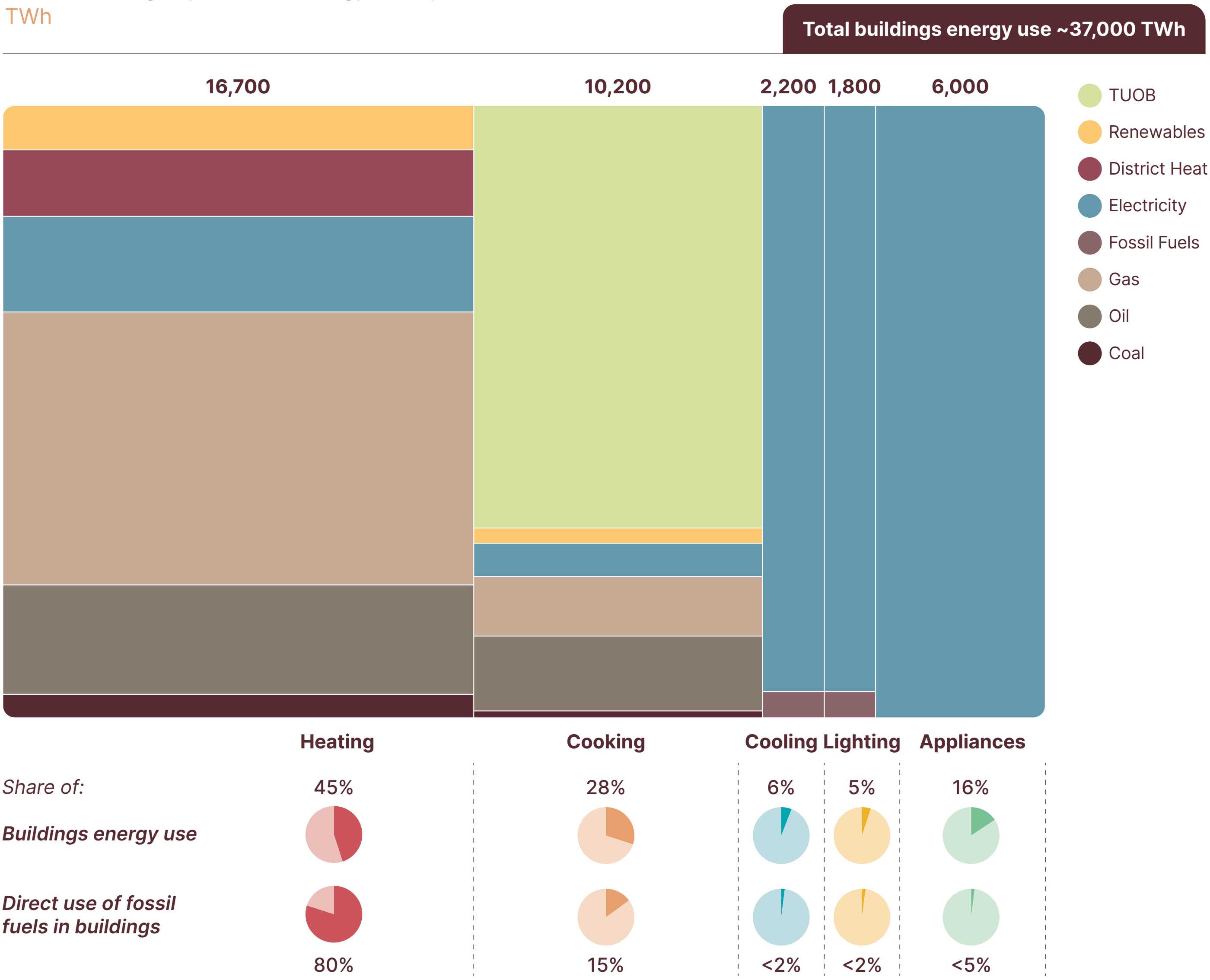
Residential buildings account for 60% of operational emissions, despite comprising 80% of global floor space [Exhibit 1.2 and Exhibit 1.6].[13] In comparison, commercial buildings make up 20% of global floor space but produce 40% of operational emissions and account for 30% of buildings final energy demand. Commercial buildings are a very diverse group of buildings, including offices, hotels, restaurants, hospitals and schools.

Overall, as Exhibit 1.3 shows, 35% of total buildings energy use is already electrified. This means that as the power sector is decarbonised, operational emissions will fall in turn [Exhibit 1.4].

Exhibit 1.3

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



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.

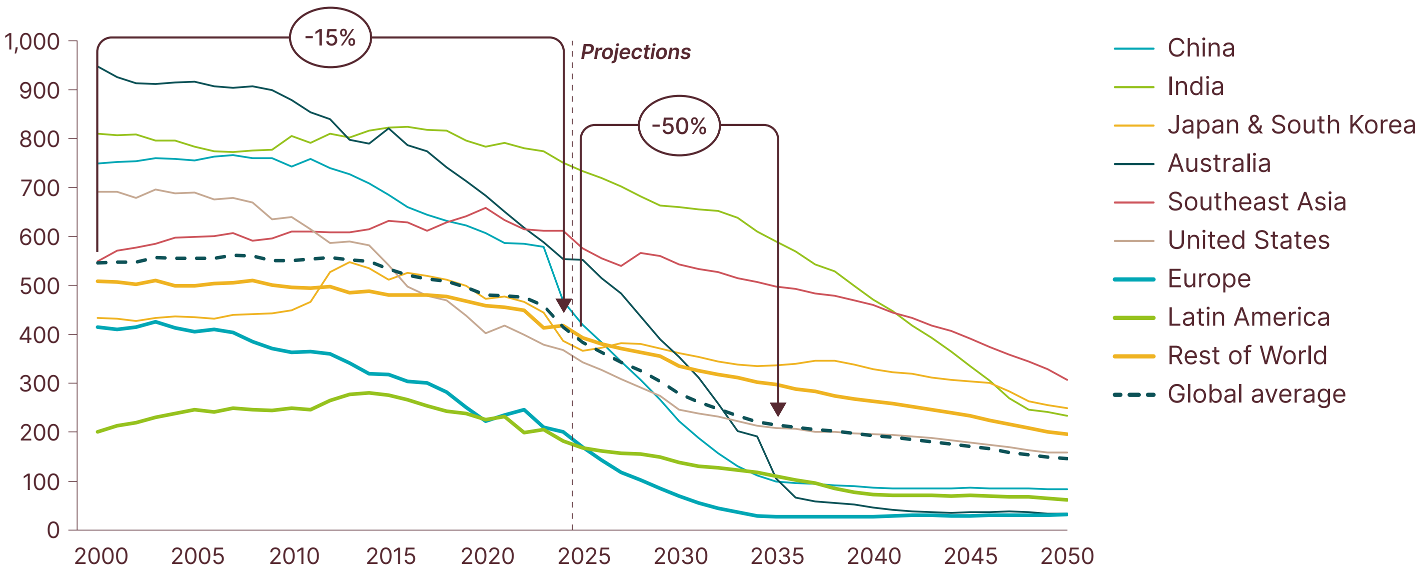
SOURCE: Systemiq analysis for the ETC; IEA (2022), *World Economic Outlook 2021*; IEA (2023), *World Economic Outlook 2022*.

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

Exhibit 1.4

Globally, the carbon intensity of electricity generation has fallen 15% since 2000 and, even with no new policy action, is likely to halve in the next ten years

Carbon intensity of electricity generation, projections to 2050
gCO_2e per kWh



NOTE: Projections are from the Economic Transition Scenario which assumes no new policy action to accelerate the transition.

SOURCE: BNEF (2024), *New Energy Outlook 2024.*

1.2 Emissions from the construction of new buildings

Embodied emissions arise from a wide variety of processes, materials and machinery used to construct buildings. In comparison to operational emissions, where robust data on household energy use and the emissions intensity of different fuels exists, national or global databases are lacking. This reflects the lack of a consistent measurement framework, the fact that regulation to date has largely focused on measuring operational energy, and the huge variation in the way buildings are built and the materials used.

This is, however, beginning to change, with many countries in recent years taking significant steps forward in terms of measuring and understanding embodied carbon. As this report argues, it is now possible for regulation to implement minimum requirements for embodied, or whole-life carbon, to drive accelerated action to address embodied carbon this decade.

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 [Exhibit 1.5].

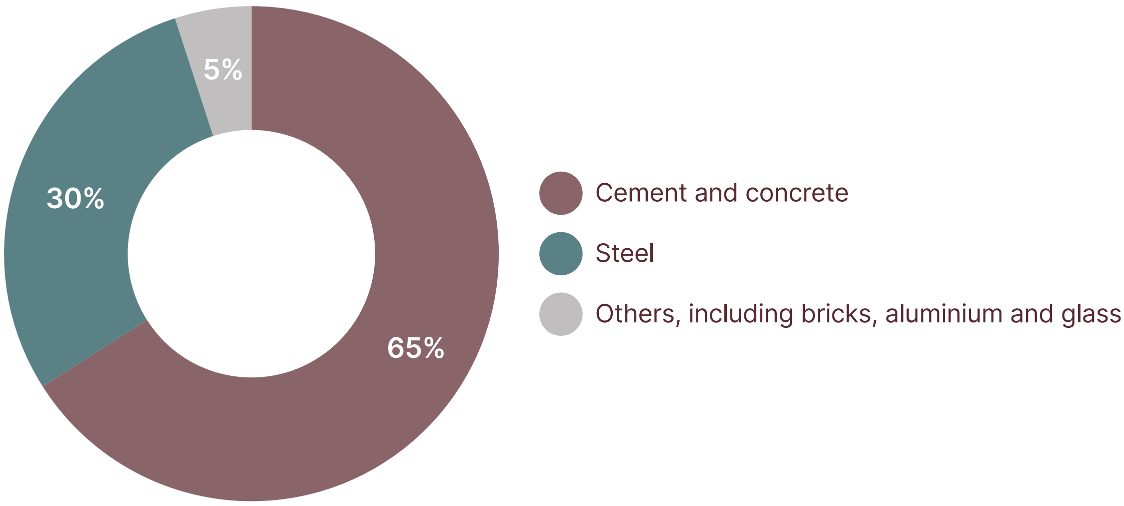
Global floor area is set to increase 50–60% by 2050, from 250 billion m^2 to 390 billion m^2, which will drive significant demand for steel, cement and concrete [Exhibit 1.6].[14] It is important to note that these projections represent net floor area, accounting for construction and demolition. This means that gross construction is actually higher.

As we explore in Chapter 10, constructing an additional 140 billion m^2 would generate 75 $GtCO_2$, holding today's global average embodied carbon per m^2 constant (0.5 $GtCO_2$ per bn m^2).[15] This report outlines the opportunities to utilise new materials and design and construction methods to reduce this to 30–40 $GtCO_2$.

Exhibit 1.5

Cement, concrete and steel account for 95% of embodied emissions relating to material production

Cement and steel contribution to global construction material carbon impact
% of total



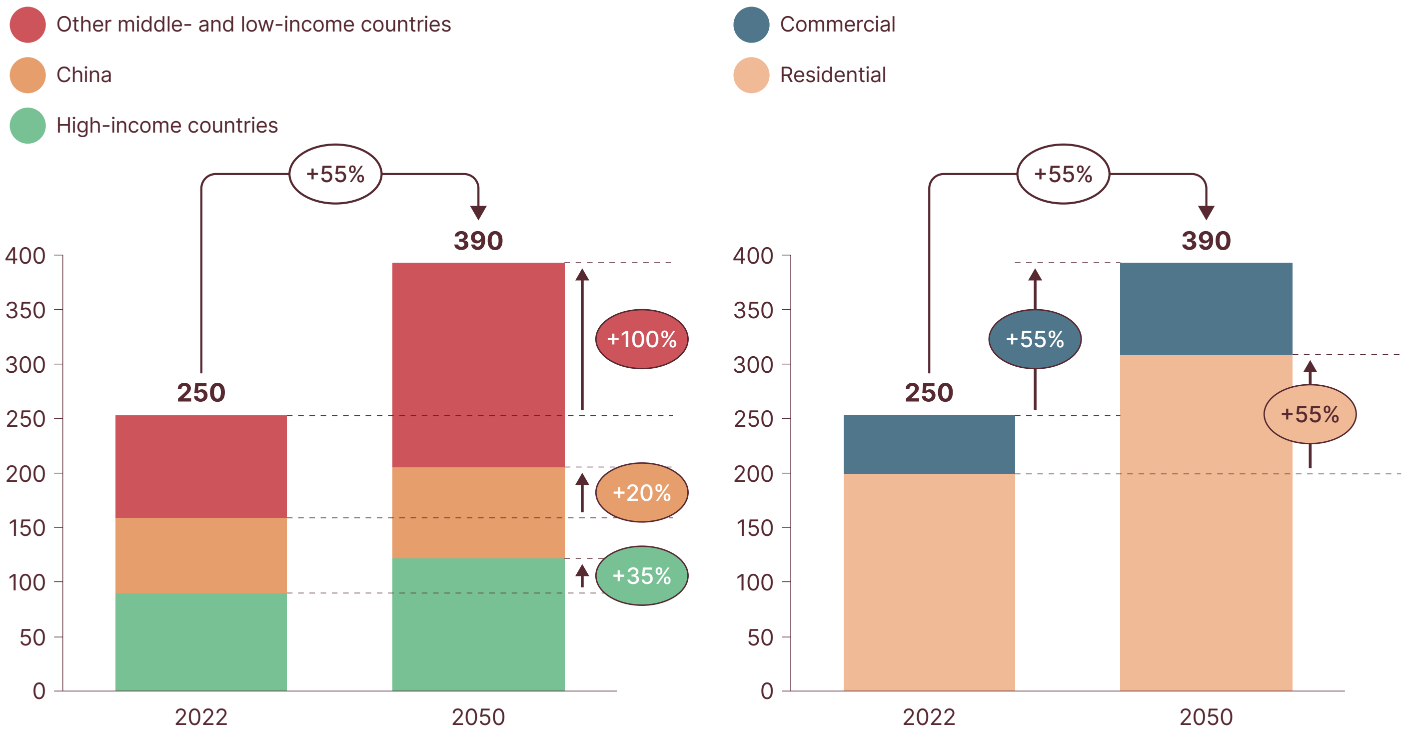
SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today.*

14 IEA (2023), *World Energy Outlook 2023.*
15 Systemiq analysis for the ETC.

Exhibit 1.6

Global floor area is set to increase 50–60% by 2050, driven by a doubling of the building stock in middle- and low-income countries

Growth in global floor area, projections to 2022 to 2050
Billion m²



NOTE: Projections from the IEA's Net Zero scenario.

SOURCE: IEA (2023); *World Energy Outlook*, https://www.iea.org/reports/world-energy-outlook-2023, re-used under license: CC BY 4.0.

1.3 The nature and size of the global building stock

The term "buildings" covers a very range of different building types. And the type and size of a building, its ownership, and its location have huge implications for the applicability of clean heating technologies, for the potential to improve energy efficiency, for the optimal actions that can be taken to lower embodied carbon in that new buildings, and for the ability to finance any changes. While it is broadly accepted that each building must be assessed on an individual basis as there is no one-size-fits-all solution to decarbonising buildings, this report acknowledges the need for stronger national strategic visions. These visions are essential to enable the transition at pace and scale and thus this report seeks to identify the technologies and solutions that are likely to dominate.

Residential buildings

Drawing on data from OECD countries, key differences in residential buildings across countries include:

- **Building archetype:** Drawing on data from the OECD, 60% of buildings are houses and 40% are flats and apartments [Exhibit 1.7].[16] This varies massively across countries, with flats accounting for 65–75% of building stock in Spain and Korea, compared to 15–20% in Australia and the UK. In cities like Shanghai, flats account for 90% of floor space.[17]

16 OECD database, available at www.oecd.org/en/data.html. [Accessed 01/08/2024].
17 Wenyi Zhang (2024), *Composition of residential buildings in Shanghai 2022, by type.*

- **Size:** Average floor space per person varies from over 65 m² in the US, to around 45 m² in France and Germany, to below 30 m² in many Eastern European countries.[18]

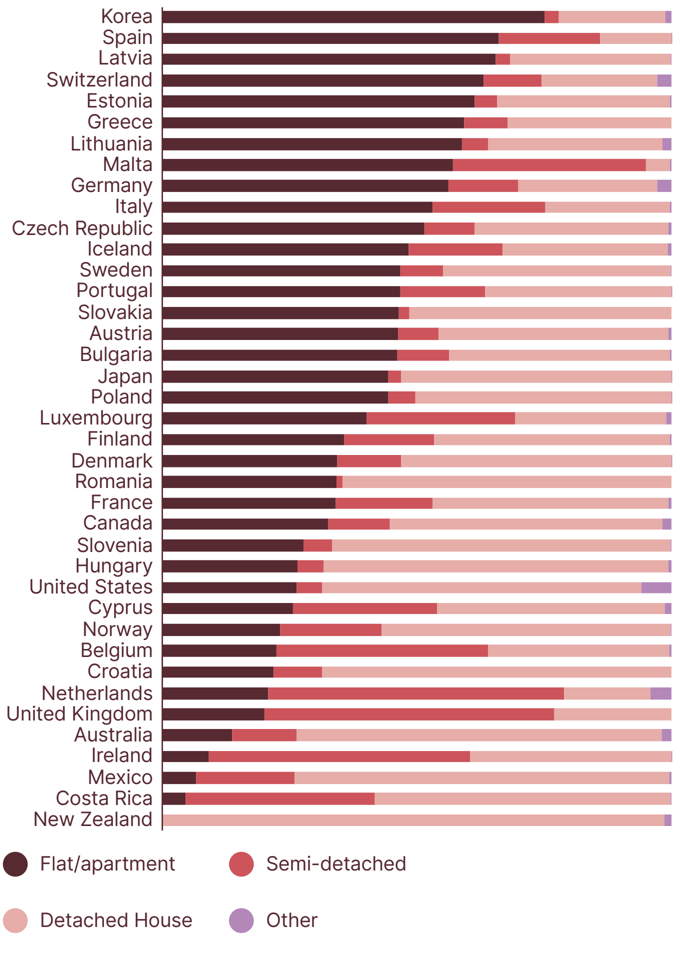
- **Ownership:** Around 75% of buildings are privately owned in Europe, but again this varies massively at 45% in Germany, 65–70% in the UK and US, and over 90% in Hungary and Romania [Exhibit 1.7]. On average in Europe and North America, 15% of buildings are privately rented and 10% are social housing.[19]

- **Degree of urbanisation:** 40% of people across Europe and the US live in cities, 35% live in towns and suburbs, and 25% in rural areas.[20] These proportions will vary hugely across other continents. In general, there is a global trend towards greater urbanisation as lower-income countries develop.

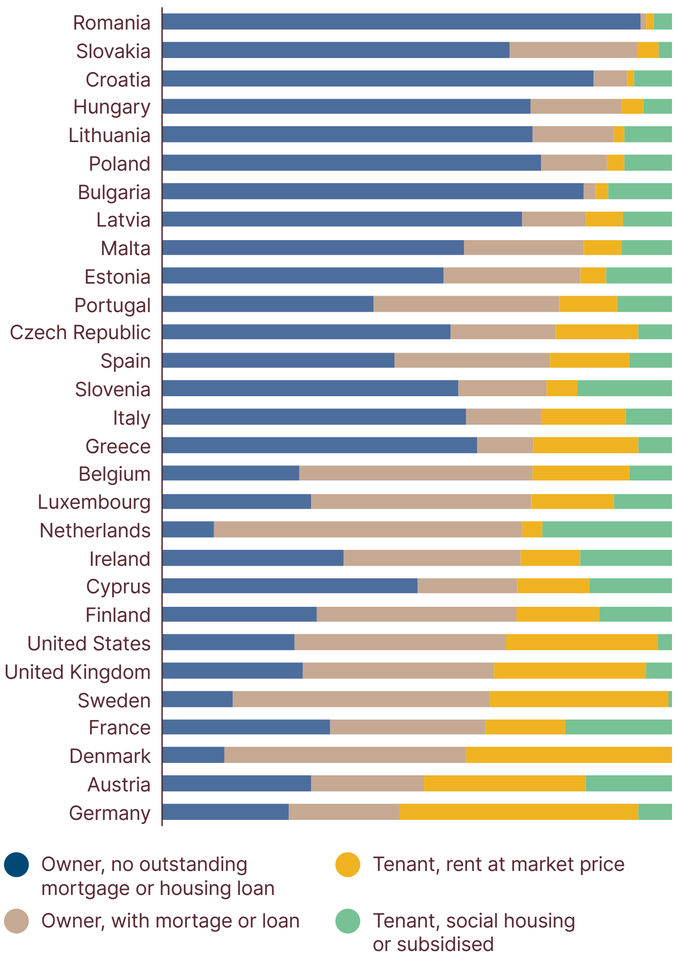
Exhibit 1.7

Residential building stock varies considerably; key factors determining technology choices are the type of dwelling and ownership

Occupied residential building stock by dwelling type in OECD countries, 2020
% of total



Distribution of population by building ownership, selected countries, 2021
% of total



SOURCE: OECD Database, available at www.oecd.org/en/data.html. [Accessed 01/08/2024]; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024]; US Census 2022, available at www.census.gov. [Accessed 01/08/2024].

18 European Commission, *EU Building Stock Observatory*, available at www.building-stock-observatory.energy.ec.europa.eu/database. [Accessed 01/08/2024]; National Renewable Energy Laboratory (2022), *US Building Stock Characterization Study*.
19 Eurostat, *2021 for Europe*, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024]; US Census, *2022 for US*, available at www.census.gov. [Accessed 01/08/2024].
20 Eurostat, *2021 for Europe*, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024]; US Census, *2022 for US*, available at www.census.gov. [Accessed 01/08/2024].

Commercial buildings

Globally, commercial buildings make up 20% of floor space, but this varies across countries [Exhibit 1.8]. In Germany, for example, commercial buildings account for a third. The term "commercial building" refers to a very large and heterogeneous stock of buildings across different sectors. In Europe and the US, offices account for 25–30%, compared to almost 40% in China. Education and wholesale/retail buildings are typically the second and third largest, at around 15–25% respectively. Other sub-sectors include warehouses, hotels and restaurants, hospitals and sports facilities (see Chapter 7).

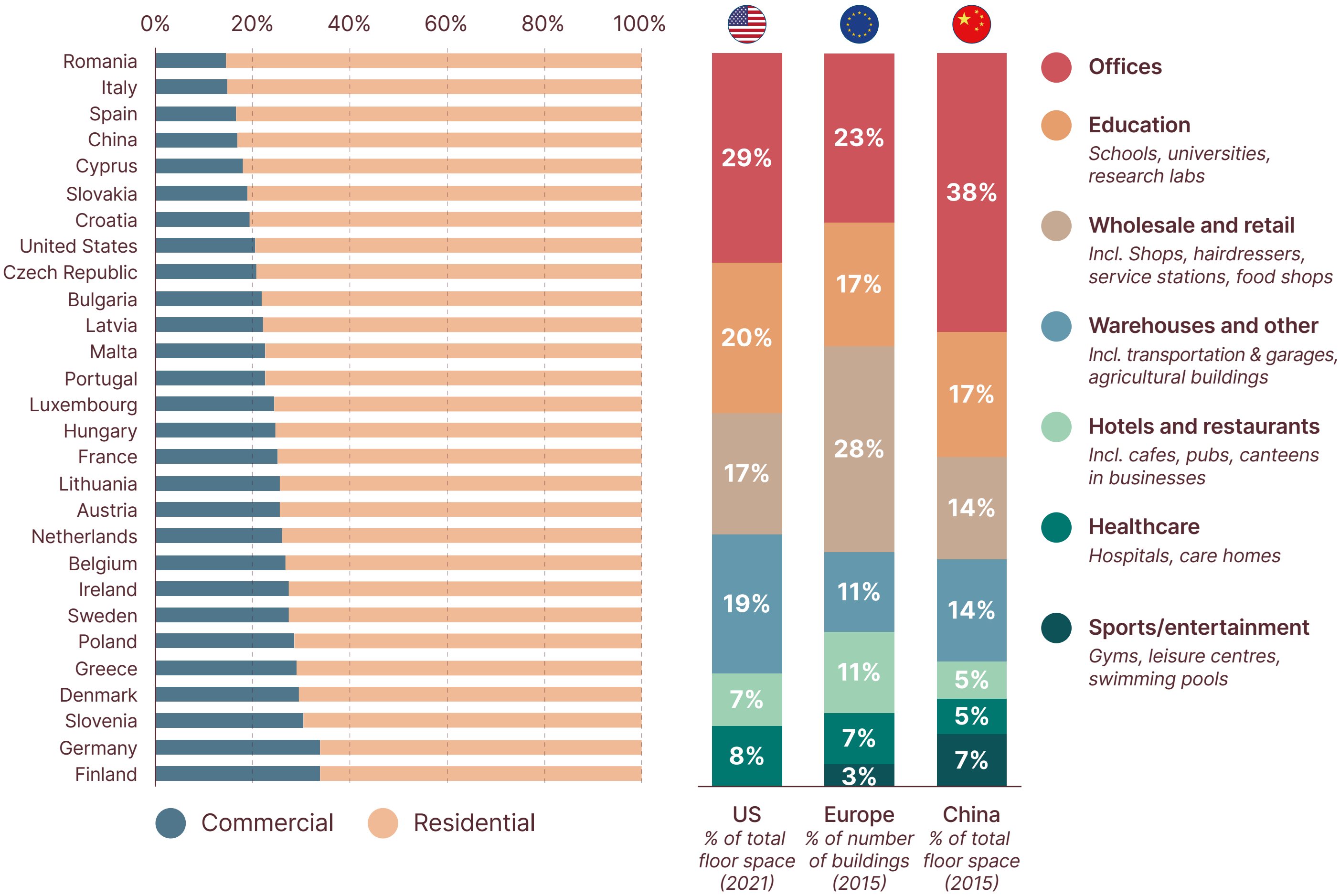
The significant heterogeneity in commercial buildings – more so than for residential – makes determining optimal transition pathways even more challenging. In Chapters 2 to 6, we assess the technologies and solutions which can deliver operational emissions reductions by application (heating, cooling, cooking, lighting and appliances), drawing primarily on residential examples. Chapter 7 then discusses the specific characteristics and challenges of commercial buildings.

Exhibit 1.8

"Commercial buildings" refers to a very large and heterogenous group of sectors including offices, schools, hotel and retail

Built floor area by residential / commercial, 2015
% of total floor area

Commercial buildings by sector
% of total floor area or number of buildings



NOTE: For the US, sports facilities are included in "warehouses and other".

SOURCE: National Renewable Energy Laboratory (2022), US *Building Stock Characterization Study*; Building Performance Institute Europe (2015), *Europe's Buildings Under the Microscope*; Baijiahao (2018), *Real estate and constructions: What are the sub-sectors? What are the sizes?*; Eurostat, available at www.building-stock-observatory.energy.ec.europa.eu/database/. [Accessed 01/08/2024]; US Energy Information Administration (2018), *Commercial Buildings Energy Consumption Survey*; Pan L, Zhu M, Lang N, Huo T. (2020), *What Is the Amount of China's Building Floor Space from 1996 to 2014?*

1.4 The energy transition for buildings: key characteristics and implementation challenges

The energy transition is imperative not just to reduce emissions, but also to deliver upon critical social and economic development goals. The quality of building stock varies significantly across and within countries, with lower incomes, energy poverty, and poor living standards and health being closely linked. As we outline in this report, with the right policies, decarbonising buildings and improving social outcomes can go hand in hand.

Electric heating and cooking technologies will significantly improve air quality and are inherently more efficient with lower running costs. Building more efficient and flexible homes will increase comfort levels, improve living standards and further lower energy bills.

There are two core pillars to decarbonising buildings:

1. The first is transitioning to clean technologies and lower-carbon materials. For energy used in the operations of buildings, this primarily means switching from fossil fuel based heating and cooking within buildings to clean – and overwhelmingly electric – technologies. This must be underpinned by a rapid decarbonisation of the power system to ensure that the electricity used in buildings is low and eventually zero-carbon. For energy used in the construction of buildings, embodied emissions, this means decarbonising the production of critical materials (i.e. steel and cement), switching to lower emission materials where possible (e.g., via sustainably sourced timber), and electrifying transport and construction.

2. The second is improved energy productivity. This means using less energy for the same standard of living and can be achieved through energy efficiency (i.e. using less energy to deliver the same output by technical efficiency improvements to AC and through improved insulation), material efficiency (i.e. using less material for the same quality of new building by lightweighting building design and modular construction which reduces waste), and service efficiency (i.e. better utilisation of existing buildings such as shared working spaces).

Since it will take time both to fully decarbonise electricity generation and to decarbonise the production of steel, cement and other construction materials, improved energy productivity will play a critical role in reducing cumulative emissions during the transition to net-zero and limiting warming to 1.5°C.

Increasing the energy productivity of buildings will also have a wide range of other economic, social and environmental benefits:

- Because more energy efficiency buildings need to consume less energy, a smaller clean power system is needed. This reduces the scale of the clean electricity generation build challenge, and total investments needed in renewables, grid upgrades, and storage.[21]

- Because buildings built with passive heating and cooling designs require less energy, it will help to ease balancing challenges for the electricity grid, especially at peak times, helping to create a resilient and flexible energy system.

- Buildings which use less energy, especially at more expensive peak times, will have significant social benefits, lowering energy bills for households, improving living standards, and health and equality.

- The combination of needing to build a smaller clean power system and using less materials in construction will have lower negative impacts on planetary boundaries, including less demand for materials, minerals and land.

Achieving the two pillars of building decarbonisation – installing clean technologies and improving the energy productivity of buildings - poses some distinct implementation challenges not found in other sectors:

- In the decarbonisation of the power system, light and heavy industry, aviation, shipping and heavy trucking, almost all the investment decisions required to drive decarbonisation will be made by professional managers in businesses rather than by individual consumers. And while in some cases be a green cost premium to be faced (with for instance, a higher steel price per tonne and higher shipping freight rates) at the level of the products purchased by individual consumers, the cost impact is very small.

- In passenger road transport, individual consumers will need to make decisions about car purchases, but within a number of years EVs will be cheaper to buy upfront than internal combustion engine vehicles (ICEVs).[22] Indeed in China that point has already been reached. In addition, comparing the cost and performance characteristics of EV and ICEs is relatively straightforward.

21 ETC (2021), *Making Clean Electrification Possible*.
22 BNEF (2024), *Electric Vehicle Outlook 2024*.

- However, in the residential building sector, individual households will need to decide between multiple possible clean technologies both "active" (e.g., heating and cooling systems) and "passive" (e.g., improved insulation) – the installation of which will entail some disruption within their homes. And while clean heating technologies (in particular heat pumps) can deliver lower operating costs, installing them currently comes with higher upfront investment in most countries. But the availability and cost of finance varies greatly between low and high income households. More generally indeed, feasible and optimal solutions vary greatly by specific household circumstances, such as the availability of space and current quality of insulation.

- In the construction sector, building a low-embodied carbon building entails a complex array of decisions and trade-offs across different materials and decision-makers (e.g., developers, suppliers, material produces, construction companies). Compared to the industry and transport sectors, where products are relatively standardised and mass-produced, there are limits to how far new developments, material and design choices can be standardised. The sector is typically highly fragmented (e.g., high levels of sub-contracting), compared to other sectors with a relatively small number of large corporates operating in the space.

The buildings energy transition therefore relies on action from a wide variety of actors, each of whom have very different incentives to change:

- Owner-occupiers and tenants will be motivated to improve comfort, while avoiding disruption and lowering costs to operate buildings.

- Homeowners and building owners will be motivated by reducing capital investment costs, lowering costs to maintain buildings and by improving the value of their assets.

- Net-zero commitments of financial institutions, developers and the private sector will create demand for new net-zero buildings and retrofit of existing buildings.

- Policymakers and lower-income households will be motivated by the need to improve wellbeing, health and productivity.

This report sets out the actions required by government and the private sector to minimise the financial and distributional impacts on households, to ensure a fair and just transition, and to rapidly reduce emissions.

Public policies must be designed to address these distinctive implementation challenges and distributional effects present in the buildings sector. Despite these challenges, the actions required to decarbonise the energy used in buildings will ultimately lead to improved outcomes for society, through lower and more stable energy bills, improved housing quality and living standards, and reduction in GHG emissions.

Section A:
Decarbonising the energy used to operate buildings

Total global energy use in buildings amounts to 37,000 TWh or 130 EJ today; this is around a third of total final energy consumption across the global economy. This comes from four key energy sources [Exhibit 1.3]:

- Direct use of fossil fuels account for almost 40%, providing 13,800 TWh in 2022. Within this, gas accounts for 60%, oil for 30%, and coal for almost 10%.
- Electricity use accounts for a further 35% (12,800 TWh), with three-quarters of this powering cooling, lighting and appliances. Today, only 15% of heating is electrified. The decarbonisation of the power sector will therefore drive the decarbonisation of a large share of building operational emissions.
- TUOB in cooking accounts for ~20% of total energy use (7,000 TWh), primarily in lower income countries.
- The final 5–10% of energy provided is from renewables (e.g., solar thermal water heating and geothermal) and district heating – although it is important to note that 90% of district heating, which involves generating heat in a centralised location and then distributing it to individual buildings, is generated by fossil fuels.

Decarbonising the energy used in buildings involves a mix of three key actions:

1. The replacement of all technologies which currently combust fossil fuels in buildings.
2. The rapid decarbonisation of power systems so that electricity used in homes is generated without carbon emissions.
3. The greater adoption of efficient technologies, ranging from best in class appliances, to distributed generation such as rooftop solar and building fabric insulation.

The specific mix of technologies needed will depend on how energy is currently used in buildings, with each use case having its own decarbonisation options that can be combined in various ways. Therefore, this section will examine each use of energy within buildings – heating, cooling, cooking, appliances, and lighting – outlining the decarbonisation options and considerations for each use case. In Chapters 2–6 we focus on these uses of energy in residential buildings, before turning to the specificity of commercial buildings in Chapter 7. Chapter 8 will bring the whole story on operational energy use together, discussing the system-wide implications of electrified buildings. Chapter 9 will then discuss the refrigerant leakage and venting challenge in both residential and commercial buildings.

Heating

2

Key messages

- Building heating can and should be almost entirely electrified, primarily with heat pumps, either in individual homes or within heat networks. In most circumstances, heat pumps can provide low-carbon heat at a total cost of ownership comparable, and in many cases lower, than fossil fuels. There is, however, no one-size-fits-all solution; a range of technologies will be used to solve the challenges of specific building types and climates.
- Hydrogen is not a viable alternative to replace gas heating at scale; 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 not be scalable until the mid-2030s.
- A whole-building approach is required to create zero-carbon ready buildings. This involves consideration and optimisation across three types of technology: 1) installation of clean heating technologies which can be powered by clean electricity, 2) improvements to the building envelope and 3) consideration of a suite of smart and flexible technologies (e.g., smart system, solar and batteries).
- Insulating the least efficient homes must be a government priority, and combined with heat electrification can lower energy bills and improve comfort levels. However, for the average home, deep retrofit is not a pre-requisite for installing a heat pump, as long as radiators and systems are appropriately sized.
- While not a pre-requisite for heat pumps, there is a suite of passive heating retrofits, many of which are relatively low-cost (e.g., loft insulation and draught proofing) which can greatly improve living standards, reduce energy bills and ease peak energy demand.
- Deployment of heat pumps and improved insulation could halve 2050 final energy demand for residential heating compared to a BAU scenario that maintains existing fossil fuel use. This will enable the almost complete elimination of all fossil fuel use for residential building heating by 2050.
- However even in this case, electricity used to heat buildings could still grow from 2,600 TWh today to 4,000–5,000 TWh in 2050. Without strong action on technical efficiency and insulation, it could be 10,000 TWh.

Heating building space and water accounts for 45% of total energy use in buildings across the world, but for 80% of direct fossil fuel use, and thus for the vast majority of today's emissions which would not be eliminated by the decarbonisation of electricity supply alone. Decarbonising heating is therefore the most important challenge in the buildings sector. This chapter describes and assesses the technologies available to achieve decarbonisation and the implications within the residential sector. Chapter 7 considers the specific challenges related to commercial buildings.

The sections below set out the analysis which supports these conclusions, covering in turn:

1. The starting point: a large role for fossil fuels in residential heating, primarily in developed countries.
2. Technologies available to solve the problem and relative costs: multiple variants of heat pumps as the primary solution.
3. Passive heating: improved insulation in new and existing buildings.
4. Combining different approaches in new and existing buildings: indicative overall mix.
5. Implications for energy productivity, electricity and fossil fuel use.
6. Actions required from government, business, and consumers

The implications of heating decarbonisation for peak electricity demand will then be explored in Chapter 8.

2.1 The starting point: large-scale use of fossil fuels for heating primarily in northern latitude countries

Heating is the biggest buildings decarbonisation challenge, accounting for 45% of final energy use in buildings and 80% of direct fossil fuel use. Of the 11,000 TWh of fossil energy used directly to provide on-site heat, 67% or 7,400 TWh is gas, 27% or 2,900 TWh is oil, and the remaining amount is coal. Coal is also dominant in some district heating systems, particularly those in northern China.

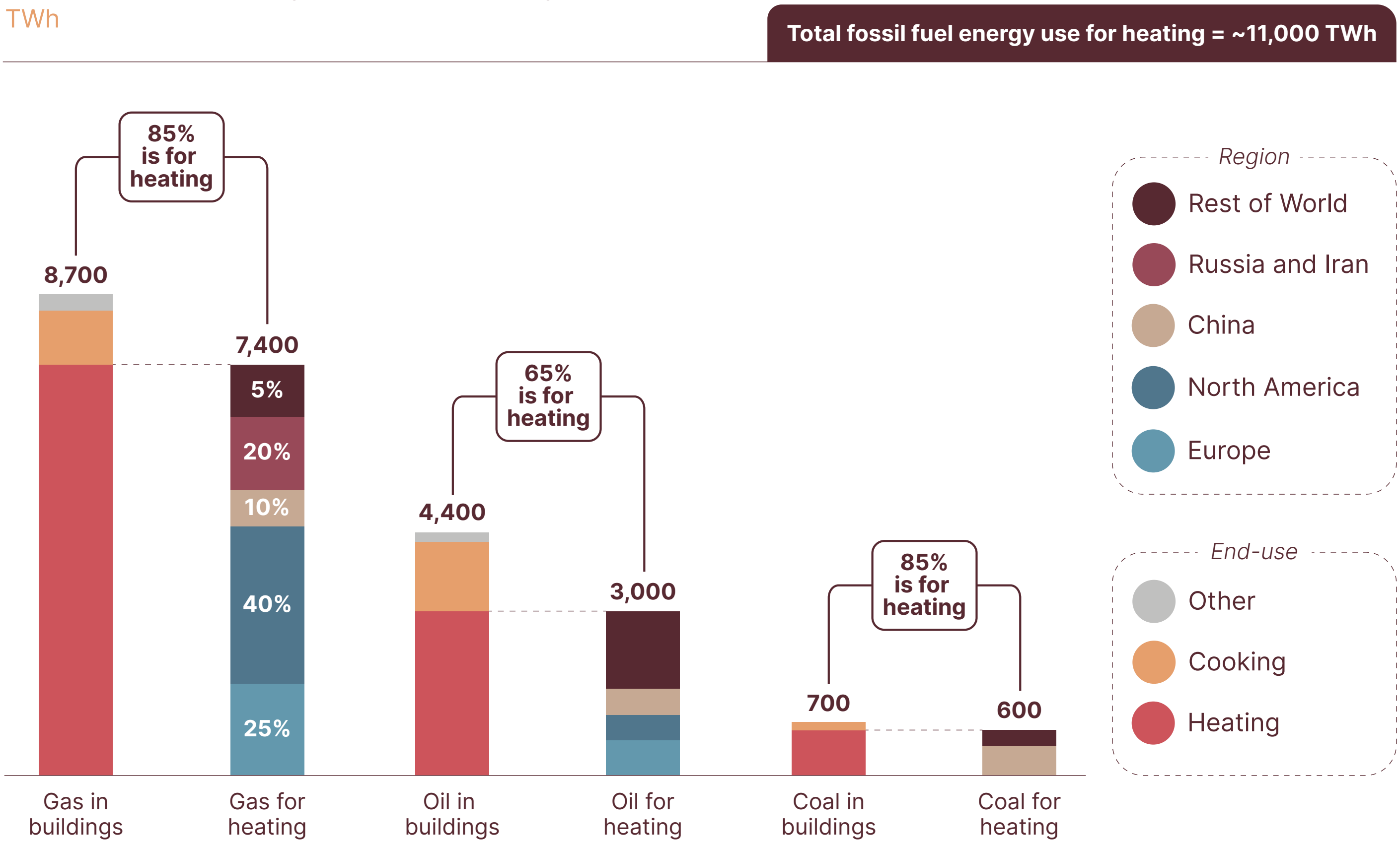
Fossil-based heating is concentrated in northern latitude countries with relatively cold winters [Exhibit 2.1]. Around 75% of total fossil fuel use for heating buildings, and over 60% of total gas use in buildings, is in the US and Canada, Europe and China. Russia and Iran are also major users of gas in buildings, accounting for 10% and 7%, respectively, of total gas use.

There are an estimated ~720 million gas and oil boilers supplying 10,400 TWh of energy for heating today, including 240 million gas boilers in the US and Canada, 150 million in Russia and Iran, and 140 million across Europe.[23] In addition, there is 600 TWh of coal heating existing buildings, predominately in China.

Exhibit 2.1

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



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*.

23 Systemiq analysis for the ETC, based on average fuel use per household per year.

Three-quarters of global heating energy is for space heating, and a quarter is used to heat water.[24] This is despite space heating only being required in around 40% of households across the world. By contrast, water heating is required by all households for bathing and washing; however, energy needs are comparatively smaller and a large share of hot water needs in lower-income countries are unmet. The fuels used for water heating largely mirror those used for space heating, although with larger shares for electricity and for non-electric renewables (e.g., solar thermal where the heat of the sun is used to direct heat water). Overtime, however, water heating may account for a rising share of residential building energy demand, as space heating is electrified using highly efficient heat pumps and as building insulation is improved.

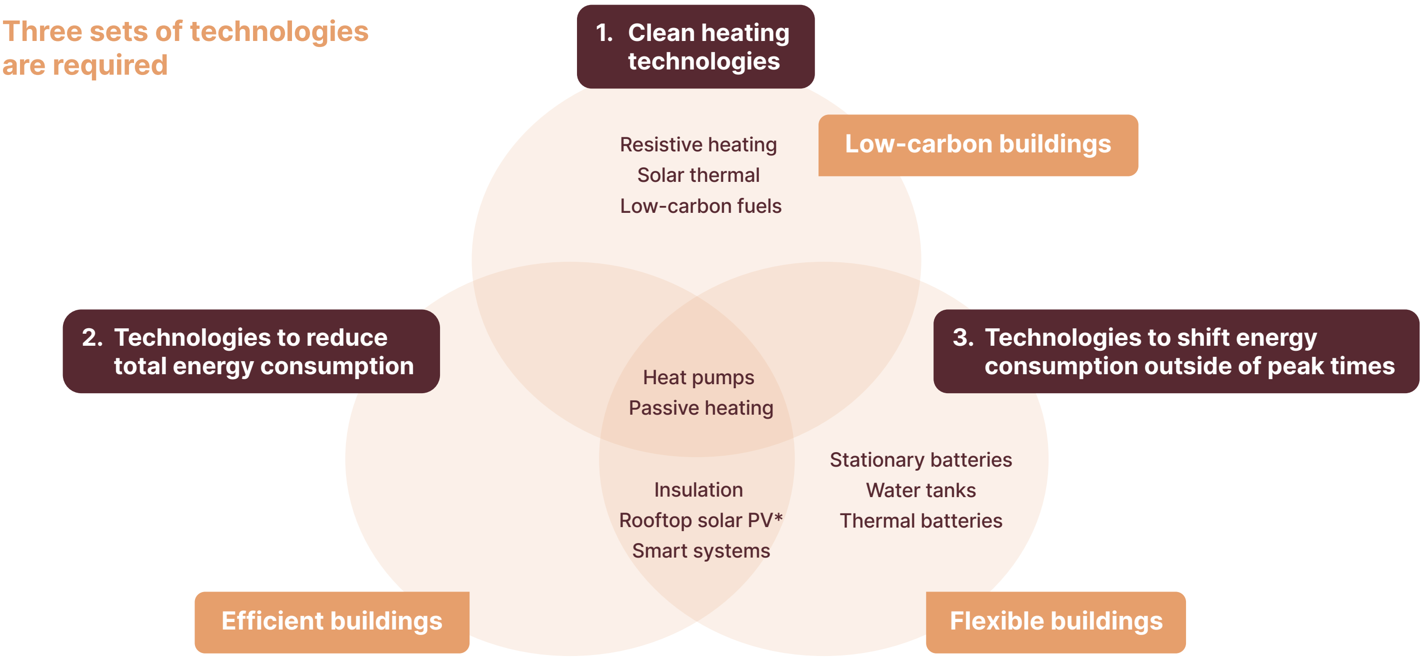
The direct and indirect use of fossil fuels to heat buildings produces about 4.1 $GtCO_2$. To reduce and eventually eliminate these emissions, it is essential to replace the direct use of fossil fuels in buildings with clean heating technologies, primarily electric. Electrification must be combined with rapid decarbonisation of electricity generation, which is critical economy-wide and not just for residential heating.

Alongside a focus on electrification, however, it is important to consider the full range of possible means to improve energy efficiency, and to focus on the role which electrified building demand will play within future zero carbon electricity systems. It is therefore important to simultaneously consider opportunities to [Exhibit 2.2]:

- Reduce household and commercial demand for heat consumption via building design and improved insulation sometimes called "passive heating" technologies. This will reduce the emissions from electricity during the transition to zero carbon electricity production, and reduce required electricity inputs in the long term. Section 2.3 assesses these options.
- Reduce electricity input from the grid, instead generating electricity at a building or community level, via the installation of rooftop solar PV. These opportunities are considered in Chapter 8.
- Reducing in particular energy requirements at peak times, which impose high costs if electricity is the energy source. This can be achieved either via the improved insulation actions discussed in Section 2.3, or via energy storage solutions at building level (whether in heat or electricity form), combined with smart systems. These opportunities are discussed in Chapter 8.

Exhibit 2.2

The net-zero transition will require buildings to become lower-carbon, more efficient and more flexible in their energy consumption habits



NOTE: *Rooftop solar PV does not reduce overall energy consumption from buildings, but reduces imports from the grid.

SOURCE: Systemiq analysis for the ETC.

24 IEA (2023), *World Economic Outlook 2022*.

2.2 Clean heating technologies: efficiencies and costs

Multiple technologies could be deployed to decarbonise building heating and different solutions will be most appropriate in different circumstances. But heat pump technology should play the dominant role given its inherent efficiency advantage, which enables it to provide low-carbon heat at a lower running cost than fossil fuels; concerns about the effectiveness of heat pumps are largely misplaced and technology improvement will make them even less valid. Heat networks, some of which will use heat pump technology, will often be cost effective in new builds.

2.2.1 Alternative clean heating technologies

There are four main types of potentially zero-carbon heating technology which could be used to provide space and/or water heating in residential and commercial buildings [Exhibit 2.3]:

1. **Electricity-based solutions via either:**

   - **Electric heat pumps** which use the same compression technology as air-conditioners but work in the reverse direction. As Exhibit 2.4 shows, there are several types of heat pump, and different variants will be most appropriate in different solutions. But their common and distinctive feature is that that they can deliver multiple kWh of heat for each kWh of electricity input. The actual size of this multiplier – or "coefficient of performance" (COP) - varies by type of heat pump, but is already usually over 3 (i.e. an efficiency rate of over 300%), and can reach 5 for ground source heat pumps.[25] Annex 1 provides more details on heat pump technology.

   - **Electric resistive heating**, which generates heat by passing an electric current through a resistor. The main technology for electric resistive space heating is the convection heater, while electric water heating can be delivered via immersion heaters (where a resistive heating element is placed in water in an insulated storage tank), or immediate heaters (where water is passed over a resistive heating element, which reaches higher temperatures but is less efficient). All applications are close to 100% efficient in turning electrical energy into heat.

2. **Zero-carbon heat sources:**

   - Solar thermal systems use the radiated heat of the sun to directly heat water in panels, which is then stored in a hot water cylinder. They are used almost entirely for water rather than space heating but are an efficient and cost effective solution in locations with strong solar radiation.

   - Geothermal heat can also be used a heat source for district heating.

25 A heat pumps "coefficient of performance" is predominately determined by the temperature on a given day and so its efficiency is often quoted in terms of its "seasonal coefficient of performance, which measures the average efficiency of a heat pump over the winter months. Please refer to Annex 1 for more information.

3. **Low-carbon fuels used in boilers.**

   - Biomass boilers burning wood chips, which must be produced in a sustainable fashion in order to be genuinely low-carbon. These are bulkier than gas boilers, with space also required to store biomass. Burning biomass has adverse local air quality effects via particulate matter and nitrogen dioxide, and is therefore subject to increasingly tight regulation which will limit their application to particular locations.

   - Bio-methane burnt in existing gas boilers and distributed via the existing gas grid. However, the widespread supply of sustainable biomethane is expected to be limited and limited to specific countries, such as Brazil.

   - Hydrogen burnt in variants of gas boiler and also distributed via the existing gas grid. This has been proposed as a solution in a number of countries, but for reasons set out in Box B is unlikely to be an optimal solution in individual homes. It may, however, play a role in niche locations or district heating systems.

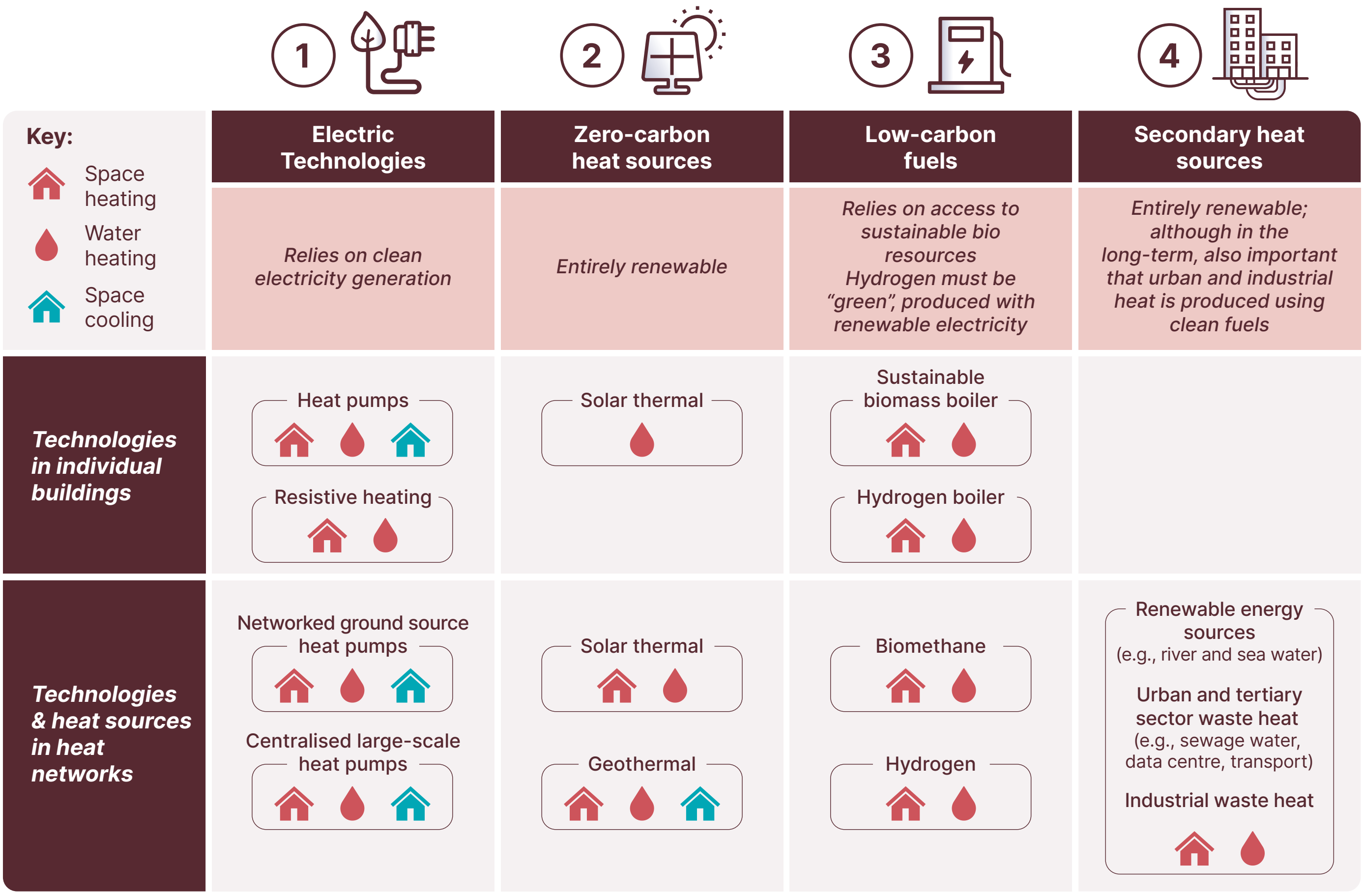
   - As the ETC set out in our 2021 report, *Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible*, as a general principle, the world's limited supply of sustainable bioresources should ideally be allocated to uses (e.g., long distance aviation) where alternative decarbonisation options (e.g., electrification) are not feasible. Building heating is not one of those priority applications.[26]

4. **Secondary heat sources:** District heating systems can also utilise existing heat sources, such as urban waste heat (e.g., sewage water, data centres, metro systems), and industrial waste heat.

Exhibit 2.3

There are four main groups of clean heating technologies; heat networks do these at scale

Full set of possible clean heating technologies:



SOURCE: Systemiq analysis for the ETC.

26 ETC (2021), *Bioresources within a net-zero emissions economy*.

Among these technologies, reversible heat pumps can be used to also provide cooling, but all the other technologies can only provide heating. The technologies also differ in relation to whether and how they can provide water heating [Exhibit 2.3]:

- Water-based heat pump systems (air-to-water, ground-to-water, and water-to-water) can provide water heating using water cylinders which impose space requirements [Exhibit 2.11]. The cost effective solution may often be to combine heat pump warming of water to a moderate temperature, with electric resistive heating to reach a high temperature for hot water needs. In comparison, air-to-air heat pumps cannot provide water heating and require an additional electric resistive water heater.

- Electric resistive heating can work either via an immersion heater inside a cylinder or via an immediate heater which requires much less space, with water heated by passing through a heat exchanger. The immersion heater/cylinder combination has the advantage that it can enable the use of off-peak electricity, reducing consumer costs and peak electricity requirements in the grid.

These different technologies can either be deployed in individual homes or at centralised locations, with hot water then distributed to individual homes. This is known as a "heat network", and ranges from community heating (e.g., one block of flats or a street), to larger-scale district heating (e.g., cities and towns) [Exhibit 2.4]. Heat networks are generally much more efficient than individual technologies, with the ability to reach much higher temperatures, utilise low-temperature heat from existing sources, and minimal losses through highly-insulated pipes.[27]

Networked ground source heat pumps sit somewhere in the middle of this spectrum using shared ground arrays that gather low-temperature heat (e.g., around 10°C) from boreholes 150–300m below the ground and feed it to individual heat pumps in homes, which then upgrade the heat to around 50–60°C [Box C].

27 Vattenfall, *Benefits of Heat Networks*, available at www.heat.vattenfall.co.uk/why-heat-networks/benefits-of-heat-networks/. [Accessed 15/10/2024].

Exhibit 2.4

Heat pumps are not just one technology – they can be deployed at different scales and there are different types depending on the heat source / sink combination

1 What is the scale of heating solution?

- **Individual home**
- **Heat networks**
  - **Community heating:** block of flats or a few streets (e.g., 50–500 households)
  - **District heating:** larger districts, towns and even small cities (e.g., 500–100,000 households)

2 How distributed is the heat exchange?

- **Fully Distributed:** Individual home solution
- **Heat network with distributed heat exchange:** circulates low-temperature, ambient heat to homes (e.g., 20°C), which is then upgraded via in-home heat pumps (e.g., to 60°C)
- **Centralised heat network:** Heat network circulates high-temperature water to individual homes via highly insulated pipes

3 Which heat pump technology (source / sink combination) best suits building and household needs?

	Description	Upfront cost	Efficiency	Can it deliver cooling?	Can it be integrated into wet heating systems?	Can it heat water?
Air-to-air	A reverse AC which blows hot air into a room	Lowest	Medium COP of 3–5	Yes – if heat pump is reversible	No	No
Air-to-water	Heats water which is circulated via radiators	Medium	Lowest COP of 3–4	No	Yes	Yes
Ground or Water source -to-air or water	Extracts heat from ground or water + delivered to building via hot air or hot water	Highest	Highest COP of 5–6	Yes (ground)	Yes	Yes
Waste heat to water	Extracts heat from waste heat (e.g., industrial, data centres, metro)	Highest	Highest COP of 5+	No	Yes	Yes

Key heat pump technologies

- Individual air-to-air
- Individual air-to-water
- Networked ground source
- Centralised large-scale air-to-water (e.g., cascade system involving a second heat pump to further upgrade heat)
- Centralised waste heat to water

SOURCE: Systemiq analysis for the ETC.

Box B **Hydrogen: Potential role in district heating but not individual homes**

In countries with large natural gas networks, a number of governments and industries have been considering the use of hydrogen gas, most notably the UK and Germany [Exhibit 2.18]. Hydrogen has been presented as a "drop-in" replacement of natural gas that can utilise existing pipelines and infrastructure, and trials (at the building, neighbourhood, and pipeline level) have been undertaken to demonstrate its viability and safety. With trials underway, it is not yet possible to conclude on the physical viability of widespread hydrogen heating, though nothing so far has raised significant concern.

Economic considerations, however, argue against a significant role for hydrogen in residential heating.

As we argued in our 2021 *Making the Hydrogen Economy Possible* report, using hydrogen should be prioritised in sectors where electric technologies are neither technically or economically feasible at scale. This is not the case for buildings, where the competitiveness of clean electrification has rapidly increased in recent years.

Indeed, in recent years the IEA has consistently revised down its forecast for hydrogen use in buildings, from meeting 12% of global heating demand in 2050 in a forecast made in 2021, to 3% in its 2023 forecast.[28] In the UK, a third trial of hydrogen heating was shelved in early 2024, in response to public opposition.[29] In Europe and the US, concerns have been raised about the influence of incumbent energy companies in pushing for hydrogen as a replacement of natural gas.[30]

Following additional research undertaken for this report, we believe that hydrogen should be ruled out as large-scale option to replace existing fossil fuel boilers for the following reasons:

- **Hydrogen is not a "drop-in" replacement:** Households will still need new boilers which can deal with either a gas/hydrogen blend or 100% hydrogen and in some homes, additional ventilation and pipe replacement will be needed. While hydrogen would mean existing natural gas infrastructure could be repurposed, it would still require significant retrofitting, or even rebuilding, given the fact that hydrogen and natural gas have very different physical properties (e.g., compared to natural gas, hydrogen molecules are much smaller, increasing the risk of leakage, and are more flammable).

- **Using green hydrogen would require 5–6 times more electricity than heat pumps:** As illustrated in Exhibit 2.5, the process of producing green hydrogen (i.e. using renewable electricity) and converting this to heat in a boiler has an overall of 50–55%. This compares to 300%+ for heat pumps.

- **System costs could be 25% higher compared to electrification:**[31] This reflects higher electricity generation requirements (although some costs would be offset by the fact hydrogen can be produced with curtailed electricity), and the cost of developing hydrogen pipelines and storage infrastructure.

- **Consumer costs could be 85% higher compared to electrification:**[32] Even though the cost of a hydrogen boiler is likely 3–4 times cheaper than an air-to-water heat pump, overall costs are expected to be much higher. This is because hydrogen is much less efficient, with higher running costs.

- **Using clean hydrogen for home heating would delay the decarbonisation of buildings until at least the mid-2030s:** There is uncertainty over the pace of clean hydrogen supply pipelines, especially in light of recent high electrolyser prices, and hydrogen-ready boilers are not available on the market yet.

28 IEA (2021), *Global Hydrogen Review 2021*; IEA (2023), *Global Hydrogen Review 2023*.
29 The Guardian, *Third pilot of household hydrogen heating shelved by UK government*, available at www.theguardian.com/environment/article/2024/may/09/third-pilot-of-household-hydrogen-heating-shelved-by-uk-government. [Accessed 24/09/2024].
30 Richard Lowes and David Cebon, *Wrong side of history: Wake up to the hype around green hydrogen for heating*, available at www.rechargenews.com/energy-transition/wrong-side-of-history-wake-up-to-the-hype-around-green-hydrogen-for-heating. [Accessed 22/10/2024].
31 Jan Rosenow (2024), *A meta-review of 54 studies on hydrogen heating*.
32 Ibid.

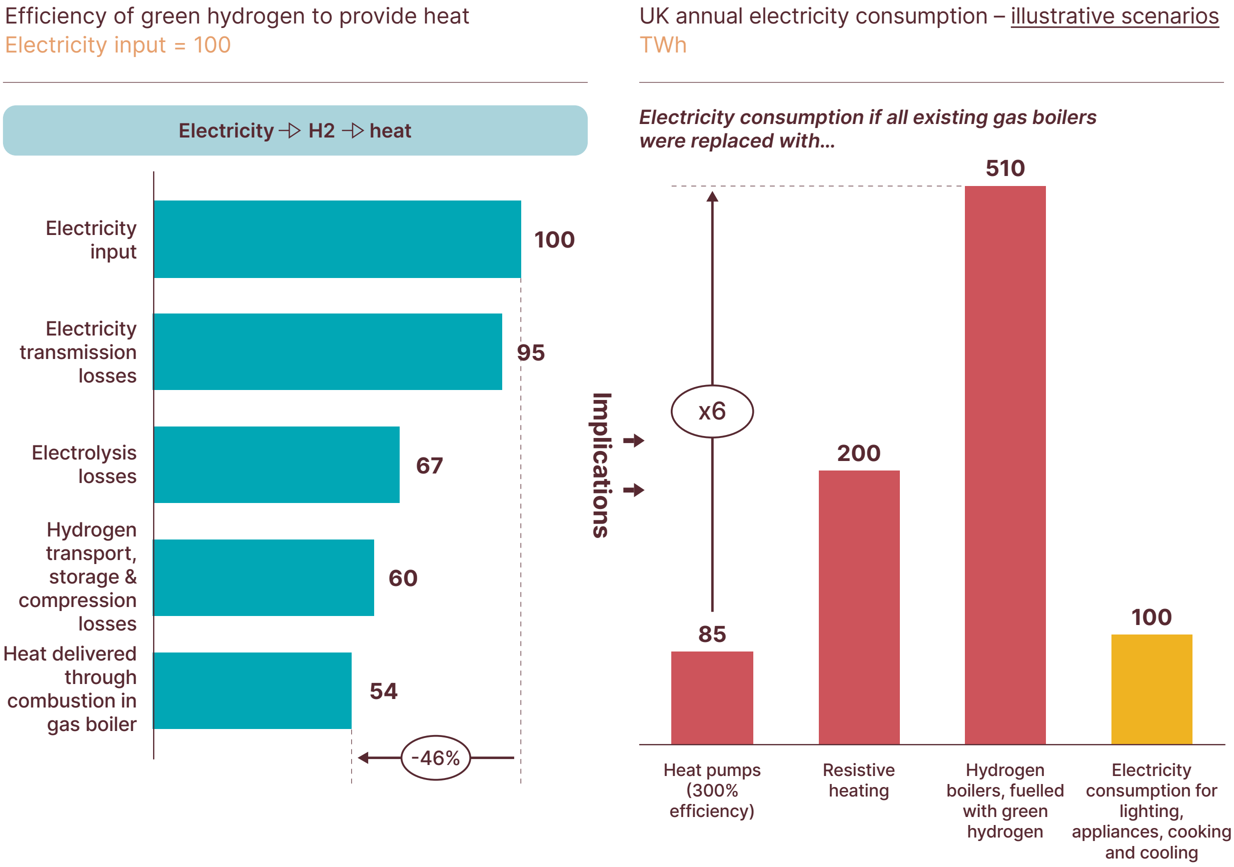
There may, however, be some circumstances where hydrogen is a viable economic solution in individual homes – specifically, in homes located close to the production of low-carbon hydrogen sites and where supply can therefore be guaranteed and cheaper.

Beyond direct use in homes, hydrogen will still play important roles in the net-zero transition of buildings:

- It is a key technology to store large amounts of energy over time, providing seasonal grid balancing in a renewables-dominated energy system.
- Hydrogen could also play both a direct role in district heat networks, for example, in locations close to industrial clusters with high hydrogen use/production, and an indirect role, where waste heat from industry powered by hydrogen can be utilised.

Exhibit 2.5

Green hydrogen (electricity to hydrogen to heat) has an efficiency of 50–55%; this means 5–6 times more electricity would be required compared to heat pumps



SOURCE: Systemiq analysis for the ETC; IEA (2023), *Energy Efficiency Database*; ONS (2022), *Energy consumption in the UK 2022*; ETC (2021), *Making the Hydrogen Economy Possible*.

Box C **Kensa's networked ground source heat pumps**

The successful retrofit of 273 social housing flats in Thurrock, England, demonstrates the potential of networked ground source heat pumps to deliver a rapid and whole-street transition in two of the most challenging segments of the market – low-income households and blocks of flats with limited space.[33] The retrofit of the three tower blocks involved:

- Drilling 109 boreholes and laying ground arrays in the car park, which remained open during the installation.
- Installation of the Kensa "Shoebox" heat pump and SunAmp thermal battery which helps provide hot water into resident's airing cupboards and replacing existing night storage heaters.
- Cavity wall insulation using an abseiling team to avoid costly and disruptive scaffolding.

The heat pumps are able to achieve efficiencies of around 500%, meaning energy bills fell 60–70% for most residents, even though energy consumption for many households actually rose, lifting them out of energy poverty. The project was jointly financed by Kensa Contracting and Thurrock council, who partly funded the investment from a government grant.

In future rollouts, residents will pay a monthly service charge to cover the cost and maintenance of the shared ground arrays. This financing model, where private investment funds the upfront costs, will be key to overcoming financing barriers and slow individual decision-making.


Social housing tower blocks in Thurrock, showing riser pipework (from borehole to each floor)


One of 100 boreholes in the car park


Remaining traces of ground array installation visible in the building car park


Example of ground arrays


Kensa "shoebox" heat pump and water tank

33 Kensa Contracting, Chadwell St Mary's, Thurrock Council, available at www.kensacontracting.com/thurrock-council/. [Accessed 14/10/2024].

2.2.2 Relative costs of different technologies

The relative cost of alternative heating technologies depends both on upfront costs and running costs; and running costs in turn depend on both the efficiency of the different technologies and the cost per kWh of the different energy sources – in particular the relative cost of electricity and gas. This relativity varies greatly by region and country of the world, and across specific countries within Europe [Box D].

In this section, we focus on costs for existing residential buildings and compare typical costs for an average household in Europe, while recognising that actual experience will differ significantly in line with specific circumstances. Chapter 2.4 discusses new buildings and Chapter 7 discusses commercial buildings. For a typical European household living in a two to three bedroom house, the cost of a boiler would be about €2,500–3,000, and running costs to provide 10,500 kWh of heat a year would be €1,250–1,500 at the average gas price of €0.12 per kWh which applied in 2023. We assume a current electricity to gas price ratio of 2.5 for this "average" customer.

Box D **Factors determining the relative costs of heating technologies**

The total cost of ownership (TCO) of alternative heating technologies depends on 3 factors:

- **Upfront cost:** These vary significantly by heating technology and also between countries since installation costs vary with the cost of labour. This section presents typical upfront costs for the different technologies for a 2-3 bedroom house in Europe. It compares the clean technology costs with those for a new gas or oil boiler, which could cost between €1,500–4,500 depending on size and property characteristics; we assume an average of €3,000.

- **Efficiency and energy input required.** Here heat pumps have a major advantage against all other technologies since they can deliver multiple kWh of heat per unit of electricity input.

- **The cost of energy inputs,** and in particular the relative cost of electricity vs. gas, which varies greatly between countries. For example, in the UK, electricity costs four times more than gas, vs. two–three times more in the US and France, but below 1.5 times in Norway and Sweden. One reason for this is the generation mix, with electricity prices lower in Scandinavia because of abundant hydro resources, and in France because of nuclear generation. But another is that levies and taxes applied to electricity are often much higher than those applied to gas. In Spain and Germany, for example, levies and taxes on electricity are around €0.2 per kWh, compared to €0.02 per kWh for gas.[34]

Absolute fuel costs also vary greatly across countries, with electricity costing an average of €0.29 per kWh in Europe in 2023, compared to €0.11 per kWh in the US.

Efficiency and the cost of energy together determine running costs, which together with upfront costs determine the TCO, taking into account differences in the cost of capital (i.e. the financing cost). These financing costs vary greatly between households of different income and wealth levels.

34 Regulatory Assistance Project (2022), *A policy toolkit for global mass heat pump deployment*.

Compared with these typical gas heating costs, in existing residential buildings:

Upfront capital costs are higher for heat pumps and biomass boilers, but lower for resistive heating [Exhibit 2.6]:

- Heat pump capital costs vary significantly by type of heat pump and across countries. On average across Europe, air-to-air heat pumps cost around €3,000–5,000, while air-to-water heat pumps cost around €7,000, but can be as high as €11,000 in markets like the UK.[35] Ground-source systems can cost €15,000, but much less if deployed on a network basis.

- Exhibit 2.7 shows that the cost competitiveness of heat pumps relative to gas boilers varies significantly across countries and there are many, more mature markets such as Sweden and Japan where air-to-air heat pumps are already cheaper than gas boilers. Air-to-air heat pumps are also generally cheaper in countries where AC is commonly used, such as Italy, given the technology is the same. Costs in other markets, such as the UK, Germany and the US should fall with technology development and scale growth (see Chapter 2.6).

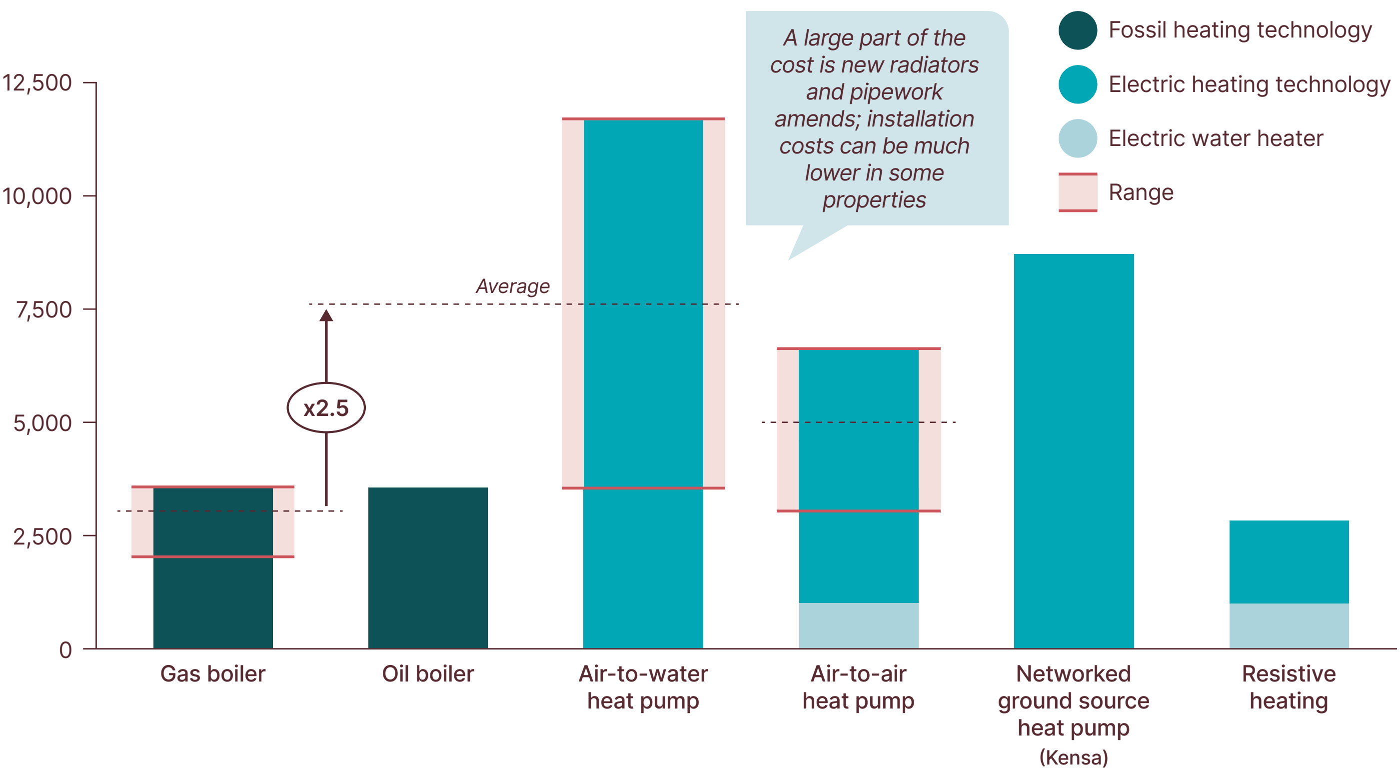
- Electric resistive heaters are the cheapest technology upfront, with a cost of around €1,500–2,000.

- Biomass boilers with automatic feeders are more expensive than gas boilers costing about €15,000.

Exhibit 2.6

Air-to-water heat pumps typically cost 2–3 times more than gas boilers to install, but costs vary hugely across countries and buildings; resistive heating has the lowest upfront capex

Average capex cost in Europe (technology and installation)
€



NOTE: Costs do not include subsidies, but do include labour costs. For air-to-water heat pumps, they also include the cost of typical radiator upgrades required.

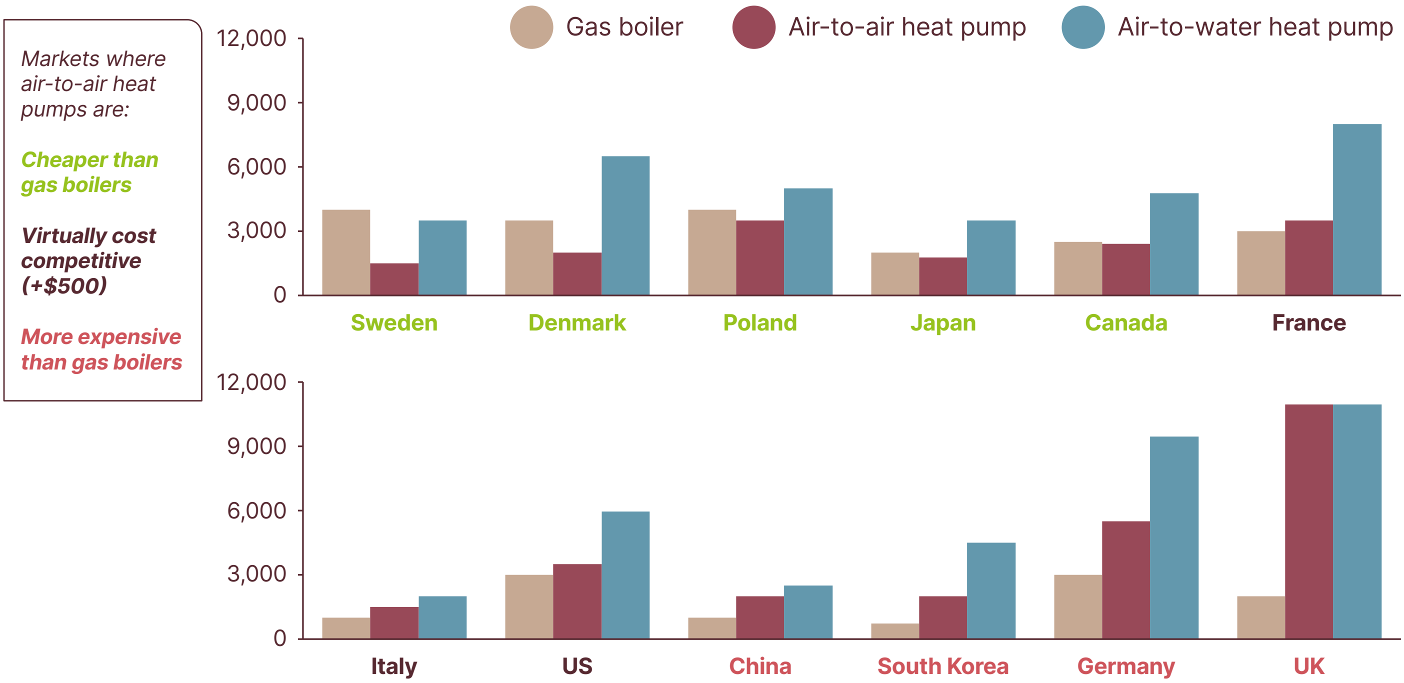
SOURCE: Systemiq analysis for the ETC; IEA (2022), *The Future of Heat Pumps*; Kensa (2024).

35 Costs include the cost of required radiator upgrades and ductwork.

Exhibit 2.7

In some mature markets, the upfront cost of an air-to-air heat pump is competitive with gas boilers, but air-to-water heat pumps remain more expensive

Capex cost of the cheapest main model in selected countries, 2022 (technology and installation)
$



NOTE: Costs exclude subsides.

SOURCE: Systemiq analysis for the ETC; IEA (2022); *The Future of Heat Pumps*, https://www.iea.org/reports/the-future-of-heat-pumps, re-used under license: CC BY 4.0.

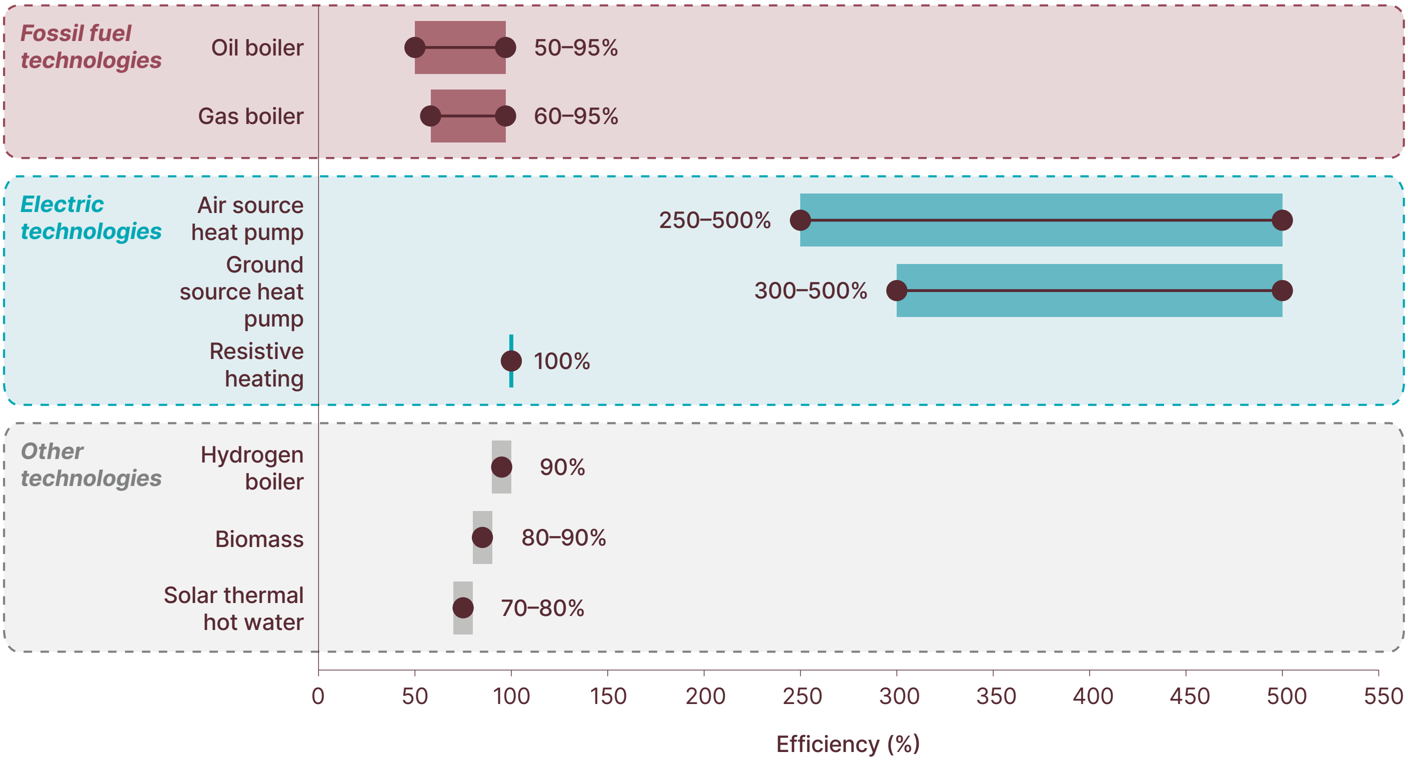
Heat pumps are far more efficient than all of the other technologies, delivering around 300% efficiency today and with further significant improvement likely in future. Resistive heating is around 100% efficient in both space and water heating applications, while biomass boilers are typically slightly less efficient than gas boilers [Exhibit 2.8].

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

Exhibit 2.8

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*.

The relative total cost of ownership (TCO) between technologies depends on the combination of the upfront capital cost, the efficiency achievable, and the ratio of fossil fuel to electricity prices. Exhibit 2.9 presents estimates for a range of different assumptions in European countries. It shows that:

- Upfront capital costs are highest for networked ground source heat pumps and lowest for resistive heating, with gas and oil boilers somewhat less expensive than each of the heat pump options.

- At the average gas and electricity prices observed in Europe in 2023, the operating cost is lower for each of the heat pump options than for gas or oil boilers. This is because the efficiency benefit of the heat pumps (e.g., around 300% for air-source and 500% for ground-source) exceeds the electricity/gas price ratio, which in 2023 averaged 2.5 across Europe.

- At these average prices, the TCO is very similar for all of the options apart from resistive heating which is significantly more expensive.

However, actual gas and electricity prices for individual European countries varied significantly around the European average, and Exhibit 2.9 illustrates the range of TCOs which would result from the highest and lowest gas and electricity prices observed. This shows that in some countries with very low gas prices, gas boilers would have a lower TCO than the heat pump alternatives, but in others gas and oil boilers would be significantly more expensive.

The price differential between gas and electricity is therefore a major determinant of TCO. Exhibit 2.10 shows the different price ratios which apply in different European markets and the implications for heat pump economics relative to gas boilers. Whereas the electricity to gas price ratio was around 4:1 in the UK in 2023, it was around 1.5:1 in Sweden.

On average, across Europe it was around 2.5:1:

- Given this average ratio, and allowing for higher upfront cost, a heat pump would need an efficiency of 340% (a CoP of 3.4) to be competitive with a gas boiler.

- But with a 2:1 electricity/gas price ratio, a heat pump achieving a 2.7 COP would be competitive.

In many but not all parts of Europe, heat pumps are therefore already lower cost than gas boilers on a TCO basis, and deliver significant operating cost reductions in return for an upfront investment. These relative economics are likely to improve further over time as large scale deployment enables a decline in upfront heat pump costs and as technological innovation delivers efficiency increases.

Further significant improvements in the economics of heat pumps would be achieved if:

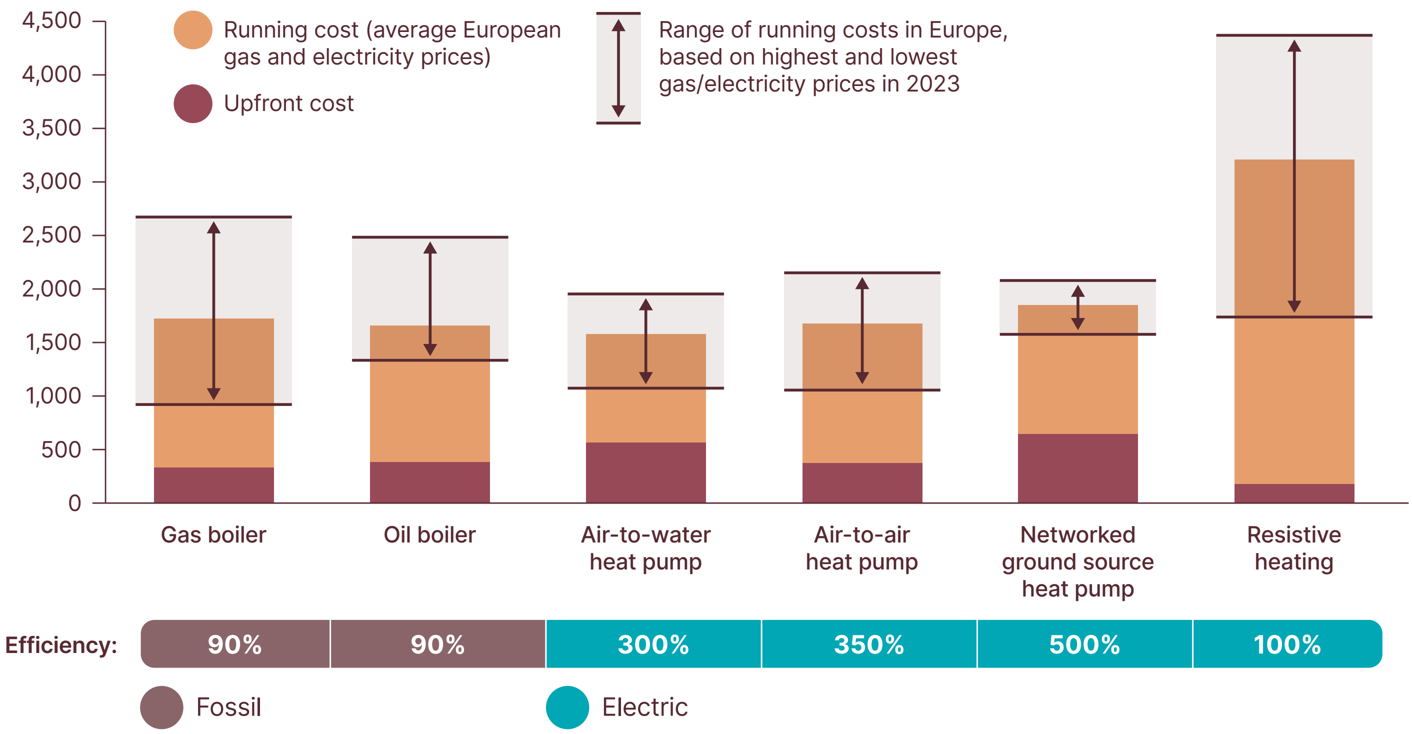
- Households used low cost off-peak electricity to power heat pumps – the potential to do this without any sacrifice of heating quality increases with insulation (see Chapter 8).

- The relative price of electricity to gas declines. The measures which could drive this development are described in Section 2.6.

Exhibit 2.9

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



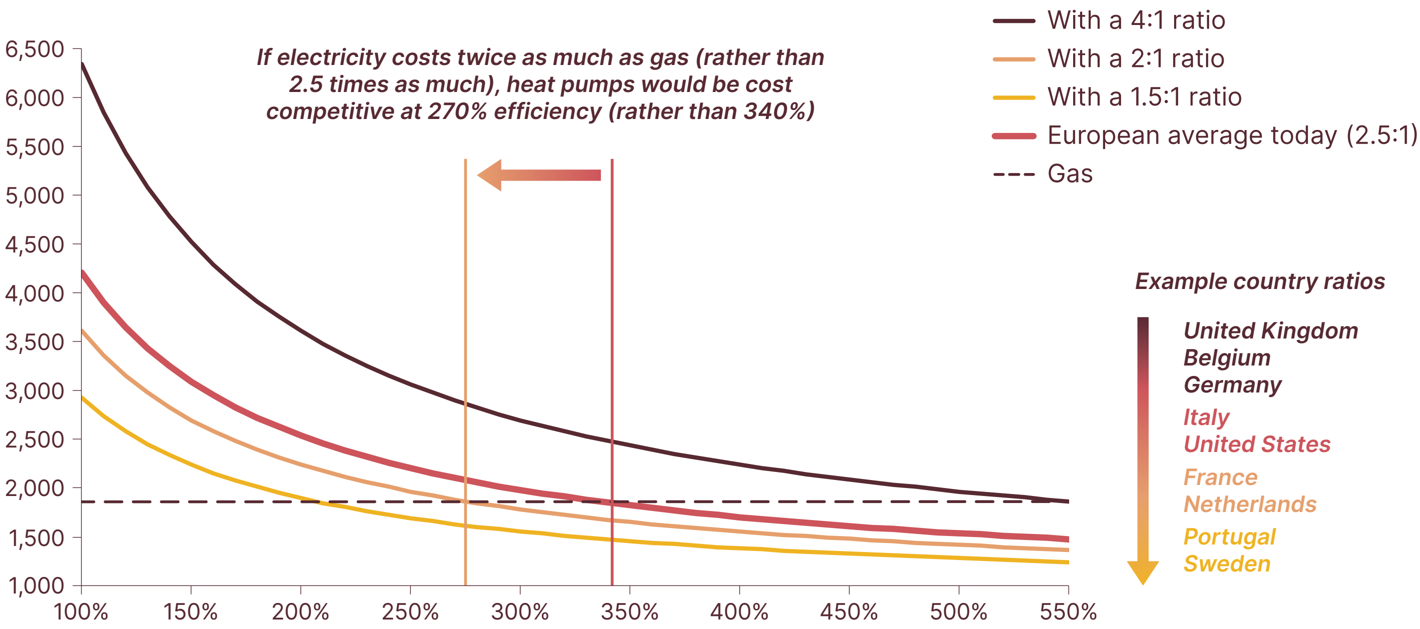
NOTE: Assumes an average heat demand of 11,500 kWh a year per household, based on an average across the US and select European countries. Average, min and max running costs are based on 2023 retail prices. Assumes 5% discount rate. Excludes subsidies and maintenance costs. Networked ground source heat 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].

Exhibit 2.10

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].

Overall therefore, the economics strongly support a shift from gas boilers to heat pumps and most households in Europe and other parts of the world will enjoy lower costs as result of this shift. But it is important to recognise, however, that individual circumstances will differ significantly from this average, with for instance:

- Lower income households tending to face a higher financing cost, which increases the impact of higher upfront equipment costs.

- Major differences between households in terms of space availability to house different units of equipment [Exhibit 2.11]. For tightly space constrained households, heat pumps may not be feasible and electric resistive heating a more feasible solution, but with higher operating costs as a result.

It is therefore essential that strong overall public policy support for heat pump developments is combined with policies which address the significant distributional issues, including appropriate subsidy support for lower income households. These policies are described further in Section 2.6.

These complexities in existing buildings do not, however, undermine the overall conclusion that heat pumps will and should play a dominant role in the decarbonisation of both residential and commercial building heating. In new buildings, heat pumps should clearly be the default [Chapter 2.4].

Exhibit 2.11

Heat pumps often have additional space requirements, such as the need for a hot water cylinder, and outdoor/wall space with a ~1 m buffer

Size of individual technologies:

District heating
0.7×0.5×0.3 m
A heat interface unit, roughly the size of a combi boiler

Hydrogen boiler
0.7×0.5×0.3 m
A hydrogen boiler, roughly the size of a combi boiler

Resistive heating
0.5×1×0.1 m
Electric panels on walls in multiple rooms in house

Networked ground source heat pump
0.6×0.6×0.6 m
Individual heat pump

Hot water cylinder
2×1×1 m
These vary massively in size depending on hot water needs

Most clean heating technologies need to be combined with a water storage tank

Air-air heat pump
1.5×1×1 m
Units on wall in multiple rooms in house, or air-duct system

Air/ground - water heat pump
2×1×1 m + 1 m buffer
Heat pump on ground + buffer space to allow for air flow

Solar thermal
2×2 m
2–4 panels on roof

Biomass boiler
1.5×1×3 m

Total building space requirements:

	Small space requirements		Medium space requirements					Large space requirements	
	District heating	**Hydrogen boiler**	**Solar thermal**	**Resistive heating**	**Air-water heat pump**	**Air-air heat pump**	**Networked ground source heat pump**	**Biomass boiler**	**Individual ground source heat pump**
Inside the home	A heat interface unit, roughly the size of a combi boiler	A hydrogen boiler, roughly the size of a combi boiler	Hot water cylinder	Electric panels on walls + Electric water heater	Hot water cylinder + Radiators on walls	Unit on wall + Electric water heater	Individual heat pump in house + Hot water cylinder	Biomass boiler + Hot water cylinder	Hot water cylinder
Outside the home			+ 2–4 panels on roof ~2×2 m		+ Heat pump on ground + buffer space	+ Outside condenser unit (on ground or walls) + buffer space		+ Storage space for wood and pellets	+ Heat pump + ~700 m² + for ground loop

NOTE: Assumes an average 3–4 person house.

SOURCE: Systemiq analysis for the ETC.

2.2.3 Heat pump myths, realities and technological progress

Despite the strong general case for heat pumps, there continues to be scepticism – largely amongst homeowners – about their effectiveness and significant opposition to their deployment. This reflects a number of myths which are unfounded today and which will become even less valid as heat pump technology improves and costs reduce.

Heat pump myths vs. valid concerns

- **"Heat pumps cannot deliver the same heat as gas boilers":** In comparison to gas boilers which are able to quickly provide heat on demand, heat pumps work by being turned on for longer but at lower temperatures. This does not mean heat pumps are less effective at providing heat or comfort, but reflects how heat pumps operate. This is because today's air-to-water heat pumps typically operate with lower flow temperatures than gas boilers (i.e. the water which runs through central heating systems is 35–50°C, compared to 60–80°C for gas boilers) – although, as discussed below, innovation is seeing heat pumps reach higher and higher flow temperartures. Attaining the same levels of comfort is not an issue, provided heat pumps are sized and installed correctly, though in some cases additional changes to building heating will be required. For example, many existing buildings will require radiators to be replaced and upsized, enabling more heat to be transferred into the room. Surveys of households who already have heat pumps consistently report very high levels of satisfaction with the space and water heating provided.[36]

- **"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, especially as policy enables the relative cost of electricity to fall. Refrigerants are liquid at very low temperatures (e.g., below -30°C), meaning they can extract heat even in below zero temperatures. 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.[37]

- **"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. But as will be argued in section 2.3.2 and Box E below, this argument has been hugely overstated, as long as radiators and heat pumps are properly sized - without these, similar comfort levels would struggle to be achieved in some buildings.[38] In addition, high-temperature heat pumps which can reach temperatures of around 65°C are increasingly available on the market, reducing the need for radiator upsizing or insulation; these are not materially more expensive to purchase but have higher running costs as they operate at a lower efficiency than standard heat pumps (although they are still significantly more efficient than gas boilers).

36 Ibid.
37 Carbon Brief (2024), *18 misleading myths about heat pumps*.
38 A key challenge in the UK, however, is microbore plumbing – pipework smaller than 15 mm in diameter. This restricts the flow and heat exchange of air-to-water heat pumps, making them less effective and less efficient

Rather than these three issues, the crucial challenges relating to heat pumps are those mentioned above:

- The high upfront costs and the implications for affordability, especially for low income household facing high financing costs.
- The relative cost of gas and electricity in many countries, which means consumers are not able to full benefit from higher efficiencies.
- The space availability to install a heat pump plus a hot water cylinder, for the outside unit, and for additional and/or large radiators.

Innovations in heat pump technology

Heat pump technology has been used in homes for over 50 years, but currently only meets around 10% of global heating needs in buildings.[39] As heat pump markets continue to scale, innovation is rapidly improving the technology and addressing many of the key concerns about their performance:

- **Efficiency:** Heat pump technology is becoming more efficient due to, a) variable speed motors which enable a heat pump to operate a different speeds rather than simply on and off, and b) improvements in inverter technology which prevents a fall in performance at lower outdoor temperatures. Average efficiency is expected to gradually improve to around 400–500% by 2050.[40] As a result, the operating cost advantage of heat pumps vs. gas boilers will steadily increase.
- **Flow temperatures:** Developments in high-temperature heat pumps are increasingly making it possible to use them to heat even poorly insulated houses. Initially these involved a "cascade system" – effectively two heat pumps in one, resulting in much lower efficiency. But some new models now use different refrigerants which can reach higher temperatures for the same amount of compression (e.g., around 60°C compared to 40°C).[41] It is important to note, however, that running a heat pump to a higher temperature by default reduces its efficiency and increases running costs.
- **Water heating:** Because they work to lower flow temperatures, heat pumps can't deliver hot water on demand like a "combi boiler". This means they require a hot water cylinder, which gradually heats and stores hot water over time. This is an issue for installing heat pumps in smaller properties. The hot water challenge has not currently been solved by any products on the market today, but the combination of high temperature heat pumps and innovation in heat exchanger technology is expected to reduce the size of, or eventually the need for, hot water cylinders. Technologies which combine preheating of water in moderately sized cylinders, plus resistive heating boosters to deliver water at the desired temperature are also possible.
- **Size:** Heat pumps are generally getting smaller in size, improving their applicability in smaller homes. Today a typical air-to-air heat pump inside unit is around 1.5 m² and an air-to-water heat pump is around 2 m². One issue today is the tendency of installers to oversize heat pumps, but as installers gain experience they will be able to right-size heat pumps.
- **Noise:** Survey evidence reports just one noise complaint for every 3,000 installations.[42]

Potential for heat pump cost reduction

Alongside these innovations to drive improved heat pump performance and usability, there is also significant potential for cost reduction, which will result from economies of scale and learning curve effects as the market for heat pumps grows massively, and with increases in the supply of skilled installers [see Chapter 2.6]. It is striking for instance, that air-to-air heat pumps are today more expensive than air-conditioner units, despite the fact that the core items of equipment are identical.

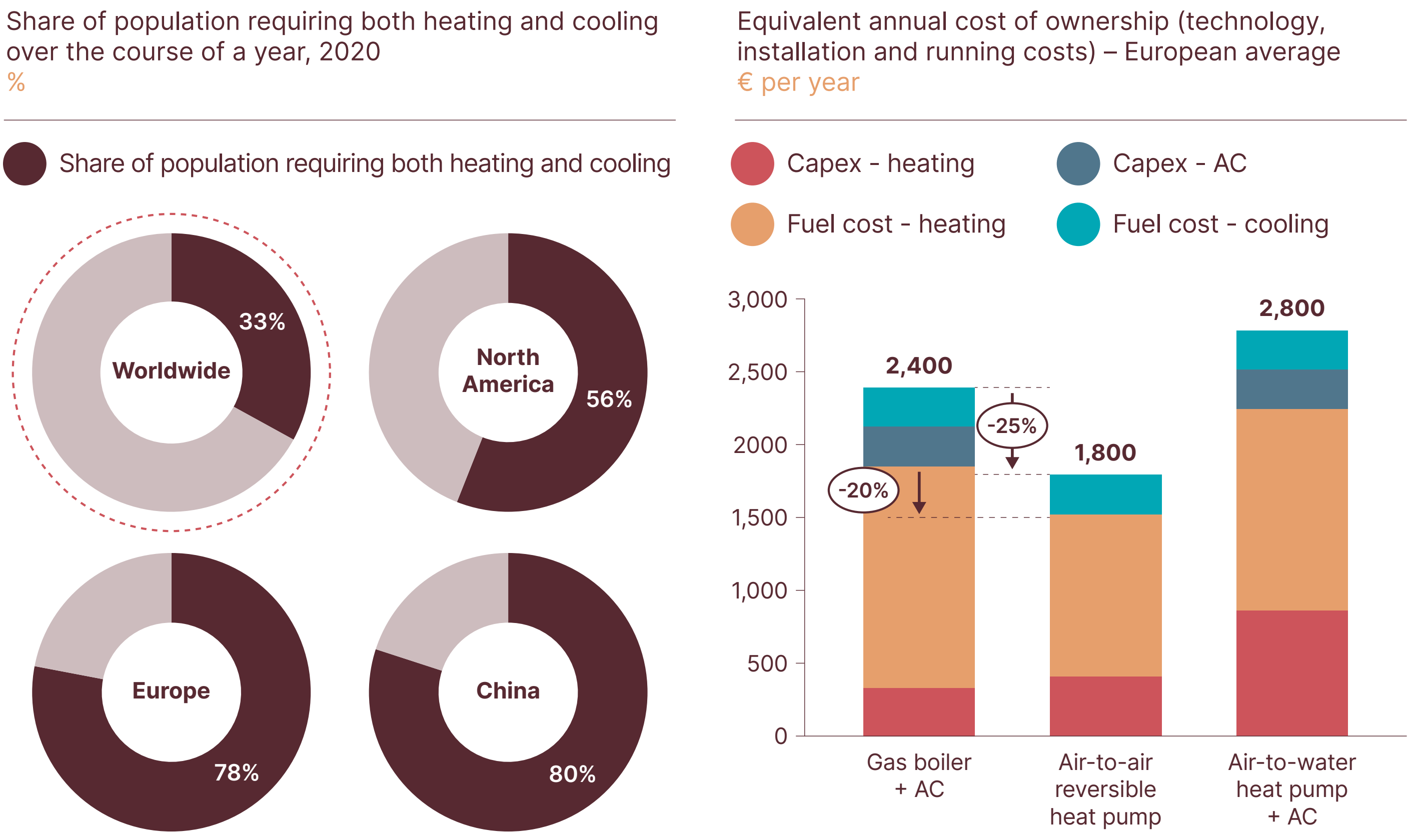
Reversible air-to-air heat pumps

The fact that heat pumps and air conditioners are essentially the same means that units which have a valve to reverse the flow of refrigerant can provide both space heating and cooling. This is will be a huge driver of adoption, as cooling needs grow (see Chapter 3), with around a third of the global population requiring both heating and cooling over the course of a year. In countries with both heating and cooling needs, reversible heat pumps/air conditioners are likely to be significantly less costly than combining air-to-water heat pumps plus separate air-conditioning units [Exhibit 2.12]. While not typically used for cooling, air-to-water heat pumps could also provide low-level cooling by passing chilled water through underfloor heating pipes.[43]

39 IEA, *Heat Pumps Overview*, available at: www.iea.org/energy-system/buildings/heat-pumps. [Accessed 29/07/2024].
40 Based on ETC interviews with experts across the technology and buildings landscape.
41 The main innovation has been working out how to safely use propane (known as R290).
42 Institute of Acoustics (2023), *Noise from ASHPS – What do we know?*
43 Daikin, *Can heat pumps be used for cooling?*, available at www.daikin-ce.com/en_us/daikin-blog/can-heat-pumps-cool.html. [Accessed 30/09/2024].

Exhibit 2.12

When accounting for both heating and cooling energy consumption, air-to-air heat pumps are increasingly cost competitive with gas boilers as it avoids a second capex cost for AC



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; no carbon price on gas is assumed. Assumes 5% discount rate. Cooling annual energy consumption based on Greece, Cyprus and Malta. Heat pump and AC efficiency assumed at 300%.

SOURCE: Systemiq analysis for the ETC; Eurostat Database, available at www.ec.europa.eu/eurostat/data/database. [Accessed 01/08/2024]; Odyssee-Mure (2021), *Unit consumption of air conditioning*; IEA (2020), *Is cooling the future of heating?*

2.2.4 Heat networks

The technologies described above can be deployed at the individual house level, but can also be deployed in various forms of networked or district heating solutions.

In data on buildings energy use [see for example, Exhibit 1.3], "district heating" is often considered its own fuel category; but in reality there is a huge variety of fuels and technologies covered by this term.

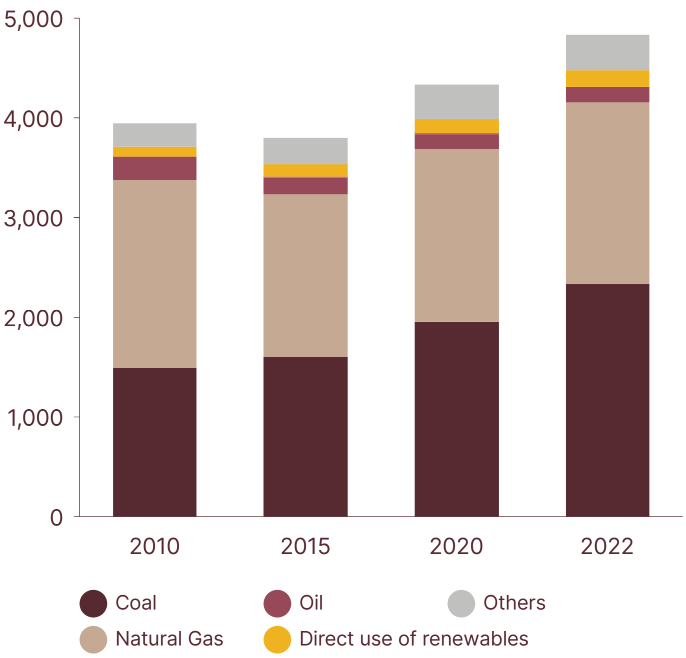
Currently, 90% of energy delivered via heat networks, 1,600 TWh, is supplied by fossil fuels (predominately coal and gas), as shown in Exhibit 2.13. This means there is additional challenge of decarbonising these networks, which are common in China, Russia and, to a lesser extent, Europe. In China in particular, district heat networks are predominantly coal based and thus have a high carbon intensity, 25% above the global average.

Exhibit 2.13

In China and Russia – and to a lesser extent, Europe - there is an additional challenge of decarbonising existing district heating networks

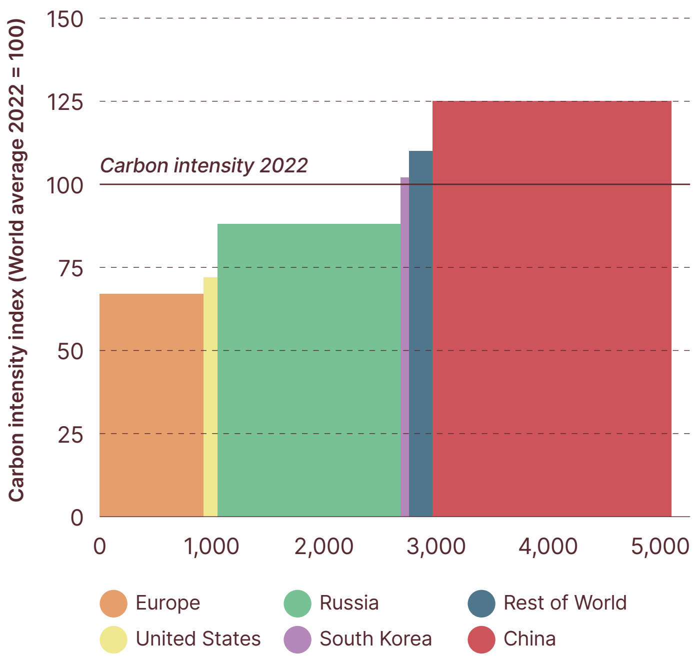
90% of district heating is supplied by fossil fuels

Global energy supply to district heat networks (buildings and industry) TWh



China and Russia have significantly more carbon intensive networks

Global district heating by carbon intensity and energy use Carbon intensity index & TWh



SOURCE: IEA 2023; *District Heating*, https://www.iea.org/energy-system/buildings/district-heating, re-used under license: CC BY 4.0.

There is a large variety of technologies which can be deployed both in new heat networks and to decarbonise existing high-carbon networks. Indeed, the last few years have seen momentum for heat networks pick up, driven in Europe for example by energy security concerns. Key examples include Denmark and Finland growing their geothermal heat networks, Canada and Scotland exploiting wastewater waste heat with heat pumps, and China utilising waste heat from nuclear power plants.[44]

The suitability of different technologies is highly situation-specific, depending on space availability, the number of buildings connected and their distribution, and access to heat sources. However, it is possible to draw the following conclusions:

- Heat networks provide efficient and often lower-cost clean heating at scale. They can overcome slow individual action, enabling street-by-street decarbonisation. Therefore, understanding the potential to deploy these across countries through national heat plans and zoning should be a top priority.[45]

- There are significant untapped secondary heat sources such as metro tunnels, data centres and industry; the energy transition will also lead to growing waste heat opportunities from heat intensive processes such as carbon capture and synthetic fuel manufacture. These also offer innovative opportunities for financing their development, with the removal of waste heat providing huge benefit to businesses (e.g., data centres).

- Continued improvements in the size and scale of heat pumps mean these will be a core solution to decarbonising existing heat networks. Heat pumps can also be combined with secondary heat pumps to achieve much higher efficiencies, for example a COP of over 5 and 6, compared to 3.

- Many countries, such as the Nordic countries and the US, have considerable renewable heat sources such as geothermal; these offer significant low-cost potential which should be maximised.

- Low-carbon fuels such as biomethane and hydrogen may play a role in the decarbonisation of existing heat networks, where reliable supply may exist (e.g., close to industrial sites).

2.3 “Passive” heating techniques

As described above there is a wide range of “active” technologies which could be used to decarbonise the supply of heat to homes or commercial buildings, with multiple variants of heat pump technology likely to play a major role whether in individual buildings or in networked solutions.

But it is also possible to rely on natural elements such as the sun and a building’s envelope to maintain a comfortable indoor temperature and therefore reduce the use of mechanical heating systems.[46] These so called “passive” techniques can play a critical role in developing a clean, efficient and high quality building stock. They must be maximised in new developments and utilised, where cost effective, in existing buildings.

By reducing energy requirements from active heating they:

- Help reduce emissions while electricity is still generated using high-carbon sources, and while heating is still directly fuelled by fossils.

- Reduce the scale of the investment needed in clean power generation and in transmission and distribution.

- Significantly improve outcomes for households, leading to more comfortable and higher quality homes and lower energy bills.

Passive heating techniques focus on capturing and retaining heat inside a building by optimising:

- **Orientation** to maximise solar exposure during the winter months (e.g., in the northern hemisphere, windows and living areas facing south – although this must be balanced against the need to avoid solar gain in the summer months).

- **Thermal mass in the building fabric:** Materials such as stone, brick and concrete are able to slowly absorb and store ambient heat during the day and then radiate this at night. This helps to avoid sudden spikes in indoor temperatures.

44 IEA, *District Heating*, available at www.iea.org/energy-system/buildings/district-heating. [Accessed 24/09/2024].
45 Zoning is the process of dividing a region or city into different areas with specific rules for land use, development, and design.
46 A building’s envelope is everything that separates the internal building from the external environment, including the roof, doors, windows, floors and walls.

- **Minimising heat loss in the building envelope:** Materials and design choices are important to create a barrier between hot and cold temperatures. Key solutions include:
    - Insulation: Materials with high thermal resistance, therefore resisting heat transfer, include fibre glass, mineral wool and foam. Insultation should be appropriately applied to walls, floors and roofs.
    - Windows: Amount of glazing (e.g., double or triple) and coatings (e.g., low-emissivity glass which reflects heat back into a room).
    - Air tightness: High-quality construction and effective use of seals around windows and doors can help reduce air leakage. While this is very important to prevent draughts, it is also critical to ensure a building has sufficient ventilation and air quality.

As we will explore further in Chapter 8, high thermal mass and a low heat loss rate are key to increasing the flexibility of building energy demand, reducing peak heating needs and shifting electricity demand to non-peak hours.

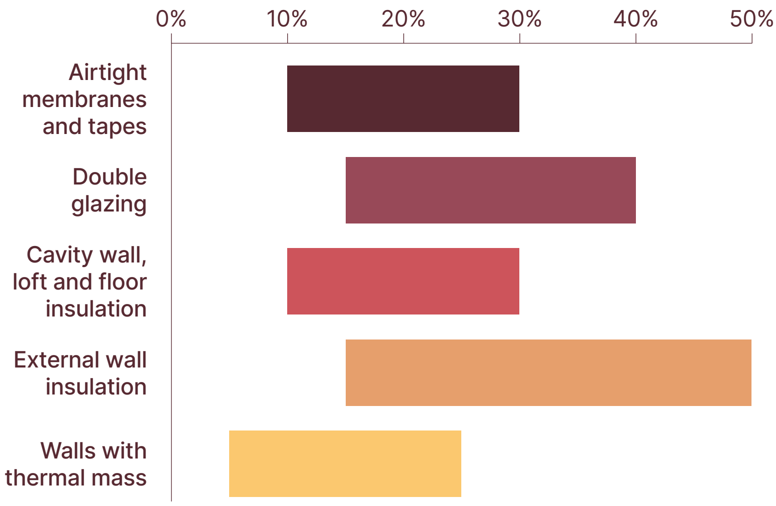
Designed for northern hemisphere countries (e.g., with a focus more on heating), the Passive House Standard is the gold standard for energy efficient new buildings, incorporating passive building techniques to lower energy consumption by 70–90% compared to typical buildings.[47] As Chapter 9 explains, the costs of building to Passive House standards can be prohibitive (especially for existing buildings), but there are many low-cost and high-impact things that can be done.

Identifying the appropriate balance between designing a building with passive heating and passive cooling (see Chapter 3.2) techniques will become more challenging in many parts of the world, as warming climates mean that buildings have high heating needs in winter and high cooling needs in summer.

Exhibit 2.14

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	High 30%
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 m^2. 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*.

47 Buildpass (2020), *The 5 fundamental principles of passive house.*

2.3.1 The opportunity for passive heating in new buildings

It is significantly cheaper and easier to ensure buildings are constructed with passive heating techniques compared to retrofitting at a later date. The impact on energy consumption will vary massively across techniques and buildings; however Exhibit 2.14 shows that heating demand can be reduced by 15–30% on average.

Similarly, the additional cost to developers will vary depending on material and labour costs, and know-how. Exhibit 2.14 sets out rough estimates of cost to developers; it is important to note that these are not necessarily additional costs, with regulation in many countries already requiring a focus on these.

From an economy-wide perspective, investing in passive heating techniques are likely to reduce the overall costs of the transition. The challenge is that the costs are borne by developers but the returns accrue to households via lower energy bills. If these reduced costs are reflected in the prices people pay for new build housing, and in subsequent house values over time, there will be a strong incentive to construct energy efficient buildings. But if house prices fail to reflect the fundamental economics – for instance, as a result of imperfect information and consumer understanding – this incentive will be weakened.

Chapter 8 will discuss the role of regulation and private sector action in ensuring new builds are built to maximise efficiency and comfort.

2.3.2 The potential to retrofit buildings for passive heating

In existing buildings, the main passive heating techniques that can be retrofitted are improvements to the loft, floor, walls, and windows. Packages of insulation increase overall efficiency but come at increasing cost:

- **Light insulation measures (~5% reduction in energy consumption):** These include easy to implement measures, for example, low-cost or less disruptive loft insulation using boards or rolls of mineral wool, fibreglass or cellulose, or draught proofing using self-adhesive foam strips around window frames, brushes at the bottom of doors and letterboxes, and sealing cracks.

- **Medium insulation measures (~10–30% reduction in energy consumption):** This level of reduction would typically require 2–4 significant interventions, for example, adding insulation to the inside of walls, insulating cavity walls with polystyrene beads, mineral wool or polyurethane foam, adding insulating boards underneath floorboards, and replacing windows with double glazing.

- **Deep insulation measures (~30–60% reduction in energy consumption):** This typically refers to a package of four or more insulation measures, often involving more structural changes to the building fabric, such as insulating external solid walls.

As detailed in section 2.4, the vast majority of households should be able to install a heat pump without the need for deep insulation, provided the heat pump is sized and installed correctly with appropriate radiator replacement.

However, there are significant wider benefits to improving insulation in existing homes, including greater comfort and lower energy bills. As we outline in Chapter 8, reducing heat loss within homes is also core to enabling households to shift the timing of their heat demand, use electricity at lower off peak prices, and reduce the challenges and costs created by high peak electricity demand in renewable dominated power systems.

The challenge is that some insulation measures have high upfront costs and it can be difficult for households to estimate how much this investment will reduce annual energy bills. Exhibit 2.15 sets out some illustrative scenarios for costs and energy savings, comparing the years to payback investments in efficiency improvements in inefficient and average buildings. However, it is important to note that costs vary massively across countries and type of building. Key points, focusing just on the financial incentives, are as follows:

- The incentive to insulate decreases with higher heat pump efficiencies, but all households have a financial incentive to explore light and low-cost insulation measures.

- Households in inefficient properties have an incentive to explore deeper insulation, especially if they are using resistive heating. However, access to low-cost finance (e.g., from governments) will be required to enable households to afford the upfront costs. Without government support, it is unlikely that households living in a property with average levels of energy efficiency will invest in insulation at scale. However, households may still have a strong willingness to pay for insulation to improve comfort and building value.

- For households that have a winter heating and summer cooling need (e.g., many parts of the US and Southern Europe), the returns will improve when considering that improving insulation will reduce both heat loss and AC energy loss.

This suggests the following policy priorities:

- Improving the energy efficiency of the least efficient properties should be a critical priority this decade, with very strong economic and social paybacks. Government subsidies are likely to be required, since households living in poor quality, less efficient homes are likely also to have lower incomes.
- For the average property, governments should provide low-cost or zero-interest finance, overcoming lower paybacks for the average household.
- Providing clear guidance on low-cost insulation measures that can be safely and easily done by homeowners themselves, and offering free advisors to assess the most cost-effective measures for individual properties.

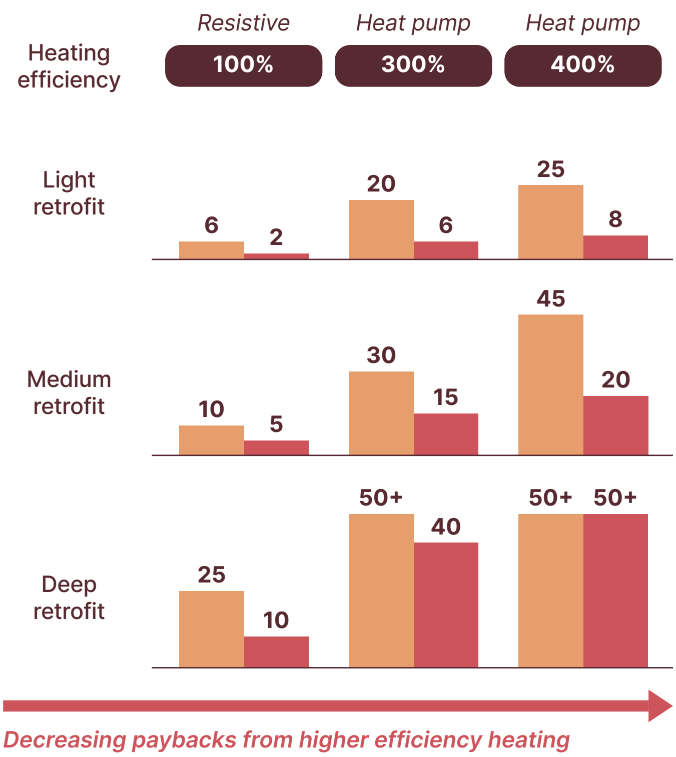
Exhibit 2.15

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)*
Upfront cost	€1,000	€5,000	€25,000
% reduction in energy consumption – Average property	5%	15%	30%
% reduction in energy consumption – 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].

2.4 Optimal combinations of heating technologies and improved insulation

Given both the clean heating technologies described in Chapter 2.2 and the passive heating technologies described in Chapter 2.3, optimal approaches to building heat decarbonisation will entail multiple different combinations of actions, varying by region and by specific building. But broad conclusions on the predominant technologies and most important policies can be reached.

2.4.1 New buildings

Strategies to ensure that new buildings are zero-carbon ready should combine very high standards for building design plus regulation to require the installation of a zero carbon heating technology which in the vast majority of situations will be electric.

This implies the need for:

- Regulation to prohibit the installation of fossil fuel boilers in new builds from 2025 in high-income countries and from 2030–35 in middle-income countries.

- More ambitious building codes which regulate actual energy performance, with more stringent minimum requirements for energy intensity (i.e. the typical kWh per m^2 a building can consume); this will tend to limit the installation of resistive heating for primary space heating needs and encourage heat pump solutions.

- Guidance and training of the real estate sector to better inform prospective buyers about their heating system, future bans on fossil fuel heating, and running cost implications of resistive heating vs. heat pumps.

- Collaboration of developers with wider industry stakeholders (e.g., utility companies, heat pump companies, financial institutions) to finance new heat networks, and with the real estate sector to ensure proper building operational handovers.

This combination of policies is likely to drive very widespread deployment of heat pump based solutions, but with the particular type of system varying by building type and location:

- Networked ground source heat pumps will be the economic solution in many large scale developments of apartment blocks and housing estates, and will deliver households the highest possible efficiency and lowest operating costs.

- Air-to-air heat pumps will be particularly attractive in regions which have cooling as well as heating needs. They will need to be accompanied by electric resistive or solar thermal water heating.

- Air-to-water heat pumps will be the cost effective solution for many detached properties which do not have cooling needs, which have the space for hot water cylinders, and would prefer to continue using a wet heating system (e.g., in many parts of Europe such as Germany, the Nordic countries, and the UK). For new builds, research suggests that underfloor heating provides the most efficient and effective heat transfer, but as long as radiators are appropriately sized they can achieve a similar performance.[48]

It is therefore important to ensure that householders are well informed about future operating costs as well as upfront costs, to avoid the danger that developers focus solely on minimising the latter [Exhibit 2.16].[49] This distinction is also relevant for landlords and tenants.

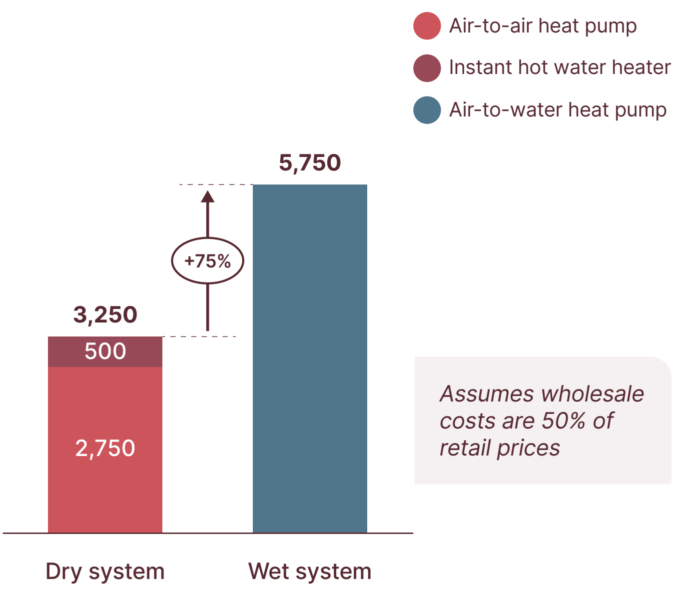
48 Fitton, R., et al. (2024), *Energy House 2.0 Systems Report*.
49 Wholesale costs for clean technologies are very uncertain; we have assumed 50% of retail prices.

Exhibit 2.16

Installing air-to-air heat pumps is significantly cheaper for developers, but leads to higher running costs for homeowners

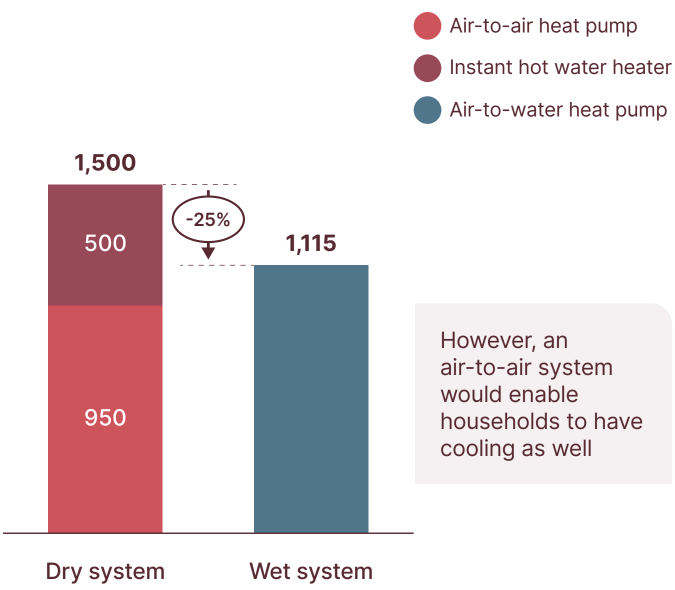
Capex costs – developers

Wholesale costs of heating technologies (Europe)
€



Running costs – homeowners

Annual running costs of heating technologies (Europe)
€ per year



NOTE: Figures presented represent the average of costs from ETC literature review. Costs do not include the cost of subsidies. Assumes an average heat demand of 11,500 kWh a year per household; water heating is 15% of this. Fuel prices reflect averages from 2023; no carbon price on gas is assumed.

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

2.4.2 Existing buildings

To convert the existing building stock to zero-carbon emissions over time, requires a balanced approach which combines the rapid transition to clean heating technologies, plus significant improvements to building insulation quality. Every building is different, and the optimal depth and sequence of intervention will vary greatly according to individual circumstance.

There are three key areas of action [Exhibit 2.17]:

- Retrofitting the least efficient existing buildings must be a government priority this decade. Energy efficient buildings, living standards and property values are closely linked and are critical to ensuring the costs of electric heating technologies (especially where electricity costs over two times more than gas) are manageable.
- Ensuring households fully realise opportunities for low-cost and low-effort retrofit measures (e.g., DIY draught proofing, loft insulation), which can reduce energy consumption by approximately 5–15%.
- When installing a clean heating technology, all homes should consider the full suite of possible retrofitting measures but take a balanced view based on the costs, level of disruption and implications for total upfront and running costs. For the average home, deep retrofit is not a pre-requisite for installing a heat pump, as long as radiators and systems are appropriately sized [Box E].

Exhibit 2.17

Three aspects to creating "zero-carbon ready" buildings: all buildings must have clean heating and smart/flexible technologies, and undertake cost-effective fabric improvements

	Install clean heating technologies	Improve building fabric	Install smart and flexible tech
Possible interventions	*Heat pumps, resistive heating*	*Insulating walls (internal, external, cavity), lofts and ceilings, double glazed windows, draught proofing, ventilation improvements*	*Solar PV, batteries, smart systems*
New buildings	All buildings in high-income countries from 2025. In other countries, from 2035	All buildings should be built to much higher energy efficiency standards – the additional cost to developers of achieving a 20% reduction in kWh per m² is typically around 1–5%, which can often be recouped via a higher selling price	All buildings in high-income countries should be smart-ready and solar-ready
Existing buildings	All buildings by the early-mid 2040s in high-income countries. In other countries, the aim should be 2050.	See the "Improve building fabric" table for existing buildings below	With falling costs, rooftop solar PV and smart systems offer opportunities to lower energy bills Time of use tariffs are needed to incentivise investment in batteries and water storage

Improve building fabric, existing buildings:

	Inefficient buildings	Average building	
Light retrofit: *easy to access improvements (e.g., low-cost or less disruptive)*	✓	✓	All buildings should explore low-cost measures
Medium retrofit: *2–4 interventions*	✓	✓	Most buildings can take a balanced approach to further insulation; deep retrofit is not a pre-requisite for a heat pump in the average house
Deep retrofit: *package of whole-house interventions*	✓		Retrofitting the least efficient buildings must be a government priority

SOURCE: Systemiq analysis for the ETC.

Box E **Debunking the myth that heat pumps only work in deeply insulated buildings**

In many countries, past policy has sometimes been guided by the belief that fabric extensive improvements are necessary either to provide sufficient comfort or to improve the economics of electric heating technologies. In part, this reflected a concern that "premature electrification" could drive up electricity demand before electricity generation has been decarbonised.

However there is a growing recognition that this should no longer be the default for the average existing building.[50] This is partly because power system decarbonisation means that in many countries switching from gas to an electric solution will deliver significant emissions reductions even if electric resistive heating is used. But also because of a reassessment of the feasibility and economics of heat pump deployment in imperfectly insulated houses:

- **In most cases, a very high insulation standard is not necessary for a heat pump to provide sufficient comfort.** It is important to understand that insulation does not directly impact a heat pump's technical performance, which is determined by the temperature differential between the heat source and sink (see Annex 1). But air-to-water heat pumps operate at lower flow temperatures to gas boilers, which can lead to a decrease in comfort if a heat pump system is not properly sized or installed. There are two ways to mitigate against lower temperatures:
    - Increase how much heat is emitted into a room by upsizing radiators – this is generally a lower-cost and easier approach; it can often be done in a day and in many cases, existing radiators are suboptimal for new gas boilers as well (e.g., age or quality) and should be replaced in any case.
    - Reduce how much heat is lost out of a room – as we outlined in Section 2.3, there is a wide spectrum of improvements that can be made to building fabric in existing buildings from low-cost draught proofing, loft insulation, to double glazing and external wall insulation. In many cases, the lower cost options will be sufficient to ensure that heat pumps can deliver the desired level of comfort.
- **Heat pumps have a very similar total cost of ownership compared to gas boilers in many countries. As outlined above, there are many countries** where heat pumps are already cheaper than gas boilers; although in countries where electricity costs three or more times more than gas (e.g., the UK), this is not the case. There is a growing body of literature confirming that the need for building fabric improvements before installing a heat pump has been overstated.[51] Analysis of a UK council's building stock suggests that only 6% of buildings need major fabric modifications and 24% need moderate modifications before installing a heat pump (e.g., cavity wall insulation); 60% require radiator improvements and/or minor fabric improvements (e.g., draft proofing, loft insulation), and 10% are heat-pump ready.[52]

50 For example, see Eyre, N., et al. (2023), *Fabric First: Is this still the right approach?*
51 For example, see Passivhaus Trust (2024), *The right time for heat pumps: decarbonising home heating in a staged retrofit*; Pehnt, M., et al. (2023), *Lowering flow temperatures is key in the switch to efficient clean heat*; Nesta (2024), *Insulation impact: how much do UK houses really need?*
52 Cornwall Council and Etude (2024), *Cornwall Housing Decarbonisation Strategy*.

2.4.3 Implications for the balance of different technologies

There is no one-size-fits-all solution to clean heating, but it is clear that the technology will be overwhelmingly electric and predominantly heat pumps.

The deployment of specific technologies will vary depending on a building's current heating solution [Exhibit 2.18], building type and size, and building ownership. The key technologies and their typical applicability are:

- **Air-to-air heat pumps** in countries with cooling needs, those with ducted heating systems that distribute hot air around a building, and in new buildings.
- **Air-to-water** in existing buildings in countries with wet heating systems (i.e. countries that currently rely on natural gas).
- **Networked ground source heat pumps** in blocks of flats and terrace housing, including new builds and social housing where decision-making and financing can be easier.
- **Heat networks** in dense, urban areas, in locations close to a secondary heat source providing ambient heat, and in countries that have existing heat networks (including existing expertise and skills).
- **Resistive heating** where heat pumps are unsuitable or unfinanceable. In some cases, higher-income households may prefer higher energy bills over the changes to their home that installing a heat pump may incur; and some households may choose to use resistive heating in addition to heat pumps to provide a boost to the temperature in specific locations or in very cold weather. Resistive heating can also be a cost-effective solution for rooms that are used infrequently. Extensive use of resistive heating will, however, significantly increase overall and peak electricity demand, and policy should therefore strongly favour the installation of heat pumps.
- **Electric water heating** to accompany air-to-air heat pump installations, and air-to-water heat pumps where households do not have the space for a water tank.

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 which will be used to decarbonise building heating. But it is still useful for national strategies to define a broad sense of direction, including an indication of which technologies are most likely to prove optimal in the specific national context. Such a vision can help ensure the sufficiently rapid development of clean technology supply chains to meet future demand, and inform householder choices.

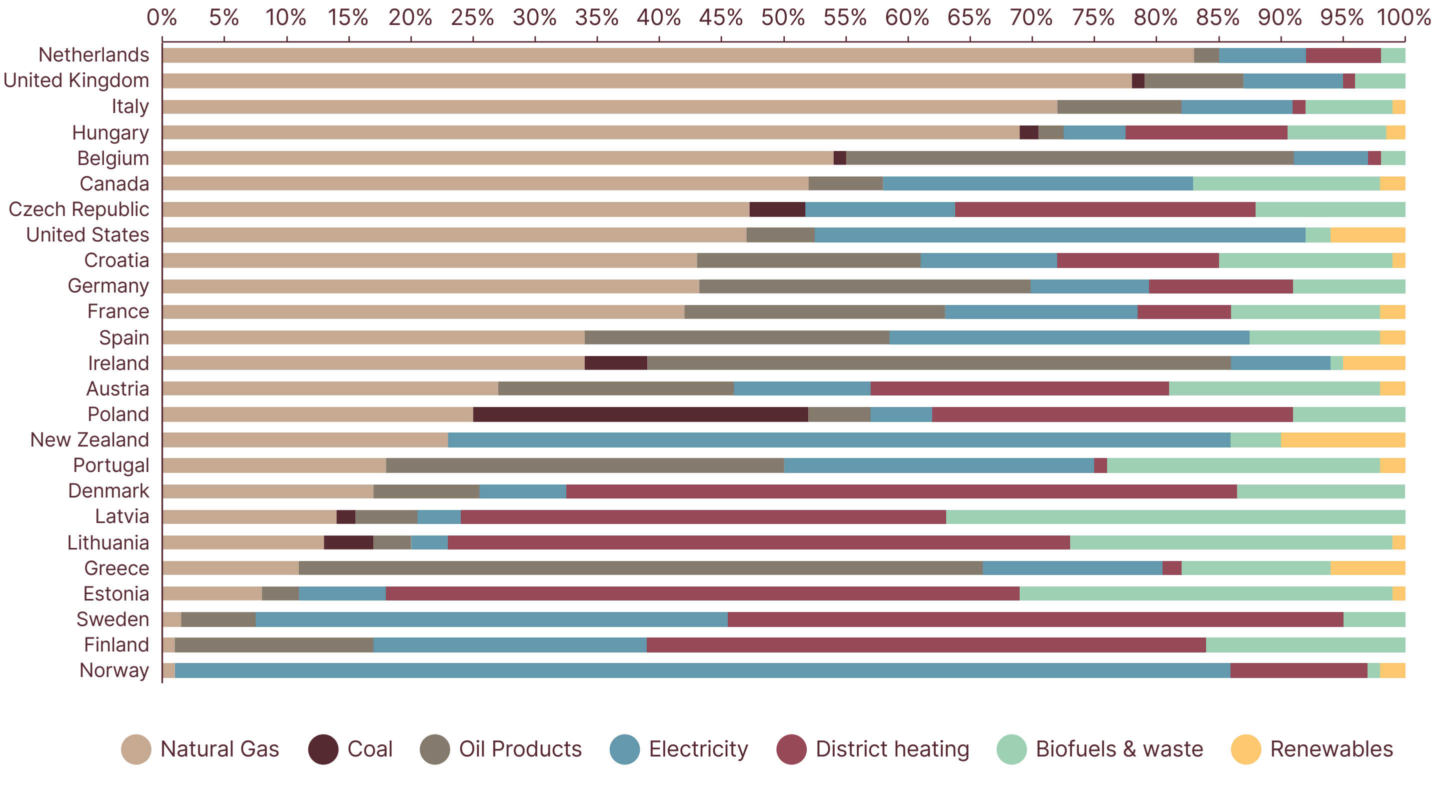
Exhibit 2.19 therefore indicates for France and the UK, the technologies which seem most likely to dominate in particular categories of the building stock. Key differences are likely to include:

- Air-to-water heat pumps will be more common in the UK, as it has more properties with existing wet heating systems, while air-to-air heat pumps will be more common in France with its greater cooling needs.
- Networked ground source heat pumps could be prevalent in both countries, while France has a large share of existing district heat networks, meaning the private sector has the skills and capabilities to scale up new heat networks more easily.
- In both countries, strong policy and regulation is required to ensure that rental properties and social housing do not rely on resistive heating as the primary energy source, given that the far higher running costs would have adverse distributional impacts on lower-income households.

Exhibit 2.18

Natural gas accounts for at least 25% of heating in most OECD countries and up to 70–75% in the Netherlands, the United Kingdom and Italy

Fuel share (%) for residential and commercial heating demand in selected OECD countries, 2014
% of total



NOTE: United States data includes only residential heating.

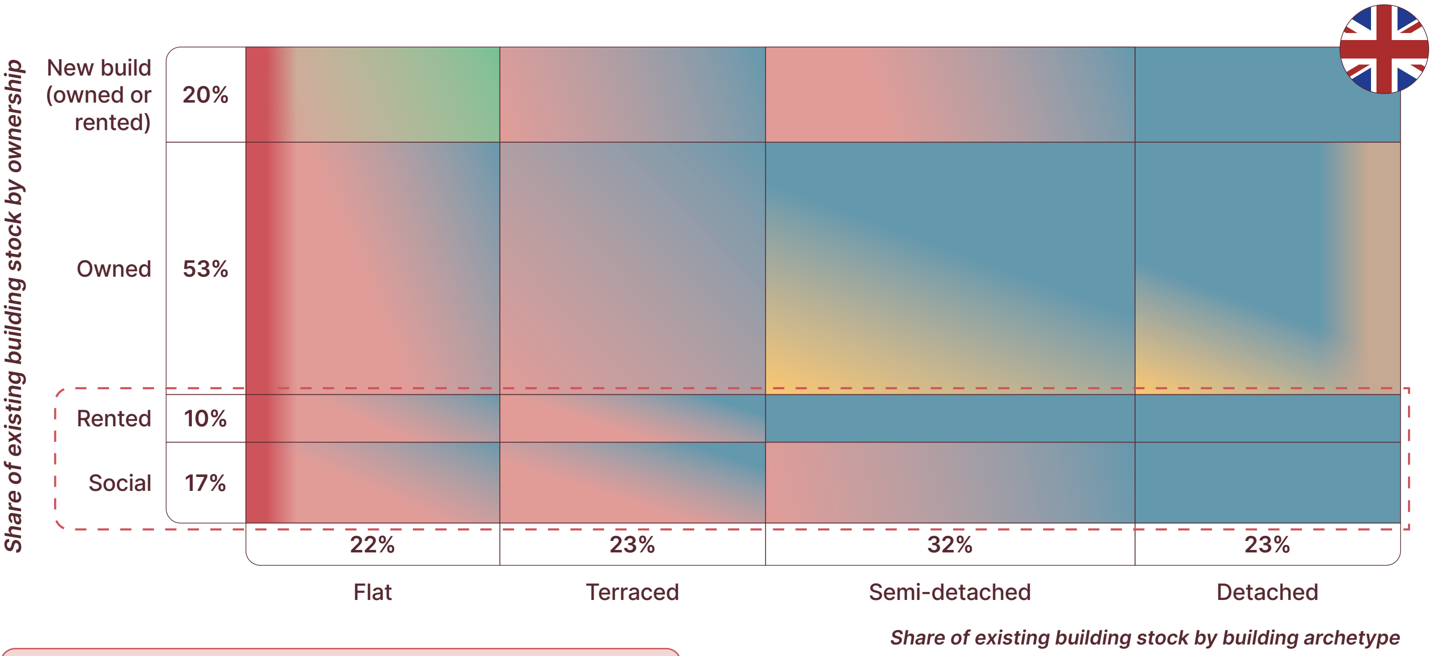
SOURCE: Vivid Economics (2017), *International Comparisons of Heating, Cooling and Heat Decarbonisation Policies*.

Exhibit 2.19

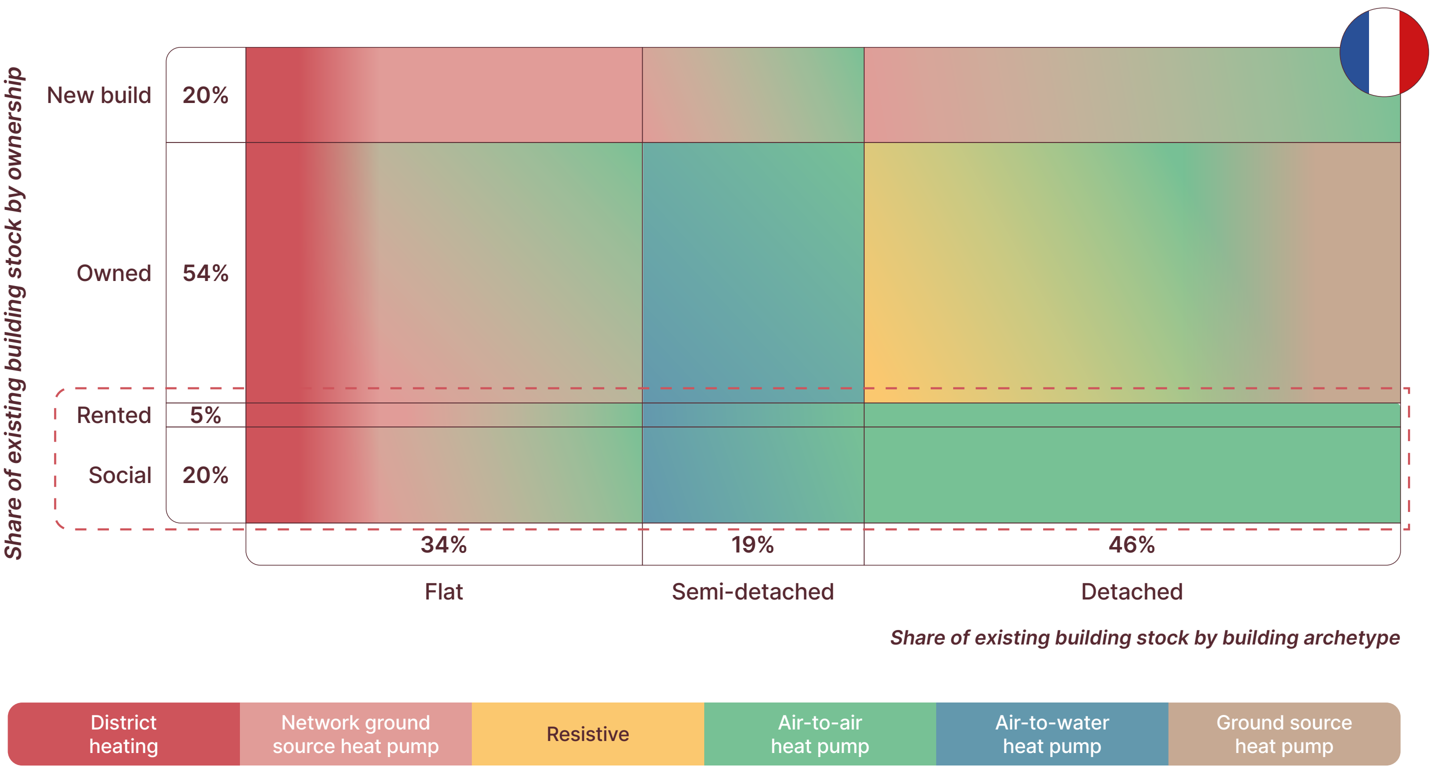
While it is not possible to estimate an exact tech mix, there is value in understanding the broad trajectory of clean heating technologies to guide policy, investment and skills

Illustration of probable dominant space heating technologies across different building archetypes and ownership – UK and France

% of stock in 2050



Rented and social: *Relies on strong regulatory and financial action to ensure low-cost but low efficiency resistive heating isn't dominant*



SOURCE: Systemiq analysis for the ETC.

2.5 Implications for the energy needed to heat buildings

There should be three key stages to the energy transition in buildings:

- **Preventing new builds from installing fossil fuel boilers.** The EU is the furthest along, with the revised Energy Performance Buildings Directive (EPBD) requiring all new public buildings to have zero on-site emissions from 2028 and all new buildings from 2030. There are no national timelines in China or the US, although New York has banned fossil heating in new builds from 2026.

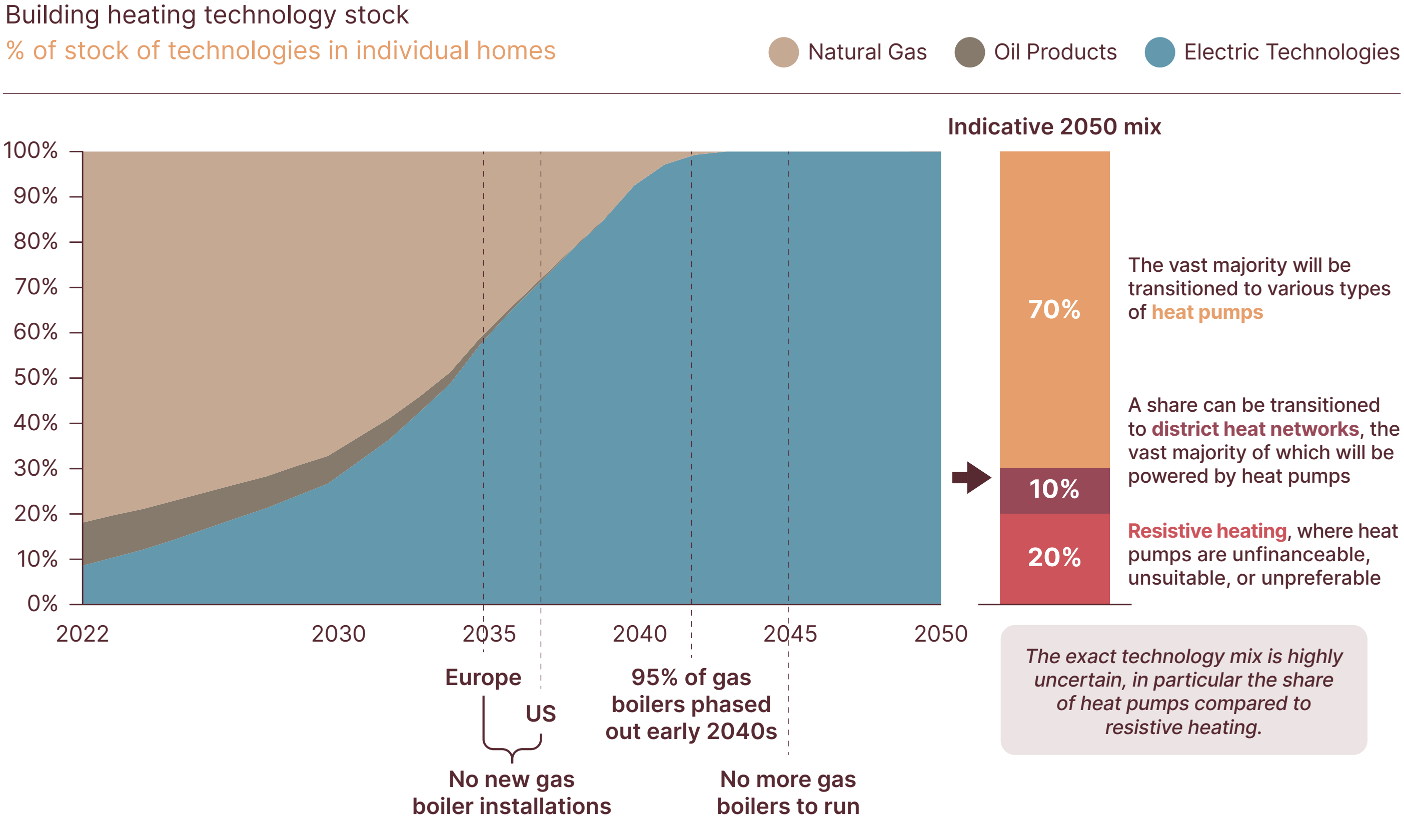
- **Preventing existing buildings from installing fossil fuel boilers.** The extension to the EU's Emissions Trading Scheme to buildings in 2027 will drive action, but no firm bans on the sale of fossil fuel boilers have successfully been implemented yet within Member States.

- **Preventing buildings from running a fossil fuel boiler.** The EU's revised EPBD requires EU Member States to plan for the phase out of fossil fuel boilers, but no binding target has been set yet. With the exception of Denmark (which aims to convert all remaining gas boilers to heat pumps or district heating by 2029), no specific national timelines for when the domestic gas grid could be switched off have been set.[53] Box F discusses the key questions that countries should begin thinking about to prepare for this.

Exhibit 2.20

In Europe and the United States, 95% of gas boilers could be phased out by the early 2040s, with no more gas boilers to run by 2045

Building heating technology stock
% of stock of technologies in individual homes



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

53 European Heat Pump Association, *Which countries are scrapping fossil fuel heaters?*, available at ww.ehpa.org/news-and-resources/news/which-countries-are-ending-fossil-fuel-heaters/. [Accessed 15/08/2024].

In our *Fossil Fuels in Transition* report, we outlined an ambitious scenario for how rapidly the stock of fossil fuel boilers could go electric in Europe and North America [Exhibit 2.20]. In some other countries with large heating needs, the transition is likely to occur later given later targets for achieving net-zero emissions across the economy (e.g., China has a national net-zero target of 2060). Overall, globally (and including commercial buildings – see Chapter 7) our scenario sees:

- Gas use in buildings for heating falling 75–90% by 2050, but by only 10–15% by 2030.
- Oil use falling 90–95% by 2050, with falls of 20–35% possible by 2030.
- Coal use entirely eliminated by 2040.

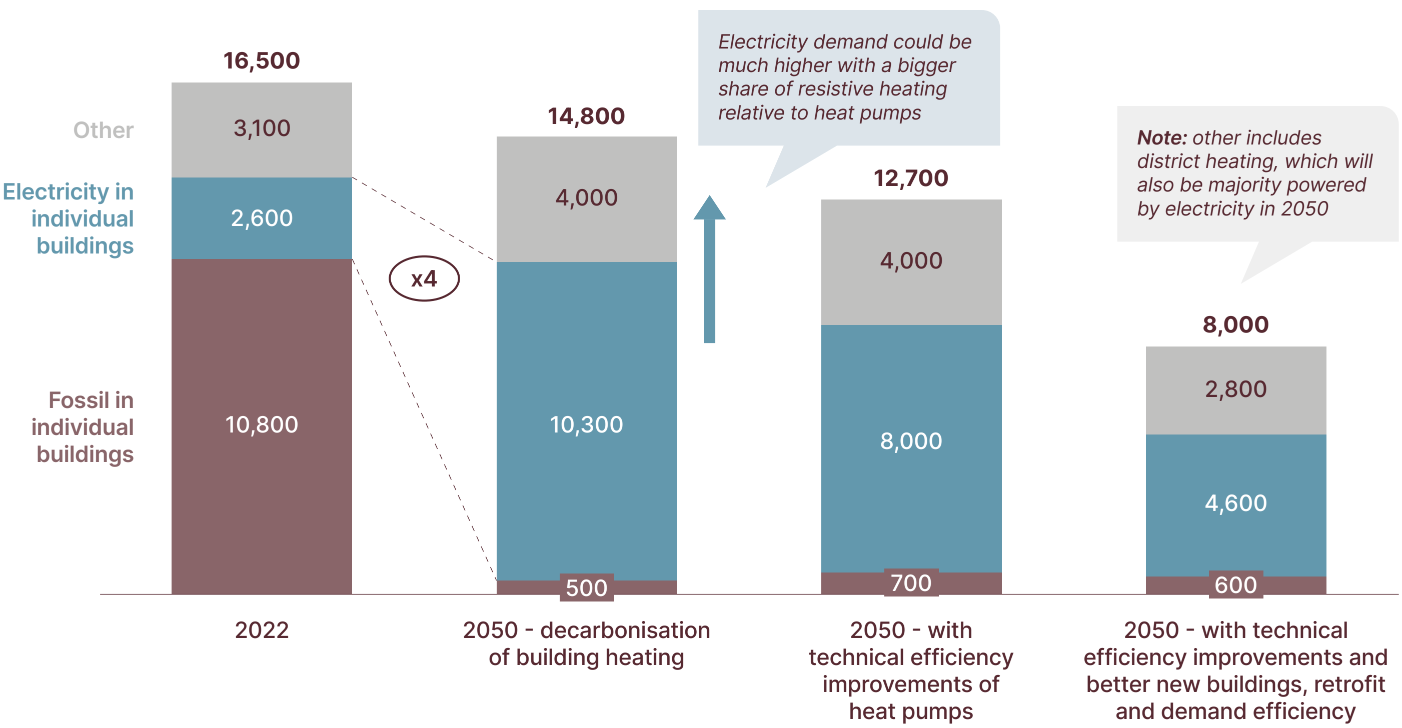
As heating is electrified, final energy consumption for heating will fall by 10–15%, due to the superior efficiency of heat pumps. This will, however, result in a potential quadrupling of electricity demand for heating, from 2,600 TWh to over 10,000 TWh. With strong action on energy productivity, including heat pumps increasing in efficiency from 300% to 400–500% and with improvements to building fabric, electricity demand could in principle be reduced to 4,600 TWh [Exhibit 2.21]. The extent to which this potential is achieved will depend on the forcefulness and effectiveness with which governments pursue energy efficiency improvements.

Exhibit 2.21

Electricity demand from heating could be four times higher than it is today, but with strong action on energy productivity, the increase could be less than double

Global final energy demand for heating by fuel in 2050

TWh



NOTE: Other includes district heating and renewables.

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

Box F **Future of the gas grid**

Phasing out gas boilers leaves decisions about what happens to the existing gas network. As we evidenced in Box B, a hydrogen home heating system would be higher cost, inefficient and likely delay the transition. This means that while the long distance transmission network could be used for hydrogen (whether used in industry or as a long duration energy store within power systems), the distribution network of pipes which deliver gas to homes will need to be largely decommissioned.

This poses big questions around how this is done and who pays:

- **Who pays:** Gas networks in most countries (e.g., the UK) are privately owned regulated assets, with the cost of maintaining and upgrading the network recouped through energy bills. The challenge is that as more households electrify, these costs will be shared across a smaller customer base; at the same time, the gas grid must be maintained and kept safe until the last building is disconnected.

- **Equity:** This is further compounded by the fact that lower-income households may be the last to electrify due to the upfront costs of heat pumps, unless governments support their transition with subsidies and low cost finance.

- **Coordination:** Street-by-street electrification strategies will be key to prevent situations where there are only a few buildings on a local distribution network and it becomes economically unviable to keep the gas grid going for them.

Analysis of the UK suggests that decommissioning the gas grid could cost up to £25 billion.[54] Leaving the private sector to bear these costs would lead to adverse equity impacts, meaning costs will undoubtedly need to be partially publicly financed, either with the government directly financing decommissioning or by providing financial support to lower-income households faced with higher bills.

It is critical that policymakers and network operators begin planning for how to cost-effectively decommission the grid. Key next steps should be:

- Setting a clear policy direction that hydrogen will not be used in homes.

- Developing local street-by-street strategies to phase out fossil fuel heating.

- Setting national targets for the phase out of fossil fuel boilers and when the gas network for buildings could be switched off.

- Working with grid owners to understand the extent to which the gas grid could be switched off in a granular fashion.

54 Arup (2023), *Report for the National Infrastructure Commission and Ofgem: Future of Great Britain's Gas Networks.*

2.6 Actions for policy and industry to support the rapid adoption of clean heating technologies at scale

Ensuring the affordability, attractiveness and accessibility of clean technologies when compared to existing fossil alternatives is crucial for triggering wide scale, rapid adoption.[55] While it is technically and economically feasible to electrify building heating using predominantly heat pumps, realising this potential will require a comprehensive set of well-designed policies and private sector action to overcome nine critical barriers to decarbonising building heating.

Affordability: Making heat pumps more competitive to install and operate.

1. Heat pumps today have higher upfront costs compared to fossil boilers, reflected in the limited scale of existing industry and supply chains.

2. Purchasing energy in the form of electricity is more expensive than energy purchased as gas.

3. Incentives between building owners and occupiers often differ.

Attractiveness: Making heat pumps straightforward to purchase, install and operate.

4. Today, consumer awareness of heat pumps in some countries is limited, with a lack of trusted information or expertise.

5. Poorly designed policies in many countries are currently hindering installation progress.

Accessibility: Coordinating and planning for rapid and large-scale fossil fuel replacement.

6. Coordinating the electrification of heating with scaling up renewables and national and local grid upgrades.

7. Coordinating investments to ensure a skilled supply chain can meet ambitious deployment trajectories.

8. Coordinating across millions of individual actors effectively.

9. Planning for the future of the gas grid as more and more households disconnect.

55 The three As of tipping points refer to the conditions necessary to accelerate sector wide decarbonisation. These conditions are: 1) Affordability: Ensuring that the cost of zero-carbon solutions is competitive with traditional alternatives. This involves achieving cost parity to make these solutions financially viable. 2) Attractiveness: Making zero-carbon solutions appealing and easy to use. This includes improving the user experience and demonstrating the benefits of these solutions. 3) Accessibility: Providing the necessary infrastructure and support to enable the widespread adoption of zero-carbon solutions. This involves creating an enabling environment that facilitates the deployment and use of these technologies. These conditions are crucial for triggering tipping points that can lead to significant reductions in emissions and drive the transition to a low-carbon economy. Systemiq (2023), *The Breakthrough Effect*.

2.6.1 Making heat pumps more competitive to install and operate

Lowering the upfront costs of heat pumps

Even though heat pumps are already becoming cost competitive with gas boilers on a total cost of ownership basis, their higher upfront costs is a critical affordability challenge. While the cost of installing an air-to-air heat pump can be comparable to a gas boiler, there are some countries where costs can be €1,000–3,000 more. Air-to-water heat pumps are more expensive than gas boilers in nearly all markets, and on average cost around €3,000–6,000 more. It is interesting to note that air conditioners, which are virtually the same technology, cost 2–3 times less than an air-to-air heat pump in some countries, implying a significant potential for cost reduction:[56]

- Capex costs, which typically account for ~40% of total consumer costs, will tend to come down as market scale increases and competition grows. Given the mechanical complexity of heat pumps, we are unlikely to see the dramatic cost reductions achieved in solar PV and batteries, but a price fall of 25% by 2030 is likely feasible.[57]

- Labour costs, which typically account for ~60% of costs, might be reduced by productivity improvements as installation methods are refined and standardised, but could rise if skilled workforce availability fails to keep pace with rising demand. There are also concerns that subsidies in some countries may be dampening potential falls in labour costs, with installers having less incentive to compete on price.

- On the supply side, currently announced production capacity plans for heat pump manufacture fall 35% short of 2030 demand forecasts.[58] However, this largely reflects demand and policy uncertainty as opposed to any material manufacturing constraints. Scaling up heat pump manufacturing has relatively short lead times of 1–3 years – so with the right policies, potential constraints should ease quickly.

A critical first step to encourage cost reductions and the development of supply chains is for governments to give manufacturers and installers certainty and confidence in the pace of heating electrification. In recent years, a number of regulations and timelines for the phase out of fossil fuel heating have been weakened or rolled back on, for example in the UK and Germany [Box G]. This uncertainty drags on private sector and household investment.

Governments must outline a clear national strategy for the phase out of fossil fuel boilers, including:

- Immediate bans on fossil fuel boilers in new homes.

- Medium-term targets (i.e. 2035 in high-income countries) to ban the sale of fossil fuel boilers in existing homes.

- Long-term targets to fully phase out fossil fuel boilers (e.g., mid-2040s in high-income countries in all homes).

- Outlining street-by-street decarbonisation approaches to drive economies of scale and lower costs (see Section 2.6.3).

Strengthening international collaboration to scale up clean technologies will also be very important. For example, the Buildings Breakthrough Initiative, launched at COP28, which aims to ensure near-zero emission and resilient buildings are the new normal by 2030.[59]

56 In ETC (2023), *Material and resource requirements for the energy transition*, we outlined how material efficiency and recycling and ensure demand for critical materials from clean energy technologies can keep pace with supply.
57 Based on interviews with ETC members and relevant industry experts.
58 IEA (2023), *Energy Technology Perspective 2023*. Figures as of August 2023.
59 Global Alliance for Buildings and Construction, Buildings Breakthrough, available at www.globalabc.org/buildings-breakthrough. [Accessed 10/08/2024].

In addition, policy can actively drive innovation and demand by:

- Setting rising quotas on manufacturers for heat pumps as a share of all heating system sales, for example the UK's Clean Heat Market Mechanism. This could be combined with incentives to develop local manufacturing, with strategies to ensure sufficient supply of critical materials, such as the EU's Critical Raw Minerals Act. Over the medium-term, it will also be important to increase the recovery and recycling of materials through end-of-life management regulations, such as the EU's Waste Electrical and Electronic Equipment Directive.
- Early investment this decade to decarbonise social housing and public buildings.
- Providing financial support to households, ensuring that any subsidies are time-limited and targeted to lower-income households to ensure that they don't dampen the impact of competition on potential cost reductions.
- Providing financial incentives for research and innovation in the technology.

In addition, action is required from a wide range of other private and public sector actors to help households afford the upfront costs [Box H].

Box G **EU heat pump policy developments and uncertainty**

In line with the EU's Green Deal goals, the REPowerEU plan aims to more than double the annual rate of deployment, rolling out close to 6 million new heat pumps each year from 2025.[60]

However, after a decade of continuous growth, heat pump sales across the EU fell 5% in 2023, from 2.78 million in 2022, to 2.68 million.[61] This follows the huge 35% jump in sales between 2021 and 2022. While macroeconomic factors – most notably, high inflation, high interest rates and falling gas prices – have played a role, a less favourable policy environment has further dampened demand and market confidence. As a result, manufacturing capacity has far exceeded demand, leading to an oversupply.

Key uncertainties and changes include:

- **Lack of national strategic vision:** The publication of the European Commission's Heat Pump Action Plan, which was due in early 2024, was delayed until after the EU elections at the end of 2024. It is expected to set out a clear strategy for meeting heat pump deployment targets and the unexpected delay led to significant uncertainty across the sector.[62]
- **Inconsistent financial support:** In Italy, a tax credit – which gave homeowners a credit of up to 110% for heat pump installations and insulation – was abruptly removed in early 2023. In the Netherlands, subsidies have been cut by up to 50%. In France, a complex subsidy programme have meant homeowners have struggled to access the generous funding of up to 70% of the cost of installation.[63]
- **Delays and weakening of gas boiler bans:** In the UK, proposals to ban the installation of fossil fuel boilers in new builds from 2025 and their sale in existing buildings from 2035 was delayed, with no clear timeline currently in place. In Germany, public and political backlash led to a significant watering down of a policy to require new heating systems to be powered by a minimum 65% renewable energy from January 2024. The revised bill exempt buildings in any municipality which does not have a clean heat strategy.

Implementing a clear strategy, timelines for phasing out fossil fuel boilers, and consistent financial incentives is key. This must be supported by policies to rebalance gas and electricity prices, with electricity costing, on average, 2.5 times more than gas across Europe.

60 REPowerEU - 2 years on, available at https://energy.ec.europa.eu/topics/markets-and-consumers/actions-and-measures-energy-prices/repowereu-2-years_en. [Accessed 29/11/2024].
61 European Heat Pump Association (2024), *Pump it down: Why heat pump sales dropped in 2023.*
62 European Heat Pump Association, *20 organisations urge EU Commission: publish Heat Pump Action Plan for a net-zero Europe*, available at www.ehpa.org/news-and-resources/press-releases/19-organisations-urge-eu-commission-publish-heat-pump-action-plan/. [Accessed 29/11/2024].
63 RAP (2023), *Olympic mindset: Making France a heat pump leader.*

Box H **How to share the upfront costs of heat pumps with households?**

It is not feasible for many households, and especially low income households to bear all of the costs of installing heat pumps, and it would be too expensive for governments to meet a significant share of costs for all households. Subsidy support packages must therefore be focussed on lower income groups, using a mix of public and private delivery channels, including:

- **Governments:** Which can provide both grants and low or zero-interest finance.
- **Public infrastructure banks:** Investing in decarbonising social housing should be a top priority. They can also pool investments in local areas, overcoming high individual transaction costs for financial institutions.
- **Financial institutions:** There is room for significant innovation in terms of "mortgage top-ups" and offering favourable green interest rates for heat pumps and energy efficiency retrofits. Financial institutions have an incentive to do this because lower energy bills will enhance a household's ability to repay and the property's value. With residential real estate accounting for a very large share of many banks portfolios, product innovation will be key to meeting financed emission commitments. Governments could encourage this by providing guarantees to cover losses above a defined level.
- **Energy and technology companies:** If mandated to sell a certain share of heat pumps, the private sector may essentially share costs with households by lowering prices, or also offering low-cost finance. Utility and other energy companies should finance shared ground arrays for networked heat pumps, which are repaid by a standing charge.

Rebalancing gas and electricity prices

Across most of Europe and the US, air-to-water heat pumps already cost 25–30% less a year to run (assuming 300% efficiency) and air-to-air heat pumps plus an electric water heater cost around 5% less a year to run.[64] But in some countries, such as the UK, the difference in annual running costs is much greater. The key determinant is how much more expensive a kWh of electricity costs, relative to a kWh of gas.

There is a clear relationship between heat pump adoption and a lower ratio between gas and electricity prices. The UK has the lowest heat pumps per household in Europe, with electricity costing over four times as much as gas [Exhibit 2.22].

Actions which could achieve a rebalancing of electricity and gas prices are therefore a priority. Exhibit 2.10 showed the major impact that a smaller differential has on the efficiency a heat pump needs to achieve for TCO parity. In Europe, with electricity costing on average 2.5 times more than gas today, an air-to-water heat pump needs to average 340% efficiency over a year to be cost competitive; this would fall to 270% if electricity only cost two times as much.

There are a number of ways governments can pursue rebalancing:

- Removing environmental levies which are currently disproportionately placed on electricity (a legacy from when electricity was generated from higher-carbon sources such as coal) and shifting them either to general taxation or onto gas. This rebalancing should be done gradually, in line with rising heat pump adoption, and combined with targeted support for lower-income households still using gas. It is important to remember that all households, even those still using gas for heating, will benefit from lower prices for their other electricity consumption.
- Governments could also take a more targeted approach by offering relief on electricity used for space heating. Since 2021, Denmark has applied a lower tax rate to electricity used for heating, with taxes on existing electricity consumption remaining the same.[65]
- Carbon pricing for fossil fuel consumption (such as in in the coming updated Emissions Trading System (ETS2) in Europe).

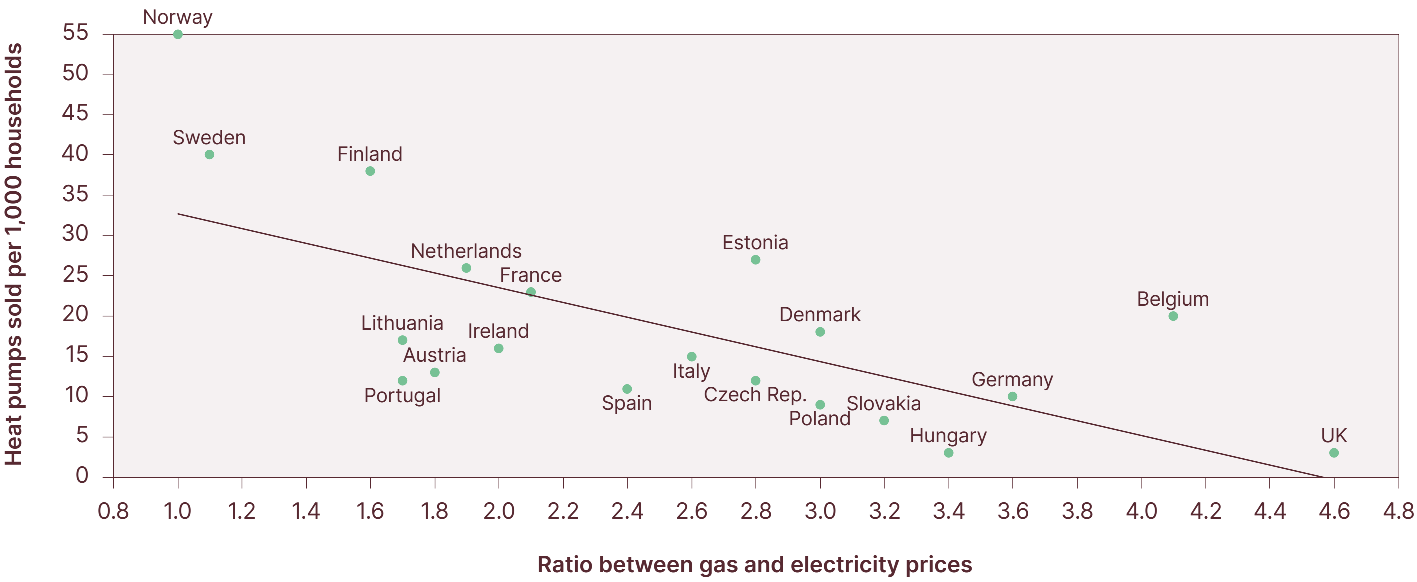
64 Systemiq analysis for the ETC, based on 2023 energy prices.
65 With home electricity metres being unable to separate electricity use for heating vs. other appliances, the tax rate is lowered for electricity use above 4,000 kWh.

- Appropriate power market design, to ensure wholesale and retail prices better reflect lower cost renewables (e.g., reducing the frequency of gas setting marginal prices), and a rapid scale up of renewable generation and grid upgrades to ensure clean power supply keeps pace with electricity demand.[66]

Exhibit 2.22

Rebalancing electricity prices is critical to incentivising the electrification of heating and ensuring households benefit from highly efficient heat pumps

Relationship between the ratio of electricity to gas prices and annual heat pump sales, 2023



SOURCE: Jan Rosenow (2024), Linkedin, *Bigger spark gap means fewer heat pumps*, available at: www.linkedin.com/posts/janrosenow_what-explains-that-some-countries-see-a-lot-activity based on data from European Heat Pump Association and Eurostat. [Accessed 10/08/2024].

Overcoming the split incentives of landlords and tenants

Around 15–30% of households live in privately rented accommodation across the OECD. The challenge is that landlords have an incentive to install the cheapest clean heating technology (e.g., resistive heating), but this leads to sub-optimal outcomes for tenants and electricity grids:

- Resistive heating has 3–4 times higher running costs.
- Resistive heating requires 3–4 times more electricity than heat pumps, and if installed in a high share of the housing stock, would impose high peak electricity requirements unless time of use tariffs and investment in insulation and household level storage resulted in a significant demand shift away from peak hours.

Ensuring that, as much as possible, landlords install heat pumps should therefore be a government priority. Key policies include:

- Minimum energy performance standards for private rental properties, set such that resistive heating in poorly insulated properties would be infeasible.
- Provision of low-cost finance that can be repaid directly through rental income.
- Scaling up district/networked solutions which reduce the need for individual landlord decision-making.

66 ETC (2021), *Making Clean Electrification Possible.*

2.6.2 Making heat pumps straightforward to purchase, install and operate

Improving consumer awareness and trust

Unless, or until, governments ban the sale of fossil fuel boilers, the transition over the next decade relies on households choosing to purchase a heat pump. The challenge in many countries is that awareness of heat pumps and accurate information is very low. In the UK, 60% of households have no interest in installing a heat pump, and 85% are unaware of the climate benefits.[67]

Key actions required include:

- **Information and awareness campaigns** to debunk misconceptions and explain the benefits to energy bills. Governments should lead by example, installing heat pumps in prominent and older public buildings.
- **Community initiatives,** such as local pilots, demonstrations and forums where households can see successful installations in similar properties can bolster trust in the technology and enable the sharing of lessons learned and benefits.
- **"One-stop shop"** advice and delivery services can guide households through complicated energy efficiency retrofit and technology decisions, and streamline the overall installation and retrofit process to reduce disruption.
- **Skills accreditations schemes** to provide consumers with a directory of trusted and experienced heat pump installers.

Optimal planning policy

Planning restrictions are, in some cases, restricting heat pump uptake. In the UK for example, heat pumps are not allowed to be placed on walls (therefore preventing uptake in flats) and must have a 1 m boundary around outside units, creating issues for terraced housing. Restrictions on changes that can be made to listed or protected buildings (e.g., for historical or aesthetic reasons) also restricts uptake. Governments should therefore review whether existing regulations are unnecessarily restrictive, or whether their objectives could be achieved via other means, for example, standards for maximum noise levels.

2.6.3 Coordinating and planning for rapid and large-scale fossil fuel replacement

Delivering the replacement of fossil fuel boilers at scale will be a significant coordination challenge:

- Coordinating the electrification of heating with scaling up renewables and grid upgrades.
- Coordinating investments in skills.
- Coordinating millions of individual actors effectively.
- Planning for the future of the gas grid as more and more households disconnect [see Box F].

Early and coordinated investment in renewables and grids

Investing in a clean power system alongside heating electrification is critical to ensure that there is sufficient system-wide capacity to actually enable a large-scale switch to heat pumps, and to ensure, crucially, that the increase in electricity demand is met with low-carbon renewable generation. This requires investments in low-carbon power generation and in transmission and distribution grids ahead of need.[68]

In addition to upgrades to national transmission networks, an often overlooked issue is the upgrades required to the local distribution network. In most countries, especially those which rely heavily on gas, the local grid has not been designed to deal with large peaks from electrified heating, or for EVs, and so must be upgraded to support greater loads. This means that secondary substations, which lower the electrical voltage so it can enter homes, will need significant reinforcements. In addition, many properties will need fuse and service cable reinforcements; the latter of which can involve disruption to roads.[69]

One challenge is that in many countries, there is a concerning lack of data on existing infrastructure and how many areas will be affected. Critical actions include:

67 Mitsubishi Electric (2023), *The Future of Residential Heating in Britain*.
68 ETC (2023), *Financing the Transition*.
69 Regen (2024), *Electrification: The local grid challenge*.

- Network system operators must begin a large-scale data collection exercise to understand current capacity and expected constraints.

- National planning for priority distribution network upgrades, which should be carefully reflected in regulator's price controls and investment allowances.

- Reform of the regulatory price control process to drive a focus on anticipatory and long-term investment.

Investing in skills and training

The pressing supply-side challenge is skills. The number of heat pump installers needs to increase by at least a third in the US and Europe by 2040, but will be even higher in countries that don't have a strong AC installer base either.[70] In the UK, a more than eight-times increase in installers is needed by 2030.[71] Retraining existing boiler engineers is generally a more straightforward process, but still requires significant retraining to safely work with electricity. Non-technical skills such as communication and interpersonal skills are also key to help overcome household concerns.

Poor quality installations risks serious setbacks to consumer acceptance in the transition and will add to energy bills. There is a tendency today for installers to oversize heat pumps to ensure they meet comfort expectations; this increases both capex and running costs. It is not just heat pump installers that are required. As many additional building envelope specialists, retrofit coordinators, scaffolding operatives, and construction workers could also be needed.[72]

Priority policies include:

- For new entrants, coordination across the education and private sector is required to design training and career routes in clean technologies, including apprenticeships and hands-on experience.

- For existing engineers, policymakers should provide financial incentives to companies and trainees, underpinned by a national awareness and skills campaign.

- Skills campaigns for architects, developers and builders to promote the installation of heat pumps in new builds.

- This needs to be underpinned by an improvement in the quality of training, including sharing learnings, best practice and incentives for continued professional development. Certification schemes, such as the US' Energy Star programme, should be developed, ensuring installers meet very high standards and can give consumers confidence.

Street-by-street approaches to coordinate millions of individual actors

Street-by-street approaches will need to play a key role. These place more responsibility on local authorities to identify areas suitable for coordinated switching via heat networks, networked heat pumps, or mass heat pump adoption. This requires local policymakers to:

- Develop a deep understanding of their housing stock and households, undertaking surveys to assess likely solutions, attitudes and plans to replacing boilers.

- Setting local targets, with financial incentives from national governments.

- Host community groups to better understand barriers and drive consumer awareness.

Heat networks and networked heat pumps are, in themselves, a key solution to overcoming coordination challenges. These have the benefit of overcoming slow or uneven household decision-making, as the government and private sector drive investments. This requires:

- Street-by-street mapping and zoning to understand and clarify where heat networks or networked heat pumps could be suitable, including the availability of waste heat and the feasible distance this can be moved.

- Explore financing strategies and sources, with a wide number of private sector companies Investment in ground arrays:

    - Coordinating investment from utility companies, government, heat pump companies, and financial institutions for laying shared ground arrays, which can then be recouped via standing charges.

    - Exploring new sources of finance from the private sector for secondary waste heat (e.g., data centres investing in heat being taken away).

70 Systemiq analysis for the ETC; IEA (2022), *The Future of Heat Pumps*.
71 Nesta (2022), *How to scale a highly skilled heat pump industry*.
72 UK Climate Change Committee (2020), *Sixth Carbon Budget*.

Cooling

3

Key messages

- Air conditioning (AC) will be by far the dominant cooling technology, but with roles also for evaporative cooling, dehumidifiers and fans.
- AC is already electrified so decarbonising cooling is primarily a question of decarbonising wider electricity systems as rapidly as possible.
- Power sector decarbonisation is critical as demand for cooling is projected to more than double by 2050 from 2,000 TWh to 5,000 TWh. This may actually be underestimating the increase in electricity requirements for cooling due to warming climates and rising incomes.
- “Passive cooling” via better building design and urban planning can reduce a building’s cooling energy needs by 25–40%. Many actions to achieve this are low-cost, such as increased external shading through planting trees and painting roofs white. Getting this right in new buildings is critical; better building codes could reduce global electricity needs for cooling in 2050 by around 20%.
- The single most effective lever to reducing electricity needs for cooling is to improve the efficiency of the stock of ACs, with the market average efficiency of units sold today being far below already best available technology and with significant potential for further improvement.
- Consumer behaviour, such as setting thermostats at reasonable levels, also has a significant influence, with very major differences in typical cooling temperatures across the world.

Cooling accounts for 3% of global energy-related emissions and 6% of operational energy use – around 1 $GtCO_2$ and 2,200 TWh.[73] It is already virtually 100% electrified, meaning there is no technology transition required at energy use level. However, there are three important issues relating to the net-zero transition for cooling:

- Cooling is the fastest growing component of operational energy use, with demand growing all over the world. Exhibit 3.1 shows how cooling energy consumption is set to more than double by 2050 without strong action on energy efficiency and behaviour change. Cooled floor area today is two-thirds the size of heated floor area; by 2050, it will be 25% bigger. One key challenge is to ensure that electricity generation is decarbonised rapidly to offset this rising demand.
- Despite growing access, more than 40% of people living in hot climates will not have access to cooling by 2050, either because they cannot afford it or they don’t have access to electricity [Exhibit 3.2].[74] Expanding access to cooling is a health and equality imperative. Often overlooked is the relationship between temperature and humidity; above a certain combination of heat and humidity (known as the “wet-bulb temperature”), humans are unable to regulate their temperature by sweating, creating severe risks to human health. The challenge is how to continue improving access to cooling, using a combination of air conditioning, dehumidification (where appropriate) and fans, and ensuring this is as efficient as possible.
- Air conditioning contains refrigerants which, if leaked or released into the atmosphere, contribute to global warming. This issue is explored in more detail, looking across both AC and heat pumps, in Chapter 9. New refrigerant chemicals can dramatically reduce this global warming effect. In addition, it is essential to ensure that AC is installed and maintained properly, and refrigerant is properly disposed of at end-of-life.

73 The 1 $GtCO_2$ emissions relates just to fossil fuel use to generate electricity. As we explore in Chapter 9, refrigerant leakage and venting from AC also contributes to global warming and is an overlooked issue.
74 IEA (2019), *Helping a warming world to keep cool.*

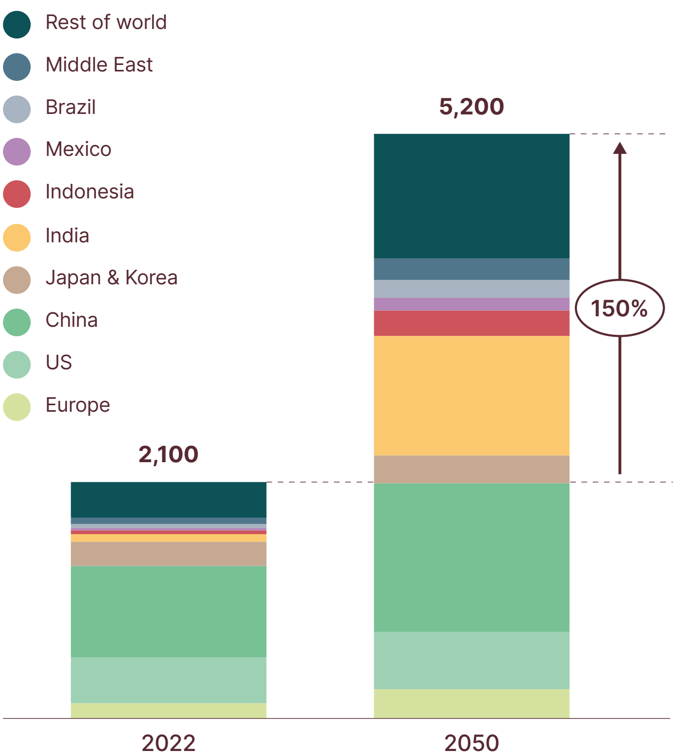
This section will cover:

- Active cooling technologies, discussing AC and evaporative cooling.
- How to manage growing demand for cooling with improvements in the energy efficiency of AC, promoting optimal consumer behaviour, and the vital importance of "passive cooling" techniques.
- Implications for the energy needed to cool buildings.

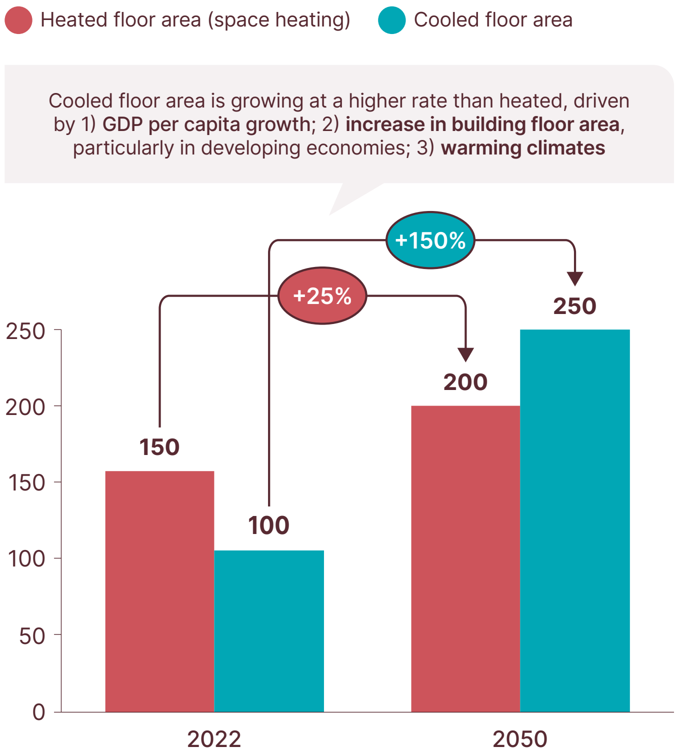
Exhibit 3.1

Cooling is the fastest growing buildings energy use, with global cooled floor area set to overtake heated floor area by 2050

Space cooling (residential + commercial) energy consumption by region, IEA baseline scenario, 2022–50
TWh



Heated floor area vs. cooled floor area (residential + commercial), IEA Net Zero scenario
Billion m^2



Rapid growth in cooling demand in countries with carbon-intensive electricity grids highlights the importance of rapidly scaling up renewables across the world.

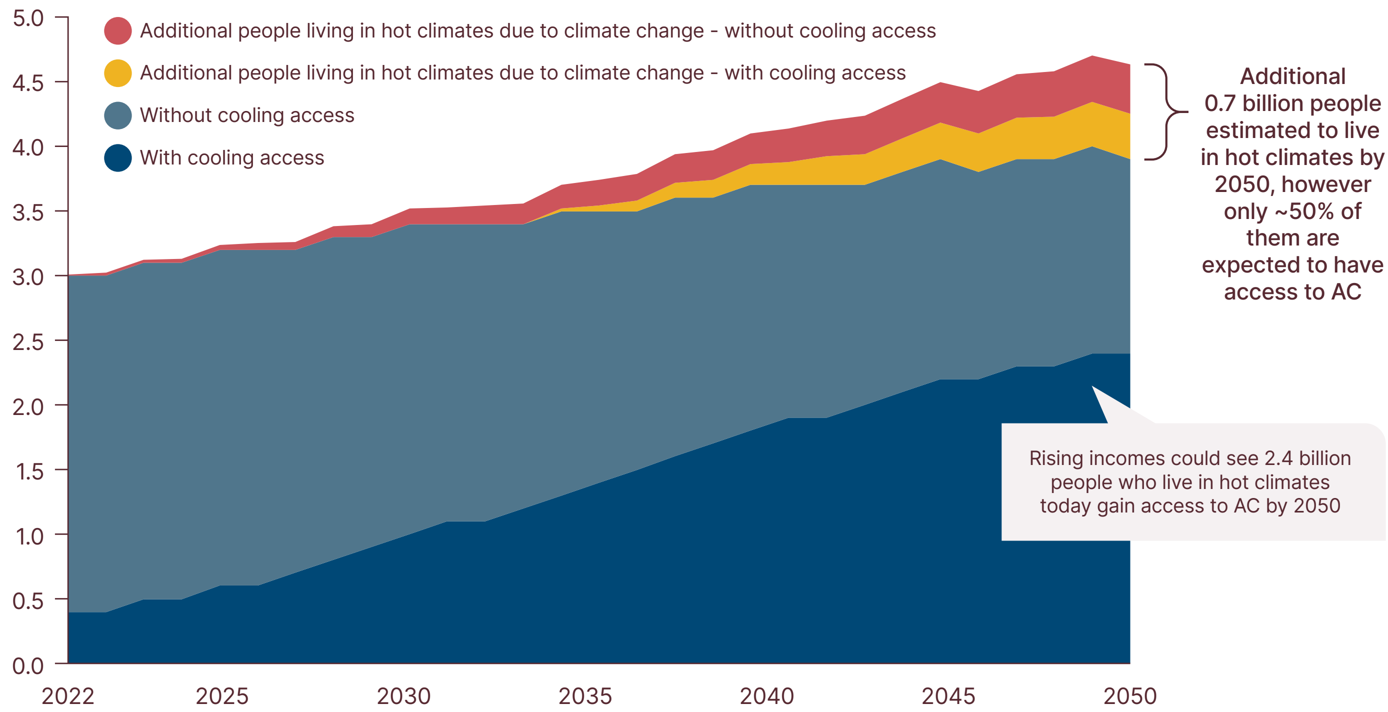
NOTE: IEA estimates of global cooling energy use in 2050 split into regions using IEA projections of AC stock in different countries in 2050.

SOURCE: Systemiq analysis for the ETC; IEA 2023; *World Energy Outlook*, https://www.iea.org/reports/world-energy-outlook-2023, re-used under license: CC BY 4.0.

Exhibit 3.2

Climate change will result in an additional 0.7 billion people needing cooling by 2050, yet more than 40% of people living in hot climates are expected to have no access to AC

Population living in hot climates with and without access to AC
Billion



NOTE: A climate is assumed to be "hot" when the sum total of the difference between the daily mean outdoor temperature and the base temperature of 10°C (cooling degree days with base temperature of 10°C) adds up to at least 5,000 over the course of one year.

SOURCE: IEA 2019; *Helping a warming world to keep cool*, https://www.iea.org/commentaries/helping-a-warming-world-to-keep-cool, re-used under license: CC BY 4.0.

3.1 Active cooling technologies: AC and evaporative cooling

The comfort provided by cooling systems depends on three effects: reducing the room temperature, reducing the humidity, and circulating the air.

There are just two main technologies which are able to lower the room temperature:

- Air conditioning: ACs move heat from inside a room and expel this outside. They work just like a refrigerator, or a heat pump in reverse. They are by far the most common cooling technology, with around two billion units in operation across residential and commercial buildings. AC can be relatively cheap, with portable units at ~$500 and typical split systems units (i.e. one outdoor and indoor unit) serving one room costing ~$1,500, but costs can increase to $2,500–5,000 for multi-split systems serving multiple rooms. Existing ACs can already achieve an efficiency rate (measured by the "coefficient of performance", or COP) of over 400%, over 4 kWh cool air can be generated for each kWh of electricity used. Reversible heat pumps which have a valve to switch the direction of flow of the refrigerant, can provide both heating (heat pump) and cooling (AC).

- 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. Evaporative coolers have many advantages – they are typically more accessible and are a cost-effective solution to AC, with portable coolers costing anywhere between $50–250. Larger and roof-mounted coolers typically cost $1,000–3000. They also have very low running costs, with a similar wattage to an electric fan. There are a few limitations, including the need for a constant supply of water and fresh air, regular maintenance, and are less effective at air filtering.

Where these space cooling technologies are unaffordable, there are a number of cooling appliances that can help people to deal with the impacts of hot climates, including humidity:

- Electric fans are a very cheap (anything from $10–100) solution that cost very little to run (wattage is around 30x lower than an AC). There are currently double the number of fans than ACs in operation today.[75] By 2050, however, there could be a similar number of fans and ACs in operation in residential buildings (around 3.5–4 billion units each). Electric fans inevitably increase room temperatures slightly (since some electrical energy input is converted to heat), but this very small effect is offset by the cooling effect of air circulation on evaporation from the skin.

- Dehumidifiers are a solution in humid climates to remove excess moisture from the air, either using absorbent material to extract water from the air, or condensing water over cold coils. Costs vary across countries and based on size, but can be as cheap as $50–100, or upwards to $500. Dehumidifiers, like fans, will increase room temperature slightly as they produce hot air to operate; however, the benefits of lower humidity in humid climates has a bigger effect on comfort.

From an energy demand perspective, the extent to which demand for AC increases is the most important question.

3.2 Managing growing demand for cooling

45% of the global population live in hot climates requiring cooling and a further 50% require cooling intermittently, for example in certain seasons.[76] However, these proportions differ hugely across regions. Despite cooling being required in virtually all parts of the world at some points in a year, it only accounts for 6% of operational energy use. This is partly because air conditioning is so efficient, but also because a significant share of cooling needs are unmet [Exhibit 3.2]. For example, despite 55% of its population living in hot climates, Africa only accounts for less than 5% of global cooling energy demand. This compares to North America accounting for 30%, from just 10% of their population living in hot climates.[77]

The IEA expects the global stock of air conditioners to increase from around 2 billion today, to 5–6 billion by 2050; the residential sector accounts for around 70% of this.[78] There are three main drivers:

- **GDP per capita:** AC ownership tends to be much higher in richer countries, for example 80% of households have an AC in North America compared to around 5% of households in Africa. As incomes increase, an additional 2.4 billion people living in hot climates could gain access to AC by 2050 [Exhibit 3.2].[79]

- **Floor area growth:** Floor area in hot climates is set to expand by 150% by 2050, from 100 billion m² to 250 billion m² [Exhibit 3.1], driven by population growth and urbanisation.

- **Warming climates:** Climate change could result in an additional 0.7 billion people living in hot climates over the next 25 years [Exhibit 3.2].[80] For those already living in hot climates, it will exacerbate cooling needs, requiring ACs to be run for longer and increasing the differential between inside and outside temperature, which reduces the COP.

Without action on energy efficiency and behaviour change (explored in the following sections), cooling energy demand could increase from 2,200 TWh today, to over 5,000 TWh by 2050.[81] Cooling demand could be 15–20% of forecasted electricity supply in Indonesia and India – a huge increase from 5–10% today.[82]

75 IEA (2018), *The Future of Cooling.*
76 IEA (2002), *Share of population living in a hot climate*, available at: www.iea.org/data-and-statistics/charts/share-of-population-living-in-a-hot-climate-2022-and-penetration-of-air-conditioners-2000-2022. [Accessed 03/10/2024].
77 IEA (2020), *Is cooling the future of heating?*
78 IEA, Space Cooling, available at www.iea.org/energy-system/buildings/space-cooling. [Accessed 24/09/2024].
79 IEA (2019), *Helping a Warming World to Keep Cool.*
80 Ibid.
81 IEA (2023), *World Energy Outlook 2023.*
82 Systemiq analysis for the ETC; IEA (2023), *World Energy Outlook 2023*; BNEF (2023), *New Energy Outlook 2022.*

It is possible that cooling energy needs will increase more than current projections suggest, with three key uncertainties:

- The pace and extent to which emissions are reduced globally, and the implications for warming climates.
- The feedback loop between AC use and higher outdoor temperatures. Estimates suggest that waste heat emitted from ACs could increase the mean air temperature by more than 1°C in urban locations in the evening.[83] This could exacerbate "urban heat island effects" which result from dense concentrations of concrete and buildings which absorb and retain heat. This could drive even greater use of AC and have severe consequences for homeless people, or households which cannot afford AC.
- Around 40% of heat pump sales over the coming decades could be reversible ones which can provide heating and cooling.[84] This could drive additional cooling demand than would otherwise have occurred, for example, in parts of Europe where cooling needs may not warrant purchasing a separate air conditioner, but where households which have installed heat pumps to provide heating will then decide to use AC in summer as well.

It is, however, possible to limit the increase in energy demand for cooling without impacting living standards (i.e. without reducing the extent to which cooling needs are met). This section outlines the opportunities to:

- Increase the efficiency of air conditioning.
- Optimal consumer behaviour.
- Reduce cooling needs through passive cooling techniques in buildings.

3.2.1 Opportunities to improve energy efficiency

Just like a heat pump, ACs are able to produce more useful output for the electricity put in. Similarly, their efficiency is determined by the temperature differential between the source and sink; because the required temperature differential for ACs tends to be lower than for heat pumps (e.g., going from 35°C to 25°C, compared to going from 0°C to 20°C), air conditioners on the market today can often achieve efficiencies of 400–800%, compared to around 300–400% for heat pumps.[85]

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 better policies such as minimum efficiency standards and labelling [Exhibit 3.3]:

- In Europe and the US, the market average efficiency is around 2–3 times lower than the best available technology.
- In other high-income countries such as Canada and Australia, both market average and best available efficiencies are much lower than in Europe and the US.
- The key challenge is countries with weaker regulatory capacity but very high cooling needs, such as India and Thailand where average efficiencies are low.

In the US and EU, Minimum Energy Performance Standards (MEPS) and labels have helped more than halve AC energy consumption since policies were introduced.[86] In China, a tightening of minimum energy performance standards in 2019 saw the most efficient ACs growing their market share from 20% to 55% in two years.[87] The key question is whether there is a cost premium to purchasing a more efficient AC:

- In some countries, such as Vietnam, there is a clear price premium to more efficient AC. This means minimum energy performance standards are key, even if they increase cost.
- In some countries, such as Thailand, an AC with an efficiency of over 600% can cost the same as one with an efficiency of less than 400%. This means better energy labelling, in addition to MEPS, are key.[88]

83 Salamanca, et al. (2014), *Anthropogenic heating of the urban environment due to AC.*
84 IEA (2018), *The Future of Cooling.*
85 Ibid.
86 Ibid.
87 CLASP (2023), *China's MEPS Lead to Major AC Market Transformation.*
88 IEA (2023), *Keeping cooling in a hotter world.*

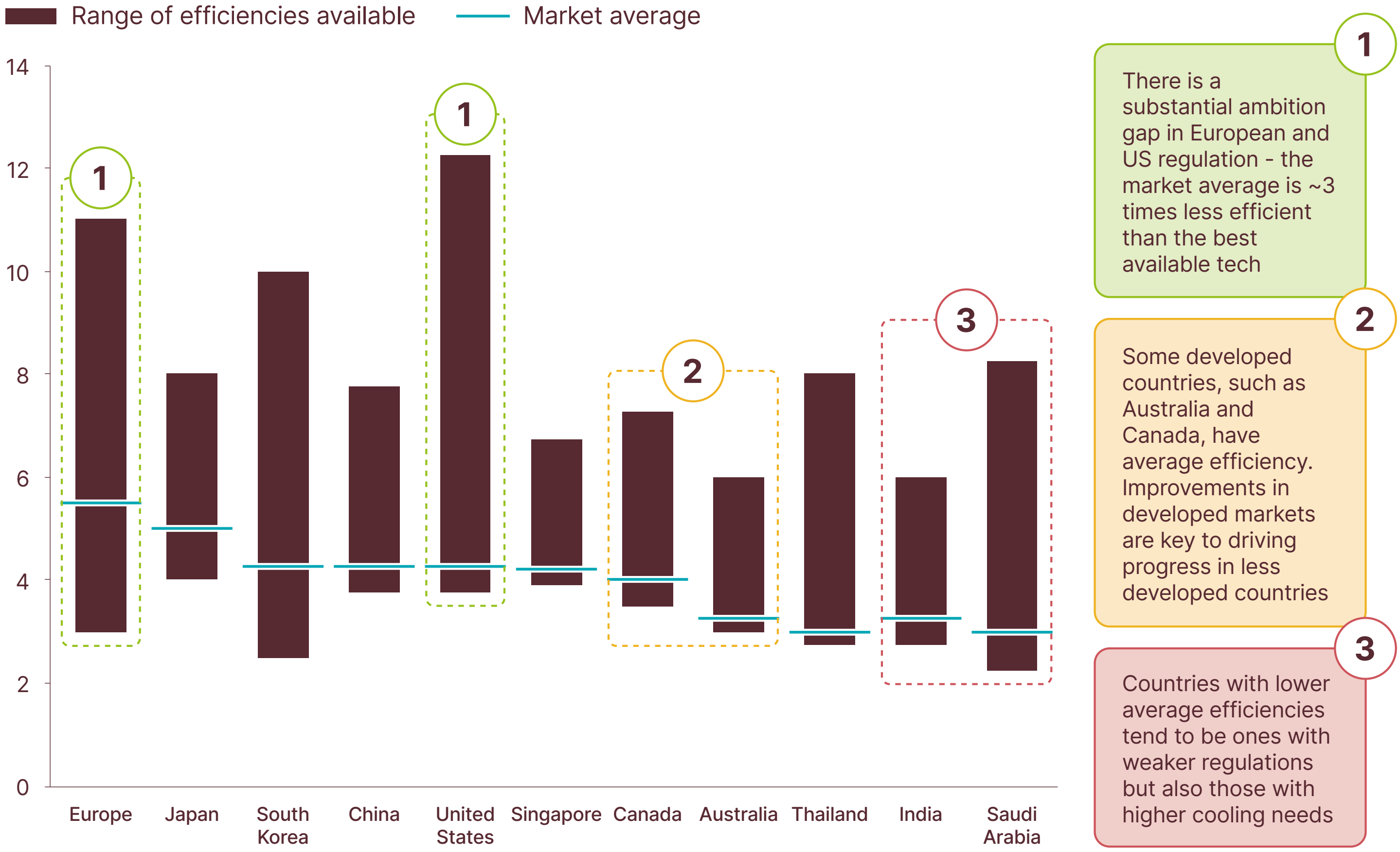
In addition, continued technological advancements will drive further improvements. Key opportunities include variable speed motors which allow an AC to scale up and down (rather than just on and off), and a transition to refrigerants which are able to transfer more heat for the same electrical input (see Chapter 9).

Driving up the average efficiency of the AC stock is the single most effective solution to reducing the cooling energy demand challenge. For example, if average AC efficiency was able to reach 700%, annual electricity requirements for cooling in 2050 could be 70% lower in India, 40% lower in China and 50% lower in the US, compared to holding current efficiencies constant. The impact on global total electricity demand could be savings of 500–1,000 TWh per year.

Exhibit 3.3

There is a huge opportunity to increase the efficiency of ACs on the market, with the best available technology typically twice as efficient as the market average

Seasonal energy efficiency ratio (SEER) of market available residential AC units in selected regions, 2018
Watt of cooling output per watt of energy input



In all countries, noticeable variation exists – in some countries this reflects price dynamics, but in other countries a low efficiency AC can cost the same as a very efficient one

NOTE: SEER is calculated by cooling output divided by energy input over a typical cooling season.

SOURCE: IEA 2018; *The Future of Cooling*, https://www.iea.org/reports/the-future-of-cooling, re-used under license: CC BY 4.0.

3.2.2 Promoting optimal consumer behaviour

Currently, there are huge differences in annual household energy consumption for cooling across countries. Though, in many instances, cooling is essential to human health, especially to deal with humidity, it is often used excessively, particularly in high-income countries:[89]

- In Texas, US, 95% of households own an AC, with average annual energy consumption of 4,000 kWh. Thermostats are typically set very low (~22°C) and are often left on all day.
- In Guangzhou, China and Hyderabad, India, 75–85% of households own an AC, with average annual energy consumption of ~700 kWh. Thermostats are typically set at around 24–26°C and are used for around five hours a day.

In richer countries such as the US and parts of the Middle East, perverse heating and cooling behaviours persist where thermostats in the summer are set lower than thermostats in the winter.[90] This suggests cooling energy consumption far above true need.

There is a risk that, as incomes grow in lower-income countries such as India, AC consumption could begin to exceed need. To illustrate the importance of avoiding such an adverse behaviour change, our analysis suggests that if households in India used their AC as much as those in Texas, electricity requirements for cooling could be six times higher in 2050, from ~400 TWh to 2,700 TWh.

Policy can play a key role in encouraging or mandating behaviour change:

- **Temperature limits in buildings:** In Belgium, public buildings have a heating limit of 19°C and an AC limit of 27°C.[91] Beijing's "energy-saving police" check that AC in commercial buildings (e.g., offices, hotels, malls) is not set below 26°C. In India, the government mandated that all AC must have a default temperature no less than 24°C.[92]
- **Penalties:** Italy introduced fines of €500–3,000 for industrial buildings that set space cooling temperatures below 25°C.
- **Encouragement:** The Japanese "Cool Biz" (cool to 28°C) and "Warm Biz" (heat to 20°C) programmes gave social permission for professionals to adopt dress codes that match varying office temperatures.

89 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*.
90 National Renewable Energy Laboratory (2017), *Residential Indoor Temperature Study*.
91 The IEA's Net Zero Scenario assumes a temperature limit of 24°C on AC.
92 Ministry of Power, *BEE Notifies New Energy Performance Standards for Air Conditioners*, available at www.pib.gov.in/PressReleasePage.aspx?PRID=1598508. [Accessed 24/10/2024].

3.2.3 The vital importance of "passive cooling" techniques

Just as with heating, there are many passive cooling techniques that can reduce the need for active cooling. The health and wellbeing imperative of passive cooling is huge, especially for households which are unable to afford AC.

Passive cooling focuses on minimising heat gain and maximising natural ventilation:

- **Orientation** of a building's longest sides against the direction of the sun to minimise solar gain, balanced against the need for solar gain for winter comfort.
- **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:** A low window-to-wall ratio (as windows lead to more solar gain) or using low-emissivity windows which let in light but reflect heat, and using shading structures such as awnings, trellises and porticos. Optimising for natural ventilation is also key, including vents, solar chimneys, and optimising building shape to maximise natural airflow.

Differences in climate will require different techniques:

- In humid climates, ventilation is key. This means high ceilings and many openings for constant air flow, allowing warm air to drift to the ceiling.
- In dry climates, with huge differences between day and night temperatures, heavy exterior walls and roofs can help keep the temperature constant for longer, creating a natural barrier between inside and outside temperatures.

The huge opportunity for passive cooling in new buildings

Passive cooling techniques could in principle reduce cooling energy needs by 25–40%, with reductions of even 75% achievable if optimal building design was combined with best possible urban design [Exhibit 3.4]. It is, however, much harder to assess the realistically achievable reduction given implementation costs and barriers, with huge variation depending on climate, labour and material costs, and the extent of technique deployed (e.g., external shading can range from trees and retractable awnings to concrete structures).

What is clear, is that many of these choices are low cost, low effort and can have a very big impact on how hot a building gets. For example, in one case study, painting the roof of a factory in Indonesia white led to a 10°C reduction in indoor temperatures.[93]

Seizing this low cost potential is, however, often held back by a lack of knowhow and awareness among developers, weak regulation, and by the fact that the benefits of passive cooling techniques will accrue to households or commercial building users, not to the property developers making decisions on building design.

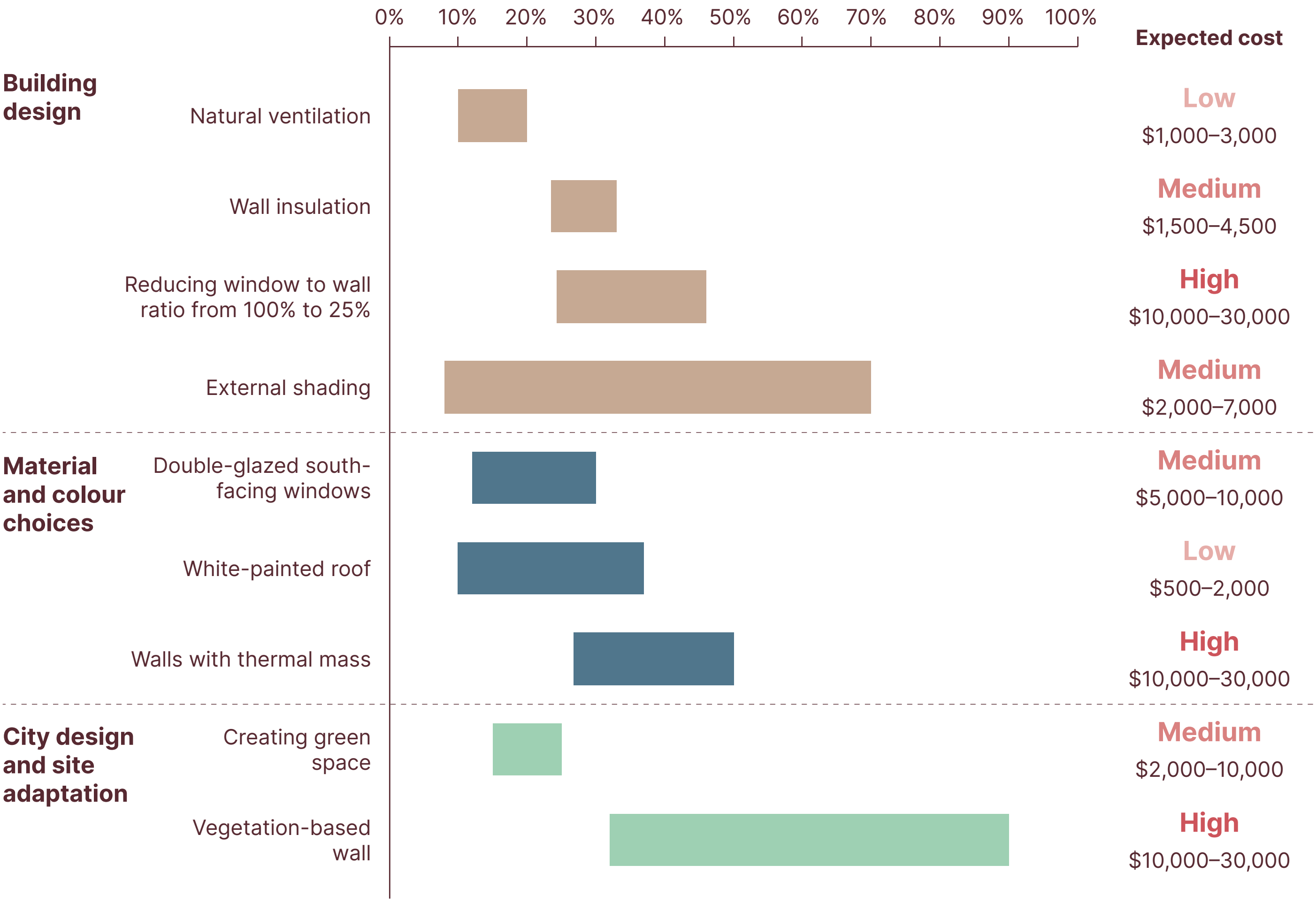
In addition, it can be challenging to make an economic case for investing in passive cooling in lower income households. Exhibit 3.5 shows that AC use and energy bills are typically lower in lower-income countries, compared to the US and Europe, meaning the financial returns to any retrofitting investment will be lower. However, the health and social imperatives are huge. This highlights the critical importance of more ambitious building codes (see Chapter 8) and training and awareness of developers of low-hanging fruit opportunities.

93 Cool Coalition (2023), *Indonesia's Cool Roofs Champion.*

Exhibit 3.4

Passive techniques can reduce cooling energy consumption in buildings by 25–40% on average and many of these are very low-cost, such as painting roofs white and planting trees

Impact on annual cooling energy consumption of passive cooling techniques
%



The cost and impact of passive cooling techniques varies massively depending on:

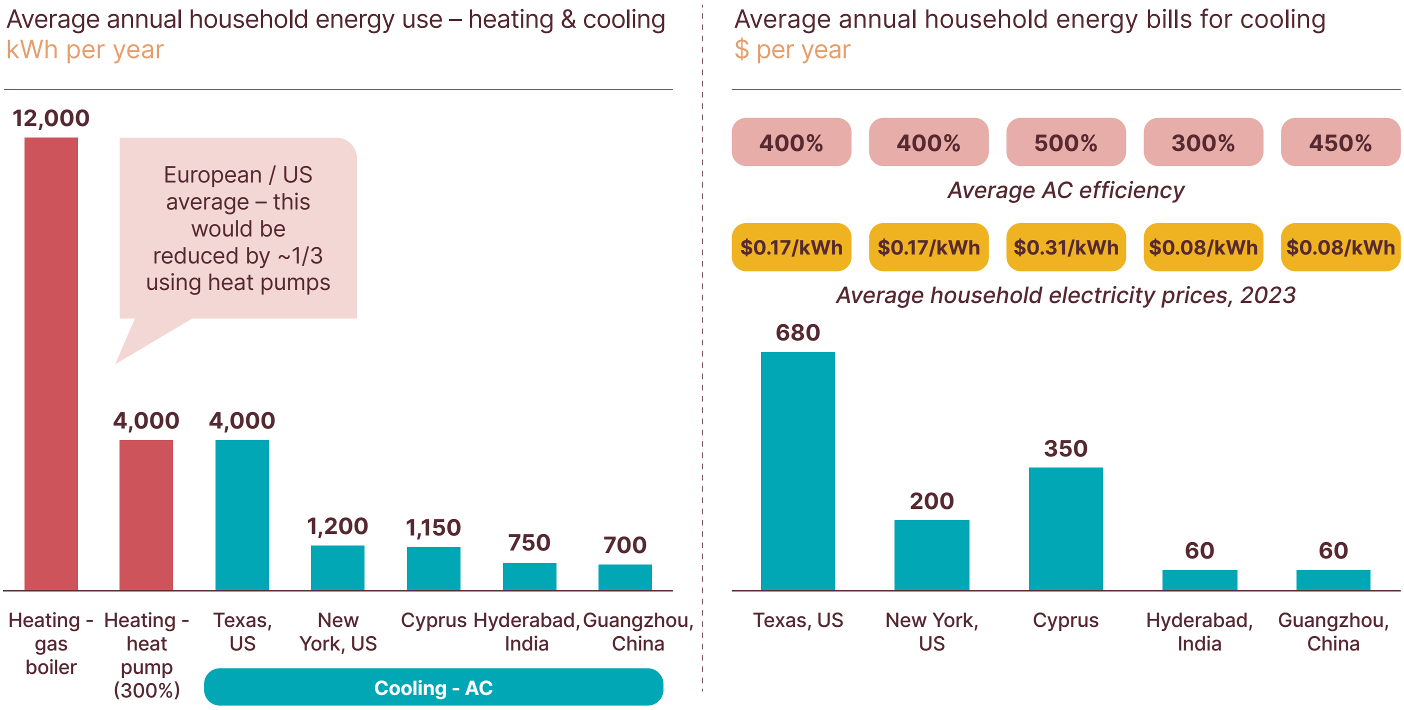
1. Climate.
2. Labour and material costs in different countries.
3. Extent of technique deployed (e.g., external shading can range from trees and retractable awnings to concrete structures).

NOTE: IRR analysis assumes a discount rate of 5% over 50 years. Based on an average single-family flat/house of 60–80 m².

SOURCE: Systemiq analysis for the ETC; 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.*

Exhibit 3.5

Household energy bills for cooling are generally smaller than heating, meaning households will be less likely to invest in retrofitting without government policy and incentives



SOURCE: Systemiq analysis for the ETC; Thunder Said Energy (2022), *Air Conditioning: Energy Consumption?*; Statista (2023), *Household electricity prices 2023*; US EIA (2020), *Residential Energy Consumption Survey*; Odyssee-mure (2023), *Sectoral profile – households*; Florides et. Al (2000), *Modelling of the modern houses of Cyprus and energy consumption analysis*; 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*; IEA (2018), *The Future of Cooling*.

The other crucial aspect with new builds is to consider how better urban design can reduce heat island effects. In humid climates, large distances between buildings is important for air circulation; in dry climates, dense and narrow streets can help provide shade. Simple things such as planting trees along streets and preserving nature can have a huge impact on creating cooler streets and wellbeing.

The potential to retrofit buildings for passive cooling

Many of the passive cooling techniques discussed above can be fairly easily applied to existing buildings, for example, painting roofs white, adding trees for shading, and some forms of insulation [Box I]. Other techniques such as redesigning for natural ventilation or selecting materials which do not absorb heat are much harder to retrofit. This highlights the importance of getting it right at the point the building is constructed, with better building codes (see Chapter 8).

Another challenge is that household energy bills for cooling are generally lower than typical heating bills, meaning passive cooling methods are not necessarily cost-effective. With key exceptions in rich, hot regions such as Texas – where AC energy use is as high as typical heating energy use in Europe and the US – annual kWh consumed for cooling in middle-income countries are around a quarter of the typical electricity input to provide residential heat via a heat pump. As set out in Section 2.2.4, this reflects differences in household income, use and thermostat settings. It might also reflect the fact that the temperature differential required in colder countries (e.g., going from 0°C to 20°C) is higher than in hot countries (e.g., going from 35°C to 25°C).

Combined with often lower electricity prices in lower-income countries, AC energy bills in some parts of India and China could be less than $100 per year. While this may be a relatively high share of annual disposable income for some households, it makes the economic paybacks to investing in retrofitting challenging. This highlights the importance of policies and the provision of low-cost finance to ensure households can reap the health and comfort benefits of passive cooling.

Box I **Cool roofs in India**

Cool roofs are one of the simplest and cost-effective ways to reduce heat in buildings by reflecting sunlight with highly reflective white paint. They can lower indoor temperatures by around 2–4.5°C and if combined with tree planting in city-wide applications can reduce the ambient temperatures by around 2°C.[94]

Following in the footsteps of New York, Los Angeles and Toronto, the city of Hyderabad, India, launched a cool roofs programme, targeting 300 million m² of cool roof area by 2028. Key policies include:

- Mandatory cool roofing in all public buildings, commercial buildings and residential buildings over 500 m².
- Government rollout of cool roofing in all social housing.
- Outreach and awareness programme, including demonstrations, city-wide advertisement boards, and volunteering programmes to coat rooftops.

Other cool roof community programmes have been run in Jodhpur, Bhopal, Surat, and Ahmedabad targeting low-income communities living in slums, which often have roofs made of heat-trapping materials, such as tin sheets, cement sheet, plastic and tarpaulin without sufficient ventilation.[95] Cool roofs can lower indoor temperatures by up to 5°C in these buildings.

94 Government of Telangana (2023), *Telangana Cool Roof Policy 2023-28.*
95 NDRC, *Cool Roofs: Community-led initiatives in four Indian cities*, available at https://www.nrdc.org/bio/anjali-jaiswal/cool-roofs-community-led-initiatives-four-indian-cities [Accessed 24/10/2024].

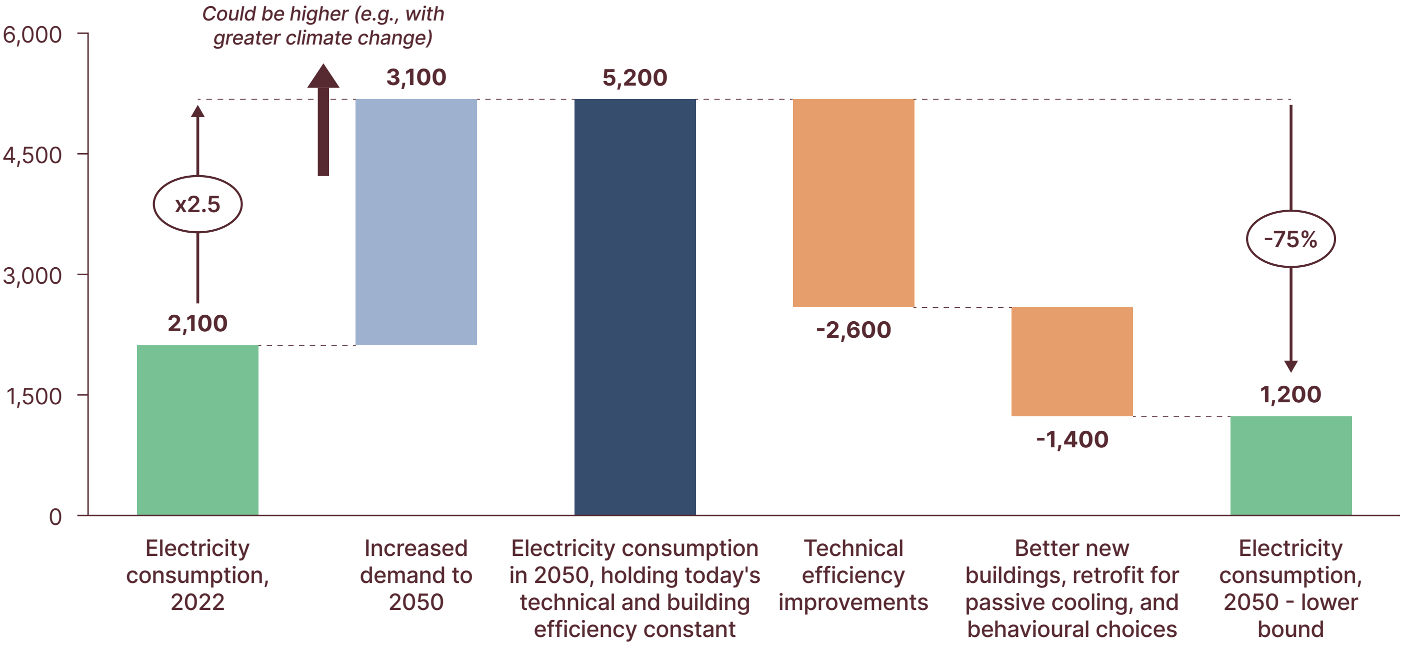
3.3 Implications for the energy needed to cool buildings

Rising demand could see electricity demand from cooling increase 2.5 fold by 2050, from 2,100 TWh to over 5,000 TWh. However, in principle this could be more than offset by energy efficiency improvements to air conditioners and by the application of passive cooling techniques to new and existing buildings. Indeed Exhibit 3.6 shows that electricity consumption from cooling could be lower than it is today, at 1,200 TWh.[96] The crucial issue is how much of this very large technical potential can in practice be achieved.

Exhibit 3.6

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*.

96 Note that this shows global totals for residential and commercial buildings (see Chapter 7 for further discussion on commercial buildings).

Cooking

4

Key messages

- High-income countries should entirely electrify cooking by 2040, and China by 2050; electric cooking is healthier, far more efficient and it can be cost competitive with gas/LPG.
- In many low income countries, the imperative is to eliminate the use of traditional use of biomass, which has adverse health impacts and is also incredibly inefficient:
  - A crucial interim solution in the 2030s is to install improved cookstoves and then transition to clean cooking fuels.
  - Liquefied Petroleum Gas (LPG) will likely be the dominant transition fuel, with modern forms of bioenergy and electric cooking too expensive.
  - Electricity will, however, play a slowly increasing role as the price of both solar PV panels and batteries decline, and as grids are extended.
- 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.

Cooking drives 3% of global emissions and 15% of direct fossil fuel use in buildings. But fossil fuels actually only account for 20% of global cooking energy use. Instead, from a final energy consumption perspective, it is 70% fuelled by the traditional use of biomass (TUOB) in lower-income countries. 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). TUOB is incredibly inefficient (as little as 10% of energy used is converted to useful heat); as a result, cooking is the second largest component of final energy demand in the building sector (~30%).

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. Currently around 1/3 of the global population, or 2.3 billion people, still cook their meals on open fires or basic stoves which TUOB.[97] This has significant adverse consequences:

- It contributes to 3.7 million premature deaths a year.
- Households can spend around 5 hours a day collecting fuel and cooking, resulting in lost education and economic opportunities, especially for women and children.
- It contributes to deforestation.

97 IEA (2023), *A Vision for Clean Cooking Access for All.*

4.1 The transition to clean cooking technologies

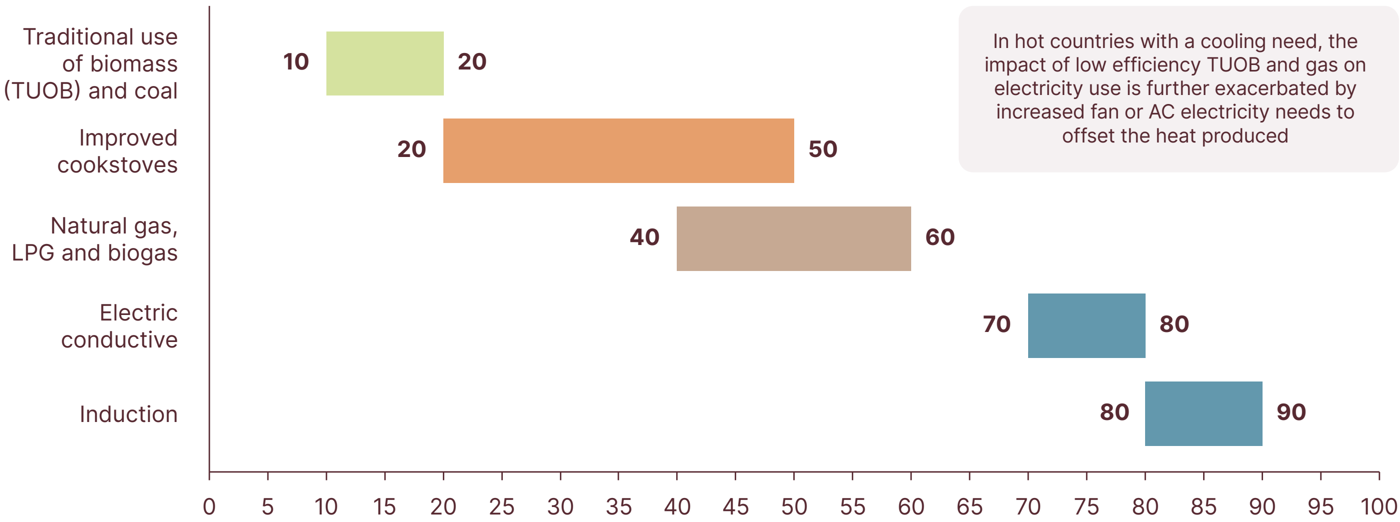
Electric cooking meets both definitions of "clean" and is already an important energy source for cooking in high-income countries. In most countries, electric cookers do not cost materially more than a gas cooker (e.g., ~€500 for a 4-hob cooker), although there is typically a price premium of ~€200–400 for an induction hob.[98] Electric cookers have other advantages including higher efficiency [Exhibit 4.1], more even heat distribution, and being easier to clean. For many households, with the right policies and incentives, electrifying cooking can be a natural step along with electrifying heating, allowing them to disconnect from the gas grid.

But progress towards electrification is likely to 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. Around 75% of the population in Sub-Saharan Africa currently lack any access to electricity, and while decentralised small-scale solar systems (combined with batteries) can provide adequate power for lighting, many appliances and refrigeration, are often insufficient to support cooking applications as well.[99,100] This reflects the significant instantaneous power requirement for many types of cooking.

Exhibit 4.1

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
%



NOTE: LPG = Liquefied petroleum gas.

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

98 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.
99 IEA (2023), *SDG7: Access to electricity*.
100 Lighting, appliances, and refrigerators require steady amounts of electricity over time whereas cooking requires high amounts of energy for limited amounts of time.

In these countries and where cooking currently depends primarily on TUOB, the transition will likely follow several stages:

- A crucial interim solution in the 2030s is to install improved cookstoves. These are much more efficient and safer, and emit less emissions. For example, having an insulated combustion chamber above and around the fire which reduces heat loss and chimneys which prevent indoor pollution. Policies to subsidise or help finance upfront costs and increase awareness of the opportunity are key.

- By 2040, strong policy will be required to ensure a transition to cleaner cooking fuels. LPG is likely to be by far the dominant fuel, despite still having emissions of 0.2–0.25 kgCO_2 per kWh.[101] This is because the cost of electric cooking will still be too high for many households in lower-income countries, as well as unreliable access to electricity from the grid. In addition, while natural gas is typically delivered to households via distribution pipelines, LPG can be distributed in large pressurised cylinders. In the last decade, 70% of those who gained access did so through LPG.[102] In China and India, policies such as providing free stoves and subsidised canisters have been critical.

- 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.[103]

- By 2050, higher incomes and improved access to electricity – either from the grid or via distributed generation – should enable the vast majority of the world's population to transition away from fossil fuel cooking. However, it will rely on strong policy to incentivise households to install electric cookers, in some cases, before their existing fossil fuel assets reach end-of-life.

4.2 Implications for energy used for cooking

Fossil fuel use for cooking in high-income countries and China should rapidly decline towards zero by 2040, but oil use (i.e. LPG) in cooking will actually increase slightly in the rest of the world in the 2030s. This will, however, be more than offset by declining oil use in buildings for heating, and also by reduced coal use for cooking.

Overall, Exhibit 4.2 shows how the fuel mix for cooking might change to 2050, with a halving of final energy consumption but a seven-fold increase in electricity use.[104]

Although low-carbon solutions to cooking exist, often at comparative cost and with many benefits compared to fossil fuels, uptake is unlikely to accelerate at the required pace without additional action on policy, finance and education:

- Education and awareness campaigns are crucial, as the transition relies on widespread changes to social and cultural norms. For example, challenging beliefs that cooking with woks cannot be done without a naked flame. Key actions include 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.

- Governments should set clear targets for expanding clean cooking access.

- Regulation to ensure minimum standards of improved cookstoves.

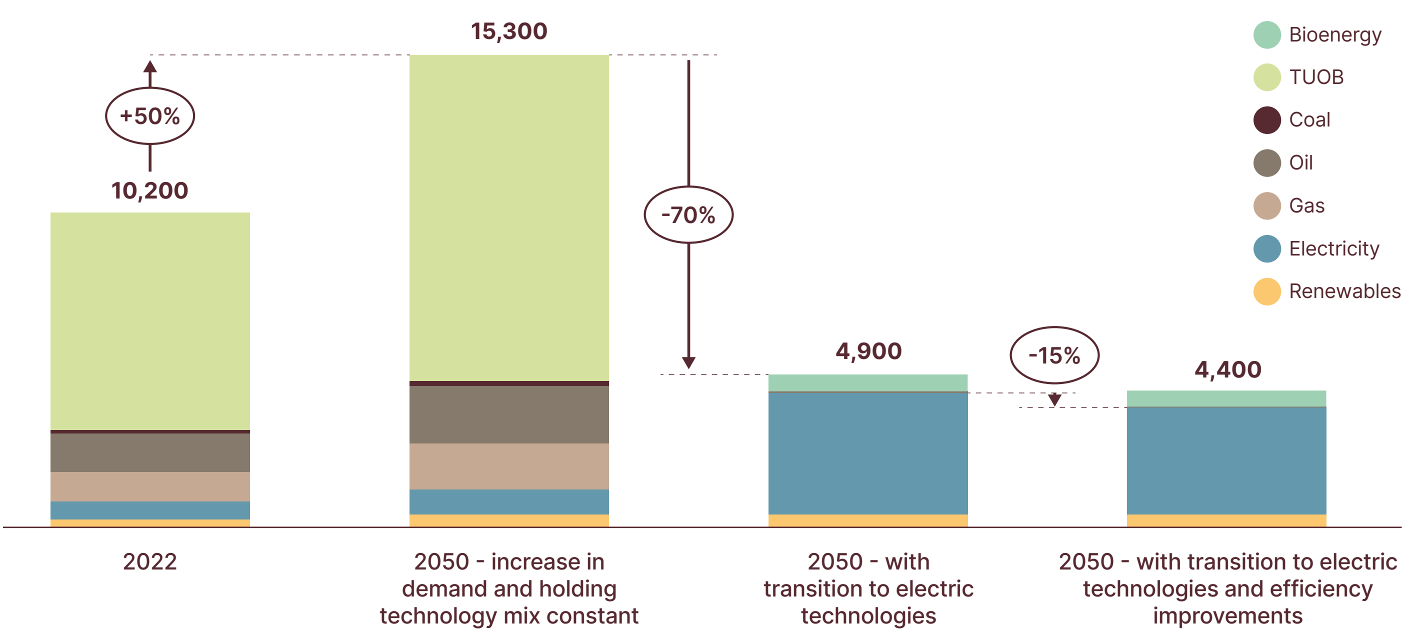
- Subsidies, grants and low-cost finance, with international development finance play a key role. Financial support should be focused both on the upfront costs and ongoing fuel costs while markets and supply are scaled up.

101 LPG is produced during oil refining or extracted from oil and gas reservoirs.
102 IEA (2023), *A Vision for Clean Cooking Access for All*.
103 Ibid.
104 Note that this shows global totals for residential and commercial buildings (see Chapter 7 for further discussion on commercial buildings).

Exhibit 4.2

The transition from inefficient biomass to electric cooking will more than halve final energy demand for cooking, but this could increase electricity demand 7-fold relative to today

Global cooking energy demand by fuel, 2022 and 2050
TWh



NOTE: TUOB = Traditional use of biomass.

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

LPG cookstove in India

Appliances

5

Key messages

- Without any action to improve efficiency, electricity demand for appliances could double, from ~6,000 TWh, to almost 12,000 TWh.
- However, improving the technical efficiency of appliances through minimum energy performance standards and labelling could offset 70% of the increase in electricity demand.
- Realising efficiency gains in hot countries is critical, as appliances produce heat which then leads to greater AC use.
- 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 in addition to using electricity often use high GWP refrigerants. This must be accompanied by investment in recycling and reuse facilities, with retailers obliged to offer trade-in schemes.

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). In commercial buildings, appliance use is typically much greater and includes a wider set of office and technological appliances (see Chapter 7); note that the electricity numbers presented in this report do not include demand relating to data centres, but this is an area of significantly growing demand.[105]

Appliances account for 8% of global emissions and are already 100% electrified, meaning there is no technology transition required at the point of end-use.[106] It is important to note that appliances account for almost the same share of global emissions as heating (11%) while currently using a third less energy. This is because the carbon intensity of natural gas which is used for 50% of heating has a lower carbon intensity (~200 gCO_2 per kWh) than the current global average carbon intensity of electricity (~440 gCO_2 per kWh).[107] This highlights the importance of rapid power sector decarbonisation to drive emission reductions.

The use of these appliances accounts for 15% of buildings operational energy use, around 6,000 TWh of electricity. A combination of rising incomes and falling consumer costs are enabling more households to afford appliances, which will deliver significant social benefits in terms of comfort, access to information, health and productivity. Currently, 20% of the global population do not have access to refrigerators, 15% don't own a TV and 25% don't have a mobile phone.[108] At the same time, energy demand will also increase from households:

- **Owning more appliances** – the IEA expects there to be 1.4 TVs per household by 2030, up from 0.9 in 2000.[109]
- **Using appliances more frequently** (e.g., using a washing machine or dishwasher more often).
- **Choosing larger or more sophisticated models** (e.g., bigger TVs with smart controls that use more energy). In addition to higher wattage, smart appliances also have additional associated electricity requirements to power the data centres which store their data; this will be explored in an upcoming ETC Brief on future power demand.

Without action to improve efficiency this could increase electricity needs by 85% to over 11,000 TWh by 2050.[110] Offsetting this demand increase with more efficient appliances will be key to managing electricity demand without limiting improvements in living standards.

105 In the US alone, electricity demand for data centres is expected to increase from around 180 TWh in 2024, to over 600 TWh in 2030. See McKinsey (2024), *How data centers and the energy sector can sate AI's hunger for power*.
106 IEA (2023), *World Energy Outlook 2023*.
107 Our World in Data, *Carbon Intensity of Electricity Generation*, available at www.ourworldindata.org/grapher/carbon-intensity-electricity. [Accessed 24/09/2024].
108 CLASP (2024), *Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience*.
109 IEA (2023), *World Energy Outlook 2023*.
110 IEA (2021), *Net Zero by 2050*.

5.1 The potential to improve energy efficiency

The efficiency of appliances and technologies tends to increase over time as manufacturers innovate, compete on quality and look to cut their own costs. Key improvements in appliances to date have been reducing excess heat production, increasing motor efficiency, improving the insulation of fridge freezers, and load sensing technology in washing machines to adjust water and energy use accordingly.

However, there is significant potential to realise much faster improvements with policies and regulation. This reflects the fact there are large differences in the average efficiency of new appliances across countries [Exhibit 5.1] and within countries [Exhibit 3.3], with the market average being far below already best available options.

Regulation has been crucial to improvements in energy efficiency. Specifically, minimum energy performance standards (MEPS) which set a clear floor for efficiency, and regulation on energy labelling. Analysis of global MEPS 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 to 20 years in most countries. In countries with the tightest regulations, energy savings have been over 50%.[111] In some cases, new more efficient appliances will cost more if only bought in small quantities, but this price premium can often be eliminated if large scale purchase and manufacture makes it possible to achieve economy of scale effects. MEPS can therefore play a role in reducing potential price premiums by increasing the market share of the new more efficient models.

Policies and R&D can improve the efficiency of new appliances, but the existing stock can take 5–20 years to be replaced; a key question is therefore how much this stock turnover should be accelerated? Policies can incentivise households to turn in their older appliances rather than delaying new model purchases, and prevent them selling old, inefficient models in the second hand market. It is crucial that turned in appliances are not “dumped” overseas in lower-income countries. Any action to accelerate the stock turnover of older appliances must be carefully designed to prevent adverse impacts on:

- **Embodied carbon:** As the grid decarbonises, it will take longer for energy savings to offset the carbon generated in manufacturing new appliances.
- **Waste generation:** Stock turnover needs to be carefully managed with circular approaches and investment in recycling.
- **Affordability and social equity:** Restricting second hand markets could prevent lower-income households being able to afford appliances.

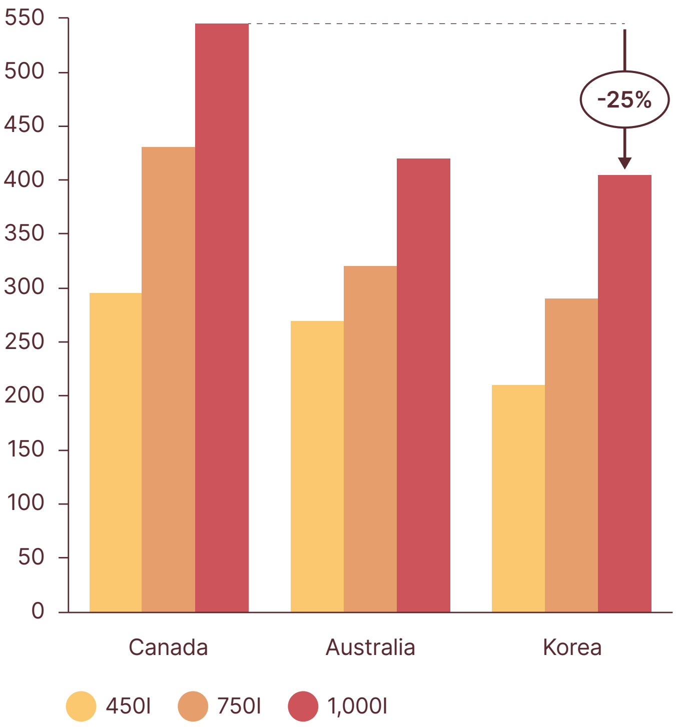
Lessons can be learned from Ghana’s 2013 import ban on second hand fridges and ACs, which had very poor energy efficiency and used Ozone-depleting refrigerants (see Chapter 8). Rebates were offered to replace old appliances and the average annual electricity consumption of fridges fell 70%, from 1,200 kWh per year in 2013 to 400 kWh per year in 2019, realising lower energy bills for households.[112]

111 IEA/4E TCP (2021), *Annual energy reduction in new-product energy consumption from EES&L programmes.*
112 Durand et al. (2024), *Environmental assessment of used refrigerating appliances: Why does an import ban make sense and what could other countries learn from Ghana?*

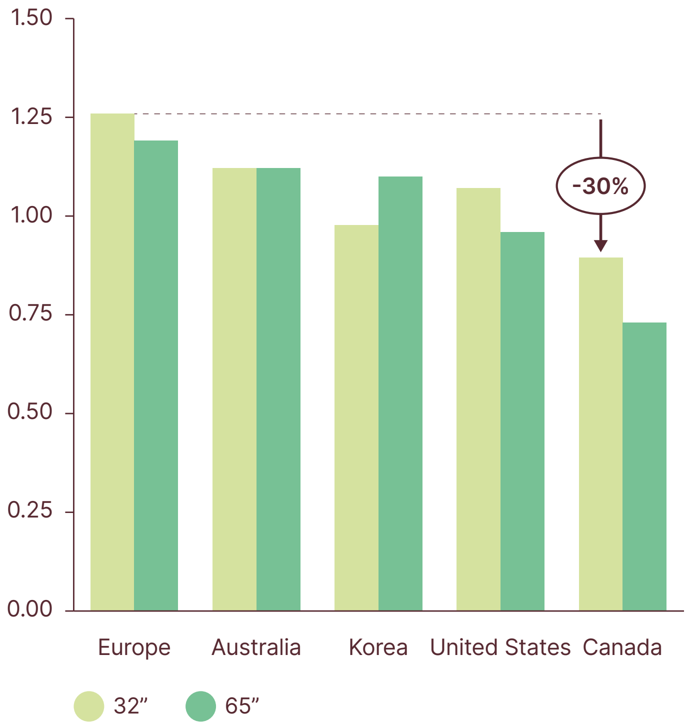
Exhibit 5.1

There are large differences in the efficiency of appliances across countries; fridge-freezers of the same size can be 25% more efficient in Korea than Canada

Average annual energy consumption for refrigerator-freezers by size, 2019 kWh per year



Average efficiency of TVs by screen size, 2018 Watt per dm²



SOURCE: Technology Collaboration Programme on Energy Efficient End-Use Equipment (2021), *PEET Efficiency Trends Analysis*.

5.2 Implications for the energy needed to power appliances

The IEA estimates that electricity demand for appliances could be 40% lower in 2050 with energy efficiency improvements, offsetting 70% of the increase in demand [Exhibit 5.2].[113, 114] Realising these gains requires a combination of regulation, education and financial incentives to:

- **Set a minimum efficiency floor.** Over 110 countries now have MEPS in place for new appliances, but these vary in terms of stringency. A critical priority is increasing the ambition and breadth of MEPS.
- **Grow the market for efficient appliances,** using a variety of policies and incentives:
  - Energy performance labelling, including translating energy efficiency into layman’s terms (e.g., impact on running costs). Making it clear how far above regulated minimum standards an appliance is would be a very helpful tool.
  - Policymakers can actively shape purchase decisions and overcome potential cost barriers with low-cost finance, subsidies or rebates for more efficient models. This will also push manufacturers towards this level, increasing innovation and driving down costs.

113 IEA (2021), *Net Zero by 2050.*
114 Note that this shows global totals for residential and commercial buildings (see Chapter 7 for further discussion on commercial buildings).

- Bulk procurement can also play a big role in lowering consumer prices, with competitive bidding at scale to lower costs. Box J in the following section on lighting explores how the government of India's bulk procurement of LED light bulbs grew the market 130-fold in just five years.

- Education campaigns which get households thinking about running costs as well as upfront costs, and provide comparisons across different models.

- International collaboration to stop dumping of poor quality and inefficient products in lower-income countries, including regional harmonisation of standards and voluntary commitments from the private sector.

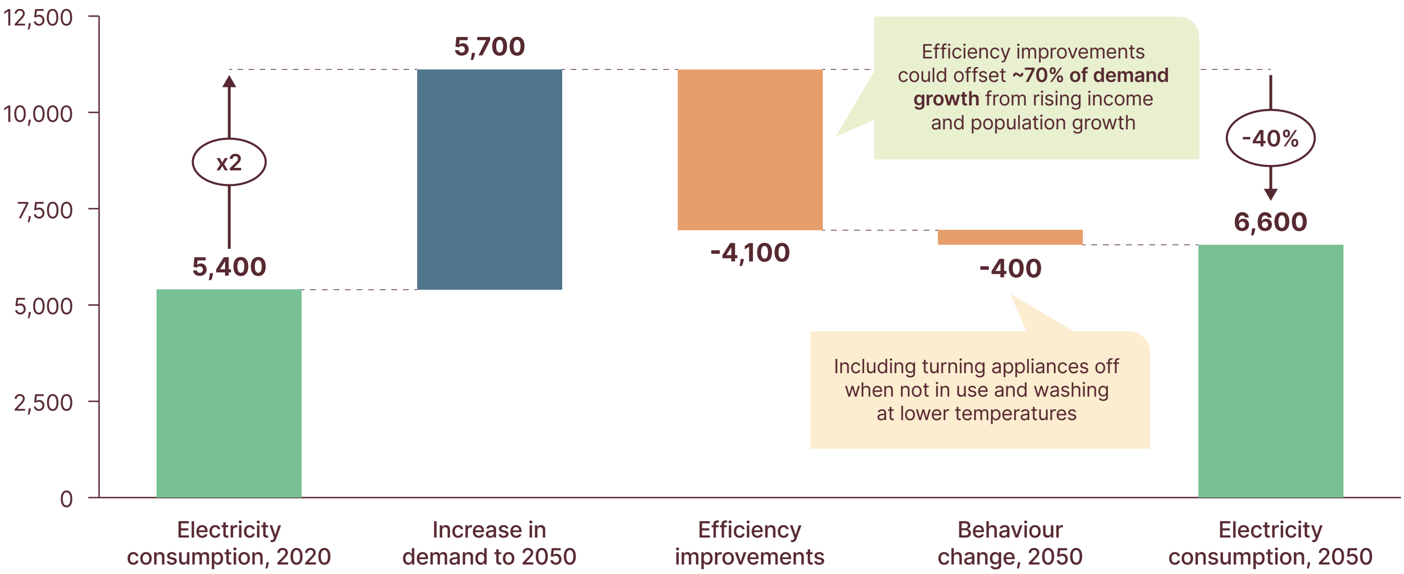
- **Drive further improvements in efficiency** with targeted R&D support (e.g., financial incentives, prizes), focussing for example on developing smart appliances which work effectively within smart building systems to provide demand-side flexibility (e.g., Bluetooth enabled devices).

This must be underpinned by gradual behaviour change, which focuses on encouraging households to turn off appliances when they are not in use and washing at lower temperatures.

Exhibit 5.2

Improving the technical efficiency of appliances could offset 70% of rising electricity demand

Global electricity consumption by appliances and equipment, 2020 to 2050
Annual TWh



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

Lighting

6

Key messages

- Without action on energy efficiency, electricity demand for lighting could double, from 1,800 TWh to 3,600 TWh in 2050.
- If all lighting demand could be delivered with LED light bulbs, electricity requirements could be even lower than they are today, at 1,600 TWh in 2050. LED light bulbs are over 80% more efficient than incandescent lighting, they run for 30–50 times longer, and have significantly lower lifetime costs.
- Government bulk procurement has proven to be very successful at rapidly growing the market for LEDs and lowering retail costs (e.g., in India).

Lighting is arguably the easiest aspect of the building energy transition. It accounts for 2% of global emissions and is virtually 100% electrified. This means for the vast majority of households, there is no technology transition required and as electricity generation is decarbonised, emissions will fall. 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.[115] Expanding access to safe, electric lighting is therefore also critical.

Lighting accounts for the smallest share of building operational energy use, 5%, or around 1,800 TWh. Importantly, global electricity consumption for lighting has remained constant over the past 10 years, as efficiency improvements have offset rising demand.

Arguably the biggest low-hanging fruit opportunity for energy efficiency across the buildings sector is the move to LED lighting, which is not only much more efficient but also has significantly lower running costs and longer lifetimes, therefore also reducing waste.

There are three main types of light bulbs:

- **Light emitting diodes (LED):** An electrical light source that can produce light with only trivial heat generation. They are able to emit light in a specific direction, reducing the need for reflectors and diffusers that trap light. They are over 80% more efficient than typical incandescent lighting, with expectations of a further 30% improvement this decade [Exhibit 6.1]. The cost of LED lights has fallen dramatically, with a 95% decline in the US from $70 per bulb in 2010, to below $10 in 2016.[116] They are now cost competitive with incandescent bulbs in most countries. They also last much longer, for 30,000–50,000 hours (equivalent to 3.5-6 years if left on).
- **Fluorescent:** These are glass tubes filled with a mixture of argon and mercury vapour which use electricity to ionise the gas and emit ultraviolet radiation. However, they can release up to 80% of their energy as heat, making them much less efficient.[117] They last for around 15,000 hours.
- **Incandescent:** These have a filament which is heated until it glows. This means around 90% of their energy is released as heat.[118] Given their low efficiency, they have higher running costs and also only last for around 1,000–2,000 hours. Halogen bulbs are a variant of incandescent bulbs, which deliver a very slight energy efficiency improvement.

Today, around 50% of new lighting sales are LED.[119] With well-designed policies, it is possible for LEDs to account for 100% of the market by 2030. This is key to offsetting the huge increase in demand for lighting expected over the coming decades. Exhibit 6.2 shows that rising demand from population, income and floor space growth could lead to a doubling of electricity requirements for lighting, holding today's average light bulb efficiency constant.[120, 121]

115 CLASP (2024), *Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience.*
116 IEA (2016), *Energy Efficiency Market Report 2016.*
117 US Department of Energy, LED Lighting, available at www.energy.gov/energysaver/led-lighting [Accessed 24/09/2024].
118 Ibid.
119 IEA (2023), *Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030.*
120 Calculated as 80 lumens per watt, based on 50% of lighting being LED (at 100 lumens per watt) and 50% being 50 lumens per watt on average. Note these estimates are based on residential and commercial buildings.
121 Note that this shows global totals for residential and commercial buildings (see Chapter 7 for further discussion on commercial buildings).

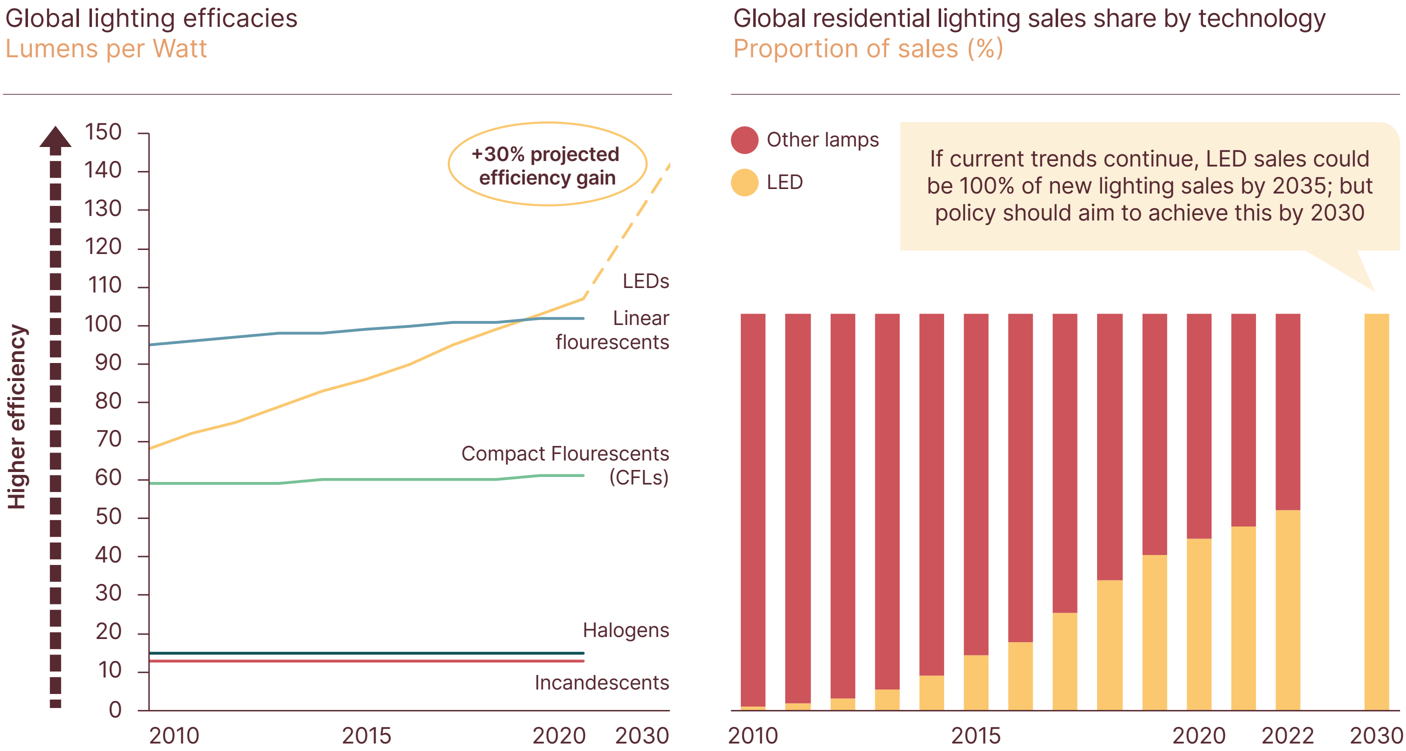
This doubling could, however, be more than offset if all lighting was LED and with expected increases in the efficiency of LED lighting from 110 lumens per watt to 140 lumens per watt. Under these assumptions, annual electricity consumption in 2050 could be lower than it is today.

It is, however, important to note that efficiency improvements in lighting (as well as appliances and the electrification of cooking) have interactions with cooling and heating demand. More efficient lightning which produces less heat will:

- Tend to increase the energy specifically used to heat buildings in the locations and at the times when heating is required, but total electricity use (for lighting and heating combined) will be no higher even if resistive heating is used and will be lower if heating is provided by heat pumps. For example, 100 W of lighting might consume 300 kWh of energy over a year. If 90% of this was lost as heat (e.g., via incandescent bulbs) this would increase heating needs by around 250 kWh, around [7%] of a households heating consumption.
- Reduce energy requirements for cooling as well as for lighting.[122] Improvements in the efficiency of lighting and other appliances are therefore particularly important in hotter countries.

Exhibit 6.1

LEDs are the leading lighting technology, but only account for half of global sales; with well-designed policies and incentives, this could be 100% by 2030



NOTE: Efficacy is a measure of how much light is produced (lumens) compared to the electricity put in (watts).

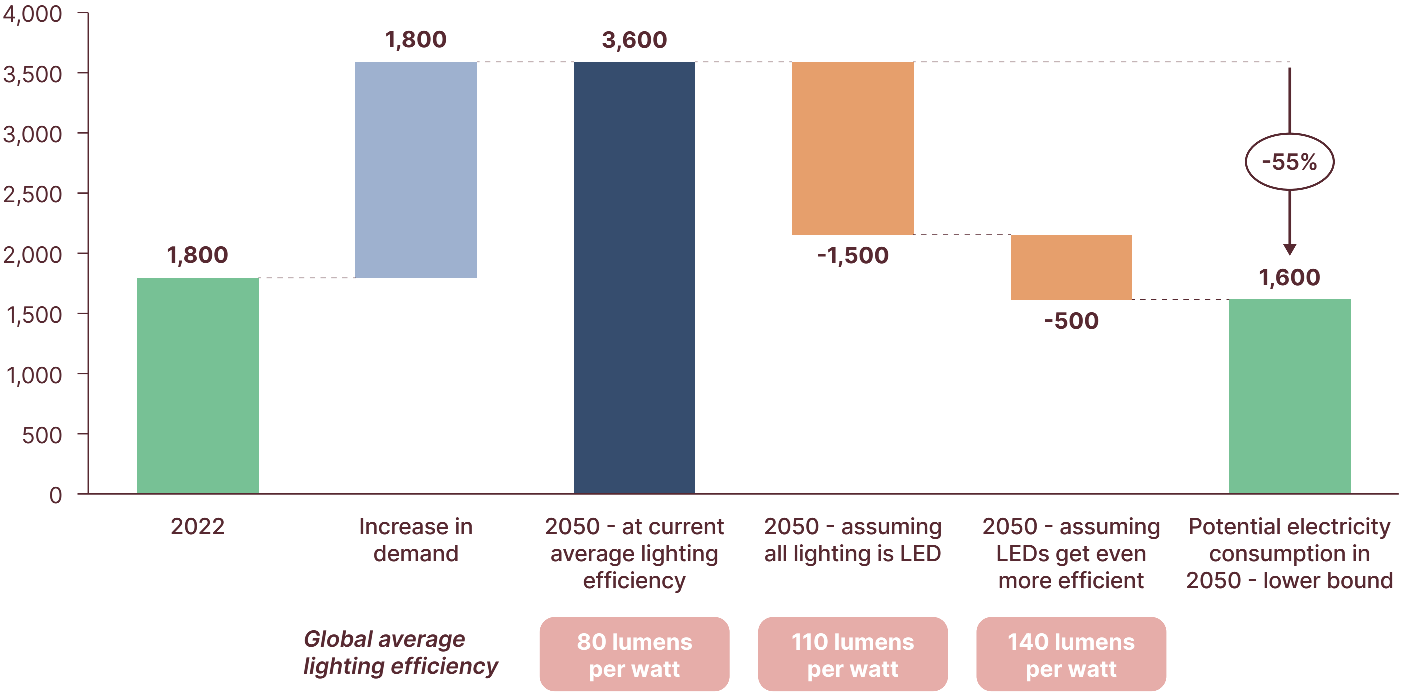
SOURCE: IEA 2023; *Global residential lighting sales share by technology in the Net Zero Scenario, 2010-2030*, https://www.iea.org/data-and-statistics/charts/global-residential-lighting-sales-share-by-technology-in-the-net-zero-scenario-2010-2030, re-used under license: CC BY 4.0; IEA 2023; *Lighting efficacy by technology in the Net Zero Scenario, 2010-2030*, https://www.iea.org/data-and-statistics/charts/lighting-efficacy-by-technology-in-the-net-zero-scenario-2010-2030, re-used under license: CC BY 4.0.

122 Analysis of US households suggests that the impact on heating and cooling energy demand is in the region of ±5%. See Connecticut Energy Efficiency Board (2014), *Residential Lighting Interactive Effects Memo.*

Exhibit 6.2

With regulation to phase out inefficient non-LED lightbulbs and continued improvements to LEDs, efficiency improvements could more than offset the rise in demand for lighting

Global annual lighting electricity consumption, 2022 to 2050
Annual TWh



NOTE: Lumens per watt is a measure of how much light is emitted per watt of energy used.

SOURCE: Systemiq analysis for the 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*.

Realising this potential reduction in electricity needs requires the following actions:

- **More ambitious minimum energy performance standards (MEPS):** These have been critical to the growth of LEDs, but could go much further given how much LED costs have fallen. In 2023, the UK announced the most stringent MEPS in the world, at 120 lumens per watt in 2023 and 140 lumens per watt in 2027. At the right level, MEPS would effectively ban the sale of inefficient fluorescent and incandescent light bulbs. Around a quarter of global residential lighting energy demand is not covered by MEPS; expanding regulation across the world is therefore vital.[123] Regulation should also focus on driving minimum standards in commercial and public buildings.

- **Improved labelling:** Only half of the world's lighting electricity consumption is covered by mandatory labelling.[124] Improvements and wider application need to focus on explaining the significantly lower running costs for LED lighting and longer lifetimes, enabling consumers to make informed decisions about lifetime costs.

- **Bulk government procurement:** Governments can use public procurement to help drive demand. In China, LED lighting is compulsory in government procurements. Governments should ensure all public buildings and street lamps are installed with LEDs. In India, bulk procurement programmes have helped to massively drive down costs [Box J].

123 IEA (2024), *Lighting*, available at www.iea.org/energy-system/buildings/lighting. [Accessed 24/09/2024].
124 Ibid.

Box J **India's LED bulk buying programme**

In 2015, India launched a bulk procurement scheme of LED light bulbs at competitive prices, much lower than those in local markets. These were then distributed to households subsidy via a replacement scheme.

The initiative resulted in:

- As of January 2022, the program had distributed over 360 million LED bulbs, saving over 47 TWh and avoiding 37 $MtCO_2$ a year.[125]
- Between 2014 and 2017, LED bulb retail costs fell 75–80%, from INR 300–350 per bulb in 2014, to INR 70–80 per bulb in 2017.
- India's LED lighting market grew 130-fold in just five years, from annual sales of 5 million bulbs per year in 2014, to about 670 million in 2018.[126]

One imperfect feature of the scheme was that a combination of fierce competition between suppliers and inadequate specification of quality standards resulted in the provision of some less efficient and shorter life time bulbs. But even allowing for this imperfection the impact on electricity use and thus emissions has been strongly positive.

LED lighting installed in homes in Assam, India, by The Energy Resources Institute

125 India Ministry of Power (2022), *Salient Features of UJALA and SLNP Programmes.*
126 Carbon Brief (2020), *Guest post: How energy-efficient LED bulbs lit up India in just five years*, available at www.carbonbrief.org/guest-post-how-energy-efficient-led-bulbs-lit-up-india-in-just-five-years/. [Accessed 24/09/2024].

The net-zero transition in commercial buildings

7

Key messages

- 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, including immediate bans on the installation of new boilers in new buildings and by 2030 in existing buildings.
- Sophisticated HVAC and building management systems have a major role to play in achieving energy efficient improvement with:
  - Significant potential for energy savings in buildings that have simultaneous heating and cooling needs, with sophisticated HVAC systems which can utilise waste heat.
  - A huge untapped opportunity is installing building management systems, such as sensors, smart thermostats, and predictive AI to flex energy consumption according to occupancy, the weather and energy prices. These can deliver significant energy savings of 10–20% without any disruptive fabric improvements.
- Strong regulation of new building design and construction can deliver efficiency improvements. This requires reform of energy performance measurement and regulation to include distinctive standards for different types of and to focus more explicitly on actual, measured energy use.
- In existing buildings, the introduction of new energy management systems will often deliver higher returns than retrofit to improve insulation. But the fact that many commercial buildings are occasionally subject to major retrofit for non-energy related reasons (e.g., to meet new tenant needs) creates an opportunity to enforce strong energy efficiency requirements at that point.
- Voluntary commitments by real estate developers, property developers and financial institutions can play a major role in driving progress towards zero emissions, if informed by improved information on energy performance.

In Chapters 2 to 7 we have assessed the opportunity to improve building energy efficiency for each type of application (heating, cooling, cooking, appliances, and lighting). In those chapters we referred to residential examples, but the technologies described are applicable to both residential and commercial buildings, and the estimates for energy savings potential with which we concluded each chapter cover both the residential and commercial sectors.

In this chapter we highlight the specific characteristics of commercial buildings which have implications for the relative importance of different applications and policies and private sector actions required to drive efficiency improvement. This chapter discusses active clean heating and cooling technologies in commercial buildings, the potential for passive heating and cooling techniques, and the regulation and voluntary commitments required.

Commercial buildings account for 20% of global building stock and operating them accounts for 40% of building operation emissions and 10% of total global emissions (see Chapter 1). The commercial building stock is projected to expand by 55% by 2050. Improving energy efficiency in commercial buildings is therefore essential.

But the category "commercial buildings" in fact includes a huge variety of types of buildings [Exhibit 1.8], including offices, schools, hospitals, hotels, restaurants and warehouses, with very different energy use per m² and a different mix of energy use types. The relative importance of these building types also varies between countries; for example, offices account for almost 40% of commercial building floor space in China, compared to 30% in the US.[127] For many countries, accurate data on commercial building energy use is less readily available than for residential. This chapter therefore relies primarily on data from the US and Europe; but the policy implications we draw out are applicable in most countries.

127 National Renewable Energy Laboratory (2022), *US Building Stock Characterization Study*; Baijiahao (2018), *Real estate and constructions: What are the sub-sectors? What are the sizes?*

7.1 Understanding commercial building energy use

Compared to residential buildings, commercial buildings tend to have a different mix of energy needs [Exhibit 7.1]:

- Lighting and appliance energy needs are much higher in commercial buildings, given in particular higher IT related energy use.[128] As a result, electricity already accounts for a higher share of total energy use providing 35–50% of commercial building energy in the US and EU, compared to around 25% in residential buildings.[129]

- Space and water heating needs are significantly less important, accounting for around 30–40% of energy compared to over 60% in residential buildings.[130] It is important to note that heating and cooling needs in commercial buildings refer here to creating comfortable room temperatures for human occupants, but not to any needs for commercial purposes (e.g., heat for manufacturing processes, or cooling for dedicated data centres).

- In general, commercial buildings have higher cooling needs than residential buildings. This reflects the fact that in many countries, commercial buildings are more likely to have AC installed than residential homes.

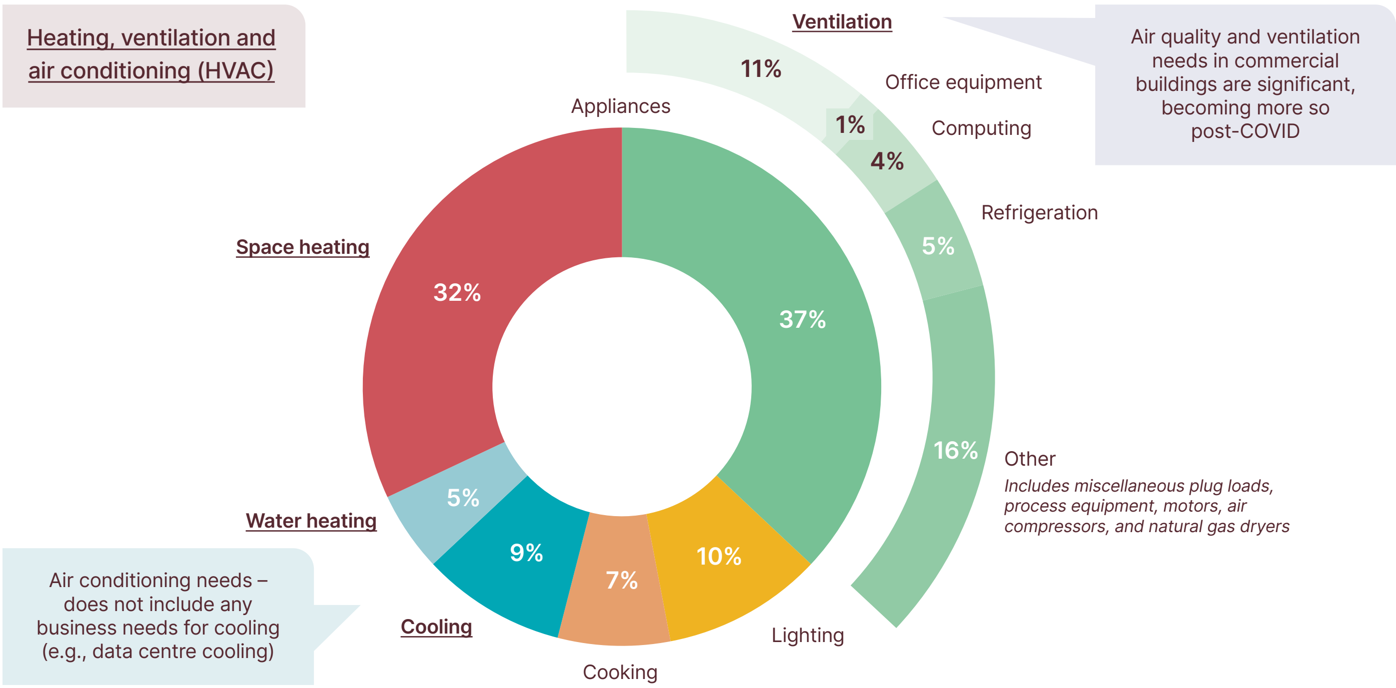
- Ventilation is one of the most important energy uses – this is especially the case post-COVID.

This aggregate picture, however, varies significantly across different types of commercial buildings in different sectors [Exhibit 7.2].

Exhibit 7.1

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



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

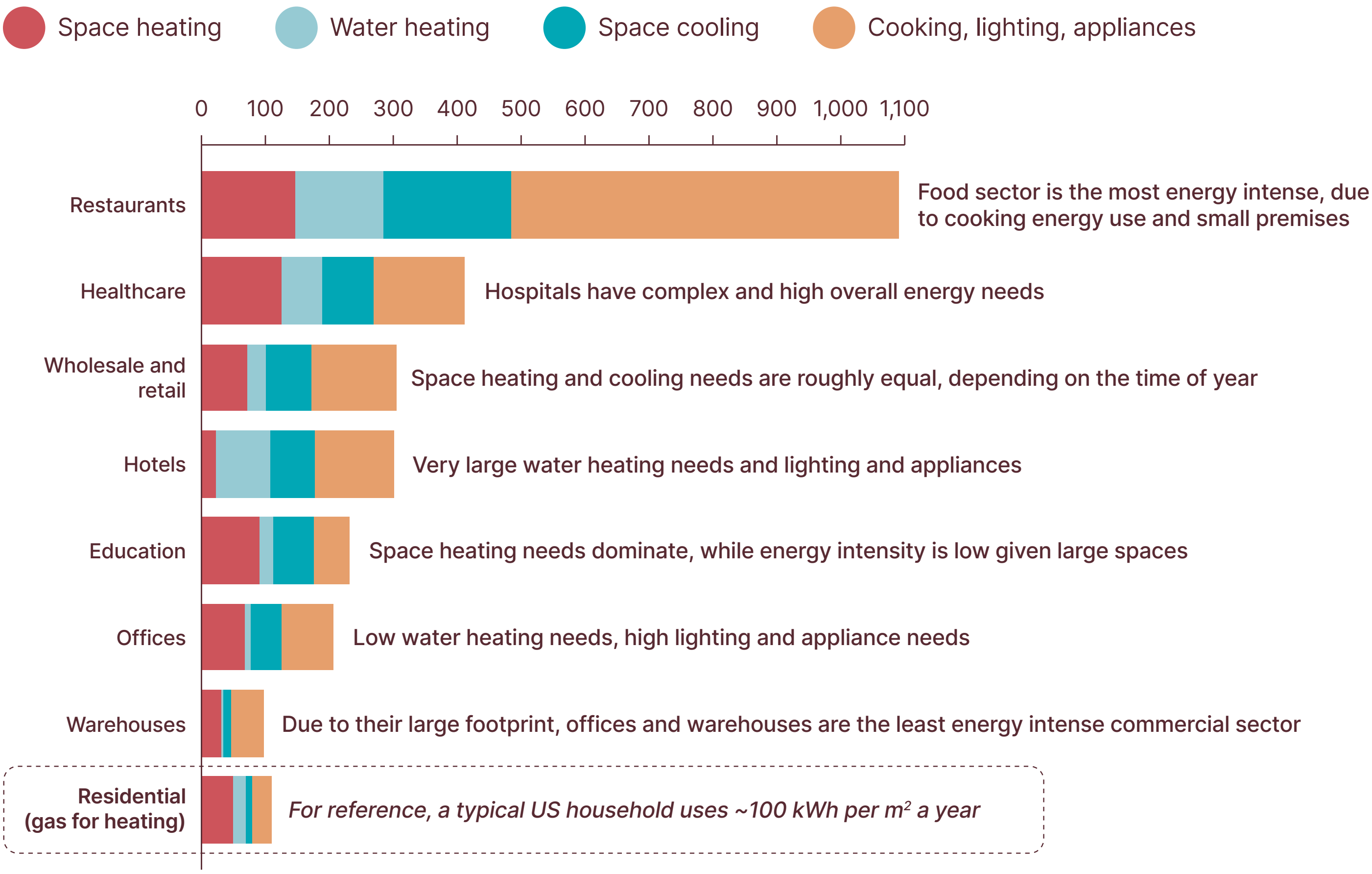
SOURCE: Systemiq analysis for the ETC; US Energy Information Administration (2018), *Commercial Buildings Energy Consumption Survey 2018*.

128 Electricity use to run machinery and equipment for industrial needs, such as manufacturing, data centres, and food processesing, are not included.
129 US Energy Information Administration (2018), *2018 Commercial 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*.
130 Ibid.

Exhibit 7.2

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 m² per year



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

At the aggregate global level, less is known about the energy efficiency of commercial buildings than residential buildings.

In most high income countries, regulation requires buildings to be rated according to some measure of energy performance. Where it does not, there are voluntary certification schemes:

- In the EU and the UK, it is mandatory for commercial buildings to acquire an Energy Performance Certificate (EPC) when they are built, sold, rented, or when there are major changes to its HVAC system.[131]
- In the US and Canada, it is voluntary to get an the Energy Star certificate from the Department of Energy.
- Across the world, building certification schemes award buildings that meet stronger energy efficiency and other environmental and health criteria, such as air quality and wellbeing.[132] These typically apply to the top 5–10% of the market.

131 European Council (2010), *Directive 2010/31/EE of the European Parliament and of the Council.*
132 Example certifications include LEED Buildings, Energy Star labelling, NABERS.

The challenge is that these rating systems typically provide imperfect indications of a building's actual energy performance:

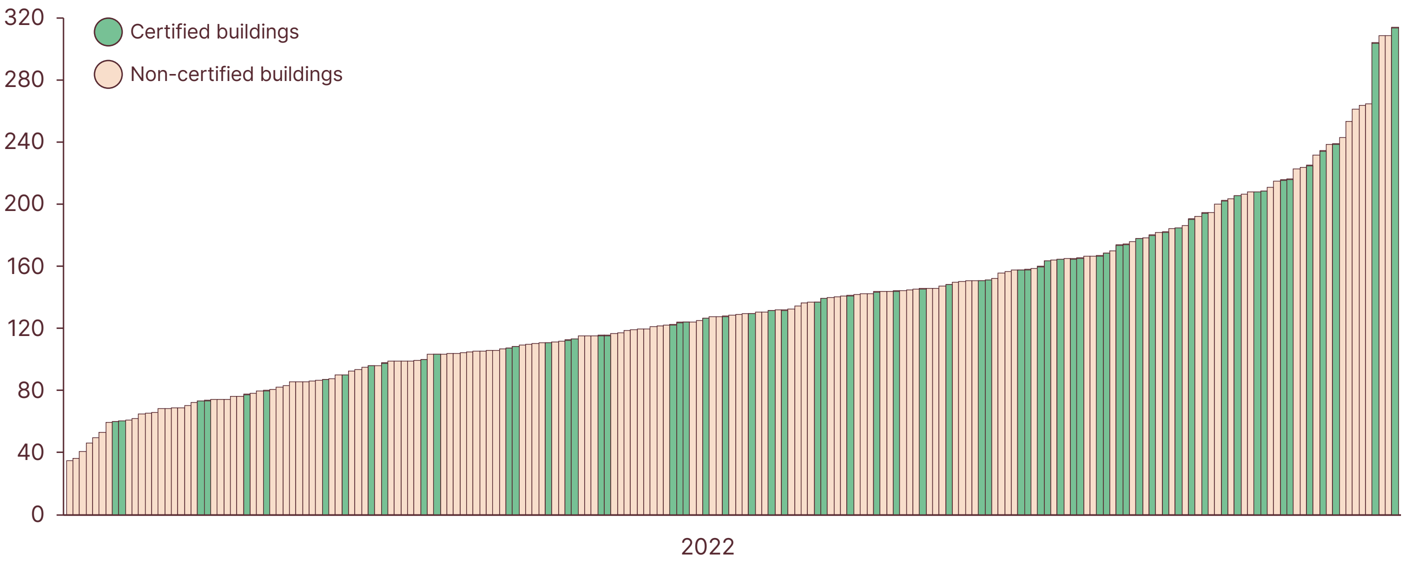
- While many certification schemes are now performance-based, requiring actual energy use data, EPCs do not.
- The vast majority of certification schemes do not have clear, publicly available targets for energy use that are broadly 1.5°C–aligned or better.[133] The methodology and criteria of EPCs is very unclear.
- While certification schemes generally have a more robust and accurate rating system, many reports have cast doubt over the quality of EPCs, including a high risk of errors and a lack of training of auditors.[134] For example, a report by the EPBD found that only 60–80% of EPCs are of good quality.[135]
- Most EPCs are valid for 10 years, meaning variables and information is often outdated.
- When comparing against benchmarks, many do not distinguish between different types of building with inherently different energy use per m².

While there exceptions – notably, NABERS – an energy rating scheme in Australia and the UK which has both clear, performance-based targets and publicly disclosed energy and carbon data – in general, certificates and certifications currently do not have a strong link to actual energy intensity [Exhibit 7.3].

Exhibit 7.3

There is currently no correlation between green building certifications and energy performance of commercial buildings

Energy use intensity of office buildings in Europe and the United States, by green building certification status
kWh per m² per year



SOURCE: LOTUF (2024), *Seeing is Believing: Unlocking the low-carbon real estate market.*

133 Leaders of the Urban Future (LOTUF) in partnership with Systemiq (2024), *Seeing is Believing: Unlocking the low-carbon real estate market.*
134 Li, Y., et al. (2019), *Review of building energy performance certification schemes towards future improvement.*
135 EPBD (2016), *Implementing the Energy Performance of Buildings Directive.*

7.2 Active clean heating and cooling technologies in commercial buildings

As we evidenced in Chapter 2, there are many clean heating technologies, but there will be no one-size-fits-all solution. This is true in residential buildings and arguably even more the case for commercial buildings, given the huge variation in types of building and energy need. For the key clean heating technologies, key nuances in commercial buildings include:

- **Air-to-air heat pumps:** These will likely be the dominant in many commercial buildings, being able to deliver space heating and cooling and work effectively in ducted systems, along with ventilation.
- **Networked ground source heat pumps:** These could be a very effective solution for large and new commercial buildings with sufficient scale to make financing the shared ground arrays easier.
- **Air-to-water heat pumps:** As with residential, these will be used in existing buildings that have a fossil fuel based wet heating system, but are unlikely to play a significant role in new buildings, given higher upfront capital costs and the fact that most new buildings will have cooling as well as heating needs.
- **Resistive heating:** With larger and more open spaces in many commercial buildings, resistive heaters would be even less efficient and have much higher running costs. They could play a role for some buildings that have very minimal heating needs. Tighter commercial building regulations are also expected to make the installation of relatively inefficient heating less feasible. Resistive water heating, however, will play a key role alongside air-to-air heat pumps.

In the past, the different elements of an HVAC system (heating, cooling, ventilation) have in many buildings been developed in isolation, and in some cases with a different energy source for heating and cooling. For example, gas-based heating or combined heat and power combined with ACs, single-zone heat pumps or ACs, or multi-split systems which deliver heating and cooling via separate ducts.

There is, however, an opportunity to shift to combined heating and cooling systems which are able to simultaneously heat and cool different areas of a building. Variable refrigerant flow (VRF) systems, for instance, involve multiple indoor units connected to on outdoor unit and a variable speed compressor, which enables the system to operate continuously but at varying speeds to match demand. Crucially, they are able to extract residual heat from a cooling zone and redirect it to a zone requiring heat. When heating demand is greater than cooling, the heat pump extracts heat also from the external environment. When cooling demand is greater than heating, excess heat is ejected into the atmosphere. This utilisation of waste heat enables them to be much more efficient, with the potential to reduce energy consumption by 30–40%.[136]

As with residential buildings, the shift from gas boilers to heat pumps or to more efficient combined HVAC systems, will often mean higher upfront cost; and this cost premium may be higher than in the residential buildings, due to larger and more complex systems, and important health and safety standards.

In some cases, tenants will be willing to pay higher rents for more efficient buildings, and developers and building owners will invest in the upfront equipment required. These “market driven” incentives could be strengthened by better information on building energy efficiency.

But in many cases, the complexity of commercial building relationships between developers, owners and tenants, with multiple different parties and contract lengths, makes it difficult for market incentives to work effectively. Tight regulation of new building energy efficiency is therefore needed to drive rapid change.

136 Trane Technologies (2022), *Electrifying buildings with VRF technology.*

7.3 Passive heating and cooling in commercial buildings

Sections 2.3 and 3.2 outlined the building design techniques that can reduce heating and cooling energy consumption by 15–40% in new residential buildings. Similar impacts can be achieved in commercial buildings, but with some differences in the typical impact of different measures:

- Roof insulation has a much smaller impact in multistorey buildings, but is key for warehouses.
- Wall insulation is also critical in warehouses, hospitals and hotels, but will play a smaller role in buildings with glass façades.
- Natural ventilation can play a very important role in reducing the need for mechanical ventilation.
- In commercial buildings, shading structures can be much more innovative and have significant impacts on energy consumption, for example green façades around data centres which also play a key role in reducing heat island effects.

Windows are a critical part of building façades for many offices, hotels, schools and retail. Various glass technologies exist to aid in passive heating and cooling:

- **Low-emissivity glass** minimises the amount of infrared and ultraviolet light that comes through glass without minimising the amount of visible spectrum light. It uses a coating of silver which is a poor radiator of heat, reflecting heat back inside for a consistent indoor temperature.
- **Electrochemical glass**, also known as “smart glass” allows buildings to control the amount of light and solar radiation that enters a building through variable glazing. It works by ionising particles within a conductive coating; when electricity is applied, the metal ions within the coatings are attracted to one face of the coating. This build up provides tinting within a double or triple glazed unit. Smart glass works best as part of a smart system, with predictive and real-time inputs (e.g., weather, location, cloud cover).

Commercial buildings also sometimes face a different set of considerations and trade-offs when it comes to building design and incorporating these techniques:

- **Aesthetics:** Certain design features can increase heating or cooling needs.
- **Natural lighting vs cooling/heating needs:** More windows can greatly reduce lighting requirements but can increase heating/cooling needs.
- **Air quality:** Natural ventilation can come at the expense of heating/cooling energy loss, whereas glass facades require more mechanical ventilation.
- Other considerations include safety and fire risk, accessibility requirements, and noise and acoustics.

Effective regulation to improve the energy efficiency of new buildings must therefore focus as much as possible on the net effect of different design features on energy use per m² (differentiated by building type) rather than mandating specific design features. The impact of passive heating and cooling techniques is maximised when also combined with other smart and flexible technologies [Chapter 8 and Box K].

Box K Combining passive building design and smart technologies: Century Pacific Tower, Philippines

ArthaLand Century Pacific Tower is a 38,000 m² office building that is the only triple-certified building in the Philippines, including a Premium LEED rating.[137] Compared to typical industry benchmarks, the building uses 45% less energy per m², 65% less water, and reduced embodied carbon from materials by 35%.

Key features include:

- Triple– and double–glazed windows, strategically oriented to insulate the building from heat while allowing natural light in.
- HVAC systems designed with thermal zoning to optimise for different cooling requirements across the building, and an energy efficiency rating (EER) of 15.
- An Energy Recovery Ventilation (ERV) system to recover the cool air from expelled interior air and transfer it to incoming outdoor air.
- Intelligent daylight and occupancy sensors to control lighting.
- 100% of its energy needs are met by a nearby hydroelectric plant.

7.3.1 Retrofit of commercial buildings for better energy management and insulation

As discussed above, there is huge potential to improve the energy efficiency of new commercial buildings. The next question is how to improve the efficiency of existing buildings and how large is the potential?

For residential buildings, as we discussed in Chapter 2, investment in improved insulation will often be appropriate, though with a focus in many cases on low cost options rather than deep retrofit. For commercial buildings, the optimal approach will differ significantly according to specific circumstances.

In many circumstances, the optimal focus is likely to be on the introduction of energy management systems rather than fabric improvement for three reasons:

- Smart technology can be much more sophisticated (see Chapter 8) and operated by building management companies.
- Making fabric improvements solely to improve energy efficiency in existing buildings can be much more challenging given the complexities created by owner/tenant relations, multiple tenants in one building, and differing contract lengths for different tenants.
- The lower relative importance of heating and cooling relative to lighting and appliances, which means the potential payback from building fabric changes can often be lower than investing in other energy efficiency improvements, such as smart energy management systems (see Chapter 8). Research by Schneider Electric shows that these systems lead to a 20% reduction in energy use on average, repaying their investment in 2–4 years.[138] In Europe, commercial buildings with an EPC rating of D would instantly move up to C or B by installing a smart system.

137 World Green Building Council, *ArthaLand Century Pacific Tower*, available at www.worldgbc.org/case_study/arthaland-century-pacific-tower. [Accessed 24/10/2024].
138 Schneider Electric, *Non-residential buildings: high efficiency potential, low-retrofit cost.*

But it is a feature of commercial buildings that many undergo periodic substantive retrofit for reasons unrelated for energy efficiency, for instance to respond to different tenant preferences for space layout in offices, new designs and amenity needs in retailing and hotels, or changed/increased IT requirements. These deep retrofits create an opportunity to simultaneously improve insulation standards, but in Europe today, it is estimated that only 5% of deep retrofits result in more than 3% of energy savings.[139]

Regulations should be designed to ensure that when deep retrofits are occurring, buildings are brought up close to required new build standards.

7.4 Actions for policy and industry to accelerate adoption of clean technologies

In residential buildings, we concluded that policy and regulation will be the most critical drivers of energy efficiency improvements and emission reductions, with a limit to the extent to which individual households will respond to market incentives or take voluntary actions to reduce emissions.

In commercial buildings, regulation must also play the leading role, but voluntary commitments by industry players could also be important if informed by improved information.

7.4.1 Regulation to drive energy efficiency improvement and emissions reduction

Stronger regulation must play the key role in ensuring that new buildings are built to high energy efficiency standards, and that when deep retrofits occur for non-energy related reasons, standards close to those for new buildings are imposed. To achieve effective regulation, the imperfections of energy performance assessment systems described in Chapter 7.1 must be addressed.

Developing commercial building codes is inherently harder than in the residential sector, given the huge heterogeneity across commercial building types and the lack of data on actual building performance meaning there is no clear starting point.[140]

However, there is a clear opportunity for more ambitious and better designed regulation. Indeed, there is a strong case for setting much earlier targets for the transition away from fossil fuel heating in commercial buildings, including:

- Set ambitious targets for reductions in energy use intensity, and identify the priority lowest-performing buildings to renovate. The EU's revised EPBD has committed to renovate 26% of the lowest-performing commercial properties by 2033.
- Create a more effective energy performance certificates system by:
    - Differentiating criteria by commercial building type and ensuring there is a strong correlation between criteria and energy performance.
    - Mandate that these must be updated at least every five years, or after any substantial retrofit.
    - Create effective enforcement and monitoring mechanisms.
    - Ensuring data is reported to national authorities, so EPC certificate can then include comparisons to the average.
- Mandate commercial buildings to improve their energy efficiency. For example, in France, building owners must annually declare their energy consumption via an online platform and reduce this by 40% by 2030. In the UK, rented commercial buildings must have a minimum EPC rating of C from 2028 (up from E today), and B by 2030.

139 European Commission (2020), *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives.*
140 For example, commercial building regulations tend to treat airport arrivals/departure lounges as "lobbies", but frequent open doors and large spaces mean that maintaining regulated lobby temperatures requires a significant amount of energy. A study found that increasing HVAC thermostats in one airport from 25°C to 27°C reduced energy consumption 25% during the hot months. See Sayed Hassan Abdallah, A. et al. (2021), *Energy audit and evaluation of indoor environment conditions inside Assiut International Airport terminal building, Egypt.*

- In countries without established building codes, regulation needs to move gradually and begin with being prescriptive (e.g., specifying passive techniques) and move to performance based over time (e.g., kWh per m^2).
- Make it mandatory that any renovation of commercial buildings must achieve a material improvement in energy efficiency.

7.4.2 Voluntary commitments and market incentives

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

1. There are cost savings and revenue streams associated with more efficient and flexible buildings.
2. 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.
3. Commercial businesses, investors and building owners will have their own net-zero and financed emissions commitments.

A well-functioning low-carbon commercial building market needs strong demand signals from lenders, tenants, investors and fund managers, with a clear link between energy efficiency and value. This requires transparency on building performance, based on actual energy use data and clear benchmarks of what "good" energy intensity is.

Building certifications can help make this link, by rating buildings for going above and beyond regulations. The challenge is that major certifications and ratings tools today do not provide transparency on carbon and energy performance and do not have clear targets that are broadly 1.5°C–aligned or better.[141] For example, Exhibit 7.3 shows that there is no correlation between certifications and energy performance. Box L sets out what is required to create a well-functioning certification market.

Box L What does a well-functioning building certification market look like?

Certifications can create a strong demand signal if they:[142]

- Measure and assess whole building emissions, including operational and embodied.
- Set out clear and ambitious minimum requirements for energy use intensity, which go far above regulated limits.
- Set ambitious goals for whole-building emissions which are 1.5°C aligned and backed by science-based pathways.
- Measure and assess performance using actual carbon and energy data.
- Provide transparency through publicly available targets, metrics and assessments.

141 Leaders of the Urban Future (LOTUF) in partnership with Systemiq (2024), *Seeing is believing: Unlocking the low-carbon real estate market.*
142 Leaders of the Urban Future (LOTUF) in partnership with Systemiq (2024), *Seeing is believing: Unlocking the low-carbon real estate market.*

Crucially, net-zero commitments from the private sector depend upon well-functioning building certification. In turn, voluntary commitments will accelerate the development of data, benchmarks and transparency:

- **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.[143] Investors and fund managers should set out clear plans to reduce financed emissions.
- **Cities and governments** should collect data on public buildings, offer policy incentives (e.g., fast tracked permitting), and provide education and awareness of best practice.

143 In the UK for example, OakNorth, a commercial lender, have committed to ensuring all new property financing deals have a path to achieving at least an EPC B rating by 2030.

Buildings in a clean energy system: Managing growing electricity demand via efficiency and flexibility

8

Key messages

- **The future is (primarily) electric.** It is technically and economically feasible to almost entirely eliminate the direct use of gas and oil in buildings by 2050, with falls of around 15–20% possible by 2030. We are moving from an energy system where energy for buildings is supplied by a variety of fuels, to a system in which it is virtually exclusively electric (including district heat networks generating heat with heat pumps).
- **This means that annual electricity requirements for buildings in 2050 could be 2.5–3 times higher than today due primarily to electrification of heating and expansion of cooling.** Electricity use in buildings could increase from 12,800 TWh to around 35,000 TWh. Crucially, the supply of clean zero-carbon electricity and investment in network upgrades needs to keep pace with rising demand to limit adverse impacts on emissions.
- **However, electrification is efficiency.** Without a shift to electric technologies, total energy used in buildings could increase from the equivalent of 36,600 TWh to the equivalent of 57,500 TWh due primarily to population growth and rising living standards. Transitioning to electric technologies reduces total energy needed to 35,000 TWh.
- **Energy efficiency levers could reduce global electricity demand to operate buildings in 2050 by a further 50%,** in theory to only around 18,000 TWh. The crucial unknown is level of uptake of these key technologies:
    - Shifting to best in class efficient technologies in heating, AC, lighting and appliances. This could reduce electricity needed to power by around 25%.
    - Building new buildings to higher standards and incorporating passive heating and cooling techniques, and retrofitting existing buildings.
    - Improving demand efficiency through the installation of smart systems and encouraging behaviour change (e.g., turning cooling thermostats up).
- **Electricity demand for buildings will create peaky demand which could be challenging for clean power systems, especially local grids, to manage.** Heating and cooling needs fluctuate over days, weeks and months, creating balancing challenges when this does not align with renewable generation. Electricity systems must be sized accordingly, leading to higher costs for storage and dispatchable generation.
- **But a whole-building approach to decarbonisation can transform buildings into energy assets.** There is huge untapped potential for buildings to provide demand-side flexibility through improved insulation, water and battery storage, rooftop solar PV and smart systems. Buildings can therefore complement the increasing penetration of cheap, variable renewables, varying the time at which electricity is drawn from the grid to match when wind and solar generation is abundant.

The previous chapters have shown the technical and economic feasibility of transitioning to clean and more efficient electric technologies. Combined with improved access to cooling, lighting and appliances across the world, the buildings energy transition will – with the right policies – fundamentally improve living standards, air quality, health and lower energy bills, while making vital contributions to reducing emissions.

However, it will create significant additional demand for electricity and, in particular, for electricity at periods of peak demand, creating major challenges for renewables-dominated power systems. This chapter assesses the scale of the challenge and the actions that can be taken to manage it, integrating insights from each of Chapters 2–7. It considers in turn:

- Final energy demand and electricity demand in buildings from now to 2050 and the challenge of balancing variable renewable electricity supply vs. building power demands.
- Opportunities to reduce overall electricity use, while delivering the same end consumer benefits.
- Opportunities to reduce peak electricity demand from buildings.
- The implications for future electricity demand of all the efficiency improvement options considered in Chapters 2 to 7.

8.1 Buildings electricity demand and renewable supply

8.1.1 Final energy demand: Total energy needed to operate buildings by mid-century

Holding today's fuel and technology mix constant, final energy demand for heating, cooling, cooking, lighting and appliances could increase by 60%, from around 36,600 TWh today to around 57,500 TWh in 2050, as populations, incomes and urbanisation increase.[144, 145]

However, Chapters 2–7 have shown it is technically and economically feasible to almost entirely eliminate the direct use of gas and oil in buildings by 2050, with falls of around 15–20% possible by 2030. Across heating, cooling, cooking and appliances, the dominant clean technologies are likely to be electric.

Electrification is efficiency. The near 100% electrification of heating and cooking by 2050 will reduce final energy demand by 30%, driven by heat pumps which are 3–4 times more efficient than gas boilers and the transition away from very inefficient biomass for cooking, where as little as 10% of energy is converted to useful heat.

While final energy demand will fall relative to continuing a fossil-fuel based heating system, the challenge is that we are moving from a system in which a variety of fuels supply buildings energy, to a system in which energy supply is predominately electric. This means that electrification combined with rising demand could lead to a 2–3 times increase in electricity used to operate building across the globe.

Today, around 12,800 TWh of electricity is consumed by the world's buildings.[146] In an electrification only scenario without additional action to realise energy productivity opportunities, this could increase to around 35,500 TWh. Household electricity demand will be further increased by the need to charge EVs. This has huge implications for the extent and pace at which countries need to build a resilient clean power system.

144 Final energy refers to energy supplied to the final consumer for all energy uses and across all fuels and technologies.
145 Systemiq analysis for the ETC; IEA (2021), *Net Zero by 2050.*
146 IEA (2023), *World Energy Outlook 2023.*

8.1.2 Peak energy demand: The daily and seasonal time profile of building energy use

The fundamental challenge with a renewables-dominated electricity system is that the availability of solar and wind varies across days, months and years. This means renewable generation, storage solutions, and any dispatchable generation must be sufficiently sized to:

- Meet the highest possible electricity demand at a given moment in time, for example, hourly demand during a cold snap.
- Meet sustained high electricity demand over months, for example, a particularly hot summer followed by a particularly cold winter.

Ensuring peak electricity demand is met therefore has huge implications for building, managing and running a clean energy system, and its costs, emissions, and, in some cases, security of supply.

A renewables-dominated clean power system faces three balancing challenges:

1. **Daily balancing** to manage demand fluctuations over the day and night when the sun doesn't shine or the wind isn't blowing. Heating needs tend to peak in the morning and evening [Exhibit 8.1], while cooling needs tend to peak in the middle of the day and into the night [Exhibit 8.2]. In comparison, the sun shines most during the middle of the day but solar generation will be non-existent at night.

   It is important to understand that from a final energy demand perspective, the transition to heat pumps will more than halve the energy required at peak times compared to gas. It will also create smoother peaks as heat pumps operate at lower temperatures for longer, compared to gas boilers which are turned on and off in response to demand. There is also growing evidence that because heat pump use doesn't coincide with peak appliance use, local distribution networks only need to increase capacity by 50% of a heat pump's peak electrical load.[147] But shifting to an electric system will still lead to a 4–6 times increase in household electricity needs.

2. **Seasonal balancing** to manage predictable month-by-month cycles in demand and supply. In Northern latitude countries, heating needs peak in the winter months of October to March, when wind supply is typically higher but solar generation is reduced [Exhibit 8.1]; cooling needs in these countries peak in the summer months where wind output can be lower [Exhibit 8.2]. In other parts of the world, cooling needs and renewable generation can vary across dry and wet seasons.

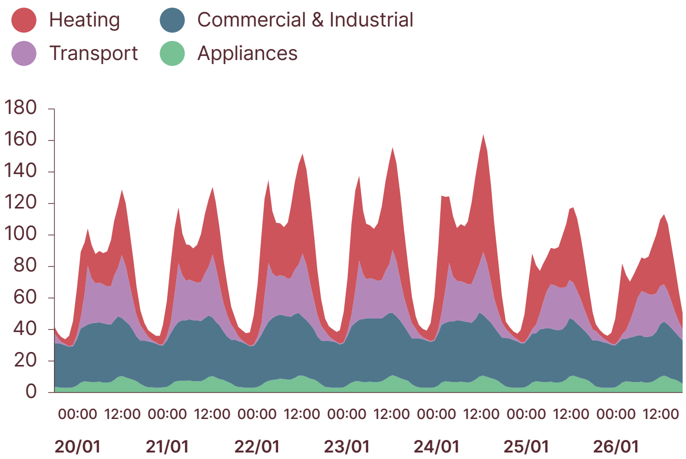
3. **Unpredictable week-by-week variations** that cannot be forecast well in advance and vary in importance each year, for example, extended weeks of "wind droughts"/anticyclones which reduce wind generation, or extreme heatwaves which increase demand.

147 Independent Networks Association (2023), *Low Voltage Design Standard.*

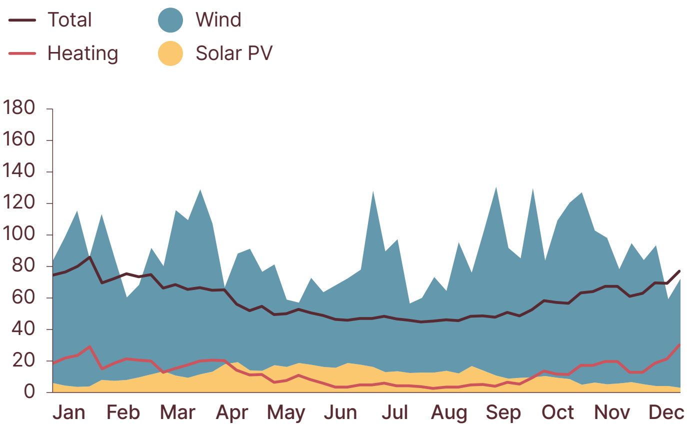
Exhibit 8.1

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



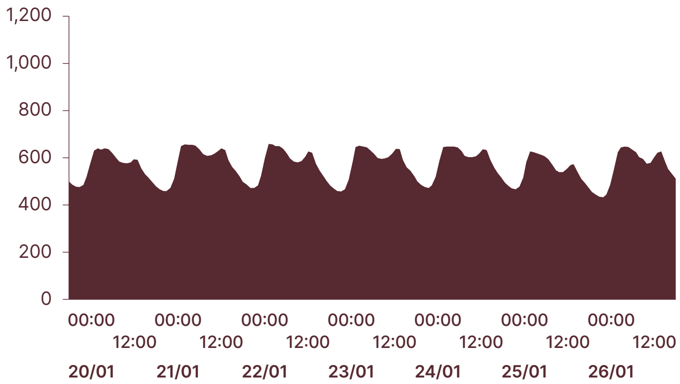
NOTE: Scenario assumes installed capacity of 75 GW of solar, 60 GW of onshore wind, and 100 GW of offshore wind, and minimum weather years out of the past 30 years (2010). Assumes a highly electrified economy, across residential, commercial and industrial sectors; excludes electricity load from storge 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*.

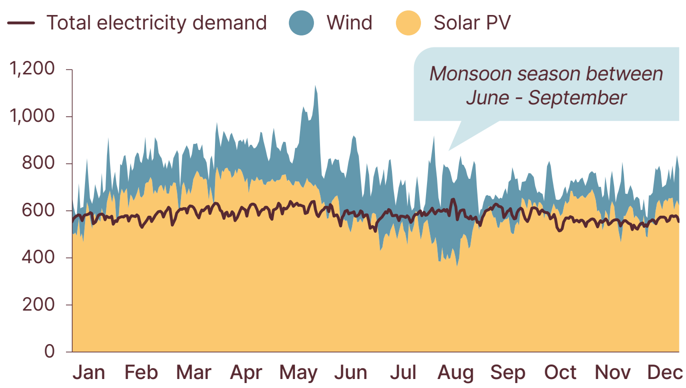
Exhibit 8.2

Cooling needs tend to peak in the middle of the day and nighttime; AC is required all year round, but solar generation falls significantly during the Monsoon months

Projected hourly economy-wide electricity demand, India, a week in January 2050
GW



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



NOTE: Scenario assumes installed capacity of 2,750 GW of solar, 650 GW of onshore wind, and 80 GW of offshore wind, and minimum weather years out of the past 30 years (2010). Assumes a highly electrified economy, with annual demand of 5,550 TWh.

SOURCE: Systemiq analysis for the ETC; TERI (2024), *India's Electricity Transition Pathways to 2050*.

The big challenge with seasonal and unpredictable variations is when increases in demand coincide with decreases in renewable generation. For example, unpredictable reductions in supply may coincide with spikes in demand (e.g., anticyclone induced wind droughts during a cold snap). In 2023, China's worst heatwave and drought in six decades simultaneously increased demand for AC and reduced hydroelectricity supply, the nation's second biggest source of power. In response, coal output was boosted to generate electricity to meet increased cooling demand.

The ETC has discussed these challenges extensively in our *Making Clean Electrification Possible* report and we are returning to the question of how best to manage these balancing needs in our 2025 work programme.[148]

In general, there are many cost effective solutions to solve daily balancing challenges at the grid level; lithium-ion batteries will be the dominant technology in most countries, supported by pumped hydro, flow batteries, compressed air energy storage, and vehicle-to-grid charging.

And as we outline in this section, there are also many solutions that can be deployed at the building-level to balance demand and supply across hours and days, including insulation, solar PV, water storage, and smart energy systems.

Managing seasonal and unpredictable variations is much more challenging, but solvable with a range of solutions that the ETC is exploring in depth in our *Power Systems Transformation workstream*, which will complete in 2025.[149] These include:

- Long-term energy storage (e.g., pumped hydro or hydrogen).
- Dispatchable generation (e.g., gas-fired turbines with CCS or burning hydrogen rather than methane).
- Interconnectors to import electricity from other countries.
- Overbuilding renewables relative to average daily demand levels in order to be able to meet peak demand on some occasions. This will produce a surplus of power supply at some times, which may be useable to produce green hydrogen.

While building-level solutions cannot bridge supply gaps beyond weeks and months, any reductions to overall electricity use over the course of a year can help preserve storage capacity and aid in seasonal balancing.

Addressing the peak demand challenge with greater building flexibility will also increase the utilisation of grids and should feed through to lower costs of electricity.

148 ETC (2021), *Making Clean Electrification Possible*.
149 Forthcoming in 2025. See also ETC (2021), *Making Clean Electrification Possible*.

8.2 Managing electricity demand: Opportunities to reduce electricity use and increase flexibility

Beyond electrification (which is, in itself, efficiency), there are five main areas of opportunity to reduce both total electricity used by buildings (final energy demand) and to reduce peak electricity needs while at the same time lowering energy bills and improving comfort [Exhibit 8.3]:

1. Realising technical efficiency improvements in key technologies.

2. Reducing energy needs and losses through better building design and improved envelopes in new buildings, and through retrofit improvements to existing buildings.

3. Installing smart systems to optimise total energy use and the profile of energy use.

4. Installing rooftop solar PV to reduce electricity imports from the grid.

5. Deploying a range of power, water and thermal storage technologies to enable households to time-shift their energy demand.

Actions 1–3 can reduce overall electricity demand – we assess the scale of the opportunity for actions 1 and 2 in this section. Actions 2–5 can reduce peak electricity demand, in particular - the scale of this opportunity is considered in Section 8.3.

Together, these actions can reduce the total size of the clean power system we need to build to meet demands for electricity. Crucially, they can reduce the frequency at which more expensive low-carbon dispatchable generation is required to fill gaps in supply. In this way, it will further help lower energy bills and emissions. These solutions therefore need to be a core part of policymakers and network system operator's toolkits.

Exhibit 8.3

Creating efficient and flexible buildings will play a key part of managing electricity demand in an energy system of variable renewables

	1 Use less energy for the same output	2 Reduce energy needs and losses		3 Household demand-side flexibility	
Technologies and Solutions	Technical efficiency improvements	Better building design and retrofit	Smart systems	Solar PV	Storage solutions
Impact on final energy consumption	More efficient technologies consume less energy	Passive heating/cooling reduces energy needs, and insulation reduces energy loss	Optimise energy consumption according to need and incentivise household behaviour change	Reduces electricity imports from the grid	Only able to time shift demand - does not reduce the amount of energy needed
Impact on peak energy consumption	Reduces scale of peaks, but unable to load-shift	Enables households to pre-heat their homes ahead of peak times	Automatically time shift energy consumption based on needs in response to peak prices	Unable to time-shift demand – unless combined with a battery	Batteries, hot water storage, or heat storage enable time shifting of energy use to off-peak times

SOURCE: Systemiq analysis for the ETC.

8.2.1 Improving the efficiency of electric technologies

The simplest and most effective way to reduce electricity demand is to install more efficient equipment. This can often be done at a minimal, or even zero, cost premium and can significantly lower bills without any action or disruption to households.

Throughout Chapters 2–6, we outlined the significant potential for technical efficiency improvements across all technologies:

- **Air source heat pumps** are expected to see gradual improvements in average efficiency to 400–500% over the next 25 years, for example, due to variable speed motors and improvements in inverter technology which prevents a fall in performance at lower outdoor temperatures.[150, 151]

- There are already **air conditioners** on the market that can achieve a seasonal energy efficiency rating (SEER) of over 10.[152, 153] Yet the average AC sold only achieves a SEER of 4–8. Even without further innovation, improved minimum energy performance standards (MEPS) and labelling should be able to realise at least a 50% improvement in the efficiency of the AC stock by 2050.

- Moving towards **induction hobs**, which are around 80–90% efficient, compared to 70–80% for electric convection hobs.

- Similarly, improving the average efficiency of **household appliances** sold, with stronger MEPS and labelling, could lead to a 40% reduction in electricity demand in 2050.

- **LED lighting** is already 80% more efficient than incandescent lighting, and is expected to get at least 30% more efficient from today's levels. If all lighting were LED in 2050, electricity needs would be almost 60% lower vs. a scenario in which LED lighting continues to make up only half of global sales.

Looking across all technologies, technical efficiency improvements could lower electricity requirements in 2050 by 20%.

However, this doesn't take into account the risk of rebound effects, where households use a technology more because it costs less to use. However, in most cases this applies to lower-income households whose demand is less than their true need; this implies that some rebound effect is positive for human welfare.

8.2.2 Building more efficient new buildings: Better building design and envelopes

Global floor area is set to increase 50–60% by 2050, from 250 billion m² to 390 billion m². Exhibits 1.6 and 3.1 show that the key areas of growth will be:[154]

- In middle- and low-income countries (excluding China), where floor space is set to double, compared to a 20–35% increase in China and high-income countries.[155]

- In hot countries requiring cooling. On a global level, cooled floor area is set to increase 150%, compared to a 25% increase in heated floor area.

- Focused on residential buildings (an additional 110 billion m²), compared to commercial (additional 30 billion m²).

- Likely focused on apartment blocks to a large extent, given these are more common in rapidly urbanising emerging markets. However, the exact mix of building archetypes is very uncertain.

150 Based on ETC interviews with experts across the technology and buildings landscape.
151 Note that air-to-air heat pumps can generally achieve higher efficiencies than air-to-water heat pumps because the water in radiators needs to be heated to higher temperatures than the air to achieve the same room temperature.
152 SEER is measured by the cooling output during a typical cooling-season divided by the total electric energy input during the same period. IEA (2018), *The Future of Cooling*.
153 Despite being fundamentally the same technology, air conditioners are typically more efficient than heat pumps because the required temperature differential for ACs tends to be lower than for heat pumps (e.g., going from 35°C to 25°C, compared to going from 0°C to 20°C). See Annex 1.
154 IEA (2023), *World Energy Outlook 2023*.
155 However, if vacant buildings in China could be better utilised to limit additional build out, this projection could be much lower.

As outlined in Chapters 2 and 3, there are significant opportunities to incorporate passive heating and cooling techniques in building design and envelopes to both:

- Reduce the need for mechanical heating and cooling in the first place (e.g., orientation to reduce solar gain, using materials with high thermal mass).

- Reduce energy loss from mechanical heating and cooling (e.g., better insulation, air tight and high quality construction).

These techniques can reduce energy consumption by 15–40% in new residential buildings, with significant benefits for energy bills, living standards and for managing electricity demand.

Once a building is built, it will likely be around for 60–100 years (although retrofit happens much more frequently in commercial buildings) and making changes is significantly more costly and disruptive. It is therefore crucial to ensure the next generation of new buildings is built to higher standards, incorporates passive techniques, and maximises efficiency and flexibility.

The vital importance of stronger building regulations

In many countries, new buildings are subject to regulations which have implications for their energy use, including:

- Building codes, which specify construction, safety and design compliance.

- Minimum energy intensity requirements (kWh per m²). These are more common in mature, regulated markets.

- In some countries, such as Spain, regulations also specify that a certain share of a building's primary energy supply must be from renewable sources driving further technology and efficiency change.

These regulations set a minimum floor which all construction must meet; unless developers believe they can charge a premium, there is little incentive to go above this.

In recent years, building certification schemes have emerged to incentivise stronger performance, by awarding those which meet stronger energy efficiency criteria (as well as other environmental and health factors such as air quality).[156] These typically apply to the top 5–10% of the market.

Going beyond this, the Passive House standard is the gold standard for energy efficient buildings, with criteria which effectively sets the frontier of what is currently possible. Exhibit 8.4 shows that certified buildings typically consume 20% less energy per m² than one built to regulated standards, while a Passive House building consumes at least 50% less.

156 Example certifications include LEED Buildings, Energy Star labelling, NABERS.

The key question is how much does it cost to build to these higher standards? Understanding the incremental cost is challenging as there is no consistent baseline or definition of an energy efficient or green building. Based on a literature review of construction in high/middle income countries, we have drawn the following conclusions:[157]

- The cost premium of moving from current standards to typical certification levels and achieving at least a 20% reduction in kWh per m² is typically very manageable (1–5%).

- Achieving a further 30% or more reduction in energy intensity has a larger additional cost premium of 2.5–17.5%.

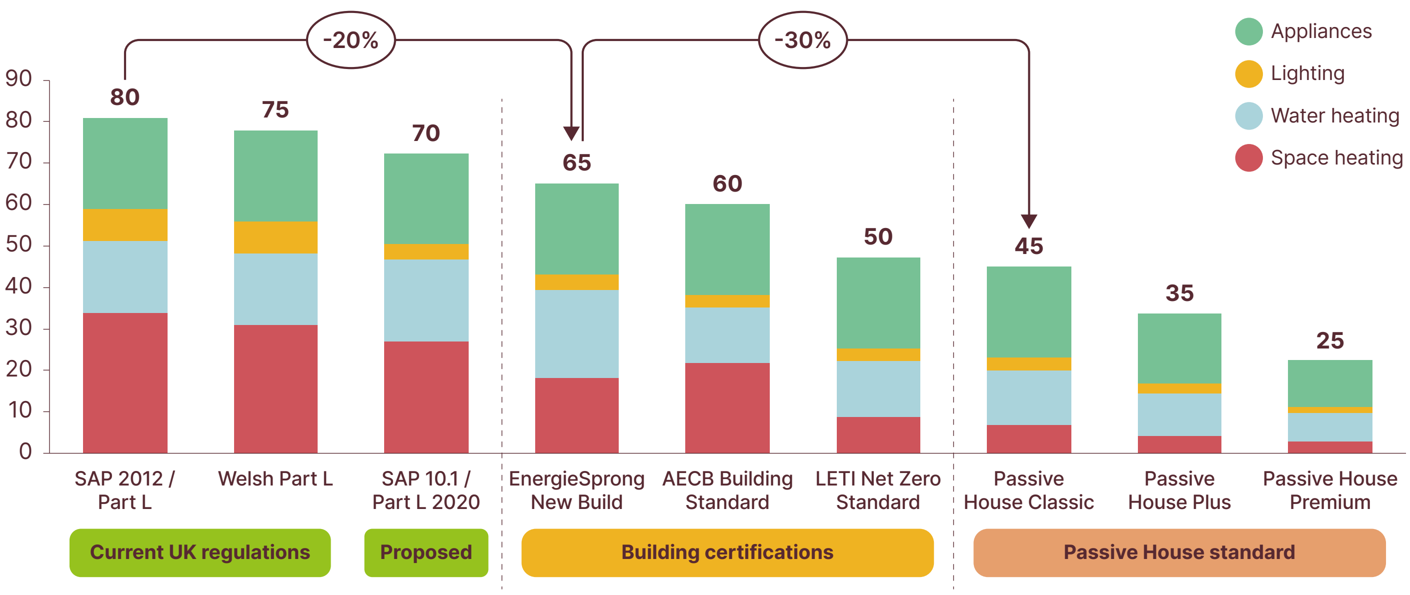
This suggests that, in countries with established energy intensity regulations, minimum requirements should move towards the level of certification standards over time, with a manageable and gradual additional cost [Exhibit 8.5]. In turn, certifications should continue to increase in ambition, pushing the industry frontier. With relatively low cost premiums and emerging evidence that energy efficient homes installed with clean technologies add to property values, major developers and housebuilders must also make voluntary commitments to build zero-carbon homes [Box M].[158]

The bigger challenge is in countries without established regulations, including large parts of Asia, most of Africa and South America, where most of the growth in new floor space will occur. Note, however, that even some US and Canadian states don't have mandatory building codes. In these countries, regulation must be gradually phased in, beginning with a code compliance approach and implementing minimum energy intensity requirements over time. While these minimum standards should be gradually tightened over time to ensure cost premiums are manageable and compliance, there is a huge opportunity for lower-income countries to leapfrog towards energy efficiency standards set by mature markets.

Exhibit 8.4

Certified and passive house buildings consume 20–50% less energy per m², due primarily to better insulation and passive heating techniques reducing active heating demand

Annual final energy consumption per m² by end-use and building standard (UK)
kWh per m²



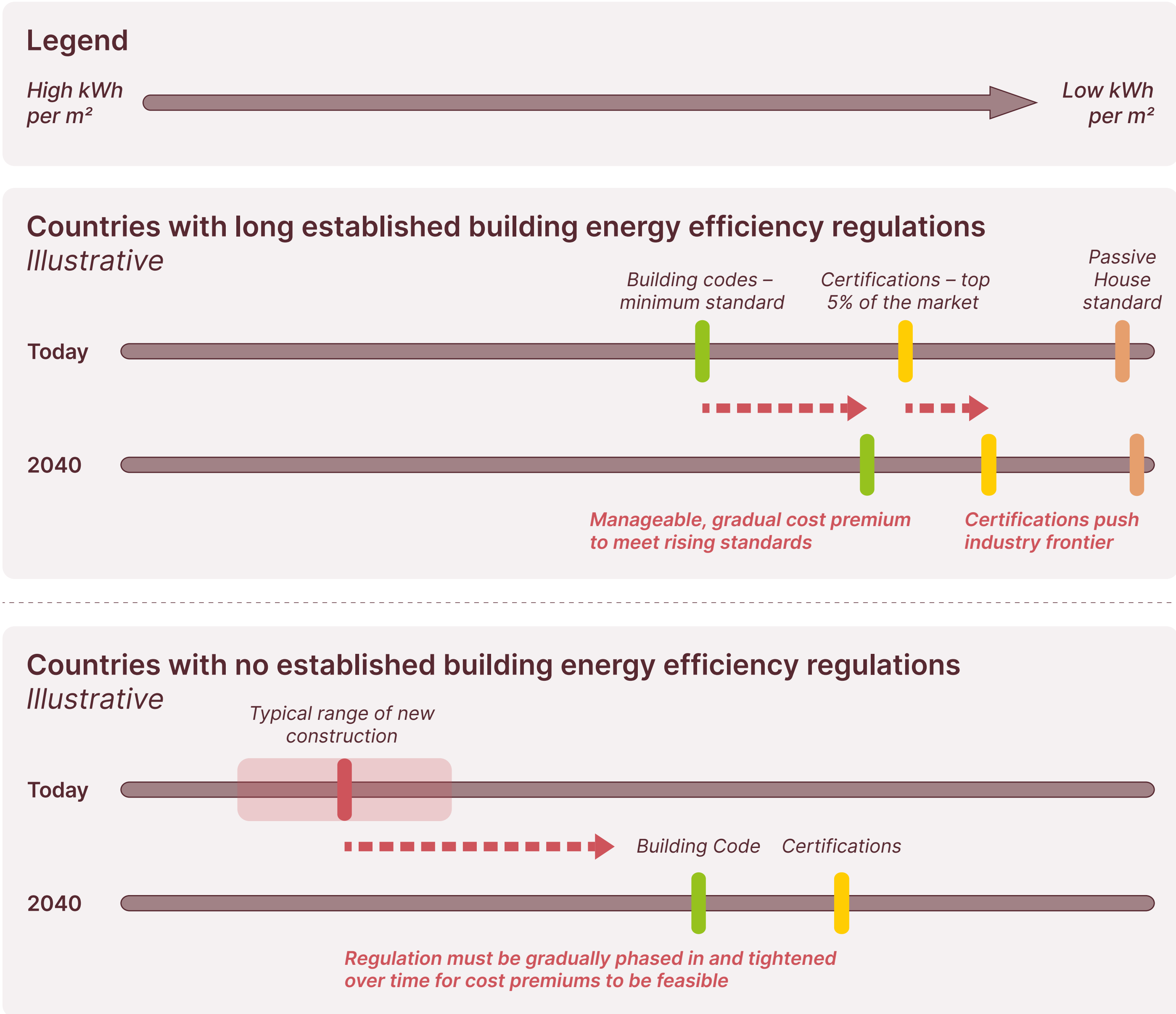
NOTE: Based on a three-bedroom semi-detached house which uses an air-source heat pump for space and water heating. Passive House Plus and Premium set annual renewable energy generation requirements of 60–120 kWh per m², implying excess supply.

SOURCE: Good Homes Alliance & Woodknowledge Wales (2020), *Building Standards Comparison*.

157 Buildpass (2021), *What is PassivHaus retrofit?*; Checkatrade (2023), *What is a Passive House and how much does passivehaus certification cost?*; Statista (2024), *Average construction cost of completed buildings per square meter in China in 2022, by region*; Chen (2020), *Evaluating the economic feasibility of the Passive House in China*; WSP (2019), *Green Building Strategies Cost Analysis*; UK Green Building Council (2020), *Building the case for net zero: A feasibility study into the design, delivery and cost of new net zero carbon buildings*; Davis Langdon (2004), *Costing Green: A comprehensive cost database and methodology*; TERI (2015), *Energy efficient buildings – a business case for India?*
158 Evidence from the UK suggests that a heat pump adds 1.7-3% to the value of the average home, solar panels add 0.5-2% and an EV charger adds 2-2.75%. See Sustainable Markets Initiative (2024), *Cleantech Homes: Lower bills, Healthier living.*

Exhibit 8.5

Building codes should move towards certification level over time, driving the industry frontier forward, while the Passive House standard defines the technical potential



SOURCE: Systemiq analysis for the ETC.

CASE STUDY

Box M **Octopus Energy's "Zero-Bill" Homes**

In the UK, Octopus Energy, in partnership with over 50 housebuilders, has pledged to deliver 100,000 "Zero Bills" homes by 2030.[159] A "Zero-Bills" home requires:

- New builds to be installed with a heat pump, solar panels and batteries, and to be built to high energy efficiency standards – enabling homes to generate more electricity than they consume.
- Octopus' Zero Bills Tariff which allows Octopus to optimise a household's energy consumption and energy exports, in return for no bills for at least 10 years.
- Emerging analysis suggests the "Zero Bills" proposition will unlock huge value for both homeowners and developers:
- Over 15 years, running cost savings can amount to £20,000 compared to a typical new home, or £50,000 compared to a typical existing home, driving significant willingness to pay from prospective buyers.[160]
- This means "Zero Bills" homes attract a valuation premium and customers have been shown to be willing to pay more. Most "Zero Bills" sites have so far fully recovered the additional costs for developers, which are typically £8,000–15,000 depending on the size of the home.

With plans to extend the proposition to energy efficient existing buildings too and other European countries, the "Zero Bills" homes initiative illustrates how the building's energy transition can go hand in hand with lower bills and improved living standards. It also highlights the importance of cross-sector collaboration and industry leadership in driving the transition.

Reasonable assumptions about the extent and pace that different parts of the world could implement and tighten building codes suggest that cumulative energy consumption from the stock of new residential buildings to 2050 could be around 20% lower.[161] But this could be significantly greater if much faster action were taken. Tightening building codes will be a gradual process, highlighting the critical importance of action this decade to drive continued and accelerated improvements.

Alongside this tightening of regulations, progress could also be accelerated via:

Market and voluntary actions, including:

- Net-zero commitments from developers to drive investment in energy efficient new building.
- Financial institutions, as part of their own net-zero commitments, encouraging action by developers, for example through favourable interest rates.
- In the commercial market in particular, net-zero commitments from businesses such as large hotel and restaurant chains and professional services (i.e. companies whose buildings are a large part of their Scope 1 and 2 emissions) could also drive demand for energy efficient buildings. Realising the potential of these demand signals requires improvements to the transparency and credibility of building certifications to create a strong link between energy efficiency and value (see Chapter 7).

159 Octopus Energy (2024), *Wave Goodbye to Energy Bills*, available at www.octopus.energy/press/Wave-goodbye-to-energy-bills-Octopus-targets-100000-Zero-Bills-homes-by-2030/. [Accessed 15/10/2024].
160 Sustainable Markets Initiative (2024), *Cleantech Homes: Lower Bills, Healthier Living.*
161 ETC analysis based on reasonable assumptions about how fast and to what level building codes could be introduced and tightened.

Public policies other than building regulation, including:

- Improving education and awareness of passive techniques and quality construction through pilots and demonstration projects, continued professional development for existing architects and developers, and sharing learnings across countries.

- Incentivising stronger action through fast-track approvals and permitting advantages (e.g., greater floor space) for energy efficient projects.

- Financial incentives, such as tax credits and subsidies and favourable lending rates.

8.2.3 Retrofitting existing buildings for energy efficiency

In Chapter 2, we showed that:

- Insulating existing homes to a very high standard is not a pre-requisite for installing a heat pump in most homes, as long as radiators and systems are appropriately sized.

- There are many low-cost and low-effort ways that existing buildings can be insulated, which can reduce energy consumption by around 5–15% and should be actively encouraged by policymakers.

- Insulation and living standards are closely linked and so retrofitting the least efficient properties should be a priority for policymakers.

The extent to which existing buildings will require retrofitting will vary massively across and within countries and estimating a global number is challenging. A reasonable assumption is that up to 75% of heated floor space could see some improvement to their levels of insulation, while it is likely that a much small share of cooled floor area will be retrofitted, given a large share of this is in middle- and low-income countries with new buildings and where affordability will be an even greater challenge.

8.3 Demand-side efficiency and flexibility: Time-shifting when buildings use energy

In today's fossil-dominated electricity system, supply is typically able to respond to changes in demand (e.g., firing up more gas turbines). In tomorrow's electricity systems based primarily on variable sun and wind, clean electrons will be cheap and abundant when the sun is shining and the wind is blowing. But balancing the timing of supply and demand will be more difficult, and will depend of the range of storage and zero-carbon dispatchable technologies outlined in Section 8.1.

There is, however, significant untapped potential for demand instead to flex in response to changes in supply, without major changes in behaviour change or a reduction in living standards. This is particularly true in buildings which have been decarbonised with a whole-building approach.

As set out in Exhibit 8.3, there are four main building-level solutions that can help to optimise household energy use and improve flexibility:

- Better building envelopes (e.g., insulation and thermal mass).
- Smart systems.
- Rooftop solar PV.
- Energy, water or thermal storage.

The incentives to invest in these will in turn depend on:

- Time-of-use tariffs: Flexible tariffs which better reflect the marginal cost of electricity generation at different times of day can create an incentive to time-shift demand.
- Sellback price: Compensation for exporting excess electricity generation back to the grid creates an additional incentive to invest in solar PV.

This chapter will step through these four solutions and comment on the actions required to rapidly increase adoption of these technologies.

8.3.1 Better building envelopes to enable pre-heating and cooling

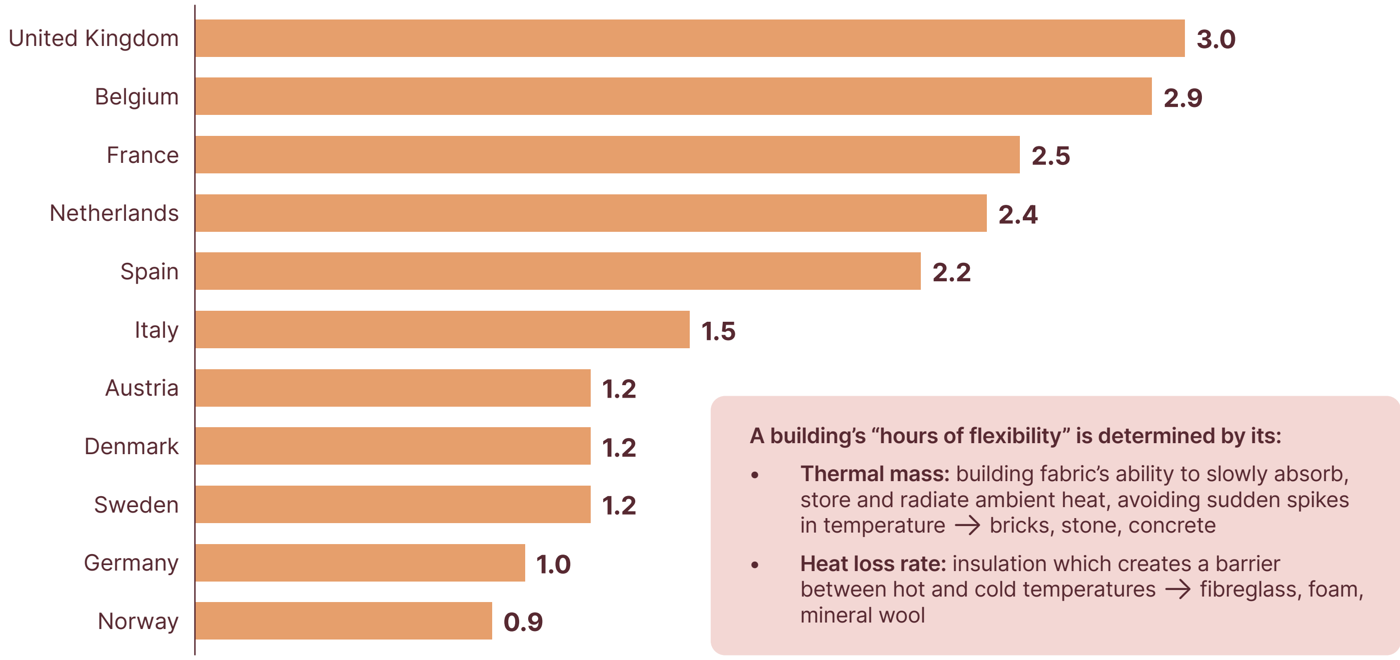
The previous section explored the importance of insulation and thermal mass from the perspective of lowering overall energy needs and losses. But crucially, this can also play a critical role in reducing peak energy demand, by enabling households to pre-heat or cool their homes ahead of peak times.

Exhibit 8.6 shows the heat losses in degrees centigrade that a typical building would experience over a five hour period in winter, with the UK's older and poorly insulated building stock losing 3°C, vs. 0.9°C and 1°C in Norway and Germany respectively. As a result, typical UK households have less flexibility to reduce peak electricity use by pre-heating homes during off-peak times.

Exhibit 8.6

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



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].

Today, there are some utility companies targeting climate-savvy consumers with dynamic tariffs that offer different peak and off-peak hourly or daily prices. For example, peak hour prices in Octopus Energy's Agile tariff in the UK averaged €0.18 per kWh in April 2024, compared to €0.08 per kWh for off-peak hours.[162] In February 2024, EDF's Tempo tariff in France averaged €0.75 per kWh on very high demand days and €0.13 per kWh on low demand days.

If there is a sufficient differential, these flexible tariffs can create an additional financial incentive for households to invest in insulation. Time of use tariffs are currently in their infancy and rely on innovation in retail markets and smart meter adoption, but are generally expected to become a more popular offering over time.

However, as more and more people adopt time of use tariffs, the spread between peak and off-peak prices is likely to narrow, though not disappear entirely – there will always be some energy use that cannot be shifted to off-peak times. Combined with the high costs of medium- to deep-retrofits, this means time of use tariffs are unlikely to fundamentally change the investment case for households to invest in insulation, especially given the uncertainty in how prices will evolve.

This underscores the importance of governments, regulators, network operations and electricity providers recognising the importance of insulation in addressing balancing challenges. As a result, optimal policies will involve governments offering financial support to households to afford the upfront costs.

162 Octopus Energy (2024), *Agile Portal*, available at https://agile.octopushome.net/dashboard. [Accessed 24/09/2024].

8.3.2 Smart systems

Smart systems, or building energy management systems, use automated processes and data to control and optimise the operation of installed technologies. They can reduce total energy consumption by 30% in commercial buildings and 15% in residential.[163] Key features include:

- Controlling heating/cooling and appliances remotely, smart thermostats, and only heating/cooling certain rooms – this helps to reduce unnecessary energy use.
- Optimising use of heat pumps and AC, turning them up and down in response to weather forecasts and time specific prices changes to meet set comfort parameters.
- Tracking and monitoring energy use and costs, enabling households to adjust their behaviour according to their budgets.

In addition to reducing overall energy consumption, these techniques can also enable demand-side flexibility. Smart systems can respond to price signals from energy providers or the grid to time-shift demand, for example, charging EVs overnight when electricity is cheaper. The true power of smart systems comes when combined with the full set of technologies – insulation, rooftop solar PV and storage [Box P].

Commercial building systems are typically much more sophisticated, including sensors (e.g., turning lights off automatically, sensing where office spaces are less occupied), connecting HVAC technologies together, and using analytics and AI to respond to real-time changes in weather, use of a building, and changes in prices, and the carbon intensity of electricity.[164] The crucial consideration for smart systems is that the energy they save must be more than the energy that the data centres that power them consume.

Box N demonstrates that the power of smart systems is greatest when combined with the other technologies described in this section – buildings need to be well-insulated to enable pre-heating and cooling, and installed with solar panels and batteries to fully optimise energy use.

We expect strong uptake of smart systems across both residential and commercial properties in high-income countries and China, even without strong policy frameworks in place. They can be fairly low-cost (e.g., around €100 for a smart thermostat, up to €500–1,000 to connect all relevant technologies in a residential house), and can have a big impact on reducing overall energy consumption and therefore energy bills. In addition, they will play a really important educational role as we transition to a renewable energy system, helping people better understand how energy supply varies over time and the impact on prices.

163 Schneider Electric (2021), *Cracking the Energy Efficiency case in Buildings.*
164 For example, see BrainBox AI and Schenider Electric products.

Box N The combined power of smart technologies: Kallang Pulse, Singapore

Schneider Electric is aiming to be carbon neutral and to fully run its buildings on renewable electricity by 2030. Schneider Electric's Asia headquarters is a 25-year-old, nine-floor building of over 18,5000 m².[165] It was retrofitted in 2018 with a full set of zero-carbon technologies: rooftop solar, energy efficient LED lighting and equipment, and an advanced building energy management system.

Over 5,000 connected Internet of Things (IoT) points including CCTV, card access points, and motion sensors generate real-time data on occupancy and energy needs. This is combined with data on outside temperature, humidity, noise, and light levels to make informed decisions on HVAC and appliance usage, maximising energy efficiency.

In addition, solar panels were installed on car park rooftops and in the gardens, enabling the building to run on 100% renewable electricity during the day.

The smart improvements to the building save an estimated 120,000 kWh of electricity and 3,700 m³ of water a year.

8.3.3 Rooftop Solar PV

Rooftop solar PV does not reduce final energy consumption from an economy-wide perspective, but it does reduce the amount of electricity households and businesses import from the grid. This lowers bills and can reduce the scale of grid upgrades and storage required at a national level, especially if excess generation is sold back to the grid.

Estimates of the levelised cost of solar PV generation have fallen 90% over the last decade, and the strike price of winning bids at auctions are often far lower than the latest LCOE estimates [Exhibit 8.8]. This reflects the dramatic reductions in the cost of solar panels, which have fallen by more than 90% since 2012, reaching $100 per KW at wholesale level in China and $150 in India. In these two countries, the total cost of equipment for utility scale solar projects (but not including land and grid connection cost) has fallen to $300 per KW.[166]

Cost for utilities-scale development in developed countries are significantly higher, and costs for rooftops systems often higher still (in particular, in the US).[167] But analysis suggests that there is a strong investment case for rooftops solar PV in most high-income countries.[168] And the collapsing cost of panels in many developing countries is unleashing dramatic increases in rooftop solar installations. Indeed in 2023, around half of global solar capacity was from distributed generation, roughly evenly split between residential and commercial and spurred on by high energy prices in 2021 and 2022.[169]

As more heating is electrified in high-income countries, and as cooling and other demands for electricity grow rapidly in hot countries, a rising share of households is likely to install rooftop solar, even if there are not specific government policies to support this development.

However, as with heat pumps, affording the upfront costs is a barrier for many, meaning the provision of low-cost finance should be a key policy priority. It is also critical that policy enables competition and for consumers to benefit from falling technology costs; for example, rooftop solar prices in the US are around 3–4 times higher than in China.[170]

Particularly strong uptake is expected from higher-income households in middle- and low-income countries that have high cooling needs, given AC use coincides with when the sun is shining. Unreliable grids will provide an additional incentive in some cases.

165 Schneider Electric (2020), *Our Smart Building Journey*.
166 Based on ETC interviews with local manufacturers and generators.
167 Lazard (2023), *2023 Levelized Cost Of Energy+*.
168 Our analysis of the financial returns of rooftop solar PV in Europe and the US based on 2023 energy prices suggest investments are paid within 10 years.
169 IEA (2024), *Solar PV*, available at www.iea.org/energy-system/renewables/solar-pv. [Accessed 01/10/2024].
170 BNEF (2024), *Evolution of the Rooftop Solar Industry*, available at www.bnef.com/themes/p2r6qv6jijv701. [Accessed 21/10/2024].

For commercial buildings, the incentive to invest heavily depends on available roof space; warehouses, for example, have a very high roof-to-floor ratio, while multistorey offices do not. Exhibit 8.7 shows how the share of total energy needs that solar generation can meet varies hugely across different commercial buildings. For those with large, flat roofs, such as warehouses, this implies the need for strong regulation which requires all new large, flat roof commercial buildings to have rooftop solar PV.

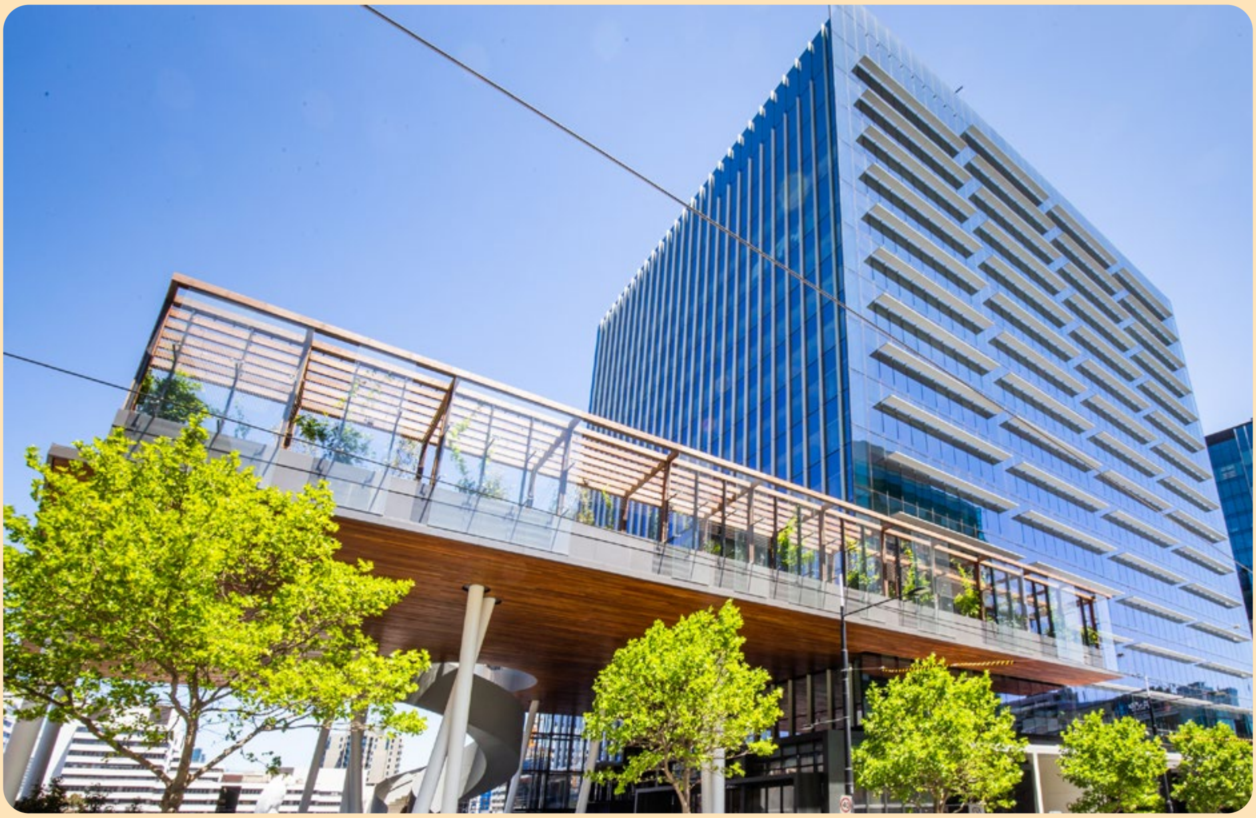
For those with minimal roof space (i.e. the 12-floor, large office illustrated), this underscores the importance and potential impact of improved insulation and smart systems [Box O]. Tall office buildings may also increasingly be able to deploy solar panels integrated into façades.

CASE STUDY

Box O **Solar PV and passive design in high-rise buildings: One Melbourne Quarter, Melbourne**

As a 13-storey office building, One Melbourne Quarter has very limited roof space.[171] But by incorporating passive design features, a 200 kW solar PV array is able to provide 10% of the building's very large base electricity consumption. These features include:

- A high performance façade with optimised shading, thermally broken double-glazing (which adds an insulating barrier between window panes to slow the effects of heat transfer), motorised internal blinds and an air-tight building envelope.
- A white roof to reduce the urban heat island effect.

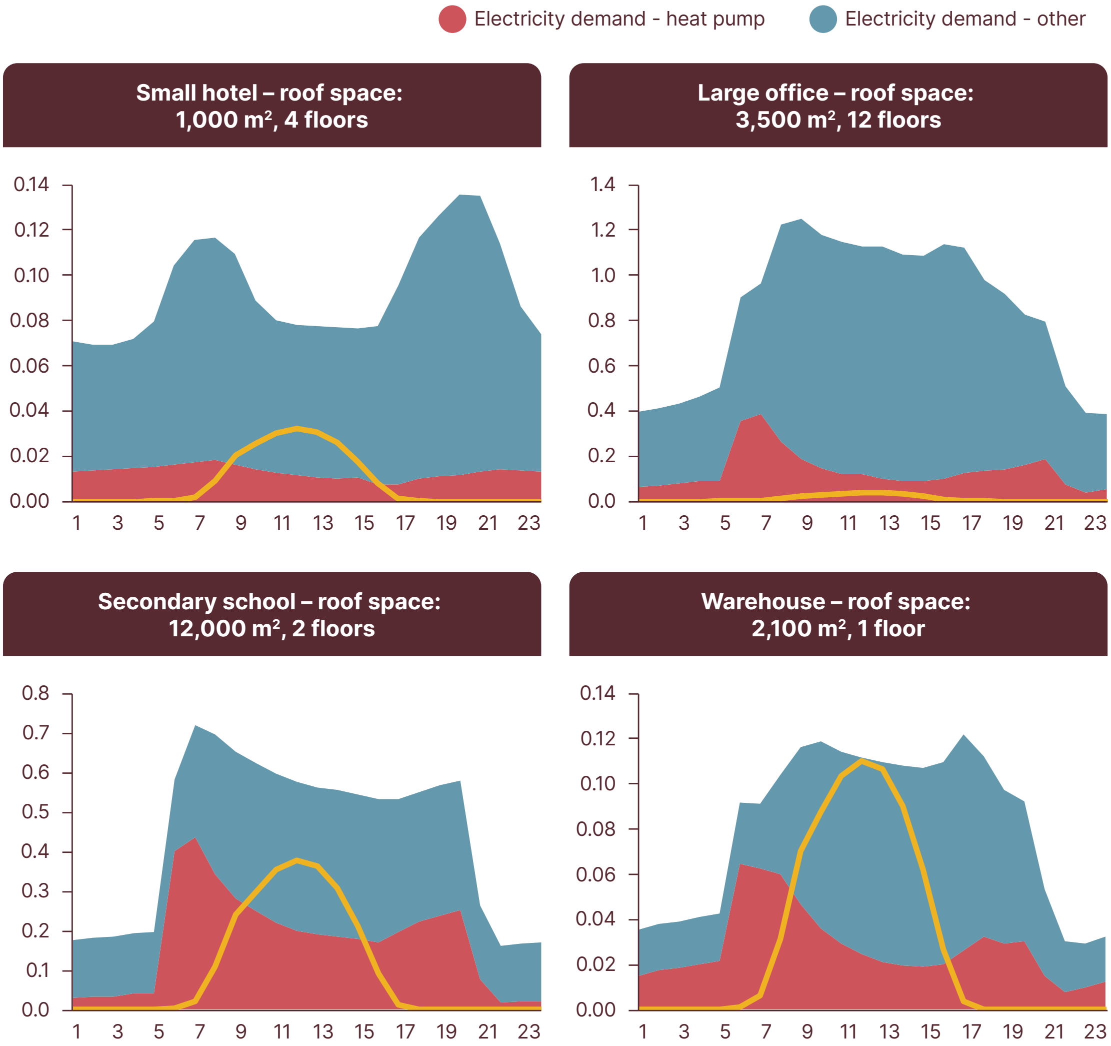


171 Arup, *Sustainable design for commercial and retail property*, available at https://www.arup.com/services/sustainable-design-for-commercial-and-retail-property/#:~:text=Sustainability%20has%20long%20been%20at,the%20projects%20we%20work%20on. [Accessed 01/08/2024].

Exhibit 8.7

Rooftop solar PV will be a key solution in commercial buildings with large roof space relative to floor space, such as warehouses

Average hourly winter energy use, by commercial building – Europe
kWh



Less likely to install solar PV

- Small roofs relative to floor space (roof : floor ratio <20%)
- Roof space further limited by HVAC equipment
- Solar PV can meet:
  - ~10% of needs in small hotel
  - ~1% of needs in large office

Highly likely to install solar PV

- Warehouses have a 100% roof to floor ratio
- Solar PV can meet:
  - 25% of needs in secondary school
  - 35% of needs in warehouse

NOTE: Winter is defined as November to February.

SOURCE: Systemiq analysis for the ETC; Schneider Electric Sustainability Research Institute (2024).

8.3.4 Storage technologies

Buildings can store hot water, power or heat at times when renewable power is abundant and cheap, for use at peak times. There are three main technologies:

- **Hot water cylinders:** Domestic hot water can be heated and stored in a well-insulated tank. The technology will play a critical role in the rollout of air-to-water heat pumps which require water to be gradually heated over time and stored. They are fairly low-cost, at around €500–1,500 for a 2–4 bedroom house. The main drawback, however, is large space requirements of around 2–3 m². The key challenge is that in many countries with natural gas boilers, the trend over recent decades has been to replace hot water tanks with combi-boilers, adding to peak demand challenges. It is crucial that hot water tanks are installed as default in new buildings, and that heating technology companies and utility companies highlight the heat storage benefits to consumers.

- **Batteries:** These are typically combined with solar PV to store excess or off-peak electricity generated for later use. They could also be used in isolation to charge from grid at off-peak times and enable households to avoid peak energy consumption from the grid. They can provide power for either electric space or water heating. As Exhibit 8.8 shows, the cost of producing batteries has fallen dramatically, but this is currently not feeding fully through to retail prices. As markets scale, consumer prices should fall too. Electric vehicle-to-grid solutions offer another opportunity to better utilise peak and off-peak electricity.

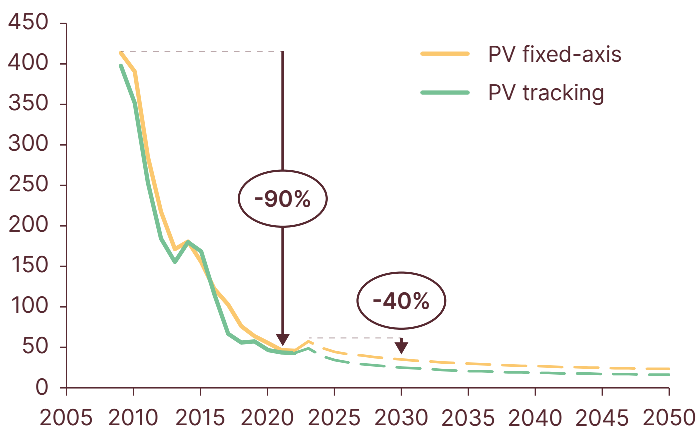
- **Thermal batteries:** There are a range of technologies which can also store heat, from bricks which have a high thermal capacity, to those which exploit the high thermal potential of phase change materials. These can be heated up at off-peak times, and water is then passed over when heat is required. They are currently used for domestic hot water needs, but could also be used to deliver space heating in a wet heating system. In residential properties, they can be around half the size of a hot water cylinder and our initial engagement with providers suggests they could cost around 50% more than a hot water cylinder. It is also possible to store cooling too, for example, in the form of ice.

Unless incentivised by policy, however, household uptake rests upon time of use tariffs and a sufficient differential (e.g., at least 30%) between peak and off-peak prices. In the absence of such retail energy market developments, governments and network system operators should actively encourage the uptake of hot water cylinders as the lowest-cost solution, for example, through low-cost finance. With water heating accounting for around 20% of total heating energy needs, mass uptake of hot water storage can have a significant impact on reducing peak electricity demand.

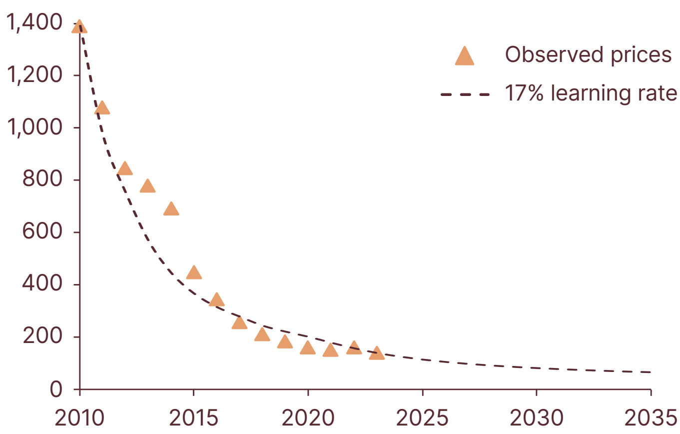
Exhibit 8.8

The cost of solar PV and batteries has fallen dramatically, and prices continue to fall

Solar PV Levelised Cost of Electricity (LCOE)
$ per MWh, real 2022 prices



Lithium-ion battery pack price outlook
$ per kWh, real 2023 prices



SOURCE: BNEF (2023), *Lithium-ion battery price survey;* BNEF (2024), *2H 2023 LCOE*.

Box P **The combined power of integrated smart systems, solar and battery storage: Lidl, Finland**

Lidl's 60,000 m² distribution centre in Järvenpää, Finland demonstrates the power of combining the technologies discussed in this report to create a truly efficient and flexible building.[172] The new centre features:

- A microgrid consisting of 1,600 solar panels and a battery storage system which produces around 450 MWh a year.
- A heat recovery system from the building's refrigerators and AC, which not only enables the building's heating to be much more efficient, but also provides around 700 MWh a year of heat for around 40 local residents.
- Schneider Electric's smart building software, EcoStructure, an advanced IoT-enabled automation system which uses real time data and predicative AI to optimise energy consumption based on building utilisation rate, energy prices, and weather.
- Light controls, sensors and ensuring all lighting is LED has reduced electricity consumption by 45% compared to a typical lighting system.

When working and controlled together, these technologies have enabled the site to lower energy costs by 50%, as well as bringing in revenue from selling excess electricity generation back to the grid. Emissions are 40% lower compared to Lidl's other warehouses.

172 Schnieder Electric (2024), *How microgrids can create carbon-neutral buildings and reduce energy costs*, available at www.blog.se.com/energy-management-energy-efficiency/2019/05/20/how-microgrids-can-create-carbon-neutral-buildings-and-reduce-energy-costs/. [Accessed 14/10/2024].

8.4 Bringing it all together: Implications for building demands on the clean electricity system

8.4.1 Reducing the total electricity needed to operate buildings

The combination of electrification of heating and the energy productivity solutions discussed above could in theory lower annual total energy demand for buildings in 2050, vs. a business-as-usual scenario without decarbonisation, by 60% [Exhibit 8.9], and electricity used in buildings by 50% [Exhibit 8.10].

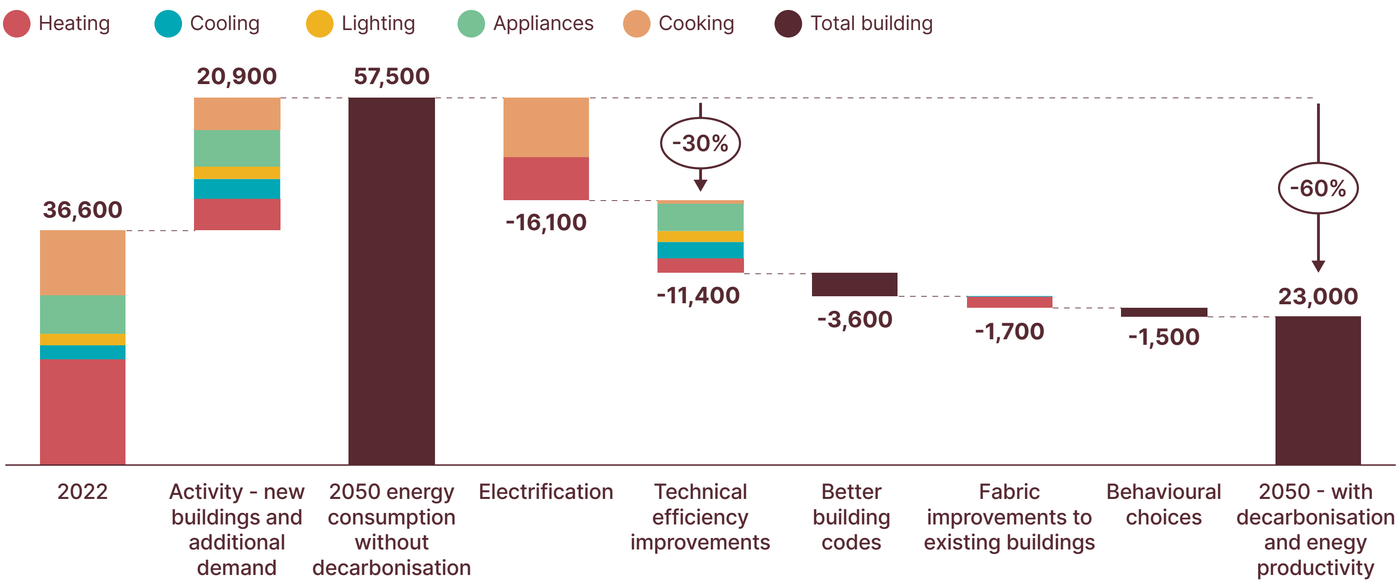
- The electrification of heating and cooking will reduce final energy consumption by around 30%.
- Technical efficiency improvements have the potential to lower final energy consumption by around 20%.
- Improving the building fabric of new and existing buildings could together lower 2050 consumption by 10% - this could be even higher with much greater ambition to improve building codes and with financial support for households.
- Demand efficiency, for example from the use of smart systems or behaviour change (e.g., policies to limit thermostats in public buildings) could reduce consumption by around 5%, but again this could be much higher with stronger policies and education.

Given the size of the prize, public policy should focus on seizing this potential wherever it is cost-effective to do so, but crucially, governments should at the same time remain committed to building a clean energy system as fast as possible. Planning and investment in renewable generation, networks and storage should be guided by the upper bound of estimates, recognising that the full potential of these energy productivity improvements is unlikely to be achieved.

Exhibit 8.9

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



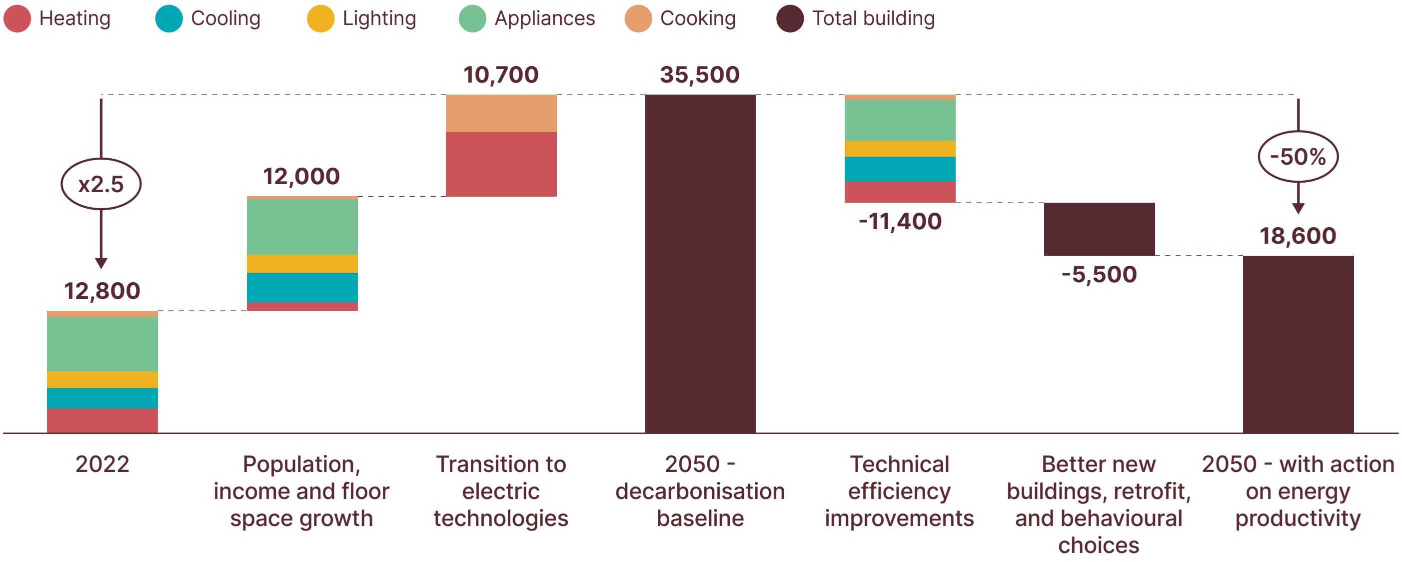
NOTE: The increase in activity to 2050 includes both an increase in fossil fuel energy use (e.g., new fossil fuel boilers and cookers largely in lower-income countries) and new electric heating and cooking appliances, largely in high-income countries and China. The electrification lever then refers to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

Exhibit 8.10

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*.

8.4.2 Reducing peak electricity demand: Buildings as energy assets

The flexibility of energy use in buildings can and must play an important role in matching the variability in electricity supply from renewables. As we will explore further in our upcoming report on Grids and Balancing, we provisionally estimate that around 20% of total buildings electricity demand in 2050 could be realistically time-shifted.[173] As discussed in Chapter 8.3, the key areas of opportunity are:

- Building more energy efficient new buildings, where regulation can and should drive much higher kWh per m² standards.
- Insulating existing buildings, which will also reduce overall energy use and bills, meaning action is not reliant on time-of-use pricing.
- Installing smart systems, especially in commercial buildings where they can be much more sophisticated and controlled by expert building managers.
- Installing rooftop solar PV and, as prices fall, batteries.

However, realising the full potential of these technologies will require unlocking key regulatory enablers, such as time-of-use pricing.

It is important to note that the solutions discussed in this section will only help to solve the daily balancing challenge. They cannot address seasonal balancing, which need to be addressed by investments within the power system rather than at building-level.

173 Systemiq analysis for the ETC.

8.4.3 The phase out of fossil fuels used in buildings

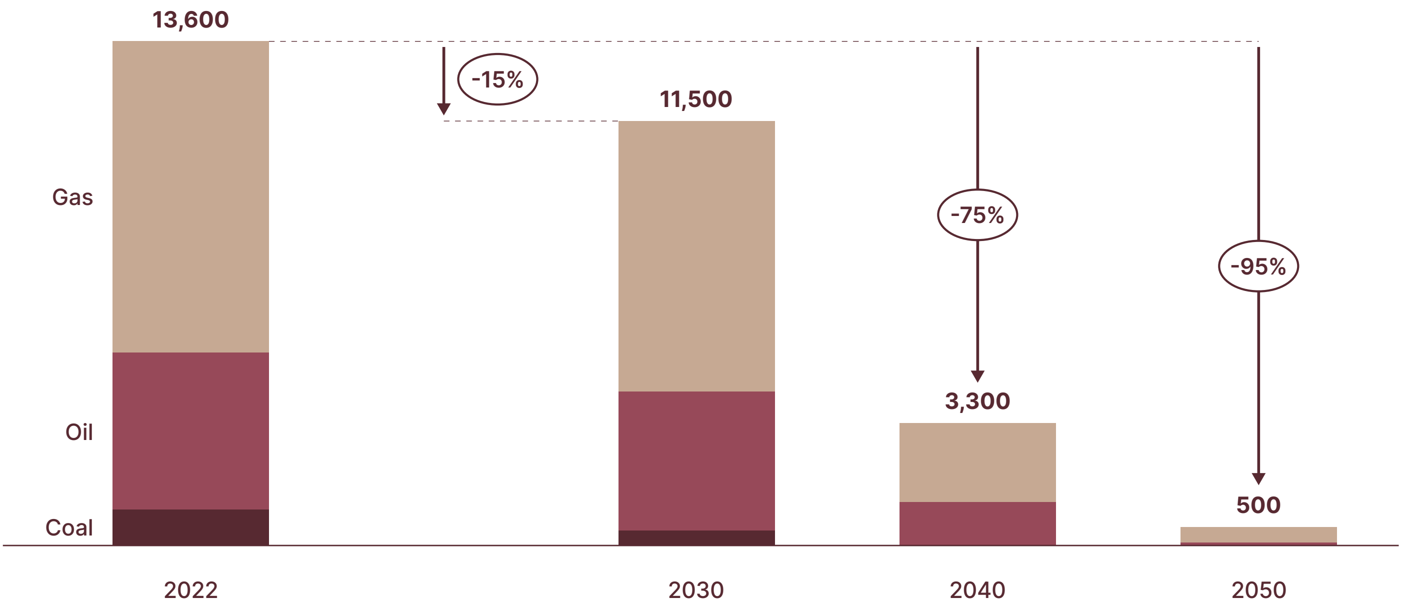
Combining the projections for heating and cooking (see Sections 2.5 and 4.2), results in the following implications for the phaseout of fossil fuels [Exhibit 8.11]:

- Coal use is entirely eliminated by 2040 in both scenarios.
- Gas use also is almost entirely eliminated by 2050 but falls only 15–25% by 2030.
- Oil use in heating declines rapidly, but initially grows for cooking (in the form of LPG). However, since oil use for heating is currently around 2.5 times larger than for cooking, a material decline of 15–25% can still be achieved globally by 2030.

Exhibit 8.11

The direct use of fossil fuels in buildings could be virtually eliminated by 2050, with a reduction of 15% by 2030 and 75% by 2040 as heating and cooking electrify

Fossil fuel demand in buildings, projections to 2050
TWh



SOURCE: Systemiq analysis for the ETC; IEA (2022), *World Economic Outlook 2022*; IEA (2023), *World Economic Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center (2014), *Annual Report of Building Energy in China*.

Reducing the impact of refrigerant leakage and venting

9

Key messages

- Refrigerants can have a high global warming potential (GWP) relative to CO_2 if they leak or are intentionally released (vented) into the atmosphere. Currently, around 2–5% of refrigerant in heat pumps and AC leaks every year, and 90% is vented at end-of-life.
- Emissions from refrigerant leakage and venting are estimated at 0.5–1 $GtCO_2e$ today and without a transition away from high-GWP refrigerant, could rise to 3 $GtCO_2e$ in 2050; this is equivalent to 15% of today's annual emissions from buildings.
- Annual emissions in 2050 could, however, be halved with regulation to ban the use of high-GWP refrigerants (hydrofluorocarbons), as per the international Kigali agreement, and with regulations and incentives for proper disposal of refrigerant at end-of-life, and skills certifications to improve the quality of installations and maintenance.
- International agreements and national regulation are already driving an industry transition towards natural refrigerants, such as propane, but action needs to accelerate.

Air conditioners and heat pumps contain refrigerants, which contribute to global warming if they are released into the atmosphere. Refrigerants are fluids that have very low boiling points and therefore change state between a liquid and gas at low temperatures. As a result, they are able to absorb and release energy rapidly. There are many different types of refrigerants, which work differently at different pressures and temperatures.

Different refrigerants have distinct global warming potentials (GWP). This assesses a refrigerant's global warming impact relative to the same quantity of carbon dioxide over a 100 year period. Exhibit 9.1 shows the spectrum of 100 year GWPs, from hydrofluorocarbons (HFCs) which can be 1,000–2,000 times more detrimental than CO_2, down to natural refrigerants such as propane which are three times more detrimental to warming. All of these refrigerants have a much shorter half-life in the atmosphere than CO_2; as a result, cutting refrigerant emissions can play a powerful and rapid role in curtailing the rise in global temperature.

The Kigali Amendment to the Montreal Protocol in 2016 was an international agreement to phase out the use of HFCs – which are used not just in AC and heat pumps, but also aerosols and foams – in high-income countries by 2036 and in the rest of the world by 2047. It is estimated that without Kigali, surface temperatures might be 0.3–0.5°C higher by the end of the century.[174]

This amendment is driving an industry transition towards using natural refrigerants, such as propane, which have a much lower GWP. In 2024, the EU passed new regulations to phase out HFCs in line with Kigali targets, including setting quotas for the import of HFCs and banning trade in HFCs with any countries which have not signed the Kigali amendment.

Crucially, these refrigerants are also beneficial for efficiency, with propane for example, able to absorb more heat for the same amount of refrigerant. This transition is also not expected to lead to any long-term cost penalties, although in the short-term there will likely be some cost impact as manufacturers learn how to use the alternative gases safely (e.g., propane is very flammable).

174 European Fluorocarbons Technical Committee (2024), *Kigali Amendment*, available at www.fluorocarbons.org/environment/climate-change/kigali-amendment/. [Accessed 24/09/2024].

Transitioning to lower GWP refrigerants lowers the impact on global warming from refrigerant which is released into the atmosphere. But the other way to address the challenge is to reduce how much refrigerant is actually released into the atmosphere; and doing so is essential to mitigating global warming effects before high GWP refrigerants can be phased out. Releases can result from [Exhibit 9.1]:

- **Leakage:** Refrigerant can escape from air conditioners and heat pump systems through leaks or improper handling. It is estimated that, on average, around 2–5% of refrigerant is leaked every year, varying depending on equipment size, age and condition, the quality of installation, and amount of maintenance.[175]

- **Venting:** Refrigerants are often released into the atmosphere during servicing, maintenance, or at end-of-life. Key risk factors include improper servicing practice, a lack of awareness of technicians, and weak regulations for proper disposal. Today, estimates suggest that close to 90% of ACs at end-of-life are vented in the US.[176] In the developing world, the number is likely even higher.

Exhibit 9.1

There are two ways to reduce harmful refrigerant emissions – a) reduce how much refrigerant is released into the atmosphere, and b) transition to low GWP refrigerant

What are refrigerants?

Found in AC and heat pumps, refrigerants contribute to climate change if leaked and/or vented. Refrigerants differ in their global warming potential (GWP):

HFCs (Hydrofluorocarbons)

Most commonly used

	GWP
R-134a	1430
R410a	2088
R-32	675

Low-GWP HFOs (Hydrofluoroolefins)

Alternatives to HFCs

R1234ze	7

Natural Refrigerants

Emerging solutions

CO_2	1
Propane	3
Ammonia	0

Industry transition

Driven by the 2016 global Kigali Agreement to phase out high GWP HFCs

What is the challenge with refrigerants?

Leakage

2–5% a year

A small amount of refrigerant typically escapes from AC and heat pump systems through leaks or improper handling.

Key risk factors include:

- Older or poor quality equipment
- Poor quality of installation
- Lack of maintenance

Venting

90%+ of refrigerant at end-of-life

Refrigerant is often released into the atmosphere during servicing and at end-of-life

Key risk factors include:

- Improper servicing practice
- Lack of training and awareness of technicians
- Improper disposal

NOTE: Global Warming Potential (GWP) – global warming impact relative to the impact of the same quantity of CO_2 over a 100-year period.

SOURCE: IEA (2023), *Energy Technology Perspectives*; BSRIA (2020), *BSRIA's view on refrigerant trends in AC and Heat Pump segments*; Net Zero Carbon Guide, *Refrigerants and their Contribution to Global Warming*, available at www.netzerocarbonguide.co.uk/guide/designing-and-building/heating-your-building/refrigerants-and-their-contribution-to-global-warming. [Accessed 10/08/2024]; IEA (2018), *The Future of Cooling*; Carbon Containment Lab (2022), *Managing Refrigerants in a Warmer World.*

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

9.1 Estimates of emissions from leakage and venting

There is relatively little research estimating refrigerant-linked emissions from ACs and heat pumps. Using estimates of leakage and venting rates from the literature, and assuming an average of 4.5 kg of refrigerant in a typical unit and that these assets last 15 years, we have estimated potential annual emissions today and in 2050 [Exhibit 9.2].[177] Key points are:

- Emissions today are likely around 0.5–1 $GtCO_2e$, which is equivalent to approximately 5% of today's total emissions from building operational energy use (12.3 $GtCO_2e$). ACs account for around 90% of this, given the significantly higher existing stock.

- With projected increases in AC and heat pump installations, and assuming no transition towards low-GWP refrigerant, emissions could triple to 3 $GtCO_2e$ in 2050. These emissions will result predominantly from cooling since:

  - Despite increasing uptake of heating pumps, the global stock of ACs is still likely to be five times larger in 2050 (with around 1 billion heat pumps to provide heat and 5.5–6 billion ACs).[178]

  - Additionally, the number of AC units reaching end-of-life in 2050 will be even higher.

- Transitioning to low-GWP refrigerant at the pace required by the Kigali agreement could, however, reduce potential annual emissions in 2050 by one third. This impact will be even greater over the longer-term, as any old appliances still using high-GWP refrigerants reach their end-of-life. Eventually, bans on high GWP refrigerants will reduce emissions to a trivial level.

- But if high GWP refrigerants cannot be eliminated at a faster rate than agreed at Kigali, it is also crucial to reduce the amount of refrigerant released into the atmosphere. Exhibit 9.2 shows the impact of lowering venting rates to 50% (although regulation especially in higher-income countries should aim to reduce this towards zero), and lowering leakage rates from 3.5% per year to 1.5% per year. It is important to note that without action to cut venting rates, addressing leakage has no impact on eventual cumulative emissions as the refrigerant that is prevented from leaking is simply released into the atmosphere at end-of-life.

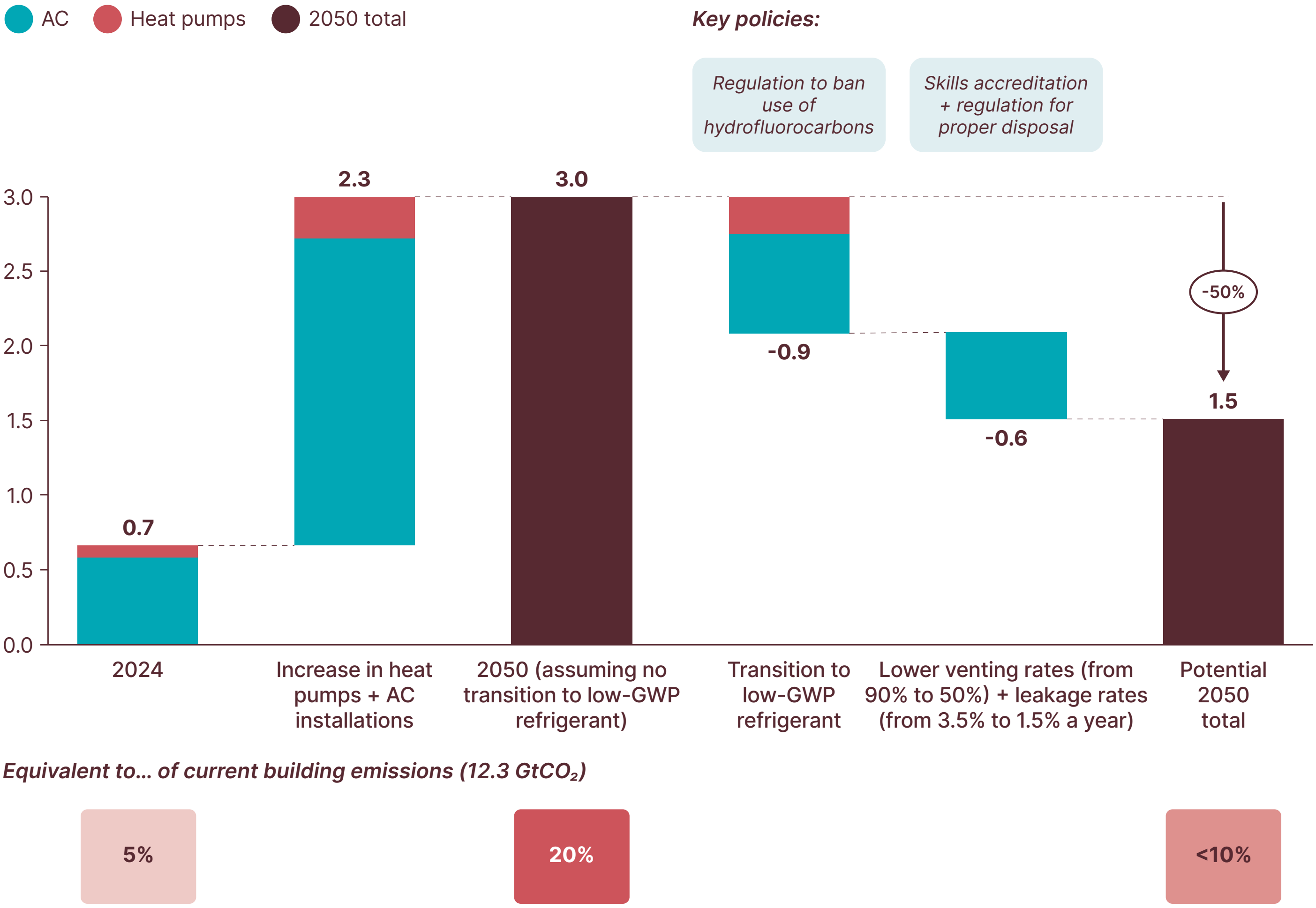
It is also important to note that any emissions resulting from refrigerants used in heat pumps are an order of magnitude lower than those would result from continued use of gas to provide building heat. Refrigerant related global warming effects must be dramatically reduced, but these effects in no way undermine the strong case for shifting from gas boilers to electric heat pumps as quickly as possible.[179]

177 The amount of refrigerant in heat pumps and air conditioners varies massively depending on the size of the unit. Typical residential systems have around 2–5 kg, with units in commercial buildings typically a bit higher (e.g., 7 kg), but units in very large commercial buildings can be as much as 20–35 kg.
178 Systemiq analysis for the ETC; IEA (2018), *The Future of Cooling*.
179 At 0.22 $kgCO_2$ per kWh and assuming annual gas consumption of 12,000 kWh, a gas boiler will emit ~2,500 $kgCO_2$ a year. A residential heat pump with 2kg of R1234ze refrigerant (which has a GWP of 675) would produce ~1,400 $kgCO_2e$ if this was all released into the atmosphere; averaged over a 20 year lifetime, this equates to less than 70 $kgCO_2e$ a year.

Exhibit 9.2

Emissions from refrigerant leakage and venting could reach 2 $GtCO_2e$ in 2050, but could be 50% lower with regulation on proper disposal and a transition to low-GWP refrigerant

Scenarios of potential annual global emissions relating to refrigerant leakage and venting
$GtCO_2e$



NOTE: The figures are based on reasonable assumptions about how the type of refrigerant in the stock of ACs and heat pumps might change over time, and use the IEA's AC projections for 2050 and the ETC's estimates on heat pumps. Assumes an average of 10 lb refrigerant charge and a 15 year lifetime for equipment.

SOURCE: Systemiq analysis for the ETC; BSRIA (2020), *BSRIA's view on refrigerant trends in AC and Heat Pump segments*; Net Zero Carbon Guide, *Refrigerants and their Contribution to Global Warming*, available at www.netzerocarbonguide.co.uk/guide/designing-and-building/heating-your-building/refrigerants-and-their-contribution-to-global-warming. [Accessed 10/08/2024]; IEA (2018), *The Future of Cooling*; UNEP Ozone Secretariat (2015), *Fact sheets on HFCs and Low GWP Alternatives.*

9.2 Actions to manage the refrigerant challenge

The refrigerant issue has not in the past received sufficient attention. Policymakers and industry must now develop coherent strategies to ensure that the electrification of building heating and the growth of AC across the world does not result in refrigerant related global warming effects which can be dramatically reduced with the right policies and regulation.

Policymakers should:

- Accelerate the transition to lower-GWP refrigerant with:
  - Stronger regulation that has clear timelines and enforcement mechanisms to ban the use of hydrofluorocarbons. Ideally this should result in a faster phase out of HFCs than agreed at Kigali.
  - R&D support to rapidly lower the costs of using alternative refrigerants safely.
- Develop accreditation schemes for skilled installers and provide sufficient funding for high-quality training.
- Regulate installation and maintenance companies to properly deal with refrigerant during maintenance and disposal, including fines for improper disposal and incentives for higher collection rates.
- Run consumer awareness campaigns to spot leaks, highlight the importance of regular maintenance, and how to properly dispose of units. Incentives should be offered for taking a unit for recycling.
- Implement tighter regulation for professionally managed residential and commercial buildings, with legal maintenance requirements.

Private sector actions:

- Manufacturing companies should provide clear labelling on the type of refrigerant used, regular maintenance guidelines, and instructions for end-of-life disposal.
- Heating and cooling engineering companies should:
  - Ensure their employees undertake sufficient training and accreditations throughout their career.
  - Offer discounts for regular maintenance checks and ensure the root cause of leaks is fully assessed.
  - Ensure they always collect old units when installing new ones.

Section B:
Reducing embodied carbon from the next generation of new buildings

10

Understanding emissions across the building lifecycle

This report has so far focused on energy used to operate buildings - and the resulting direct and indirect emissions; these account for 80% of global annual building-related emissions. However, the other 20% – 2.6 $GtCO_2$ – of global annual emissions arise from the energy and materials used to construct new buildings, maintain existing ones, and demolish them at end-of-life.

Since global building floor area is expected to more than double by 2050, these annual embodied emissions will increase rapidly unless the carbon intensity of construction is reduced. Under a business as usual scenario, cumulative new embodied emissions could equal 75 $GtCO_2$ between now and 2050. And as heating is electrified and grids are decarbonised, these embodied emissions are likely to account for an increasing share of total building emissions. Alongside actions to reduce operational emissions, a strong focus on opportunities to reduce embodied emissions is therefore essential.

Buildings are part of the wider built environment which includes the construction of roads, bridges, airports, pipelines, railways and ports. In total, annual embodied emissions from this built environment account for about 4.8 $GtCO_2$ [Exhibit 1.1] with:

- 2.6 $GtCO_2$, or 7% of global emissions, from residential and commercial buildings.
- 2.2 $GtCO_2$, or 6% of global emissions, from wider infrastructure construction, including roads, bridges, airports, pipelines, railways and ports.

This section will predominately focus on buildings, but will discuss the wider built environment where relevant.

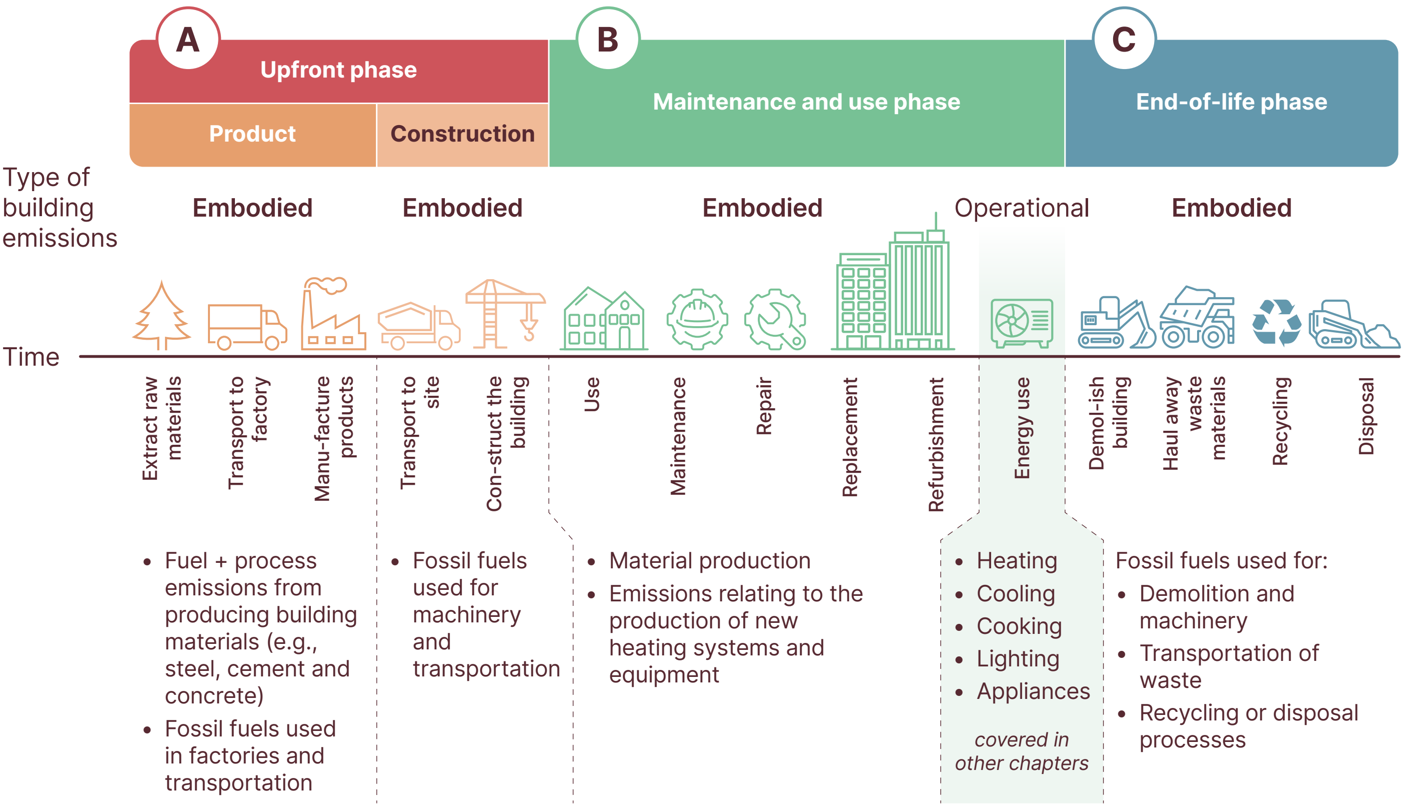
Focusing on individual buildings, Exhibit 10.1 shows how operational and embodied emissions arise over a building's lifecycle. Of the three stages, operational emissions only arise during a building's use phase, whereas embodied emissions occur in the upfront, use and end-of-life phases. There are fundamental differences between operational and embodied emissions:

- Embodied emissions are one-off occurrences at a few points in a building's lifecycle [Exhibit 10.1], while operational emissions recur every year over the long-term.
- There is a huge variety of sources of embodied emissions, from the production of different building materials such as steel and cement (which are the dominant sources of embodied emissions), to the transport and machinery used in construction and demolition. In comparison, understanding household energy consumption and associated carbon intensity is relatively easy.
- Embodied carbon is swiftly moving up the agenda for investors and developers, but is still several years behind operational carbon due to a lack of data and understanding.

Exhibit 10.1

Embodied carbon refers to the emissions arising from the construction, maintenance and demolishing of buildings

Sources of embodied and operational emissions across the building life cycle



SOURCE: New Buildings Institute, available at: www.newbuildings.org/code_policy/embodied-carbon/. [Accessed 24/09/24].

In recent years, measures of embodied carbon have improved in several countries.[180] Exhibit 10.2 presents data from case studies in Europe suggesting that, over 60 years, embodied and operational emissions each account for 50% of total lifecycle emissions. Of embodied emissions, two-thirds occur before a building is even in use, while end-of-life emissions account for less than 5%.

The ratio between a building's operational and embodied emissions will, however, vary greatly across countries and buildings depending on:

- The materials and construction techniques used.
- The building archetype (e.g., flats have a higher embodied carbon per m² because of the need for greater foundations and structures).
- The carbon intensity of electricity generation and the technologies used for heating and cooking. The estimate that 50% of lifecycle building emissions in Europe are embodied contrasts with the global figure, where embodied emissions account for only 20% of building-related emissions. This difference may be partly due to Europe's more decarbonised electricity grids, while construction materials have a similar carbon intensity worldwide.
- A building's lifetime.

This means individual buildings must take an integrated approach to lowering whole-life carbon, considering the relationship and balance between operational and embodied emissions.

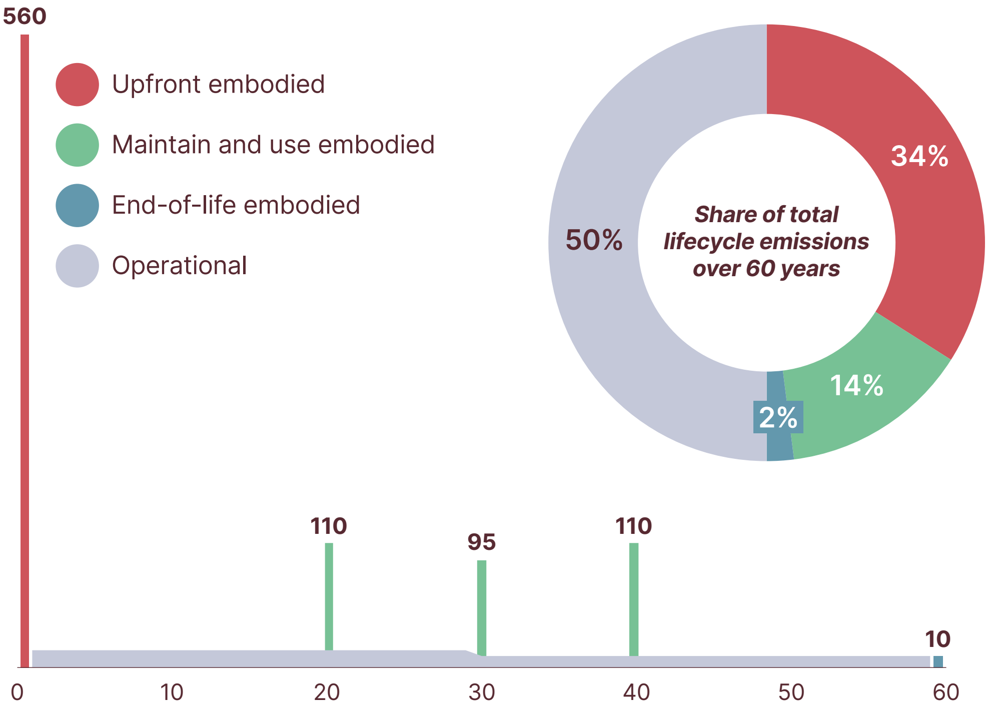
The next two chapters assess the sources of CO_2 and the mitigation potential in upfront construction (Chapter 11) and during use, retrofit and end-of-life (Chapter 12). Chapter 13 describes the actions and policies required to ensure appropriate focus on reducing embodied emissions.

180 For example, see RICS (2023), *Whole life carbon assessment for the built environment: 2nd edition.*

Exhibit 10.2

Embodied emissions are large, one-off bursts of emissions at a few points in a building's lifecycle; operational emissions occur every year a building is in operation

Whole life carbon emissions – Europe
$kgCO_2e$ per m^2



- There is a lack of data and **no consensus** on the level of embodied carbon emissions globally today
- European case studies suggest that embodied carbon accounts for **~50% of a building's lifecycle emissions** – but this can vary across countries depending on the carbon intensity of the grid, heating technology, and materials used
- The **vast majority** of embodied carbon emissions are in the **upfront stages (product + construction)**

NOTE: Based on an assessment of six buildings in Europe.

SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*; RMI (2023), *Embodied Carbon 101: Building Materials*.

The opportunity to reduce embodied carbon in buildings construction

11

Key messages

- By far the biggest source of embodied carbon is from the production of material inputs to construction, namely cement, concrete and steel.
- The MPP's sector transition strategies show that it is possible to fully decarbonise these so-called "hard to abate" sectors by 2050, using technologies available today.
- If this decarbonisation of inputs is achieved, annual new embodied emissions will fall close to zero for buildings built in 2050 and later, and total cumulative emissions from building construction between today and 2050 could be reduced from 75 $GtCO_2$ to 40 $GtCO_2$.
- But this remaining 40 $GtCO_2$ would still use up about 20% of the remaining carbon budget compatible with limiting global warming to 1.5°C.
- Improvements in material efficiency, the use of new materials such as timber, and improvements in building design and construction, are therefore essential to reduce cumulative emissions in the period before input production is decarbonised, and will in many cases deliver other economic benefits.

Upfront embodied carbon arises from the production and transportation of materials and the construction of new buildings. A building can be thought of as having five main layers:[181]

- Structure: A building's skeleton and overall shape, including its substructure (e.g., foundations and retaining walls) and superstructure (e.g., upper floors, roof and stairs).
- Skin: The outside layers, such as the façade, windows, surface material and insulation.
- Space Plan: Walls, doors and raised floors/suspended ceilings used for compartmentalisation.
- Services: HVAC, lighting and public health that supports a building's operation.
- Stuff: All other items of furniture and appliances that are installed. This report focuses on the four above layers, and does not consider the embodied carbon in producing these items.

A building's structure accounts for over half of its embodied emissions, due to steel, cement and concrete, which is also required across the other three layers [Exhibit 11.1]. As Exhibit 11.2 shows, producing many of these materials is currently highly carbon intensive.

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

Today, around 4.5 billion m² of new floor space is built every year, which results in 2.6 $GtCO_2$ of annual embodied carbon emissions. Estimates suggest that between now and 2050, global floor area could increase from 250 billion m² to 390 billion m².[182] Holding today's global average embodied carbon per m² constant (0.5 $GtCO_2$ per billion m²), constructing this additional 140 billion m² would generate 75 $GtCO_2$ by 2050.[183] 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.[184]

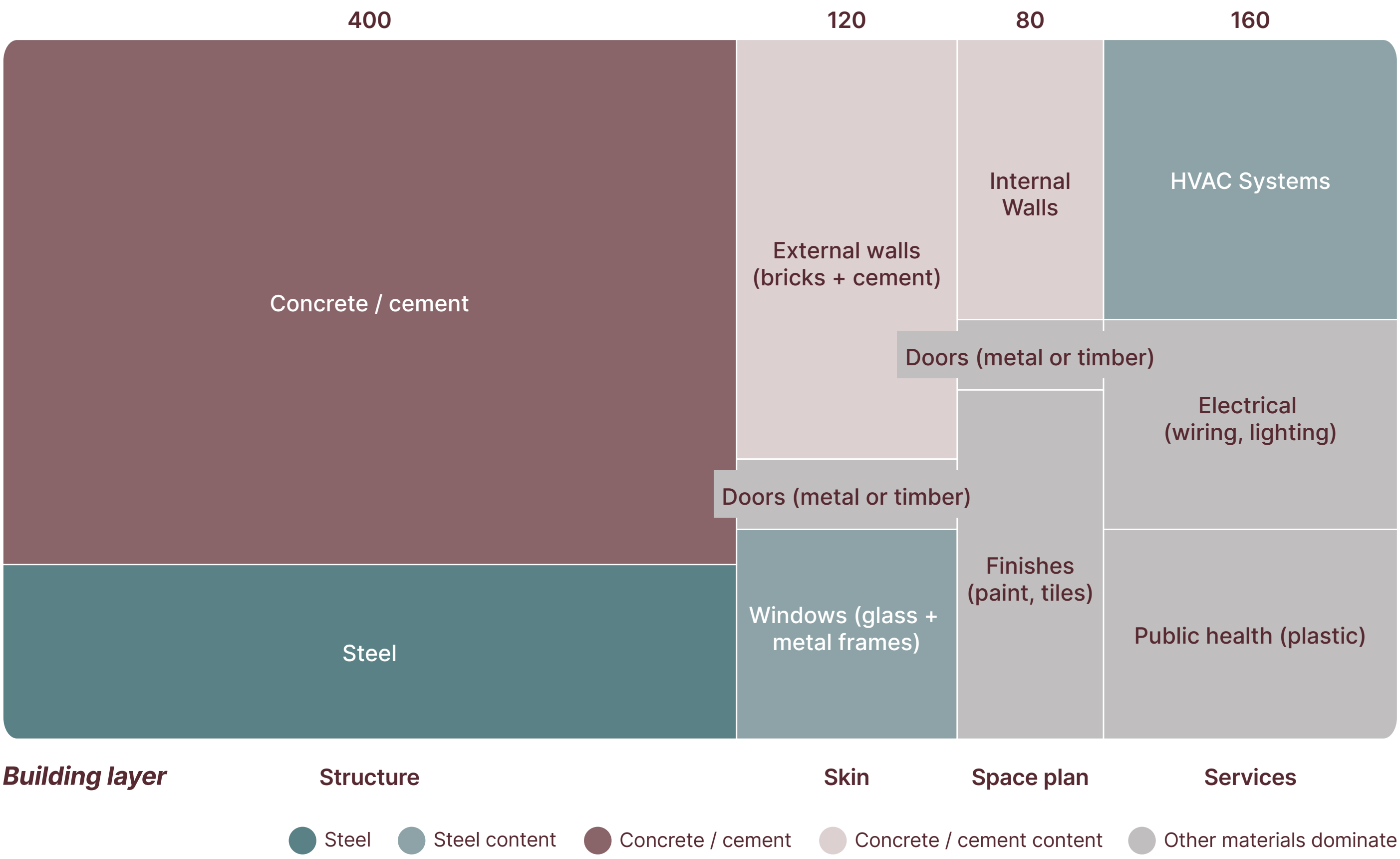
Finding ways to construct lower-carbon buildings is therefore imperative and could reduce embodied carbon from new construction to around 40 $GtCO_2$. Broadly, there are two main ways of doing this:

- Decarbonise the production of building material inputs (e.g., cement, concrete, steel, bricks, glass, aluminium) – discussed in Chapter 11.1.
- Reduce demand for high-carbon material inputs, by using materials more efficiently or substituting lower-carbon materials in place of high-carbon ones – discussed in Chapter 11.2.

Exhibit 11.1

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 m²

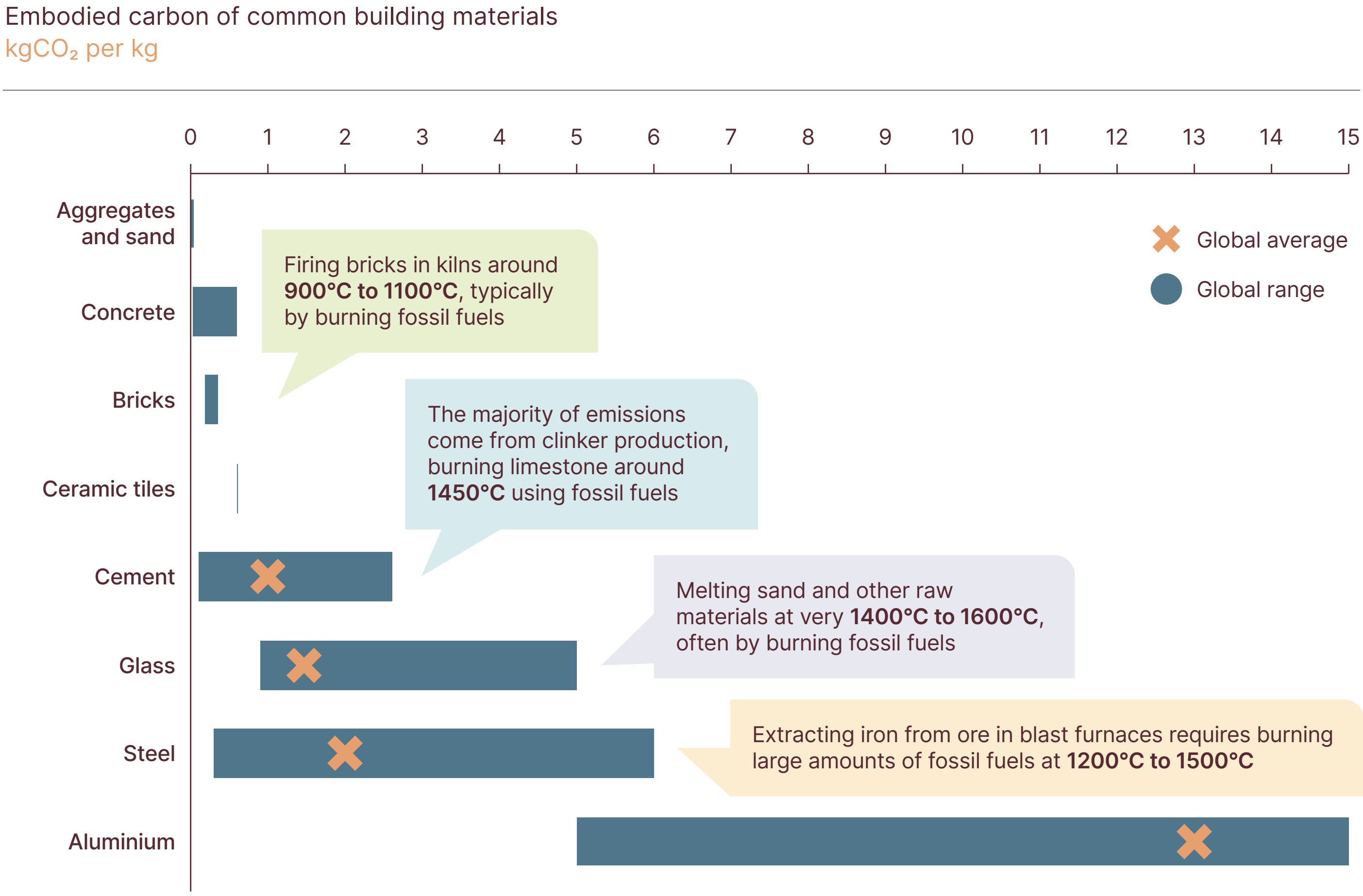


SOURCE: Systemiq analysis for the ETC; Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*; ArchDaily (2021), *How to Approach Embodied Carbon Reduction within an Architectural Project*.

182 IEA (2023), *World Energy Outlook 2023.*
183 Systemiq analysis for the ETC.
184 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.*

Exhibit 11.2

Building materials have different carbon intensities, depending on production fuels, required temperatures and process chemistry



NOTE: Carbon intensity of materials varies massively across countries, depending on fuels used.

SOURCE: Systemiq analysis for the ETC; Jones and Hammond (2019), *Inventory of Carbon and Energy (ICE)*.

11.1 Decarbonising material production

Over the last four years, the MPP has developed sector transition pathways for the heavy industry sectors, outlining the suite of technologies that exist today to decarbonise the production of steel, cement, concrete and aluminium.[185]

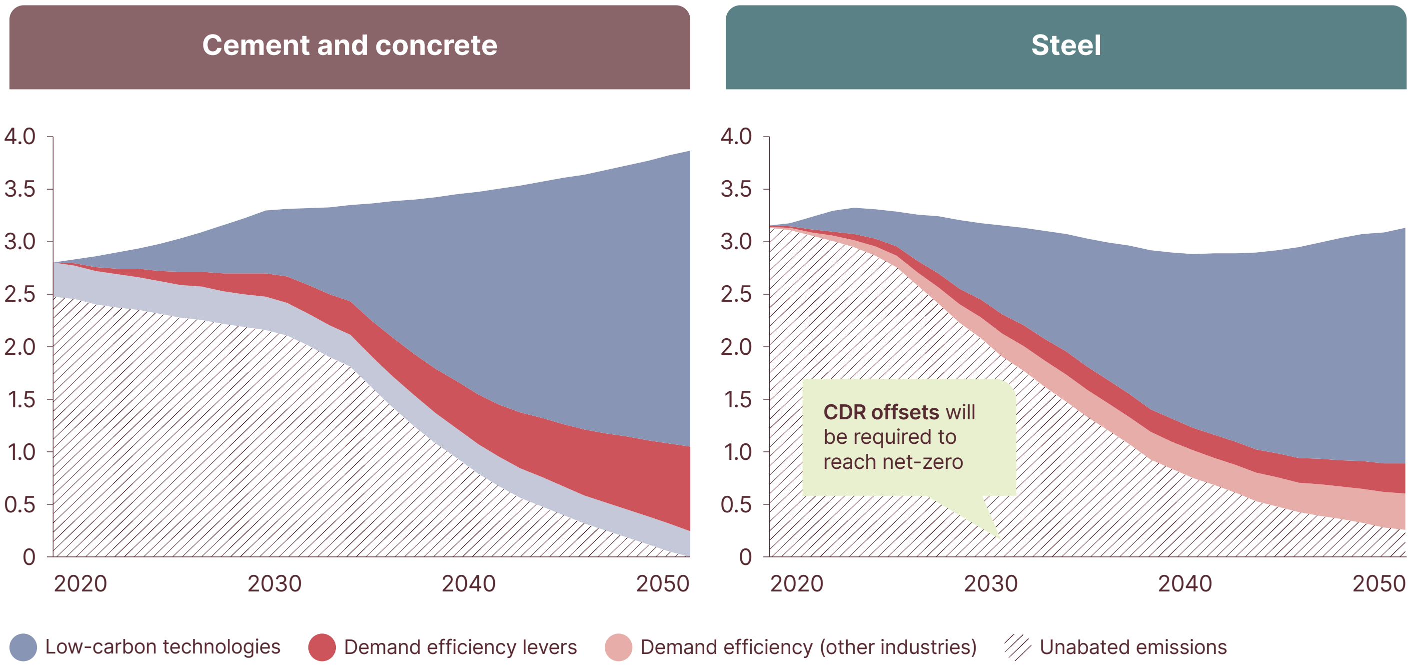
The pathways have considered both the opportunities to reduce the demand for materials while continuing to deliver unchanged benefits to society, and the opportunity to decarbonise the carbon intensity of each tonne of material used. Exhibit 11.3 shows the MPP pathways for emissions reduction in cement/concrete and iron/steel. They show that while it is possible to reduce the quantity of cement and steel demanded, action to decarbonise production will play the dominant role, delivering 65% of the emissions mitigation potential for cement and concrete, and 75% for steel.

The next two sections summarise the actions and technologies required to achieve this decarbonisation.

Exhibit 11.3

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*.

185 MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*; MPP (2022), *Making Net Zero Aluminium Possible*.

11.1.1 Low-carbon cement and concrete technologies

Cement is used in buildings because of its binding properties, and can be combined with gravel, sand, aggregates and crushed rock to form concrete. Around 85% of cement and concrete is used in buildings, and 15% in wider infrastructure. Across the entire built environment, the cement and concrete sectors account for around 7–8% of global CO_2 emissions.[186] Despite energy efficiency improvements, in the absence of any further action, emissions are expected to grow by about 40% by 2050, driven by increases in demand.

Cement production results in two conceptually different sources of CO_2 (albeit co-mingled in most existing cement plants):[187]

- Chemical process emissions (~55% of emissions): Which are an inevitable result of the chemical reaction of the clinker-making process which turns limestone ($CaCO_3$) into lime (CaO) and CO_2. These are produced irrespective of the energy source used to produce the chemical reaction, and thus are inevitable as long as limestone is used as the key feedstock.

- Energy related emissions (~35% of emissions): CO_2 is also generated by burning fossil fuels to reach the 900°C required for calcination and 1,450°C required for clinkerisation. The predominant fuels currently used are coal and petroleum coke (82%). Other fuels include natural gas (9%), industrial wastes (6%), and biogenic waste (3%).

Other emissions (around 10%) come from direct and indirect fossil fuel use to power machinery and transport. Cement embedded in concrete, however, does also reabsorb some CO_2 from the air over its lifetime, offsetting some of the carbon emissions from its production. Across all types of concrete, a conservative estimate is that 10% reduction in total concrete emissions are reabsorbed.[188] Overall, producing a tonne of cement produces around 0.6 tCO_2 and subsequent concrete production results in an additional 0.1 tCO_2.[189]

The concrete and cement sector is often labelled as "hard-to-abate" for three key reasons:

- Process emissions: Because CO_2 is released through a chemical reaction, it cannot be eliminated by increasing efficiency or changing fuel – without using carbon capture, this process cannot currently be decarbonised.

- High kiln temperature: To date it has been technically challenging to fully decarbonise high-temperature heating processes with alternative fuels.

- Highly localised markets: Concrete and cement are bulky, low-value products, rarely economical to transport over long distances. Because they are usually produced close to their use (less than 50 km for concrete and 250 km for cement), decarbonisation depends on local resources and infrastructure. Region-specific decarbonisation pathways are therefore critical.

186 MPP (2023), *Making Net Zero Concrete and Cement Possible.*
187 Ibid.
188 MPP (2023), *Making Net Zero Concrete and Cement Possible.* Based on the lower bound of the tier 1 CO_2 uptake model for concrete published by IVL, the Swedish Environmental Research Institute.
189 MPP (2023), *Making Net Zero Concrete and Cement Possible*; IEA, Cement, available at www.iea.org/energy-system/industry/cement. [Accessed 24/09/2024].

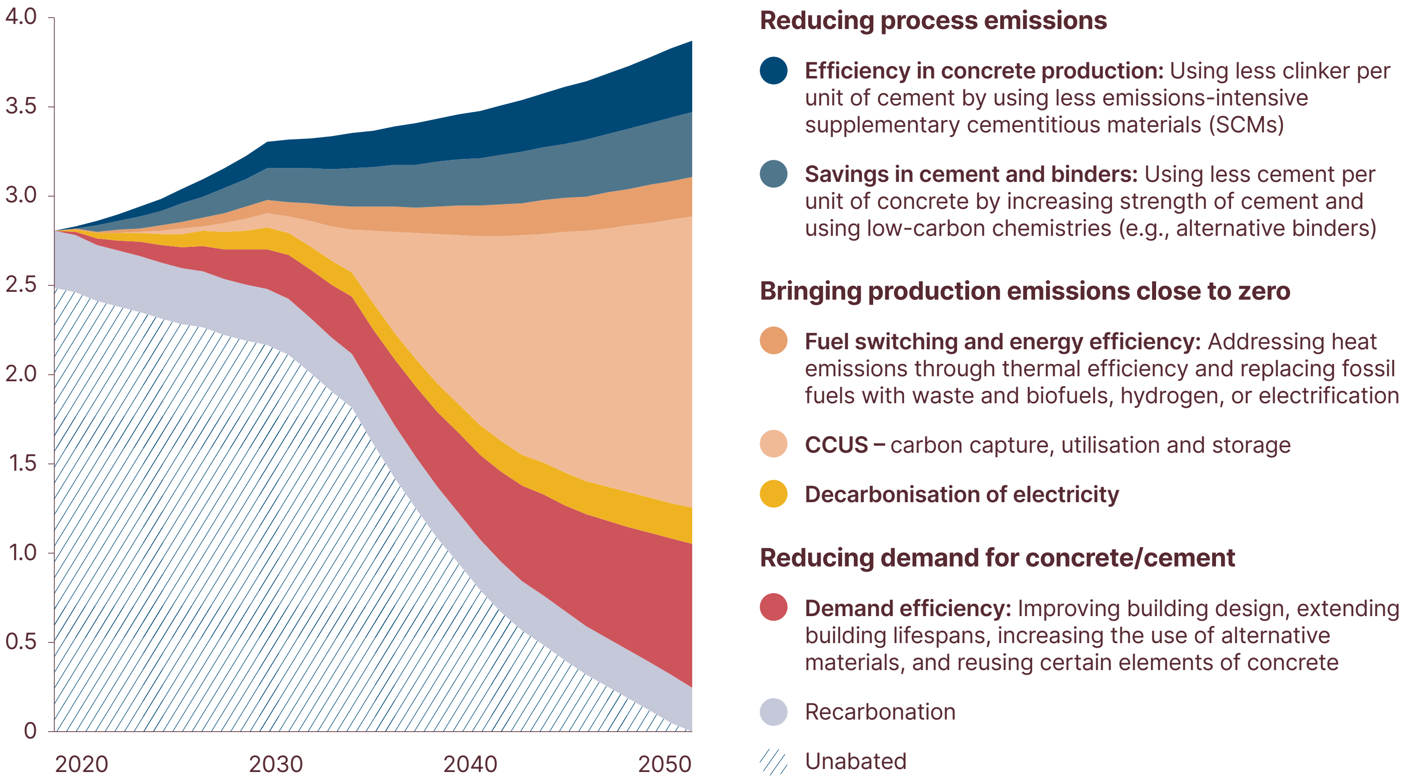
However, the MPP strategies show that decarbonisation is feasible with technologies which are available today. These are indicated in Exhibit 11.4 and combine:

- **Reductions in both the chemical process emissions and the energy related emissions,** achieved via reductions in clinker/cement (e.g., using supplementary cementitious materials that are less emissions-intensive, such as calcinated clay, natural pozzolanas, and recycled concrete) and cement/concrete ratios, plus new cement chemistries.[190]
- **Reductions in energy related emissions** via thermal efficiency improvements and the use of potentially zero-carbon energy sources such as electricity and biofuels.
- **Carbon capture** of remaining chemical process and energy related emissions.

Exhibit 11.4

A suite of low-carbon cement and concrete technologies are available today, including CCUS which will likely account for 40% of cumulative mitigation potential to 2050

1.5ºC aligned pathways to net-zero in cement and concrete
$GtCO_2$ per year



SOURCE: MPP (2023), *Making Net Zero Concrete and Cement Possible*.

190 See for instance, www.brimstone.com.

11.1.2 Low-carbon steel technologies

Globally and across all sectors, the production of primary and secondary steel accounts for around 7% of global emissions, or 3.1 $GtCO_2e$. The built environment drives around 50% of steel use by mass, but steel is also used widely across other sectors including automotives, electrical and mechanical equipment, and will play a critical role in producing wind turbines and EVs for the energy transition.[191] Different types of steel satisfy these different uses; rebar – reinforced steel used in concrete – is the most common steel used in buildings, and has an embodied carbon intensity of ~2 $kgCO_2$ per kg.[192, 193]

Today, nearly all the world's steel is made through one of three main production routes:[194]

- **Blast furnace–basic oxygen furnace (BF-BOF):** Iron ore is reduced in the blast furnace to molten iron, which is subsequently refined to crude steel in the basic oxygen furnace. The reduction reactions and refining process require temperatures in the range of 1,100°C to 1,600°C, currently achieved with fossil fuels (primarily metallurgical coal). About 70% of the world's steel was produced via this process in 2020, which emits an average of 2.1 tonnes of CO_2 per tonne of crude steel (tCO_2 per tCS).

- **Electric arc furnace (EAF):** The EAF route, accounting for 25% of global production in 2020, uses electricity to melt scrap steel. Depending on scrap availability and plant configuration, other sources of metallic iron such as direct reduced iron (DRI) or hot metal can also be used. Emissions are highly dependent on the carbon intensity of the electricity supply but are on average 0.5 tCO_2 per tCS.

- **Direct reduced iron–electric arc furnace (DRI-EAF):** The process of reducing iron ore without melting it, using a reducing gas (typically a blend of hydrogen and carbon monoxide derived from natural gas). The solid product, iron, is mainly used as feedstock in an EAF to produce steel. About 5% of the world's steel is produced via this process, which emits 1.2 tCO_2 per tCS on average when using natural gas. This carbon intensity can be reduced to zero if hydrogen is used rather than natural gas, and if that hydrogen is produced in a zero-carbon fashion.

The carbon intensity of steel used in any application can be reduced by either increasing the portion which is derived from recycled steel stocks ("secondary steel production") or decarbonising the process of "primary" steel production (e.g., by moving from coal based blast furnaces to methane of eventually hydrogen based DRI plants).

As with cement, however, achieving significant emissions reductions via supply decarbonisation will take time, with only little progress likely to be feasible over the next decade. This is for the following reasons:

- The cost of near-zero-emissions primary steel production will be significantly higher than conventional production for at least the next decade.

- While technologies are known and technically proven, they are still on the cusp of reaching commercial scale. However, industry leaders such as SSAB are committing to bringing fossil-free steel to the market by 2027.[195]

- Lengthy asset lifetimes of 20–40 years imply only a slow shift to new low-carbon technologies unless high-carbon prices force the scrapping of existing plants before end of useful life.

As a result, while it will be feasible to achieve zero-carbon steel production by 2050, cumulative emissions between now and then could be very large. This highlights the importance of reducing building demand for steel (and cement) in the way which section 11.2 will consider.

191 World Steel Association (2024), *World Steel in Figures 2024*.
192 Other key types of steel include plate (a flat steel sheet used in pipes and shipbuilding), tinplate (used in food cans and industrial packaging), electro-galvanised steel (used in cars and wall/roofing elements), and welded pipe (used to transport gases and water).
193 Jones and Hammond (2019), *Inventory of Carbon and Energy (ICE)*.
194 MPP (2022), *Making Net Zero Steel Possible*.
195 SSAB, *Fossil freedom is just around the corner*, available at www.ssab.com/en/fossil-free-steel. [Accessed 24/09/2024].

11.1.3 Decarbonising aluminium, bricks and glass

Cement, concrete and steel account for 95% of embodied emissions from construction; the remaining 5% is driven mainly by aluminium, glass and bricks.[196] In these sectors, clean electrification is the biggest lever to decarbonising material production. For aluminium, low-carbon power means 70% of emissions can be mitigated by 2035. For glass, fuel switching to electricity, bio-gas and hydrogen could reduce emissions by 75%.[197]

Interim steps to improve the efficiency of producing bricks, and to move away from coal are also key. In India, the world's second-largest producer of bricks, the government mandated that existing brick kilns using coal must either convert to "zig-zag" kilns which are significantly more energy efficient,[198] or switch to natural gas, which is less carbon intensive.[199]

11.2 Demand efficiency: using less materials, using low-carbon materials, and building less

As described above, it will be possible by 2050 to decarbonise the production of the materials used in construction. That in itself will reduce the carbon emissions embodied in new construction close to zero by mid-century and beyond.

However, many of these technologies, while technologically proven, are still on the cusp of reaching commercial scale and so will not achieve significant emissions mitigation until the mid-2030s. It is therefore essential to identify and pursue opportunities to reduce the quantity of materials used in construction, or to use alternative low-carbon materials, in the period before material production has been decarbonised. This will reduce cumulative emissions between now and mid-century and in many cases will be cost-effective.

Exhibit 11.5 describes four levers to reduce the quantity of material:

- "Build nothing" – by reusing or extending the use of existing buildings or avoiding high vacancy rates.
- "Build less" – by delivering the benefit of residential or commercial space in a more space-efficient fashion.
- "Build smarter" – by delivering the same quantity and quality of space but with less materials or less carbon intensive materials.
- "Build efficient" – using efficient construction methods to reduce energy use during construction or maximise the use of recycled materials

For any given construction project, "build nothing" obviously has the highest impact – eliminating 100% of emissions, while "build efficient", can only achieve a relatively small percentage reduction, given the dominant role of emissions from the key materials used. But in terms of aggregate impact, "building smarter" has the greatest potential, since it can in principle be applied to all buildings.

Exhibit 11.6 shows the MPP's estimate of the potential impact of the different levers at the global level for cement and concrete, with 5% of use eliminated by reducing the quantity of construction, while building smarter could in principle achieve a 30% reduction. In China in particular however, the relative importance of build nothing/less is far greater.

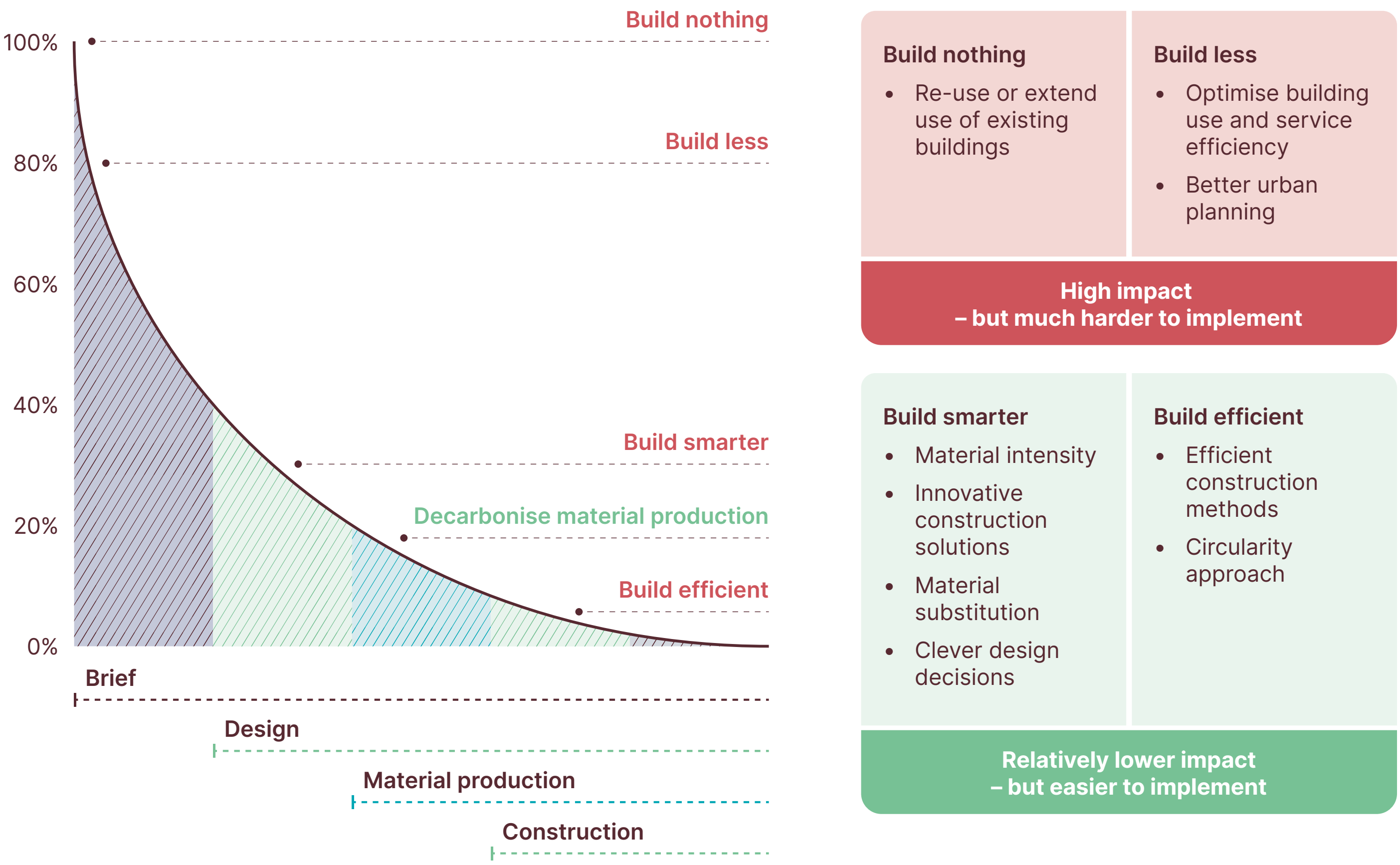
In the next three sections, we describe the specific actions required to build smarter, build efficient and build nothing/less. Altogether, these demand efficiency strategies could in theory reduce cumulative demand for cement, concrete and steel by 30-35% by 2050, though only a subset of this potential is likely to achievable in practice.

196 WBCSD & Arup (2023), *Net-zero buildings halving construction emissions today.*
197 Glass for Europe (2020), *Flat Glass in Climate-Neutral Europe, 2050.*
198 Bricks are arranged to form a chamber which forces air to travel in a zigzag pattern. This increases the length of the airflow path, enhancing combustion and heat transfer rates.
199 Tibrewal, K., Venkataraman, C., Phuleria, H. et al. (2023), *Reconciliation of energy use disparities in brick production in India.*

Exhibit 11.5

The biggest opportunity to reduce embodied carbon is to build less in the first place; but there are many ways to "build smarter" and "build efficient" without restricting urbanisation

Impact of embodied carbon reduction strategies
Reduction potential, %



SOURCE: Systemiq analysis for the ETC; Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

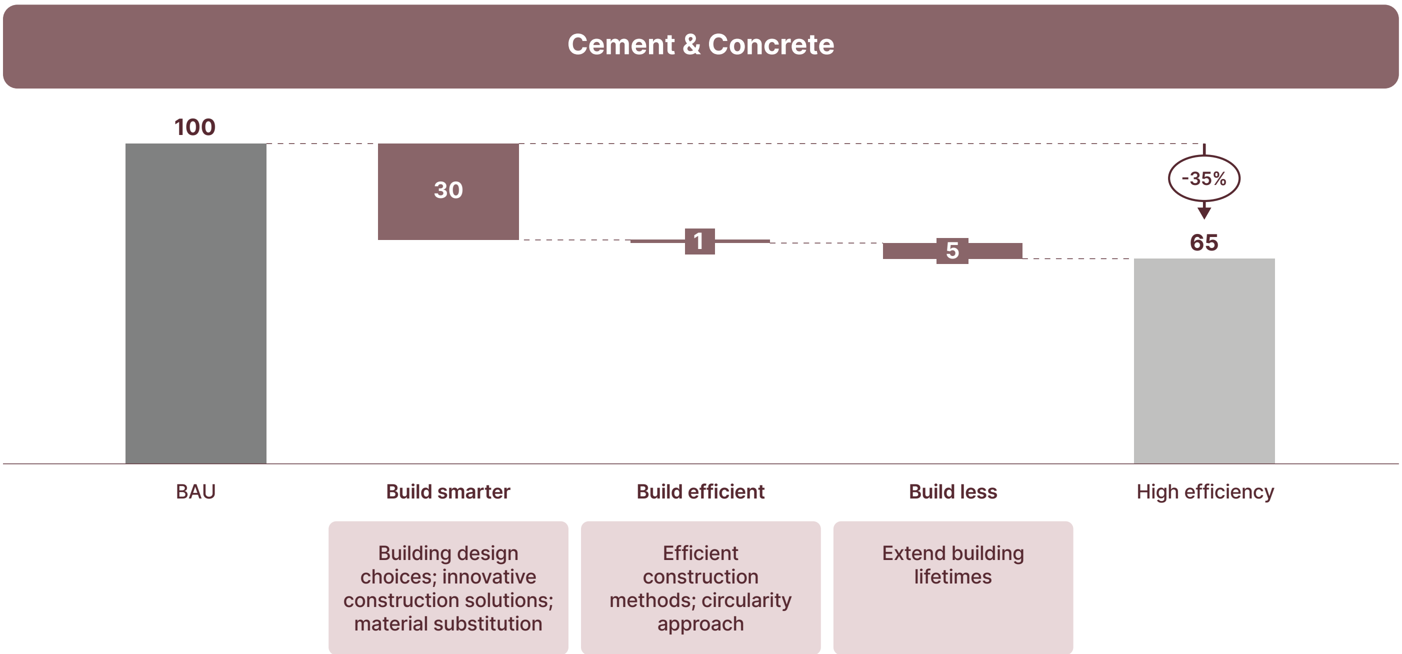
11.2.1 Build smarter: material intensity and substitution

Reducing material intensity through different building design choices and innovative construction techniques, and substituting for lower-carbon materials could in principle reduce cumulative cement and concrete demand by 15-30% and steel demand by 15% to 2050 [Exhibit 11.6]. The suite of options available to a particular development will vary significantly depending on the nature of the building, know-how and awareness, regulation and cost.

Exhibit 11.6

Strategies to reduce material demand, minimise waste and extend building lifetimes could cut demand for cement and concrete by 30–35% to 2050

Potential reduction in cumulative demand for cement, concrete and steel to 2050
%



NOTE: The impact of the levers in steel reflect the impact on total global steel demand, including construction, transport and machinery.

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

In order to reliably reduce embodied carbon, it is crucial that it is first routinely measured. This allows architects, developers and builders to then explore ways to reduce it. Drawing heavily on research by the World Green Buildings Council and Arup, this section details some of the key considerations:[200]

- In the brief stage, the embodied carbon of different building archetypes should be a key decision factor, with taller multi-story buildings typically having a much higher carbon intensity as they require more material for structural support [Exhibit 11.7]. Similarly, siting buildings in areas where ground elevation and soil conditions require relatively smaller foundations can reduce embodied emissions.

- In the design stage, architects should look to maximise floor efficiency (i.e. how much of gross construction area is useable by tenants) and minimise the wall-to-floor ratio [Exhibit 11.7].

- Architects and tenants should work together to optimise the use of buildings to enable lower embodied carbon, for example locating heavy equipment on ground floors to reduce materials required to develop suitable upper floors (e.g., heavy hospital equipment such as MRI machines on ground floors).

- With the majority of embodied carbon often in the floor systems, architects should explore different ratios of steel, concrete and timber that can reduce high-carbon material use. Different construction techniques, such as tree-column floor systems, can also reduce embodied carbon relative to standard floorplate systems by 15-20%.[201]

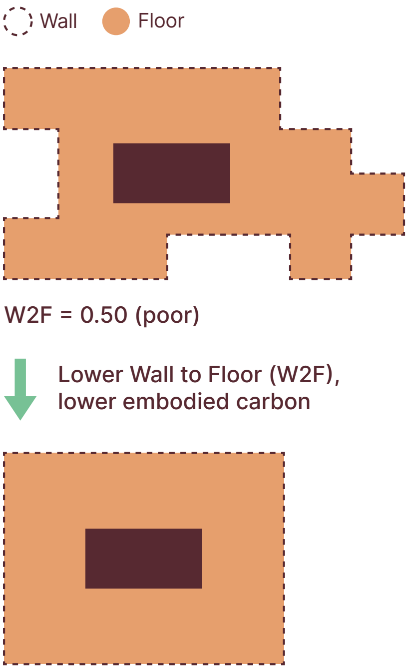
- In seeking to reduce operational emissions, architects and developers should maximise the incorporation of passive heating and cooling techniques (see Chapters 2 and 3) which have a minimal impact on embodied carbon, such as orientation, airtight construction and low-carbon material insulation (e.g., natural fibres).

200 WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today.*
201 Ibid. Tree column floor systems involve branching arms from columns to support upper floors. They reduce embodied carbon by shortening the spans of main beams required, reducing depth and weight.

Exhibit 11.7

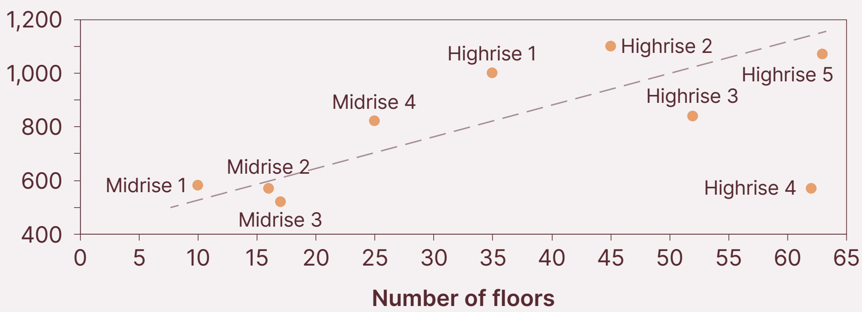
Taller buildings and those with a high wall-to-floor ratio are more embodied carbon-intensive

Wall-to-floor ratio
Illustrative



Building height

Upfront embodied carbon of high-rise buildings in London
$kgCO_2e$ per m² (gross internal area)



Taller buildings typically require:

- More structure – thicker core walls, bigger columns, larger foundations
- More space and equipment – lifts and stairs
- More building services

Embodied carbon per m² can be 50% higher to provide the same net useable area between high-rise and low-rise construction

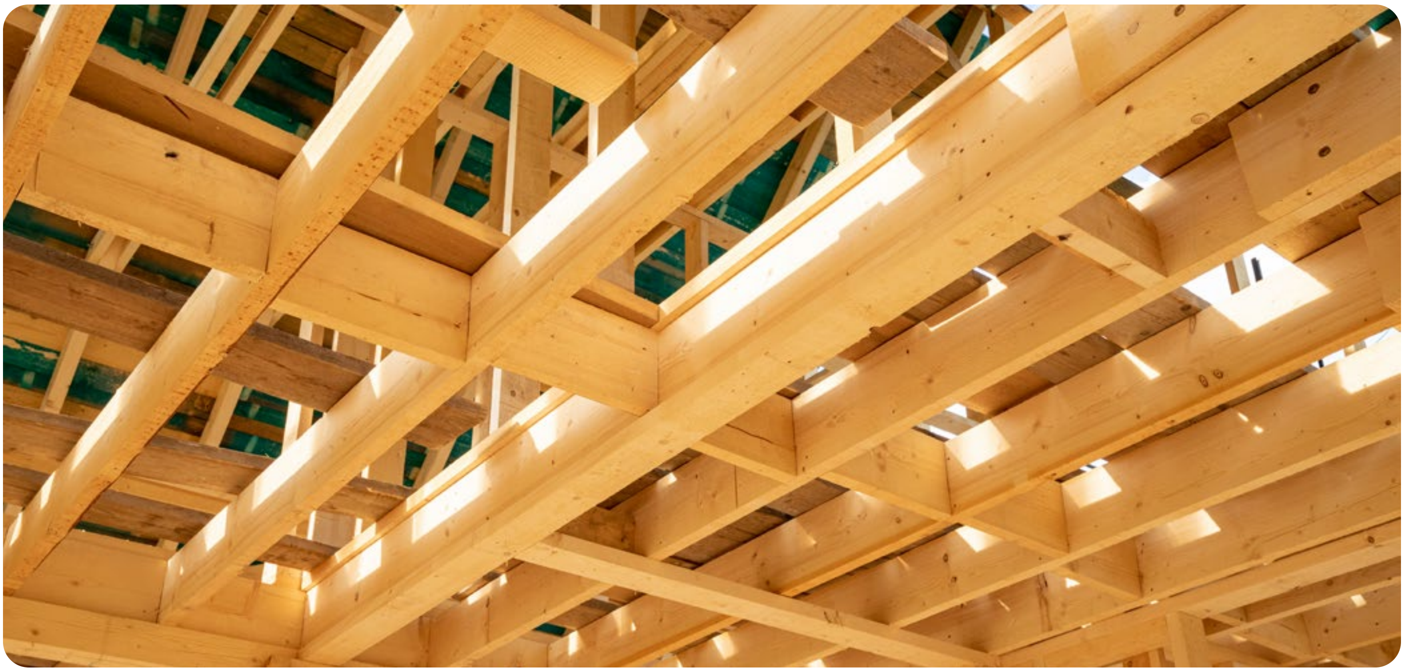
SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

There is also an opportunity to substitute less carbon-intenstive materials in place of high-carbon intensive steel, cement/concrete and bricks. These include various bio-based materials [Exhibit 11.8] and a number of other non bio-based alternatives.

Bio-based materials can play a significant role in specific regions, but on a global scale, are unlikely to displace a significant share of traditional cement, concrete and steel use due to limits to sustainable supply. In addition to being much less carbon-intensive in their production, bio-based materials such as timber and bamboo are able to store sequestered carbon in buildings. Some materials such as hempcrete, are also able to sequester some carbon during their use in buildings (e.g., due to the carbonisation of lime binder), meaning they have the potential to be carbon neutral or even carbon negative. This benefit of carbon sequestration is however only achieved if materials are dealt with effectively at end-of-life. This requires either recycling or reuse of the materials, or the application of CCS if the materials are burnt to provide a heat or power source.

These materials cannot be used in all cases. For instance, timber does not have the tensile strength of cement or steel and is thus inappropriate for some designs. Moreover, at present many regulations limit the use of timber to low- or mid-rise buildings, though higher timber buildings are increasingly being built in some countries. It is also important to ensure that bio-based materials are properly treated to manage the risks of fire, moisture or insect infestation.

Where applicable, timber (and other bio-based materials) can provide similar stability, safety and durability as concrete or brick based construction, with much lower emissions. The fact that North America uses timber for a large percentage of residential home construction, while China lacks the timber resources to do so, in part explains why American consumption of cement or bricks per capita is far lower than in China, and construction related emissions therefore far less.



Available information and costs suggest that timber and other bio-based materials may in many circumstances be cost competitive:

- Some detailed studies of the fundamental cost drivers suggest that costs can be 10–15% lower compared to a house/apartment block built with concrete or bricks, while others suggest a 10 to 25% increase (although this is not solely due to materials but also to the cost of implementing additional design considerations).[202]

- And interviews with investors and developers with experience of timber construction record cost premiums of 0 to 5%, while a study focused on Europe indicated that savings of up to 15% might be possible.[203 204]

The crucial issue is therefore not the technical feasibility of timber or other bio-based construction, nor the cost, but the realistic sustainability of bio-based materials, given constraints on the potential to extract bio resources in a truly sustainable fashion, and the alternative demands on sustainable bioresources to meet other decarbonisation priorities.

In the ETC's 2021 report on *Bioresources Within a Net-Zero Emissions Economy*, we recommended that the use of sustainable bioresources as a material – whether for construction or as a feedstock for plastics production – should be given priority over its use as an energy source.[205] And we estimated that 40 EJ of sustainable bioresource might be available for these materials rather than energy uses.

But even if this were all allocated to construction it would only displace a small share of cement demand. This figure could be increased over the long term if very large-scale timber-growing projects were launched to provide timber resources for later in the century. But it would take several decades before the timber would be available for construction and the scale of projects required to offset a significant proportion of concrete demand is very large. For instance, if 25% of the 6.4 billion cubic meters of concrete used each year were replaced by timber, the world would need to increase total forest cover by about 14% – a land area 1.5 times the size of India.[206]

While timber and other bio-based production should therefore be encouraged to provide standards are in place to ensure sustainable supply, but it is not prudent to assume that more than a small (e.g., up to 10%) reduction in cement/concrete use can be achieved via this substitution [Box Q].

202 Dams, B., et al. (2023), *Upscaling bio-based construction: challenges and opportunities*; Kransy, E., et al. (2017), *Analysis and comparison of environmental impacts and costs of bio-based house versus concrete house*; Gu, H., Liang, S. and Bergman, R. (2021), *Comparison of Building Construction and Life-Cycle Cost for a High-Rise Mass Timber Building with its Concrete Alternative.*
203 Built by Nature (2024), *Investor perceptions on the use of timber in real estate.*
204 Röck M e.a. (2022), *Towards EU embodied carbon benchmarks for buildings – Setting the baseline: A bottom-up approach.*
205 ETC (2021), *Bioresources within a Net-Zero Emissions Economy: Making A Sustainable Approach Possible.*
206 ETC (2020), *Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century: Cement.*

Exhibit 11.8

There are many alternative materials to cement, concrete and steel, but to have a lower whole-life carbon impact, they must be sustainably sourced and dealt with correctly at end-of-life

Four questions determine the whole-life carbon impact of alternative materials

	Risk of adverse impact on whole-life carbon	Risk of adverse impact on whole-life carbon	
1	**How much carbon is generated from producing the material (e.g., manufacturing and transport)?**	In almost all cases, carbon is lower than cement/concrete/steel. Using local materials to reduce transport emissions is key.	Low
2	**Is the material sustainably sourced?**	Bio materials can be sustainable if harvested at maturity and replanted. Sourcing from primary forest or unsustainable harvesting practices pose substantial risks.	High
3	**Is carbon further sequestered during the building's lifetime?**	Some materials are able to further sequester carbon, in addition to storing existing sequestered carbon.	Low
4	**How is the material dealt with at end-of-life?**	If material is not reused, recycled or burned with carbon capture, then whole-life carbon impacts can be greater than steel and cement.	High

Low-carbon material	Description and main uses	How certain is low whole-life embodied carbon?	Current market scale	Potential to scale further

 Timber	• Softwood: window and door frames
	• Glued-laminated timber: load bearing elements such as rafters, beams, slabs and columns
	• Cross-laminated timber: structures, walls and floors.
		Low
		• Producing timber for construction produces around 100–200 kg CO_2e per m^3 - but highly variable; 50% of emissions due to transporting material to site
		• Timber stores carbon over its lifetime in a building, but to realise benefits over concrete and steel, it crucially must be:
		  ∘ Sustainably sourced with replanting
		  ∘ Reused or recycled at end-of-life
		  ∘ Or, if burned, combustion emissions must be captured
			Mass market	Medium
				• Supply of sustainability-produced timber is limited
				• Risks of fire, rot and pests must be managed

 Bamboo	• Lightweight and strong • Scaffolding, foundations, flooring, roofs, beams, walls	Medium • Bamboo stores carbon over its lifetime, but must be sustainably sourced and dealt with properly at end of life • 4–6 years growth cycle means bamboo sequesters carbon rapidly • Can be harvested without killing the plant, allowing quick regeneration	Early stage	Medium • Low durability if not treated properly – risk of pests, fungi and fire • Very heterogenous material – designing standardised codes and constriction techniques is challenging
 Hempcrete	• Hemp, lime and water – used for walls, in combination with a structural frame due to low composite strength • Able to control humidity and has high thermal inertia • Hemp fibres used for insulation	High • Hemp absorbs CO_2 as it grows and stores it over its lifecycle • Rapid growing cycle of hemp (1/3 of a year) • Carbonation of lime binder further sequesters carbon • Potential for hempcrete to be **carbon negative**	Early stage	High • Fire resistant and less susceptible to pests • Hemp can be grown all over the world in different climates – supply is scalable
 Rammed earth	• A mixture of gravel, sand, silt, clay with a small amount of cement or lime • Layers are rammed into place between flat panels which are then removed • Excellent thermal mass, limited insulation • Technique used for thousands of years	High • Use of natural materials means very little carbon is generated in production • Rammed earth can also sequester carbon over its lifetime, depending on the amount of lime and cement used • However, rammed earth does use a small amount of cement; the exact carbon impact varies depending on the exact composition of material used	Mass market	Medium • Natural materials in abundance • Composition based on locally available materials • Suitable for all climates – but requires high design skills • Labour-intensive process, not suitable for modular construction

SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*; The Structural Engineer (2021), *Timber and Carbon Sequestration*; Arup (2023), *Embodied Carbon: Timber*; Xu, X., et al. (2022), *Bamboo construction materials: Carbon storage and potential to reduce associated CO_2 emissions*; Muhit, I., et al. (2024), *A holistic sustainability overview of hemp as building and highway construction materials*; Architecture Today, *From the ground up: What you need to know about building with rammed earth*, available at www.architecturetoday.co.uk/rammed-earth-jonathan-tuckey-design-webb-yates-engineers-sustainable-solutions-sga-consulting/. [Accessed 04/09/2024].

Box Q **The debate around the use of timber in construction**

Mass timber refers to engineered wood products, including:

- Softwood, which is used for windows, door frames, joists and roof trusses.
- Glued-laminated timber (Glulam), which is used for load bearing elements such as rafters, beams, slabs and columns.
- Cross-laminated timber (CLT), which is used for walls and floors.

Timber can offer the same structural safety and durability as steel and cement in certain applications, but currently restricted to certain building archetypes by regulation (e.g., low- and mid-rise buildings, which will make up around 40% of future construction). However, there are emerging examples of timber being used in high-density industrial spaces[207] and in "hybrid" high-rise buildings alongside steel and cement.[208]

Timber also has a number of benefits, including:

- Prefabrication is easier for timber, leading to lower waste.
- Timber aesthetics mean that less additional material is needed (e.g., plaster, paint, drywall), saving on material and labour costs.
- Mass timber has high-insulating capabilities, meaning less insulation material is needed.

There are two key considerations determining the whole-life carbon benefit of using timber in construction.

Sustainable supply of timber

The supply of sustainable timber is very limited due to competing demands for land, long lead times and growing demand for sustainable biomass across sectors. Currently, only 11% of timber today is certified as sustainably harvested and 85% of this is from Europe, North Asia and North America.[209] As we explored in our *Bioresources report*, the demand for sustainable biomass in a net-zero economy will greatly exceed scenarios of maximum supply. It is crucial to prioritise use across sectors where it can be used as a material, in aviation, and in applications where it can be combined with CCS to deliver durable atmospheric removals.[210]

Certainty of lower whole-life carbon emission

In general, timber has a lower carbon intensity than traditional steel and cement, but the exact carbon savings are heavily contested and depend on a range of factors. For example, lifetime carbon savings from substituting concrete by cross-laminated timber range from 10–15% to 60%.[211] Exhibit 11.9 shows that the boundary between desirable and undesirable timber substitution is very complex and depends on various factors:

- The actual embodied carbon in timber can be much higher when accounting for carbon in the tree that cannot be used for timber (bark, branches) and is burned or left to rot; although, this is also part of a natural re-fertilisation process.
- While timber has a high sequestration potential, replanted trees will take decades to re-sequester the emitted carbon.

207 See Flatman, B. (2023), *Innovative mass timber industrial scheme unveiled by dRMM in Greenwich.*
208 For example, Timber Square, expected completion in 2025, will be one of the most significant commercial developments in the UK to use a hybrid steel/concrete and timber structure. See PEFC (2024), *PEFC Project Certification at Timber Square - PEFC.*
209 Malek, E., et al. (2022), *A thematic review of forest certification publications from 2017 to 2021.*
210 ETC (2023), *Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible.*
211 Zhuocheng Duan, Qiong Huang et al., *Comparative life cycle assessment of a reinforced concrete residential building with equivalent cross laminated timber alternatives in China, Journal of Building Engineering*, Volume 62, 105357; The BioComposites Centre (2019), *Wood in Construction in the UK: An Analysis of Carbon Abatement Potential.*

- It is crucial to ensure trees are cut down at the right time in their life; cutting them down before maturation significantly cuts a tree's sequestration potential. In addition, harvesting at the right time, when trees have low moisture and not during growing season is important for successful re-growth, reducing impacts on biodiversity, and improving timber material quality.

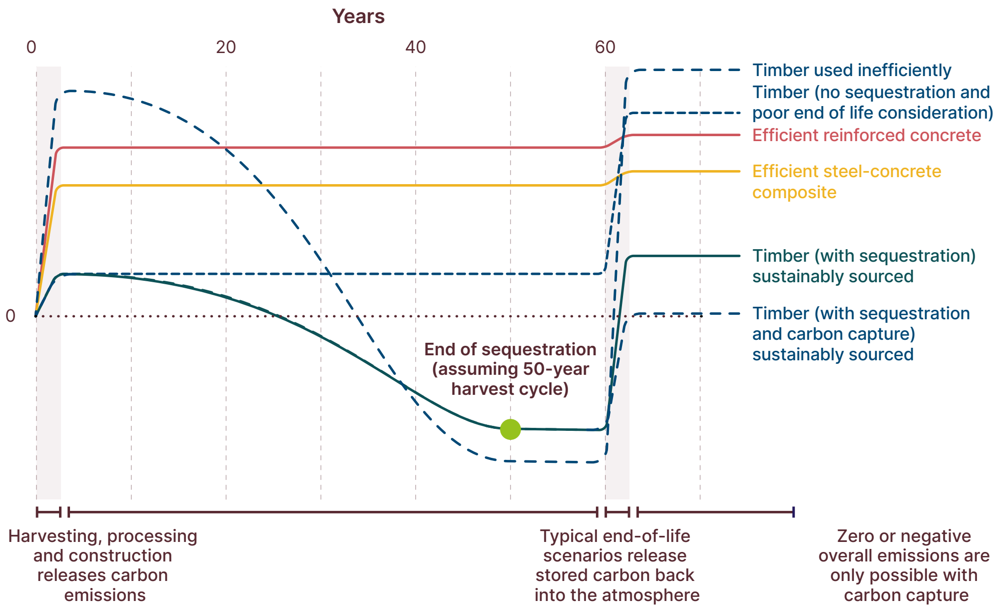
- Without strict guidance, replacing concrete and steel with mass timber could become a net GHG-emitter.

Overall, timber should be explored as a material substitute to some high-carbon steel and cement use where negative lifecycle carbon emissions and sustainable supply can be guaranteed. Hybrid construction which offsets some steel and cement use with timber could play an important role in low-rise construction in certain regions with well-regulated sustainable timber industries. This requires the industry to develop a stronger consensus around how to measure and account for the carbon of timber and regulations about when to cut down trees and safety and durability. However, given the constraints on the potential to extract timber in a truly sustainable fashion, and competing demands for its use, it is not prudent to assume that more than a small (e.g., up to 10%) reduction in cement/concrete use can be achieved.

Exhibit 11.9

Used in the right way and with proper end-of-life consideration, modern engineered timber can significantly lower a building's embodied carbon

Cumulative embodied carbon of sustainably sourced timber and timber used inefficiently
$kgCO_2e$ per m^2



For timber to have lower lifetime emissions compared to high-carbon concrete and steel, it must be:

- Sustainably sourced from standing forest which is replanted, ensuring **sequestration**
- Dealt with properly at end of life (e.g., recycled, or burned + **carbon capture**)

SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

Non bio-based materials and construction innovation. In addition, numerous research groups and companies are working to develop non bio-based alternatives. These include carbon fibre stone, which combines ground stone with carbon fibres to produce an extremely strong and lightweight material. The economics of these, and other options, are not yet clear, but it is possible that new innovations could play a significant role. Support for R&D and early deployment is therefore key.

In addition, other companies are working on new ways to use concrete and steel which could significantly reduce the quantities required and simplify the on-site construction process, via for instance manufactured reinforcement systems.[212]

The imposition of a carbon price on carbon intensive cement/concrete and steel production, by increasing the cost of those materials, will increase incentives for the development and deployment of new, alternative materials.

11.2.2 Build efficient: modular construction

A combination of efficient and circular construction has the potential to reduce global cumulative demand for cement and concrete by 1% by 2050, and by 5% for steel. However, impacts for individual construction projects can be significant.

Key actions include:

- Modular construction, where parts of a building are made in a factory, shipped to site, and put together like big building blocks. This has the potential to reduce on-site waste by up to 90%, cut material consumption by 20%, and double the speed of construction.[213] It also cuts transport related emissions, with fewer raw materials being brought to site.
- Digital tools to reduce waste in the design of buildings, including digital twinning, building information modelling systems, and 3D printing.
- Using robotics and drones to handle materials.
- On-site and off-site waste management to maximise the recovery of materials for recycling and re-use.

212 Unipart, *Construction Technologies*, available at www.unipart.com/construction-technologies/manufactured-reinforcement-systems/. [Accessed 20/11/2024].
213 Modular Building Institute, *Building Green, Living Clean*, available at www.modular.org/2023/12/26/how-modular-construction-leads-to-zero-waste-and-eco-fficiency/. [Accessed 24/09/2024].

11.2.3 Build nothing or less

Changes in policy and urban planning could in principle reduce cumulative demand for building materials by 5–10%. Some of these would require changes in household amenity, but some could be achieved with no impact on living. Four key categories can be distinguished:

- **Avoiding high vacancy rates:** This is particularly important in China, which currently 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.[214] Around 40% of China's urban households own two or more apartments, and over 20% of all apartments are not occupied.[215] Many recently built apartments in China will never be occupied and urban infrastructure in many third- and fourth-tier cities massively exceeds future requirements. As the ETC/RMI 2020 report, *Achieving a Green Recovery for China* set out, China therefore has a huge opportunity to rebalance its economy away from excessive real estate and physical infrastructure investment, and towards consumption and green investment, including a focus on the quality rather than the quantity of urban infrastructure.[216]

- **Extending building lifetimes:** Building lifetimes vary massively across regions, from over 100 years in Europe, 50–60 years in the US, 30–40 years in Japan, and just 25 years in China. The potential to extend lifetimes is therefore heavily region specific. Extending building lifetimes should be a priority in parts of Asia, where poor urban planning during rapid urbanisation resulted in inadequate and inflexible buildings – and high demolition rates. These high demolition rates sometimes reflect initially poor construction quality, but also reflect changing urban planning and land policies. This suggests a huge opportunity to get this right the first time around. Planning and investment should ensure building is designed with future uses in mind and material durability.

- **Urban planning for compact cities:** As outlined in Chapter 10, around half of global embodied carbon comes from constructing new infrastructure, such as roads, pipes and utilities. Better urban and spatial planning can therefore have a huge impact on reducing the need for additional public infrastructure and transport. The IPCC estimates that 25% of urban emissions could be saved by 2050, by making urban areas compact.[217]

  This objective is sometimes expressed in the concept of the "15 minute city", where all key public services should be accessible within 15 minutes. A recent Systemiq report 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.[218] Multi-unit dwellings also use half as much heating energy as single-unit houses.

  Policymakers and planners need to explore how to reach a sweet spot in efficiency and balance for a high-quality of life, ensuring there is sufficient green space, investing sufficiently in public transport to prevent overcrowding, and promoting access to cooling to offset urban island heat effects.

- **Reducing per capita floor use:** the amount of floor space which people occupy varies greatly across the world; average residential floor space is 55 m² per capita in the US vs. 17 m² in Asia.[219] The future quantity of building construction therefore depends on how far developing countries' per capita use might increase over time, and on whether there is any possibility to reduce per capita use of either residential space or commercial space in developed countries.

  A recent UNEP report, *Global Resources Outlook*, suggested in principle that the floor area in 2050 could be reduced by 15% via a combination of reduced vacancy rates in Chinese cities and reduced building of second houses in rich developed countries.[220] Any such changes would however have implications for living standards. As a result, there is very limited potential to reduce m² per capita in developing countries, as levels remain far below Europe and North America averages.

  In the summary figures for potential shown in the next section we do not therefore assume that these reductions can be achieved.

214 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].
215 ETC and RMI (2020), *Achieving a green recovery for China.*
216 Ibid.
217 IPCC (2021), *Sixth Assessment Report - Climate Change 2021: The Physical Science Basis.*
218 Systemiq (2022), *Efficient and balanced space use: shaping vibrant neighbourhoods and boosting climate progress in Europe.*
219 UN Environment Programme (2024), *Global Resources Outlook 2024: Methodological Annexes.*
220 UN Environment Programme (2024), *Global Resources Outlook 2024.*

11.3 Implications for embodied carbon from new construction

Combining the MPP pathways for decarbonisation of material production and opportunities to reduce demand for materials suggests that the total embodied carbon from the construction of new buildings to 2050 could be 65% lower with ambitious action [Exhibit 11.10], reducing cumulative emissions between now and 2050 from 75 $GtCO_2$ to 30 $GtCO_2$:

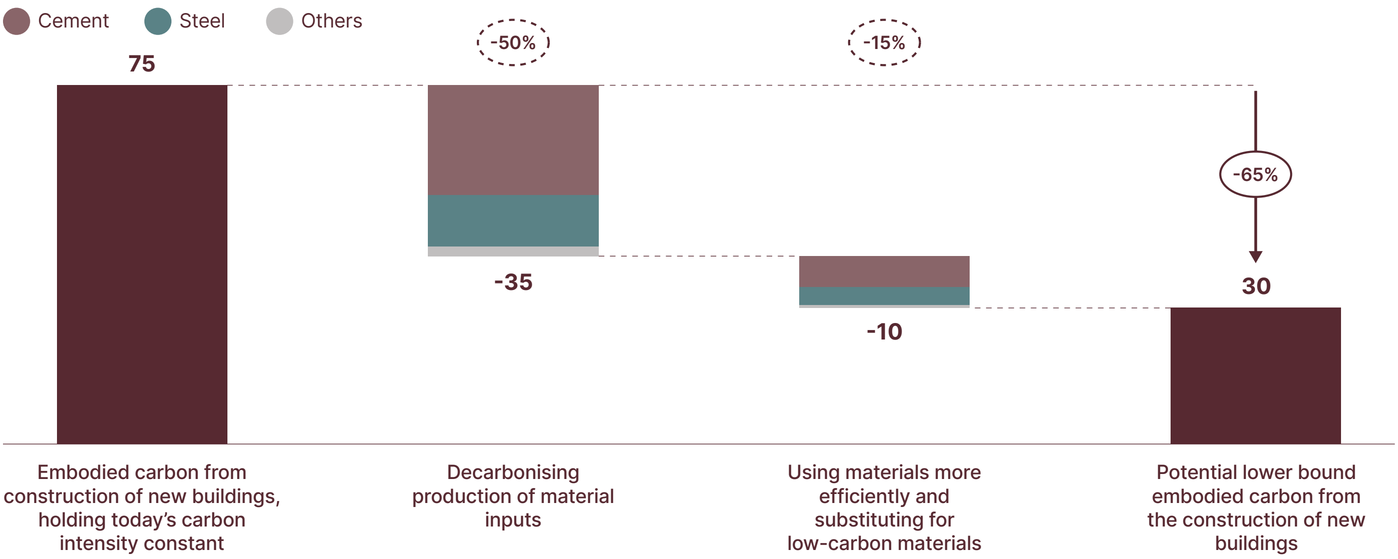
- The vast majority of this reduction is achieved via the decarbonisation of material production. This highlights the vital importance of policies – such as carbon pricing – to drive as fast as possible progress towards zero-carbon production of iron/steel, cement/concrete, aluminium and bricks.

- But a significant emissions reduction could also be achieved by using materials more efficiently and via some substitution of low-carbon materials in place of high-carbon ones. And these demand side actions become more important the slower the pace at which material production decarbonisation is achieved.

Exhibit 11.10

The total embodied carbon from building 140 billion m² by 2050 could be reduced by 65% 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
$GtCO_2e$



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

Embodied carbon from retrofitting and at end-of-life

12

Key messages

- From a whole-life carbon perspective, it is crucial that retrofits lead to an improvement in energy performance; currently in the EU, only 5% of commercial building retrofits lead to energy savings of more than 3%.
- As the grid decarbonises, it will take longer for embodied carbon to be offset by operational emissions over time, creating a more challenging carbon case for retrofitting. However, there is still a very strong social business case for improving the quality of housing and living standards.
- Energy efficiency improvements to the least efficient buildings should be prioritised this decade, realising greater emission savings of high-carbon electricity use, and improving living standards.
- While the embodied carbon associated with extending buildings is far lower than rebuilding, where rebuilding is done to very high design and material standards, maximising opportunities to use low-carbon materials and incorporate passive heating/cooling, it can be preferable from a lifecycle emissions perspective.

Buildings are often retrofitted several times over their total lifecycle before demolition/rebuilding. Building lifetimes vary greatly by type of building and by country, but as a broad indication, the structure of a building will typically last over 60 years, while its skin will need replacing or updating every 30–35 years, services every 20–30 years, and space plan every 10–30 years.[221]

Drawing on data from Europe, emissions resulting from retrofit are estimated to amount to about 25% of a building's whole-lifecycle emissions, while end-of-life emissions account for around 5% [Exhibit 10.2].

This chapter explores the potential to reduce these emissions and optimal trade-offs between reducing retrofit embodied emissions and operational emissions.

12.1 The embodied carbon of retrofitting

Buildings are retrofitted for many purposes – in commercial buildings, retrofits to the space plan often reflect new tenant requirements, while residential buildings are often retrofitted to deliver new room layouts and facilities. New health and safety requirements and aesthetics also play a role, and improved energy efficiency can and should be an objective. However, it is estimated in the EU that only 5% of commercial building retrofits lead to energy savings of more than 3%.[222]

From a whole-life carbon perspective, it is crucial that retrofits lead to an improvement in energy performance, ensuring that embodied carbon is offset by avoided operational emissions. But it should be noted that the emission reduction returns from retrofit will tend to decline, and carbon payback times increase, if electrification of heating and grid decarbonisation occurs at a faster pace than the decarbonisation of construction material production.

221 WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today.*
222 European Commission (2020), *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives.*

Exhibit 12.1 illustrates that if the carbon intensity of construction is unchanged, lower operational emissions imply a longer payback from retrofits. Exhibit 12.2 presents illustrative examples of this effect:

- At today's current grid carbon intensities of 300–600 gCO_2 per kWh (i.e. US, Germany, China), even deep retrofits will repay their embodied carbon in under five years; but this could increase to 10–30 years in countries like France and Finland with grid intensity at 75 gCO_2 per kWh.

- And once grids achieve near total decarbonisation (e.g., 10 gCO_2 per kWh) and if the carbon intensity of construction does not fall, it could take over 100 years to repay carbon embodied in a deep retrofit.

Decarbonising material production would conversely tend to shorten payback periods for any given grid intensity. While at the limit, if both electricity generation and material production were fully decarbonised, the concept of a carbon payback will cease to be relevant.

The implications of this are:

- It is vital to drive both the decarbonisation of operational energy use (via electrification and grid decarbonisation) and the decarbonisation of construction material production.

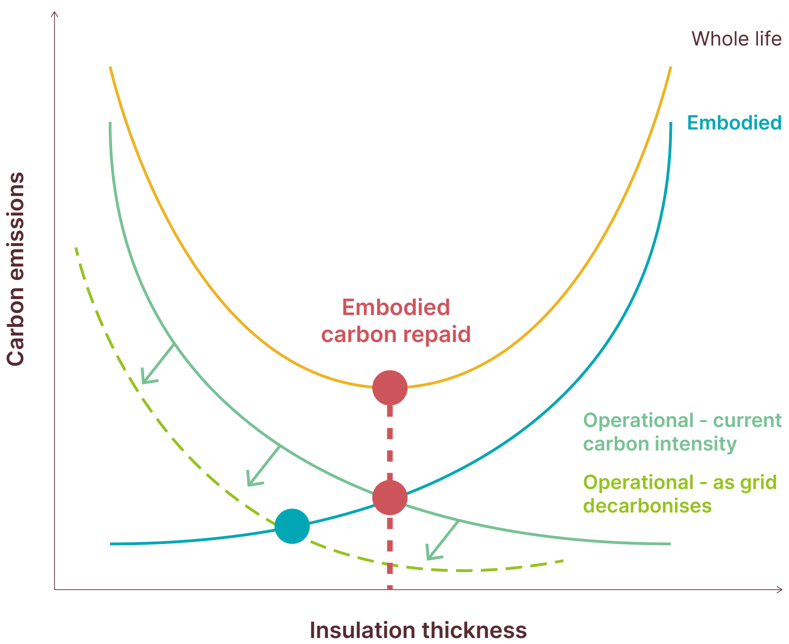
- Achieving energy efficiency improvements should be a high priority for retrofits of the least efficient buildings, and for buildings in countries which have low levels of building efficiency or high levels of grid carbon intensity.

- 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.

Exhibit 12.1

Embodied carbon from retrofitting existing buildings will be offset by avoided operational energy emissions; but as the grid decarbonises, this trade-off will become more challenging

Illustration of the balance between embodied carbon and operational carbon from insulation



- Understanding the whole life carbon from retrofitting requires weighing up embodied carbon and avoided operational emissions
- Beyond a certain point, further insulation will have a negative net impact on carbon emissions as electricity is decarbonise faster than building materials
- This point will shift over time, as operational emissions are decarbonised – creating trickier trade-offs for retrofit
- Over the long-term, embodied emissions will also be decarbonised, leaving the trade-off unchanged
- Once both operational and embodied emissions are decarbonise, there will be no carbon payback to insulation - but continued benefits to energy bills and comfort

SOURCE: Adapted from WBCSD & Arup (2023), *Net-zero buildings Halving construction emissions today*.

Exhibit 12.2

At today's electricity carbon intensities, even deep retrofits payback their embodied carbon within 5–10 years; but as the grid decarbonises, payback periods become longer

Estimated carbon payback at different types of retrofit and carbon intensity of electricity
Years

Electricity grid carbon intensity	600 gCO_2 per kWh	300 gCO_2 per kWh	75 gCO_2 per kWh	10 gCO_2 per kWh
Retrofit type	*China, Australia*	*US, Germany*	*Finland, France*	*Future electricity grids*
Light 15 $kgCO_2$ per m^2	2 years	3.5 years	14 years	100 years
Medium 40 $kgCO_2$ per m^2	2.5 years	5 years	20 years	140 years
Deep 85 $kgCO_2$ per m^2	3.5 years	7 years	28 years	200 years

Decreasing payback as the electricity grid decarbonises

NOTE: Analysis focused on all-electric households with an annual energy consumption of 8,000 kWh in the baseline scenario; Energy savings from light retrofit (15%), medium (30%), deep (50%). Based on a 100 m² house.

SOURCE: Systemiq analysis for the ETC; CRREM (2023), *Embodied Carbon of Retrofits*.

12.2 End-of-life emissions: rebuilding vs. deep retrofit

Embodied emissions relating to the end of a building's life account for the smallest share of its total lifecycle emissions, less than 5%. These emissions relate from various sources, including the energy used to power demolition machinery, to transport debris, to recycle materials, and from the waste processing. These emissions can be reduced with the electrification of transport and industry, and with careful waste management strategies to properly deal with timber and other bio-based materials at end of time, preventing them being burned or decomposing and releasing sequestered carbon.

The key question relating to buildings at end-of-life is whether it is better, from a carbon perspective, to extend a building's lifetime via a deep retrofit or to rebuild entirely to much higher embodied and operational carbon standards. There will be no one-size-fits-all answer to this question and heavily depends on the standards to which a building is built.

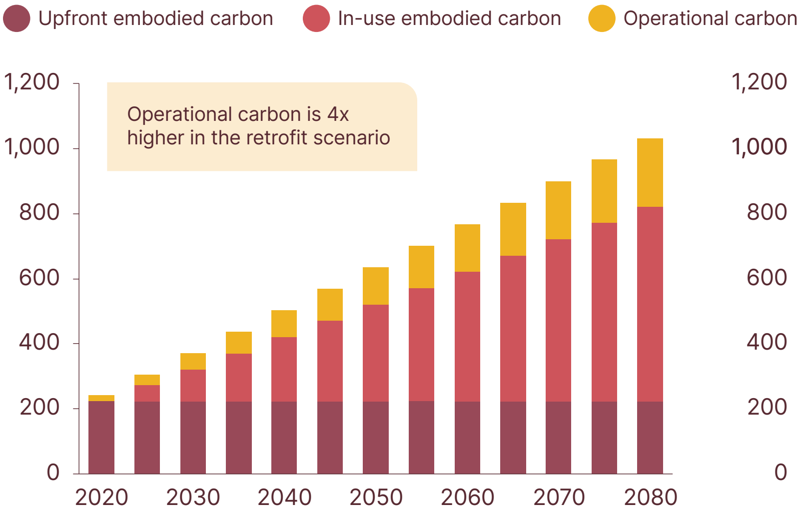
Exhibit 12.3 shows that, in some cases, lifecycle emissions from rebuilding can be the same as retrofitting. While the embodied carbon associated with extending buildings is far lower than rebuilding, where rebuilding is done to very high design and material standards, maximising opportunities to use low-carbon materials and incorporate passive heating/cooling, it can be preferable from a lifecycle emissions perspective. This case study highlights the importance of considering and measuring lifecycle emissions (see Chapter 13).

Exhibit 12.3

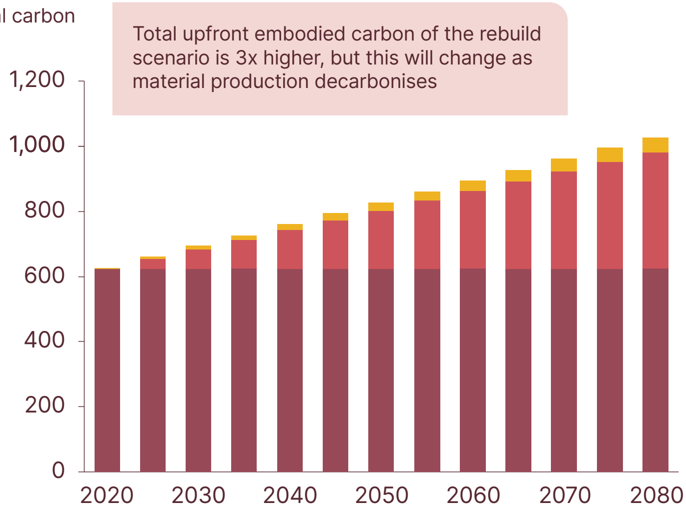
If built to the highest embodied carbon standards, lifecycle emissions from rebuilding old buildings can be as high as retrofitting

Cumulative whole life carbon emissions of a commercial building in Europe over 60 years
$kgCO_2e$ per m^2

Retrofitting building for energy efficiency



Rebuilding building to very high operational and embodied carbon standards



SOURCE: Schneider Electric Sustainability Research Institute (2023), *Towards net-zero buildings: Exploring the IntenCity case*.

Policies and industry actions to reduce embodied carbon

13

As Chapters 10 to 12 have described, 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. This reflects four challenges:

- In many countries, embodied carbon is not very well understood, with lifecycle emissions traditionally not being assessed, measured or tracked. In recent years, however, measuring embodied carbon has become a mature science in several countries. The challenge is now to scale up these skills and techniques, especially in lower-income countries, and creating the right policy and incentive environment to ensure whole-life carbon is routinely assessed.
- Market incentives to reduce emissions are often weak. There is little evidence today that good performance on embodied carbon translates to higher asset-value, attracts a lower cost of capital, or that tenants are willing to pay more for it.
- There is often a lack of awareness and skills to deploy the various demand-side strategies that can reduce material demand and costs.
- In most countries, there is no clear push from regulators on embodied carbon. Exceptions include France and Denmark which have quantitative embodied carbon limits for new buildings that decrease over time.[223] In the absence of such regulation, there is limited incentive for action, especially given high perceived and, in some cases, actual material and labour costs.

Embodied carbon is, however, rising up the policy agenda:

- At COP28, the Buildings Breakthrough was launched, with 28 governments, including China and the US, setting commitments to reduce embodied carbon in new construction projects by at least 40% by 2030. Industry groups are also beginning to set voluntary commitments to reduce embodied carbon.
- The World Green Building Council's Net Zero Carbon Buildings Commitment to reduce embodied carbon from new buildings and major renovations by 40% by 2030 has 176 signatories representing ~$400 billion annual turnover.
- And the Better Buildings Partnership has 37 asset managers and investors, which have committed to publishing their net-zero transition plans, including embodied carbon, which will be supported by the development of new buildings sector science-based targets guidance.[224]

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

- As wide as possible role for carbon prices applied to construction materials.
- The development of better information on embodied carbon and lifecycle emissions.
- Regulation to set clear whole-life carbon emission limits.
- Voluntary action informed by better measurement and motivated by carbon prices and regulation.

223 GRESB (2023). *Embodied carbon: What it is and how to tackle it.*
224 WGBC (2023), *The Commitment*; BBP (2023), *Member Climate Commitment*; SBTI (2023), *Buildings Sector Science Based Targets Guidance.*

Carbon pricing

As Chapters 10 to 12 described, while there are in theory multiple opportunities to reduce embodied carbon emissions, the nature of the opportunity varies greatly by type of building and specific country, and the optimal trade-off between reducing emissions and bodied vs. operational emissions is complex.

As a result, there are limits to the extent to which 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 both:

- Create incentives to decarbonise the production of construction materials (steel, cement, aluminium, bricks and glass). Such carbon pricing will indeed be essential to drive heavy industry decarbonisation since, while decarbonisation is clearly technically possible, it will entail green premium. MPP estimates suggest that the cost today of producing zero-carbon steel, cement and concrete could be respectively around 50%, 40–120% and 15–40% higher than traditional high-carbon alternatives.[225] While these increases will only add about 1.5–3% to the total cost of construction, developers will not voluntarily absorb these costs unless forced to do so via carbon prices or regulations.

- Create incentives to identify and implement the demand side efficiency improvements described in Chapters 10 to 12. Some of these actions would in turn reduce the overall cost-premium effect.

Better measurement

To enable regulation and voluntary action on embodied carbon, greater transparency and data on embodied carbon is crucial:

- The first step is 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. In London, this regulation has completely transformed transparency in the sector, with favourable finance rates already being attached to lower embodied carbon projects in just a few years [Box R].

- 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.[226]

- Ideally, collected data should be open source, enabling the industry to develop a much clearer idea of what good looks like and set targets accordingly.

Whole-life carbon regulation

Better data will enable regulation to begin setting minimum requirements for lifecycle emissions, being careful to sufficiently differentiate across different building types. Regulation could:

- Set specific embodied carbon limits ($kgCO_2$ per m^2), alongside operational energy efficiency limits (kWh per m^2). For example, France requires the total embodied carbon of new individual homes built in 2025 to be less than 530 $kgCO_2$ per m^2, falling to 415 from 2030.[227]

- Set whole-life carbon minimum requirements, allowing developers to make their own trade-offs between embodied and operational emissions. For example, Denmark requires the modelled whole-life carbon of new buildings to be less than 12 $kgCO_2$ per m^2 per year, assuming a 50 year lifetime.[228] This minimum will fall to 5 $kgCO_2$ per m^2 per year from 2029.

- Mandate carbon intensities for material inputs that are produced or imported, including minimum recycled content.

225 MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.
226 For example, see the World Business Council for Sustainable Development's *Built Environment Market Transformation Action Agenda*, and RICS (2023), *Whole life carbon assessment for the built environment: 2nd edition.*
227 Ministère de la transition écologique (2018), *RE2020: Eco-construire pour le confort de tous.*
228 Ministry of Interior and Housing (2021), *National Strategy for sustainable construction.*

Voluntary action

There are three key areas of action:

- Voluntary commitments from large developers and from commercial businesses who's buildings account for a large share of their scope 1 and 2 emissions (e.g., hotel and retail chains, professional services) to build ambitious low-embodied carbon new buildings.
- Green building certifications, which are currently dominated by a focus on operational carbon, should develop clear criteria and benchmarks for embodied carbon and lifecycle emissions, enabling developers to set clear targets.
- Developers and the real estate sector should develop "building passports" – a digital log that contains information on materials, technical characteristics, and energy and environmental performance.[229]

CASE STUDY

Box R **Whole-life carbon assessment regulation – London**

In 2021, the Greater London Authority (GLA) mandated that all major developments must complete a whole-life carbon assessment (WLCA) in the planning stage. Prior to this, only a handful of developers were undertaking WLCA and with very different levels of consistency. The regulation led to one of the most radical transformations in the sector, driving a significant leap forward in understanding and transparency regarding embodied carbon.

The regulation led to a rapid increase in data, skills and training:

- GLA have now been able to set benchmarks for different building archetypes which will be revised as data quality improves. For example, <750 $kgCO_2$ per m^2 for schools, <850 $kgCO_2$ per m^2 for residential and retail, and <950 $kgCO_2$ per m^2 for offices.[230] "Aspirational" benchmarks are also set 40% lower, in line with low-carbon targets set by the World Green Buildings Council for 2030.
- The Royal Institution of Chartered Surveyors (RICS) has updated their guidance and methodology for calculating whole-life carbon, focusing on avoiding underreporting in the early stages due to a lack of information on building components that have not been yet designed.

The WLCA regulation has already begun influencing decision-making, with design teams now incentivised to identify, assess and implement carbon reduction opportunities. For example, developers and designers are:

- Designing out unnecessary materials - for example, it is now common practice for most developments not to use suspended ceilings.
- Procuring reused materials and those with high recycled content.
- Avoiding carbon-intensive materials, for example procuring aluminium produced with zero-carbon electricity.

In addition, the market is beginning to attach a value to low-embodied carbon construction, with green finance rates using the outputs of WLCA.

The sector is now calling for the regulation to be implemented across the whole of the UK.

229 Global Alliance for Buildings and Construction (2022), *The Building Passport: Practical guidance.*
230 Mayor of London, *Whole Life-cycle Carbon Assessments guidance*, available at www.london.gov.uk/programmes-strategies/planning/implementing-london-plan/london-plan-guidance/whole-life-cycle-carbon-assessments-guidance. [Accessed 09/10/2024].

Section C:
Actions by government, industry and financial institutions

Sections A and B have described the major opportunity to reduce both operational emissions resulting from the use of energy in buildings and the embodied emissions which result from construction.

- Exhibits 8.9 and 8.10 summarised the feasible path for operational energy use, which in a business as usual scenario, could increase from 36,600 TWh today to 57,500 TWh by 2050, but could be reduced to 23,200 TWh by 2050 via a combination of the electrification of heating and cooking; technical efficiency improvements in heat pumps, lighting and other appliances; and insulation and other aspects of better building design to deliver passive heating and cooling. Since in this scenario, 80% of the energy used in 2050 would be electricity, this would bring annual emissions close to zero if electricity supply had by then been decarbonised.

- Exhibit 11.10 described a scenario for the decarbonisation of new building construction. Under a business as usual case, cumulative emissions embodied in new buildings could amount to ~75 $GtCO_2$ between now and 2050; but this could be reduced to ~40 $GtCO_2$ if the production of steel, cement/concrete and other building materials was decarbonised by 2050, and to a lower ~30 $GtCO_2$ if carbon intensive materials were used more efficiently, or if lower-carbon materials were used instead. Annual embodied emissions in this scenario would reach close to zero by 2050.

Achieving these feasible reductions will, however, be more complex in the case of buildings than in some other sectors of the economy, given:

- The huge range of building types, size, and design, which means that optimal solutions will need to be tailored to specific circumstance.

- The difficulty of enforcing building regulations effectively, in particular, in many lower-income countries. This could slow progress in reducing both operational and embodied emissions.

- The fact that for residential heat, upfront costs to install heat pumps are higher than for fossil fuel boilers, even though the total cost of ownership is likely, in most cases, to be lower. This means that the economics of switching from gas boilers to heat pumps is heavily influenced by each household's cost of capital, which varies greatly by income level.

Overcoming these challenges requires multiple types of action by governments, companies and consumers. There are six key priorities:

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

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

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

- Introduce carbon pricing or equivalent regulation to drive the reduction of embodied carbon emissions.

- Manage new and peaky electricity demand with flexible and efficient buildings.

- Deliver a fair transition for households.

Energy Transitions Commission

CRITICAL ACTIONS TO ACCELERATE THE BUILDINGS ENERGY TRANSITION

Heating | Cooling | Cooking | Lighting | Appliances | Embodied carbon

KEY ACTORS

Leading actors | Supporting actors

RELEVANT ENERGY END-USE	KEY ACTIONS	POLICY MAKERS	DEVELOPER & CONSTRUCTION	FINANCIAL INSTITUTIONS	ENERGY & TECH COMPANIES	BUILDING OWNERS & COMMERCIAL BUSINESSES
	Set out a clear vision for the building energy transition, supported by local delivery plans					
Heating	*Ban fossil fuel boilers in new builds from 2025, and their sale from 2035 in high income countries + China*	Leading				
Cooling, Heating	*Develop street-by-street decarbonisation plans and city-wide passive cooling programmes (e.g., planting trees and white roofs)*	Leading	Leading	Supporting	Leading	Supporting
Embodied carbon	*Commitments to reduce whole-life carbon emissions in buildings that are built, financed, and owned*	Leading	Leading	Leading		Leading
	Underpin incentives for, and trust in, clean and electric technologies					
Heating, Cooking, Embodied carbon	*Carbon pricing (e.g., on high-carbon construction materials)*	Leading				
Heating, Cooling, Cooking, Lighting, Appliances	*Ensure consumers benefit from low-cost renewable electricity generation (e.g., rebalancing gas and electricity prices)*	Leading			Supporting	
Embodied carbon, Heating, Cooking	*Investment in innovation, skills and supply chains to drive down costs and improve efficiency*	Leading	Leading	Supporting	Leading	
Heating, Cooling	*Ban the use of refrigerants with high global warming potential*	Leading			Leading	
Heating, Cooling	*Provide advice on clean technologies + insulation + smart and flexible technologies (e.g., solar, batteries, smart systems)*	Leading		Supporting	Leading	
	Create strong frameworks and standards for measuring and reducing whole-life carbon of new buildings					
Heating, Cooling, Embodied carbon	*Regulations and certifications to set ambitious limits for operational energy efficiency (kWh / m²) and use actual, not modelled, data*	Leading				
Embodied carbon	*Develop frameworks to measure whole-life carbon, mandate assessments, and set ambitious embodied carbon limits*	Leading	Leading			
Embodied carbon	*Upskill on how to design lower carbon buildings (e.g., capabilities to use low-carbon materials, material efficient construction)*	Supporting	Leading			
	Manage new and peaky electricity demand with flexible and efficient buildings					
Heating, Cooling, Cooking, Lighting, Appliances	*Minimum energy performance standards for AC, heat pumps, appliances and lighting*	Leading				
Heating, Cooling	*Commitments to retrofitting the least energy efficient buildings by 2035 with low-cost finance and guidance*	Leading			Supporting	Leading
Heating, Cooling, Cooking, Lighting, Appliances	*Rollout of smart meters and introduction of time-of-use tariffs*	Leading			Leading	Leading
	Deliver a fair and just transition for households					
Heating, Cooling, Cooking, Lighting, Appliances	*Low-cost finance and new financial products for retrofits, heat pumps, clean cooking and efficient AC*	Leading		Leading	Supporting	
Heating, Cooking	*Early planning for location-specific and co-ordinated gas grid phase down*	Leading		Supporting	Leading	
Heating, Cooling	*Investments in improving the energy efficiency of social housing and implement minimum standards for rental properties*	Leading		Supporting		Leading

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

In most countries, the direction of travel to decarbonise buildings is unclear. Only a handful of countries, such as the Netherlands, have successfully outlined plans to ban the sale of fossil fuel heating and cooking appliances and, with the exception of Denmark, no countries have set targets to switch off gas grids. There are huge gaps in the stringency of new building codes and policy regarding embodied carbon is virtually non-existent in most countries.

A critical priority this decade is for policymakers to set out a clear national vision to decarbonise buildings to give investors, developers and manufacturers certainty. Industry can then respond with their own clear commitments, sending clear signals to their supply chains and consumers.

Key actions for policymakers include:

- Short- to medium-term targets for heat pump deployment, training heat pump installers, and increasing the share of the population with access to cooling and clean cooking.
- Clear bans on fossil fuel heating and cooking in new builds from 2025, and on the sale of new fossil fuel heating and cooking technologies in existing buildings by 2035 in high-income countries and China.
- Plans to scale down sections of the gas grids gradually in the late 2030s, with a clear timeline to phase out the use of gas in buildings in the 2040s.
- Clear timelines for the increasing stringency of new building codes.

This national vision must then be translated into local delivery plans, which recognise the nuances of local buildings and households, to overcome the huge coordination challenges associated with scaling up the necessary infrastructure (e.g., local distribution grids) and scaling down the gas grid. Policymakers should:

- At the local government level, develop a deep understanding of their local housing stock and households to identify the most likely decarbonisation option sets.
- Develop street-by-street:
    - Decarbonisation strategies, including areas that could be first-movers and areas which will involve a more interventionist approach to overcome slow individual action.
    - Passive cooling strategies, recognising that the benefits of passive cooling techniques (e.g., planting trees and painting buildings white) multiply the more that neighbouring buildings adopt them.
- Conduct nationwide zoning to identify the potential for district heating and networked heat pumps.

The private sector must also make ambitious voluntary commitments:

- Financial institutions must commit to reducing financed emissions from buildings.
- Developers and builders must commit to reducing the whole-life carbon of new buildings, with clear targets for energy efficiency and embodied carbon.
- Businesses for which their buildings make up a large share of their scope 1 and 2 emissions (e.g., hotel chains, professional services companies, restaurants), must commit to decarbonising their building stock and improving energy efficiency.

2. Underpin incentives for, and trust in, clean and pre-dominantly electric technologies

Policymakers need to tackle the risks of investing in (e.g., uncertain demand, higher capital costs, lack of supporting infrastructure), and the lack of awareness and confidence in low-carbon technologies and materials. Key actions include:

- Create demand for low-carbon technologies:
    - Carbon pricing, especially on construction materials to drive the decarbonisation of steel, cement and concrete.
    - Green procurement, for example to lower the costs of LED lighting in lower-income countries.
    - Time-limited subsidies for households to fund building retrofits, heat pumps, and clean cooking technologies.
    - In some cases, quantitative mandates for companies to sell heat pumps, clean cookstoves, efficient air conditioning and low-carbon steel, cement and concrete can be appropriate to stimulate market demand.
- Rebalancing gas and electricity prices, by shifting levies which are currently disproportionately applied to electricity either to gas or to general taxation. This must be a gradual process to prevent disproportionate impacts on lower-income households who will take longer, in general, to electrify their heating and cooking.
- Ensure power market design is appropriate to support the rapid integration of renewables (e.g., via contracts for difference (CfDs)) and enables consumers to benefit from low-cost renewables (e.g., using smart metres to enable time of use tariffs, and ensuring fossil fuels don't set the marginal electricity price in most periods by using 2 way CfDs).
- Provision of low-cost finance for heat pumps, clean cooking fuels, and energy efficiency retrofits.
- Removal of subsidies for fossil fuel boilers in a targeted way in high-income countries.
- Education campaigns which clearly illustrate the household benefits, such as lower energy bills and improved comfort, and the career benefits from retraining. Local demonstrations of heat pumps and clean cooking are key.

The private sector must:

- Make voluntary commitments to increase sales of heat pumps and capitalise on opportunities for early demand from energy-savvy and conscious consumers.
- Continue investing in innovation to scale up low-carbon material markets to reduce the costs of clean technologies, especially heat pumps. Innovation should also focus on realising further efficiency gains and addressing household concerns about heat pumps (e.g., making them smaller, increasing their efficiency at higher temperatures, and improving their ability to heat water).
- Invest in quality training of heat pump installers, for example collaborating with governments in specific training courses and schools.
- Financial institutions should play a significant role in supporting households with the cost of the transition, designing new products to increase access to finance (e.g., mortgage top ups at favourable rates for heat pumps and insulation, or models which provide loans against future bill savings).
- Explore cross-sector collaboration to identify new financing approaches for networked heat pumps and district heating (e.g., collaborating with data centres to utilise waste heat).

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

There is a sizeable and crucial opportunity to ensure that the next generation of new buildings are installed with clean technologies, are efficient, and have much lower embodied carbon. Regulation will be the most important tool in driving change, meaning policymakers must:

- Develop clear frameworks to measure and assess embodied carbon, ensuring harmonisation across countries.
- Require whole-life carbon assessments as part of all new building and planning permission.
- Set ambitious minimum standards, and set ambitious targets, for reducing the whole-life carbon of new buildings within regulation.
- Ensure regulation plays an education role in lower income countries (e.g., setting out prescriptive building designs and raising awareness of the low-cost passive heating and cooling techniques).
- Develop clear standards for the use of low-carbon materials in buildings.

This should be supported by action in the private sector:

- Developers and builders to invest in skills and capacity to design and construct zero-carbon ready buildings (e.g., awareness of passive heating/cooling, and experience using alternative materials).
- Real estate companies and estate agents must raise awareness of the energy efficiency of buildings to prospective buyers, improving their understanding of current and potential performance.
- To create stronger market signals for zero-carbon ready buildings, green building certifications must be, a) made more transparent with publicly available targets and assessments, b) use ambitious science-based targets to set criteria, and c) measure performance using actual, not modelled, data.

4. Carbon pricing, or equivalent regulation, to drive embodied emission reductions

As Chapters 10–12 described, there are multiple opportunities to reduce embodied carbon emissions, but the nature of the opportunity varies greatly by type of building and specific country, and the optimal trade-off between reducing embodied vs. operational emissions is complex. As a result, there are limits to the extent to which building regulation can require specific types of decarbonisation actions.

But there is strong case for using carbon prices to create widely dispersed incentives to both:

- Decarbonise the production of construction materials (steel, cement, aluminium bricks and glass). Such carbon pricing will indeed be essential to drive heavy industry decarbonisation since, while decarbonisation is clearly technically possible, it will entail a green cost premium.[231]
- Identify and implement the demand-side efficiency improvements described in Chapters 10–12. Some of these actions would, in turn, reduce the impact of the green cost premium on the cost of buildings.

An alternative regulatory approach is to set maximum carbon intensity standards for the key materials used (i.e. kg of CO_2 emitted during the production per tonne of material), but this requires more information and enforcement capability than the imposition of a carbon price at the point of material production.

231 MPP (2023), *Making Net Zero Concrete and Cement Possible*; MPP (2022), *Making Net Zero Steel Possible*.

5. Manage new and peaky electricity demand with flexible and efficient buildings

Although electrifying buildings will result in a more than doubling of electricity demand, with the right policies and incentives, buildings can actually play a critical part in balancing renewables-dominated electricity systems. It is crucial that policymakers, regulators, network operators, and energy companies recognise the value that energy efficient buildings and demand-side flexibility can and must play.

Policymakers must:

- Provide financial incentives, low-cost finance and one-stop-shop guidance for insulation and other energy efficiency retrofit measures.
- Commit to improving the energy efficiency of public buildings with insulation, and ensure all public buildings adopt rooftop solar PV and batteries where suitable.
- Implement ambitious minimum energy performance standards and labelling regulations for appliances, lighting and heating/cooling technologies.

Energy companies also have a critical role to play:

- Introduce dynamic, time-of-use tariffs, which offer clear incentives to households to time-shift their energy use. Energy companies should experiment with tariffs which give them the ability to optimise household appliances (e.g., adjusting thermostats in response to changes in electricity supply and demand, or charging EVs overnight).
- Scale up the deployment of smart metres, enabling the use of smart systems and uptake of dynamic tariffs.
- Run education and consumer campaigns to make households aware of what usage can be time shifted and promoting behaviour change.

6. Deliver a fair and just transition for households

Without well-designed and proportionate policies and forward planning, the building transition risks leaving those on lower-incomes to be the last connected to the gas grid, living in energy poverty, and without access to clean cooking and low-cost cooling – with severe impacts on health and equality.

However, there are many things that policymakers can do:

- Provide targeted financial support for low-income households (e.g., subsidies and low-cost finance for heat pumps, insulation, and clean cooking). Development banks and green investment banks should offer low-cost finance for cooling and clean cooking in lower-income countries.
- Make early investments in improving the energy efficiency and comfort of social housing.
- Improve urban planning, incorporating a variety of passive cooling techniques to reduce urban island heat effects (e.g., green spaces, painting all buildings white).
- Conduct forward planning for scaling down the gas grid, to ensure that lower-income households are not the last to disconnect and that the costs of maintaining the grid until the last customer has disconnected are distributed over time.
- Implement MEPS for rental properties.
- Engage local citizens in a dialogue on local decabonisation strategies.
- Education and awareness campaigns of low-cost and DIY passive heating and cooling techniques, and of cleaner cooking fuels.

Private sector actions include:

- Energy companies should support vulnerable customers with financial support and advice on energy efficiency upgrades.
- Financial institutions should explore new financial products which help lower-income households access finance for energy efficiency.

Exhibit C.1

Priority policy actions by sector to tip the dial this decade

Heating

1. Ban fossil fuel boilers in new builds from 2025, and their sale from 2035 in high-income countries + China.
2. Working with energy companies and technology companies, develop street-by-street strategies to replacing fossil fuel boilers by identifying the most likely technologies, gaps in local supply chains and skills, and plans for switching off segments of the gas grid.
3. Rebalance gas and electricity prices with appropriate power market design and taking a measured and gradual approach to removing levies on electricity.
4. Commit to retrofitting the least efficient energy properties by 2035 by providing low-cost finance and clear guidance.

Cooling

1. 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.
2. Set minimum energy performance standards for AC and introduce labelling regulations.
3. Implement regulations, incentives and skills accreditation schemes for the proper disposal of refrigerant from AC.

Cooking

1. Run education and awareness campaigns, including community advocacy groups, training households and salespeople, and cooking classes to demonstrate new technologies.
2. 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.
3. Implement minimum health and efficient standards for cooking technologies, especially improved cookstoves.

Lighting and appliances

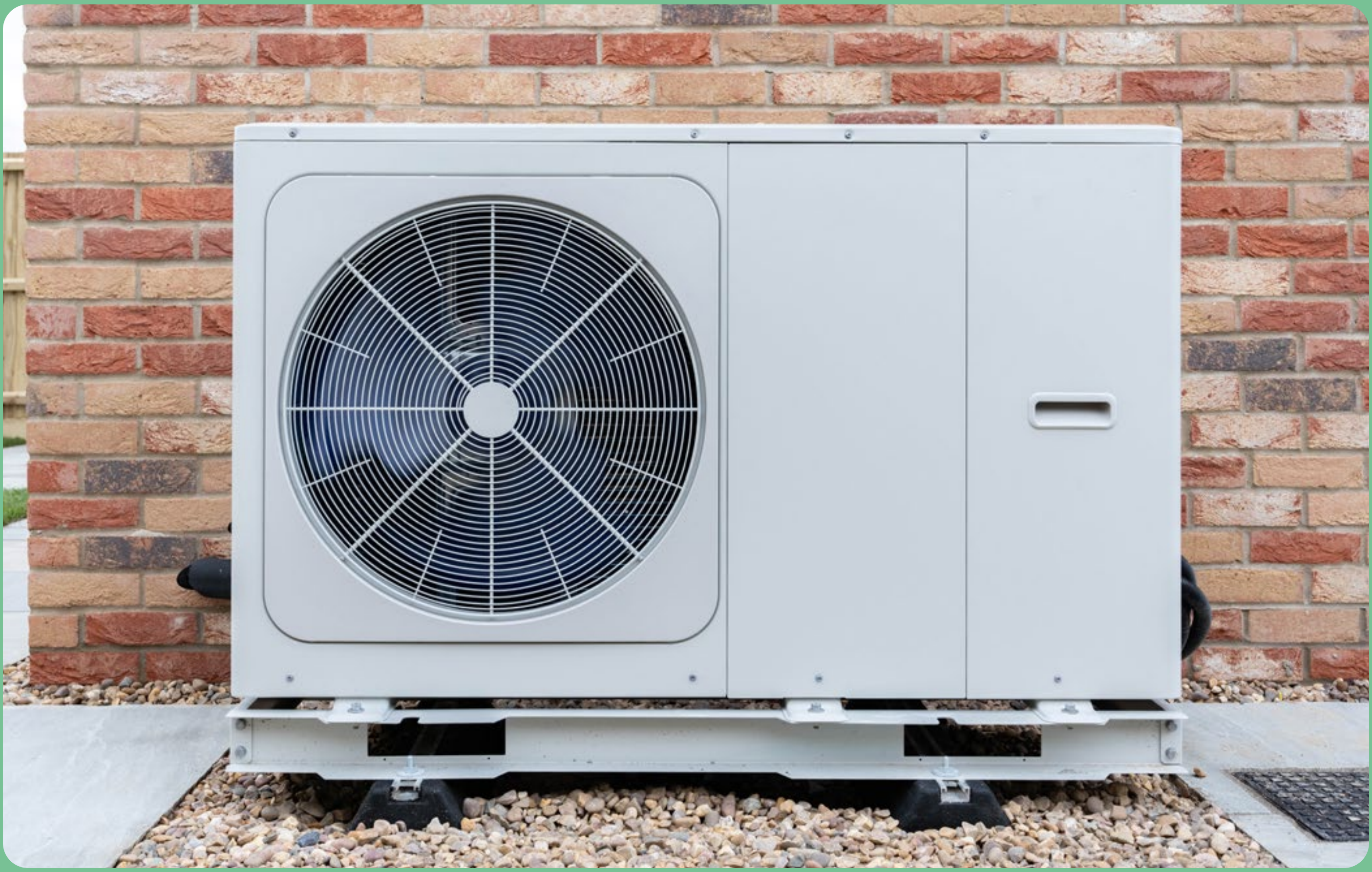
1. Implement minimum energy performance standards for lighting and a wide variety of appliances, increasing their stringency over time.
2. Bulk procurement of LED lighting and small appliances to help lower consumer prices.
3. Continue to drive further improvements in efficiency with targeted R&D support (e.g., financial incentives, prizes), focusing for example on developing smart appliances which work effectively within smart building systems to provide demand-side flexibility.

Managing electricity demand

1. Policymakers must implement ambitious building codes all over the world, with stringent requirements on kWh per m^2.
2. National and local governments, energy companies and network system operators should run consumer campaigns, highlighting the benefits of smart systems, solar and water storage.
3. Regulate the roll out smart metres to all customers and encourage dynamic time-of-use tariffs.

Embodied carbon

1. Introduce carbon pricing on high-carbon steel, cement and concrete.
2. Regulate that all new construction and large renovation projects must complete whole-lifecycle carbon assessments to improve measurement and data on embodied carbon.
3. Set minimum requirements for lifecycle emissions.



Annex 1: **Heat pumps**

How heat pumps work

Heat pumps work just like a refrigerator and air conditioning, but in reverse. Rather than removing heat from a source to the outside, they extract heat from either the air, water or the ground, and transfer that heat inside to where it is needed.

Heat pumps utilise the refrigeration cycle, which involves compressing and then expanding a refrigerant, causing it to change state via condensation and evaporation. Refrigerants are fluids which are capable to changing state between a liquid and gas at low temperatures due to very low boiling points. In other words, they are able to absorb and let go of heat energy really quickly. There are many different types of refrigerants, which work at different pressures and temperatures.

They have just four components: a compressor, an expansion valve, and two heat exchangers – one which extracts heat from a source, and one which releases heat. Exhibit A.1 explains how heat pumps work in more detail.

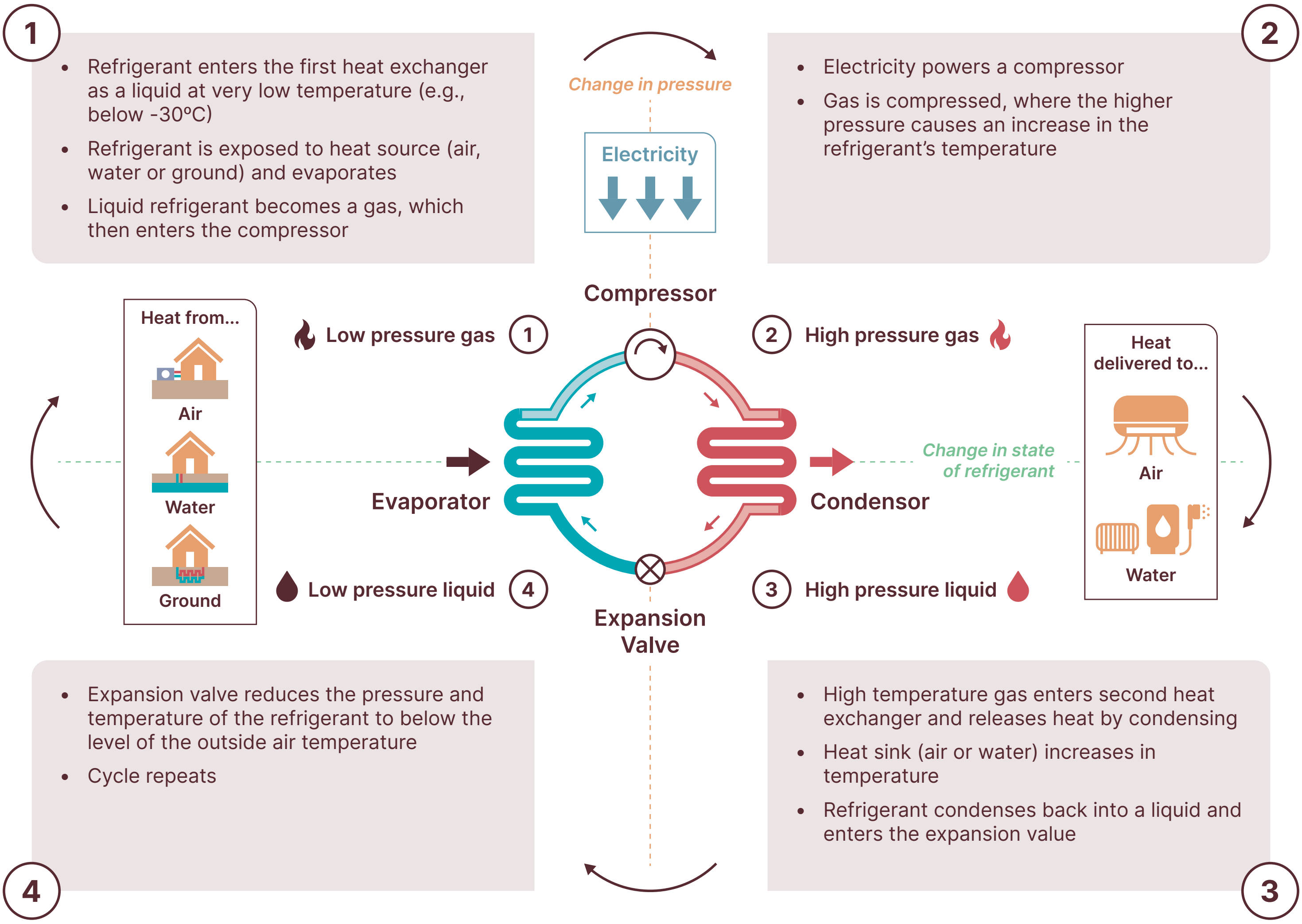
Heat pumps are not just one technology – there are a number of different types depending on the heat source and sink. They can extract heat from either the air, water or ground and heat either air or water inside a building:

- For air-sink heat pumps, air is blown over the heat pump's second heat exchanger, transferring heat. This hot air is then circulated into a room. Heat pumps with an air sink are also capable of delivering cooling as well (i.e. functioning as an air conditioner as well).

- For water-sink heat pumps, water is passed over the second heat exchanger. This hot water is then circulated around a wet central heating system, with heat transferred into the room via radiators. Water source heat pumps are therefore able to utilise existing pipework and radiators in homes that have a gas or oil boiler.

Exhibit A.1

Heat pumps work by transferring heat energy from the air, water or ground, using a small amount of electricity to power the compressor – this is what enables them to be so efficient



SOURCE: Systemiq analysis for the ETC; IEA (2022), *How a heat pump works.*

Efficiency

The efficiency of a heating technology is measured by the its energy output, divided by its energy input. In the case of a gas boiler, its efficiency is determined by how effectively heat from burning gas can be captured and transferred to water and is typically around 90%.

Because heat pumps work by transferring existing heat energy, they are able to deliver more useful heat energy than the electrical energy that powers them and achieve efficiencies of over 100%. A heat pump's efficiency – which is referred to as its coefficient of performance (CoP) – is therefore determined by the temperature difference between the heat source and the heat sink. Note that a heat pump's CoP expresses efficiency as a multiple, rather than a percentage; a CoP of 3 can be interpreted as efficiency of 300%.

It is important to note that the CoP demonstrates the efficiency of a heat pump at a moment in time, for example given the temperature outside and the desired inside temperature. Heat pump efficiencies are typically averaged over a season, to show the seasonal coefficient of performance (sCoP) for average winter conditions.

Exhibit A.2 illustrates the difference between a heat pump's theoretical possible CoP and the levels achieved in reality. This is because a heat pump needs to heat the air or water in a building to much higher temperatures than 20°C to actually heat a whole room to 20°C. In addition, there will be other technical losses, for example due to noise and friction, and electricity being used to power fans and controls.

In reality, heat pumps typically achieve a CoP of 3–4, or 300–400%, but this is expected to increase to around 5 with further innovation.

Exhibit A.2

A heat pump's theoretical efficiency is determined by the temperature differential of the heat source and sink, but in reality, there are other losses which limit a heat pump's potential CoP

$$\text{Efficiency of a heating solution} = \frac{\text{Energy output}}{\text{Energy input}}$$

$$\text{Heat pump theoretical coefficient of performance} = \frac{T_{sink}}{T_{sink} - T_{source}}$$

Ratio of the units of work put in, to the units of heat you get out

Demonstrates the performance of a heat pump at ***a point in time***

1 ***For a heat pump to deliver 20°C to the heat sink when its -5°C outside:***

Theoretical efficiency

$$\frac{\text{Energy output}}{\text{Energy input}} = \frac{\text{Energy output}}{\text{Energy input}} = 12$$

Units of heat energy for electrical energy in

2 ***For an air-to-water heat pump to heat a room to 20°C when its -5°C outside:***

Need the refrigerant to be < outside temperature
Need sink temperature to be > desired room temperature

$$\frac{40^{\circ}C}{(40^{\circ}C - -10^{\circ}C)} = \frac{313 \text{ kelvins}}{50 \text{ kelvins}} = {\sim}6$$

Units of heat energy for electrical energy in

3 ***But in reality, there are lots of other losses...***

- Inability to fully recover input energy (e.g., losses due to noise and friction)
- Power for fans, controls, inverters
- Refrigerant into expansion valve

→ ~3–5 Units of heat energy for electrical energy in

SOURCE: Systemiq analysis for the ETC; Daikin, available at www.daikin.co.uk/en_gb/faq/what-is-meant-by-the-terms-cop-and-eer-.html. [Accessed 01/08/2024].

Acknowledgements

The team that developed this briefing comprised:

Lord Adair Turner (Chair), Faustine Delasalle (Vice-Chair), Ita Kettleborough (Director), Mike Hemsley (Deputy Director), Hannah Audino (lead author), Jonny Xiao, Andrea Bath (supporting lead authors) with support from John Allen, Mike Batley, Rose Dortch, Manuela Di Biase, Apoorva Hasija, Elizabeth Lam, Philip Lake, Tommaso Mazzanti, Lina Morales, Rebecca Nohl, Shane O'Connor, Julia Okatz, Amy Paterson, Viktoriia Petriv, Elena Pravettoni, Caroline Randle, Wouter Vink (SYSTEMIQ).

The team would also like to thank the ETC members and experts for their active participation:

Nicola Davidson (ArcelorMittal); Ann Dalzell, Stephen Hill, Becci Taylor, Alan Thomson and Michael Wadsworth (Arup); James Butler (Ausgrid); Albert Cheung (BloombergNEF); Richard de Caux, Jude Ejeh and Gareth Ramsay (bp); Sanna O'Connor-Morberg (Carbon Direct); Justin Bin LYU and Yi Zhou (CIKD); Charles Haworth (CWP Global); Adam Tomassi-Russell (Deep Science Ventures); Thomas Coulter and Annick Verschraeven (DP World); Adil Hanif (EBRD); Fu Sha (EF China); Cedar Zhai and George Wang (Envision); Keith Allott and Rebecca Collyer (European Climate Foundation); Eleonore Soubeyran (Grantham Institute, London School of Economics); Matt Prescott (Heathrow Airport); Kash Burchett and Sophie Lu (HSBC); Francisco Laveron (Iberdrola); Yanan Fu (ICCSD); Chris Dodwell (Impax Asset Management); Andy Wiley (Just Climate); Ben Murphy (Kiko Ventures); Jaekil Ryu (Korea Zinc Ltd); Freya Burton (LanzaTech); John Bromley (L&G); Maria Von Prittwitz (Lombard Odier); Vincenzo Cao (LONGi); Abbie Badcock-Broe (National Grid); Nigel Banks, Emily Beynon, Emma Burns, Emma Fletcher, Rachel Fletcher and TJ Root (Octopus Energy); Rahim Mahmood (Petronas); Leonardo Buizza (Quadrature Climate Foundation); Susan Hansen (Rabobank); Udit Mathur (ReNew); Jonathan Grant (Rio Tinto); Greg Hopkins (RMI); Emmet Walsh (Rothschild); Pascal Eveillard and Emmanuel Normant (Saint Gobain); Vincent Minier and Vincent Petit (Schneider Electric); Brian Dean and Ben Hartley (SEforAll); Charlotte Brookes and Halla Al-Naijar (Shell plc); Jonny Clark (SLR Consulting); Martin Pei (SSAB); Alistair McGirr (SSE); Sharon Lo (Tara Climate Foundation); Abhishek Goyal (Tata Sons); Saurabh Kundu (Tata Steel); A K Saxena (TERI); Kristiana Gjinaj (TES); Bryan Flannigan (The Transition Accelerator); Reid Detchon (United Nations Foundation); Mikael Nordlander (Vattenfall); Niklas Gustafsson (Volvo); Molly Walton (We Mean Business Coalition); Jennifer Layke and Roxana Slavcheva (World Resources Institute); Paul Ebert (Worley); Richard Hardy (X-Links).

The team would also like to thank the ETC's broader network of experts for their input:

Matthew Bullivant (Athora); Sam Ramadori and Nicolas Bossé (Brainbox AI); Oliver Rapf (Buildings Performance Institute Europe); Ana Maria Carreño and Colin Taylor (CLASP); Peter Graham (Global Buildings Performance Network); Sophie Attali, Lucas Boehlé, Brian Motherway, Melanie Slade and Fabian Voswinkel (IEA); Henrique Roscoe Papini Lagoeiro and Graeme Maidment (London South Bank University); Tamsin Lishman, Wouter Thijssen and Matt Trewhella (Kensa); Louise Sunderland (Regulatory Assistance Project); Andy Sutton (Sero); Jose La Loggia (Trane Technologies); Alice Bond and Audrey Nugent (World Green Building Council).

Energy
Transitions
Commission

www.energy-transitions.org