The Institution of Engineering and Technology

# Decarbonising the Built Environment

This paper is the background research done for ***'Decarbonising the Built Environment: Guide for decision makers'*** **published by the Institution of Engineering and Technology (IET)** in May 2023.

**theiet.org/built-environment**

Written with the participation of Dr Richard Miller, in collaboration with the Built Environment and Energy Panels of the IET.

Please note that the views expressed in this publication are not necessarily those of the IET. The guide only intends to identify the relevant issues and to inform a public policy debate around the topic, rather than to provide a definitive solution.

The IET's Built Environment, Design and Manufacturing, and Digital panels would welcome any comments you may have on the contents of this guide and your ideas for future publications. Please get in touch by emailing **policy@theiet.org**.

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# 1 Summary

The world has woken up to the threat of climate change. Local and national governments are now rushing to put plans into place to cut carbon emissions, stop driving climate change, and adapt to inevitable changes in the climate. The Paris Agreement aims to limit global warming to well below 2°C, and the UK Climate Change Act creates a legal target of net-zero greenhouse gas emissions by 2050.

Buildings contribute carbon emissions throughout their lifecycle. From construction, through use, to demolition and disposal. Carbon emissions from buildings come in two forms: embodied carbon from construction of the building, and operational carbon from use of the building. To reach net-zero, we must eliminate or offset both embodied and operational carbon.

23% of UK emissions (115Mt$CO_2$e/year) come from operating buildings. 17% in direct emissions, using fossil fuels to provide heating and hot water, and a further 6% from electricity use. Embodied carbon in UK buildings ranges from 35% to 51% of lifetime emissions. Globally, operating buildings accounted for 28% of all energy and 30% of all carbon emissions, with an additional 11% from embodied carbon. As energy systems decarbonise, the embodied carbon footprint of buildings will rise towards 50% of total emissions.

Embodied carbon can be tackled by:

- Build less – maximise the use of existing assets and avoiding new build
- Build clever – design in low-carbon materials and minimise resource consumption
- Build efficiently – use new construction technologies to minimise waste and energy use

Operational carbon can be tackled by:

- Reducing building demand by cutting consumption and improving the efficiency of the building envelope
- Decarbonising the energy supply to buildings through net-zero electricity and net-zero heat

There has been much progress in developing, proving, and demonstrating pathways to net-zero buildings. A range of strategies and technologies have been evaluated for commercial and domestic buildings, and for new build and retrofits. We understand how to design, construct, and operate energy-efficient buildings, but fail to do so. Progress towards the Government's target of net-zero built environment by 2050 is slow and uncertain.

Despite significant barriers to the wider deployment of net-zero solutions, there are positive trends that are shifting the market. Driven by a greater awareness of the risks of climate change, users of both domestic and nondomestic properties are demanding low-carbon and net-zero buildings. The challenge is to create a supportive policy environment and to drive innovation to provide cost-effective solutions.

**Engineering Opportunities**

The engineering professions can be at the heart of breaking through the logjam and smoothing the path to net-zero. They will have the strongest influence where they can bring new design and technology together by:

- Innovating to reduce cost and risk
- Simplifying to overcome problems with skills and capacity
- Innovating to provide better solutions to specific challenges
- Improving buyer confidence through better performance evidence and information
- Reducing energy demand through better design

There are two areas of engineering opportunity: improved technology and a systems approach.

Technological innovation can improve individual components and subsystems. Engineers can take existing technologies and:

- Reduce cost
- Improve performance
- Improve manufacturability and reliability
- Tackle ease of installation, use and maintenance
- Design for remanufacture and recycling.

Areas demanding innovation include:

- Providing an energy efficient building envelope
- New energy systems, including local microgrids
- Using digital technologies throughout a building's life
- Using low-carbon building materials and methods, reducing waste, and increasing recycling

Systems thinking and systems engineering are essential to decarbonise the built environment

Decarbonisation requires managing complex interactions at every level. From individual buildings to neighbourhoods, cities and regions. Current specialisation and fragmentation of the industry makes it hard to deliver the whole-building, whole-lifecycle thinking required. There are opportunities to:

- Transfer knowledge and expertise from other industries (e.g., energy and automotive)
- Encourage a new breed of designers and engineers who understand the new technologies and how they go together
- Test new business models such as 'heat-as-a-service'
- Switch industry thinking from 'design for compliance' to 'design for performance'

**Recommendations**

Decarbonising the built environment requires collaboration. A single player can not deliver. Our overarching recommendation is that:

**Decarbonising the built environment requires new relationships and understanding between the groups involved in creating, using, and disposing of buildings. Trade and professional organisations have a key role to play in fostering a fresh approach. They**

**must show leadership and drive change. Government, innovation funders and the education base should support them.**

Specific recommendations:

- Government should set clear policy for the transition to net-zero by 2050. Policy should be consistent, long-term and outcome oriented
- Support innovation in low-carbon solutions, especially those that reduce cost and risk, and increase performance
- Provide reliable and trusted sources of information to everyone involved in the design, construction and use of buildings
- Educate and train a new workforce in systems thinking and low-carbon technologies

# 2 Introduction

The world has woken up to the threat of climate change. Local and national governments are now rushing to put plans into place to cut carbon emissions, stop driving climate change, and adapt to the inevitable climate changes. The latest IPCC report is clear and urgent [1]:

"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."

"Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts and tropical cyclones, and, in particular, their attribution to human influence, has strengthened…"

The Paris Agreement aims to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels, if possible, to below 1.5 degrees Celsius [2]. In the UK, the Climate Change Act creates a legal target of net-zero greenhouse gas emissions by 2050 [3, 4]. A recent review of the state of the UK climate in 2020 shows that the effects of climate change are already with us [5].

At COP 26 in Glasgow, 40 countries signed up the Breakthrough Agenda [6], committing to make clean power, zero emission road vehicles, near-zero emission steel and low-carbon hydrogen widely available and the default choice by 2030.

Across the world, 2300 local governments in 40 countries have passed binding motions declaring a climate emergency. That covers over 1 billion citizens [7].

In the UK, 300 councils and 8 combined authorities/city regions have announced a climate emergency. That represents 90% of the population [8].

Over 40 local leaders in the UK have committed to making their council operations net-zero by 2030. They will work with residents and businesses to bring their wider communities' emissions to net-zero as soon as possible and by 2045 at the latest [9].

Networks like the C40 Cities are championing ambitious climate action to achieve the goals of the Paris Agreement. Representing 97 cities covering 1 in 12 of the global population and 25% of GDP, they are a powerful force, promoting over 10,000 actions to combat climate change.

**Carbon Emissions from Buildings**

Buildings contribute carbon emissions throughout their life-cycle. From construction, through use, to demolition and disposal. Embodied carbon includes the emissions from the construction or refurbishment of a building. Operational carbon emissions arise from the routine use of the building.

To achieve net-zero, we must eliminate or offset both embodied carbon and operational carbon for buildings. For existing buildings, the embodied carbon is a sunk cost. We should strive to make these net-zero in operation and ensure that any upgrades and retrofits target zero embodied carbon. For new build, the goal must be net-zero for both embodied and operational carbon.

The recent energy crisis, triggered by the Russian invasion of Ukraine, has focused attention on the need to increase energy security and reduce costs. Recent reports have focused on the need to reduce fossil fuel costs and increase energy security, and the economic benefits of a net-zero transition through additional jobs and GDP [10].

### Embodied Carbon

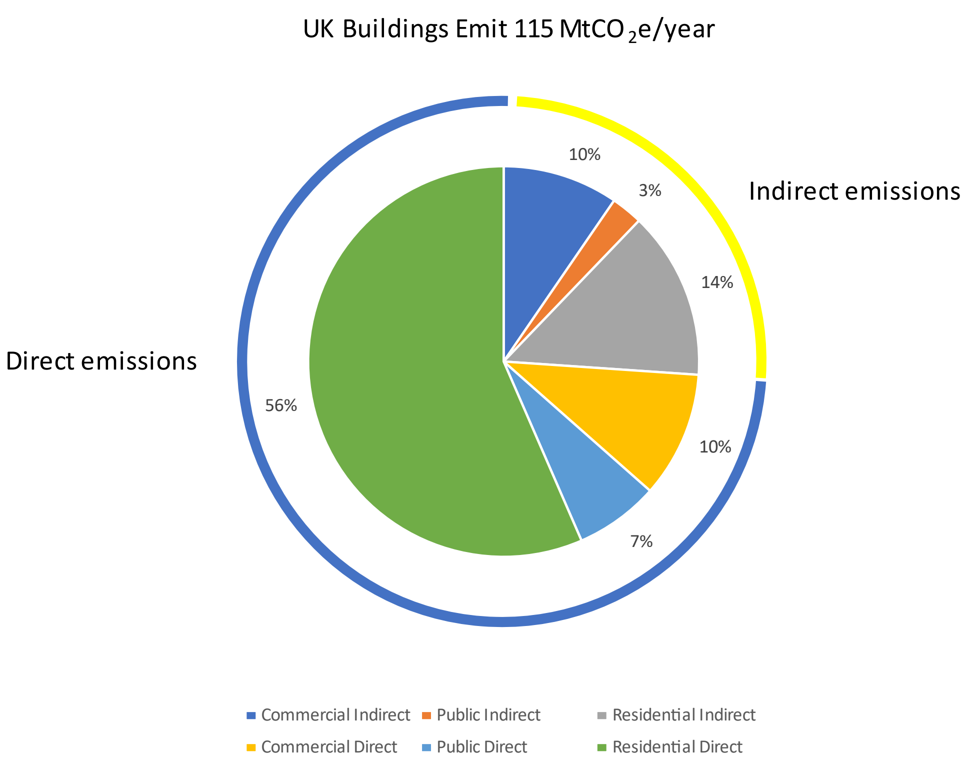
According to the World Green Building Council [11], embodied carbon in the built environment accounts for about 11% of total global emissions. With progressive reductions in operational carbon emissions, they estimate that carbon embodied in creating buildings may rise to 50% of the entire carbon footprint of new construction up to 2050. However, embodied carbon is given little policy attention compared to operational emissions [12]

The relative proportions of embodied carbon to operational carbon emissions vary with building type. The Royal Institute of Chartered Surveyors estimates the embodied carbon for buildings in the UK ranges from 35% of total emissions for an office building to 51% for a residential building [13].

### Operational Carbon

The operational performance of our buildings is critical to delivering net-zero. In the UK, the Committee on Climate Change has recommended all buildings must be net-zero to deliver the Government's goals [14].

Operating buildings causes 23% of UK emissions. 17% in direct emissions, using fossil fuels to provide heating and hot-water, and a further 6% indirect emissions from electricity use.



*Carbon Emissions from Buildings in the UK [15]*

Operation of UK buildings emits 115 $MtCO_2e$/year. 73% are direct emissions and 27% indirect. The single largest component is direct emissions from residential properties, accounting for 56%. Commercial and public direct emissions are lower at 10% and 7%. Indirect emissions follow a similar pattern with residential properties accounting for 14%.

Globally, energy for operating buildings accounted for 28% of all energy and 30% of all carbon emissions. From 2010 – 2017, total emissions increased by a quarter because of growth in the building stock [16]

**Consequential Benefits**

Beyond tackling climate change, there are additional benefits to aiming for a net-zero built environment.

Poor quality housing places considerable stress on the economic capabilities and health services of countries. In the UK, the estimated annual direct cost to the NHS of poor housing is £783 million [17].

Many governments are chasing new economic activity and new jobs in constructing and retrofitting energy efficient buildings [10, 12, 16, 18-23]

# 3 What is the Built Environment?

The built environment includes both buildings and the utilities that support them. Anything that involves the construction industry. So, roads, railways, docks, power stations, sewage treatment works, etc. For this report, we restrict ourselves to buildings.

There are many ways to classify buildings, but the most useful is by purpose. The building purpose defines the building form, and the building form defines the potential strategies for decarbonisation.

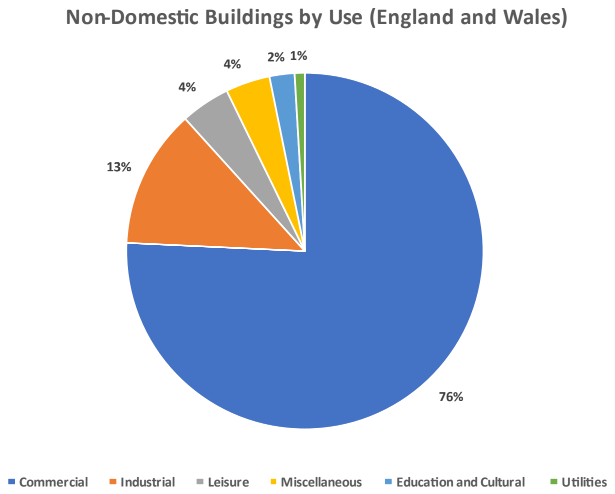
A common classification provides seven archetypes:

- Residential buildings - homes
- Educational and cultural buildings – schools, colleges, universities, libraries, museums and galleries
- Leisure buildings – theatres, cinemas, sports centres
- Commercial buildings – shops, retail sheds, offices
- Industrial buildings – factories, workshops and warehouses
- Utilities – power, water, waste and telecoms
- Others – including hazardous buildings for the manufacture, storage and use of dangerous materials

The categories are not exclusive. There is always some overlap and blurring of boundaries. A look at any traditional high street in a well-established town or city will show lawyer's offices, shops and doctors' surgeries in buildings that look like houses, were once houses, or have residential accommodation incorporated in them. However, we would still recognise most of these archetypes as having different shapes and different usage patterns.

In the UK, there are:

- 27 million homes.
- 2.4 million non-domestic properties of all types.
- In England and Wales, 2.1 million non-domestic properties break down into the following categories:



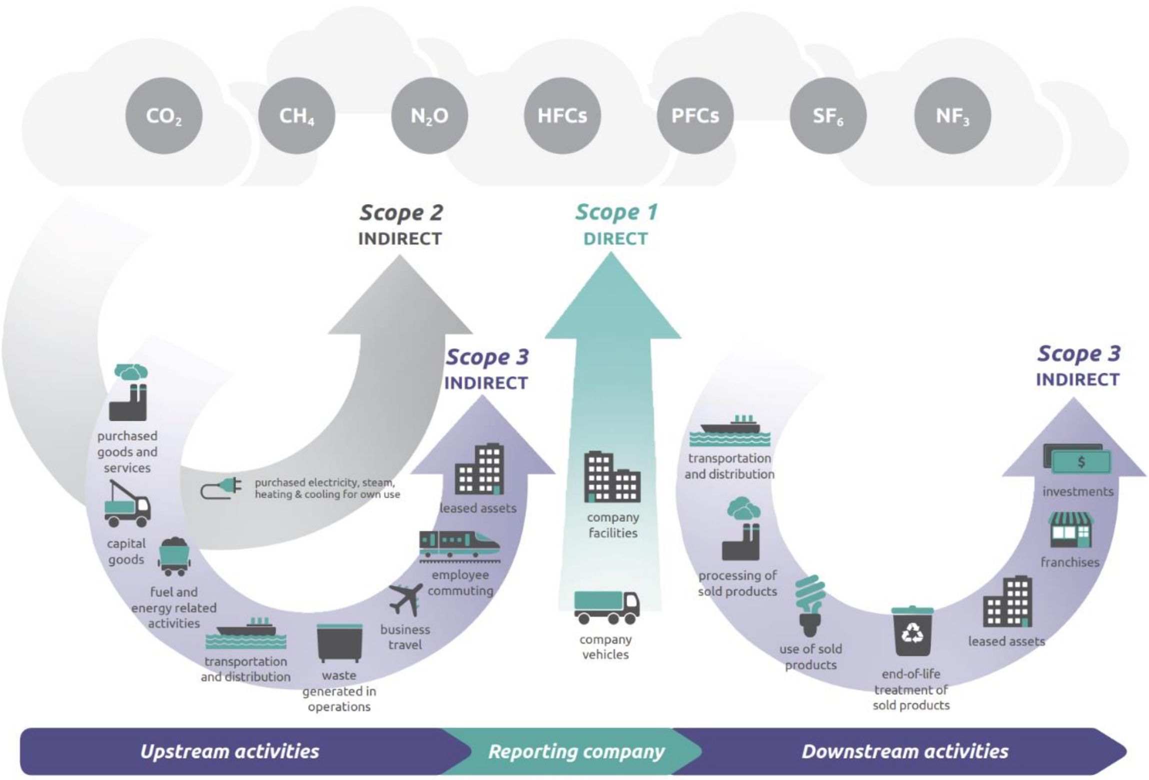

*Distribution of Non-Domestic Buildings by Use in England and Wales [24]*

## 4 Measuring Carbon Emissions from Buildings

We have already discussed the distinction between embodied carbon and operational carbon emissions and the distinction between direct and indirect emissions. These ideas are brought together in a series of standards for calculating and evaluating greenhouse gas emissions and other lifecycle impacts from the Greenhouse Gas Protocol. Standards are available for determining the greenhouse gas impact of businesses [25], products [26] and urban areas [27].

At the core of these standards is analysis according to the 'scope' of emissions [25].

- Scope 1 - direct emissions from owned or controlled sources.
- Scope 2 - indirect emissions from purchased energy.
- Scope 3 - all indirect emissions, apart from energy purchases, both upstream and downstream emissions.




*Scope 1, 2 and 3 emissions [25]*

Business is increasingly reporting their greenhouse gas emissions for all three scopes. Scopes 1 and 2 are easy, as people have detailed information on the processes they control and the energy they buy. Scope 3 is much harder as it deals with processes outside direct control and raises the problem of deciding how far upstream and downstream it is relevant to go.

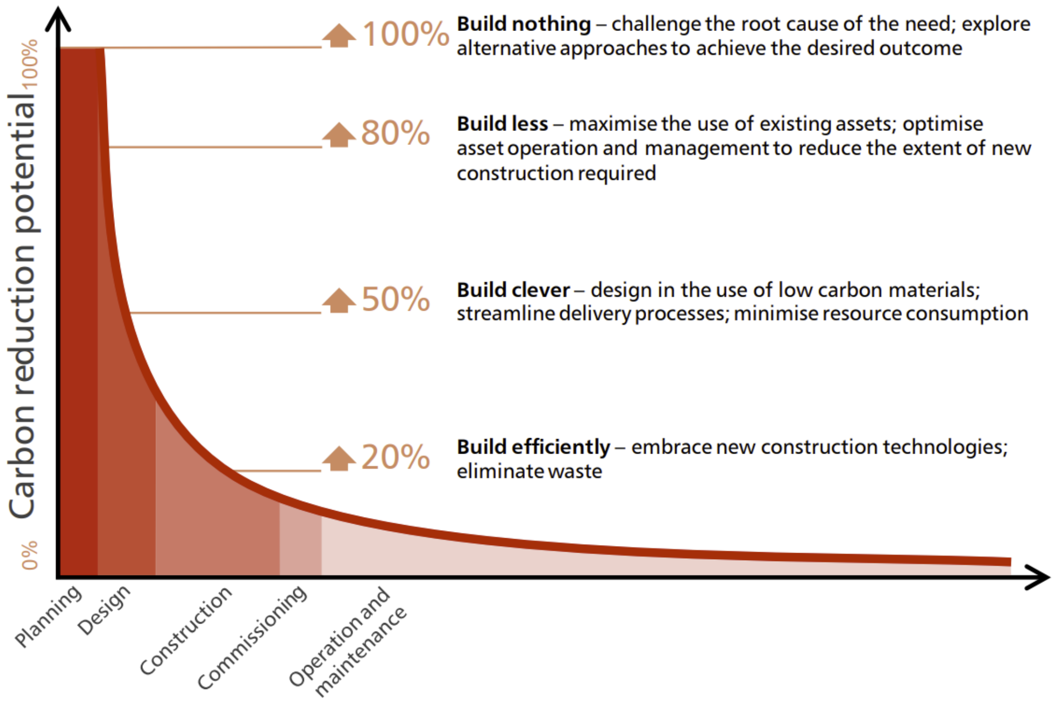
In buildings, energy and carbon, Scope 1 emissions are the direct emissions and Scope 2 indirect emissions. Scope 3 emissions combine embodied carbon, including products imported for building operations, and emissions from demolition and disposal.

Whole building lifecycle assessment uses similar data to look at the total environmental effects and makes use of international standards [28].

Coupling total carbon emissions with lifecycle cost analysis makes it possible to compare scenarios for the future use of a building. For retrofit in particular, it allows comparison between the costs and carbon impacts of upgrading the property to high levels of energy efficiency and those of demolition and re-construction. There has been a long and inconclusive debate on what to do with ‘hard to treat’ homes; for example, pre-1919 properties [29]. With good lifecycle data, it should be possible to establish for any building and planned use whether the integrated carbon costs of demolition and rebuild are lower than a workable retrofit programme.

# 5 Routes to Decarbonising the Built Environment

## 5.1 Eliminating embodied carbon




*Strategies for eliminating embodied carbon [30]*

The UK Government Treasury reviewed options for reducing embodied carbon in infrastructure, including buildings [30]. This showed the earlier you start in the construction process, the greater the amount of carbon you can save.

Good planning and optimisation of existing assets allows you to reduce the amount of new construction to the minimum. Repurposing and refurbishment of existing buildings can reduce embodied carbon. Challenging the need for new construction can eliminate additional embodied carbon altogether.

Reducing resource consumption in construction is the next best strategy. Reducing the amount of material used, and switching to low-carbon alternatives, can halve embodied carbon. Options include:

- use of recycled materials
- greater use of low-carbon materials such as wood
- better engineering design to reduce structural mass
- taking advantage of work going on in the steel, cement and glass industries to reduce energy consumption and carbon emissions in construction materials manufacturing

The construction process can also be improved. The construction industry is already switching to low carbon energy for site operations.

Waste is another area to tackle. Nearly 5 million tonnes of non-hazardous construction and demolition waste in the UK went to landfill in 2016 [31], and the construction sector now has a target of zero avoidable waste.

The same approach is now being spread by the World Green Building Council [11, 32]. They combine it with their four-point plan for reduction of embodied carbon:

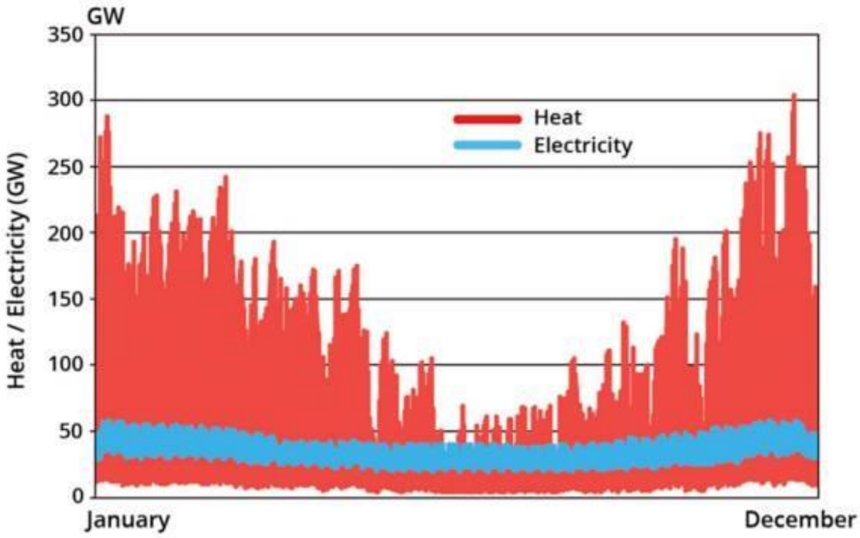
- Prevent – use good planning and design to avoid or minimise construction.
- Reduce and optimise – minimise use of virgin materials, prioritise low carbon options, and choose low carbon construction techniques which minimise waste.
- Plan for the future – extend the life of the building by designing in flexibility. Design for recycling.
- Offset – as a last resort offset residual embodied carbon emissions.

Eliminating embodied carbon means avoiding new construction, designing new types of buildings, using new materials and components, and constructing new ways.

## 5.2 Eliminating operational carbon

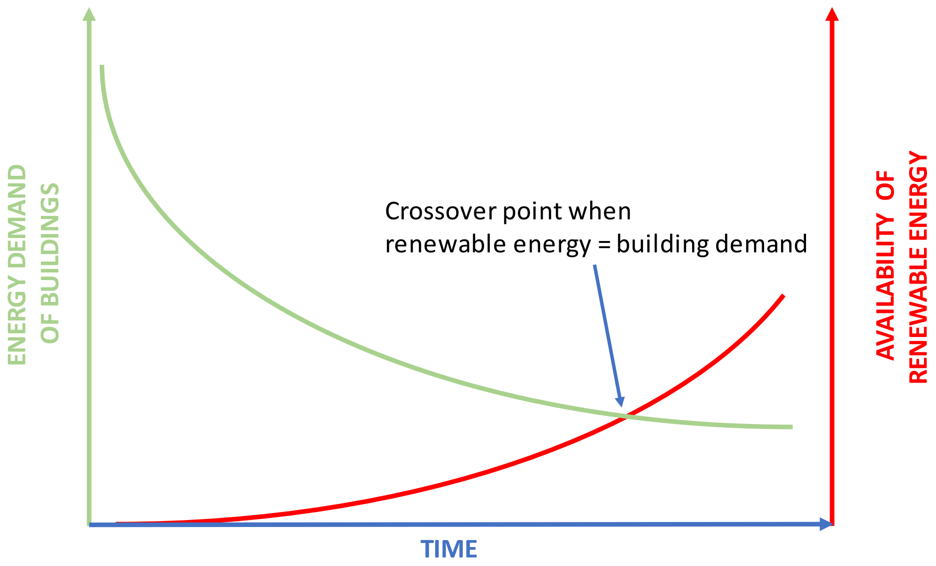
73% of operational carbon emissions from buildings are direct emissions; burning fossil fuels within the building to provide heat. The remaining 27% arise from the use of grid electricity and reflect the current carbon intensity of electricity generation in the UK. And globally, providing zero-carbon heating and cooling requires innovation and market intervention by governments [33]

A particular problem is that heating demand peaks in the Winter in the UK. At the peak, energy for heating is six times the current demand for electricity [34]. Electrification of heat is difficult, even with the efficiency gains of heat pumps. Reduction in heat consumption is essential.




*UK annual demand for heat and electricity [34]*

The carbon intensity of the electricity grid is dropping steadily. National Grid ESO projects that the UK grid will reach net-zero in the mid-2030s [35]. However, there are increasing demands on electricity generation from the decarbonisation of transport, and replacing fossil fuels as a heat source in buildings. Therefore, we cannot expect the decarbonisation of electricity to solve the challenge of eliminating operational carbon emissions from buildings. We must reduce the energy demand of buildings at the same time.




*Balancing demand reduction with availability of renewable energy*

Eventually, there is a crossover point where available renewable energy exceeds the energy demand of buildings. This crossover point is important for deciding how much to invest in reducing building demand. As we drive building demand down, costs per tonne of $CO_2$ saved increase as we move from simple and easy to implement changes to more complex interventions. We do not know when this crossover point will occur, so cannot define the optimum investment in building demand and efficiency.

We also need to be aware of the different dynamics across building and occupancy types. A commercial property rented by the square metre, including services, is a different proposition to an owned and operated university campus, and a house owner-occupier to a privately rented property. There is often a disconnect between who pays for lower carbon emissions and who benefits. Occupants may not see the effects and costs in the way they use buildings. Effective strategies for decarbonisation will be different for each situation, depending on the levers available and the relative strength and interests of the various players.

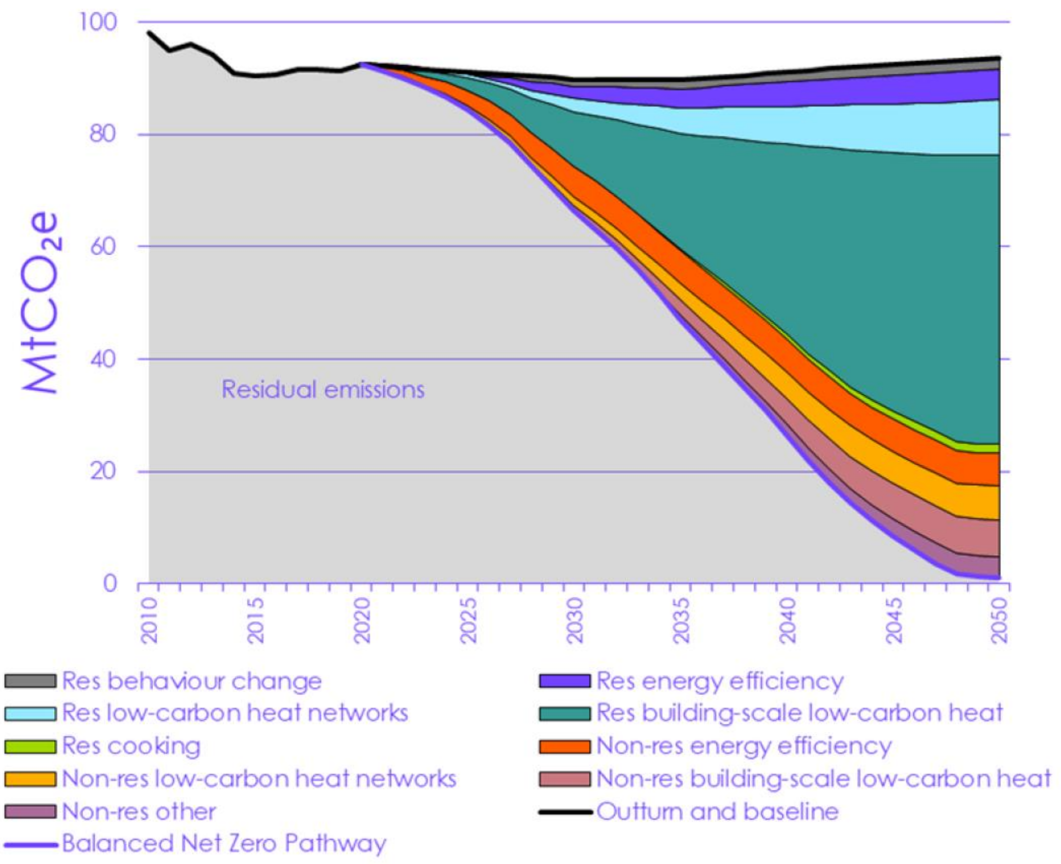
### 5.2.1 Options for reducing operational carbon emissions

Practical ways to reduce operational carbon emissions include:

- reducing building demand
    - cut consumption
        - behavioural changes by users

        - more efficient lighting and appliances
        - better building management systems, including smart and autonomous buildings and improved heating/cooling and hot water controls
    - improve the efficiency of the building envelope
        - reduce losses through better insulation
        - improved ventilation and ventilation control
        - prevent excessive solar gain
- decarbonising the energy supply to buildings
    - net-zero electricity
        - increase grid renewables, nuclear and CCS
        - improve electricity storage
        - greater use of international electricity interconnects
        - local production of electricity – energy positive buildings
    - net-zero heat
        - electrification of heat
        - use of blue and green hydrogen
        - district heat networks
        - synthetic bio-fuels and e-fuels [36]

The committee on climate change has analysed how combinations of these different options can reach net-zero by 2050 [15]. This chart summarises the potential contribution of each of the approaches.




*Strategies for Reducing Building Carbon Emissions to Net-Zero [15]*

# 6 Progress to Date

There has been considerable progress in recent years in developing, proving, and demonstrating pathways to net-zero buildings. A wide range of strategies and technologies have been evaluated.

Although differing in detail, domestic and non-domestic, new-build and retrofit/refurbishment share similar challenges and solutions.

However, delivery of low-carbon buildings has been slow. In the UK, the Climate Change Committee argues in its latest progress reports that improvements in energy efficiency of buildings have been way below the required target for over a decade [20, 37]. Globally the same gap has emerged between ambition and delivery [23].

## 6.1 Reducing Embodied Carbon

Embodied carbon will be responsible for half the total emissions for all new buildings constructed between 2020 and 2050 [38]. We cannot achieve a net-zero built environment without tackling embodied carbon.

Embodied carbon is more immediately relevant to new-build projects. However, retrofits and refurbishment projects should take care to use the lowest embodied carbon materials and solutions.

For a construction project, the embodied carbon includes all the emissions associated with the materials, transportation to the construction site, and construction on site. The strategies for eliminating embodied carbon are [30]:

- Build nothing – find other ways to meet the space needs
- Build less – maximise the use of existing assets
- Build clever – minimise resource consumption
- Build efficiently – reduce emissions on site

The first two options are the realm of planning and design. Building clever and building efficiently brings engineering solutions into the foreground.

Minimising resource consumption requires reliable data and the skills to understand it [39]. The task is becoming easier through the availability of Environmental Product Declarations [40], and other databases of embodied carbon for construction materials [41-43]. These information sources allow architects to compare alternative building designs.

One problem with these datasets is that they are neither complete nor up-to-date, something the constant development of technology makes difficult. For example, as part of the challenge of decarbonising energy-intensive industries, there is a large amount of work going on to reduce the embodied carbon of cement [44], steel [45], and glass [46]. Reductions are achieved through combining reformulation, particularly for cement, switching to electric heating, and the use of hydrogen as both an energy source and a reducing agent (steel).

We can expect the embodied carbon of core construction materials to decline over the next decade. However, we don't know which materials will decarbonise quickest, nor how that will affect the cost of use. The construction industry must adapt to emerging trends in materials carbon intensity.

There is also a powerful role for design and engineering in reducing the amount of material required to produce a building with the desired properties. With improved knowledge of the properties of materials and new computer aided design techniques, it has become possible to create lightweight structures that meet high standards of performance. A good example is the velodrome built for the 2012 London Olympics [47]

Building efficiently means reducing the emissions from on-site operations and cutting waste. Construction sites have traditionally extensively used diesel power for construction machinery and local electricity production. All major construction machinery suppliers include battery electric vehicles and fuel cell electric vehicles in their product range [48]. Hydrogen fuel cells are being substituted for diesel generator sets at off-grid sites. A good example is the Viking Interconnect for electricity import/export between the UK and Denmark. A large hydrogen fuel cell/battery combination provides all the energy (both heat and power) required for constructing the terminal site in Lincolnshire [49].

Waste is a major problem on construction sites, adding to the overall embodied carbon of a building [31]. New construction methods such as Building Information Management (BIM) [50] and industrialisation of construction through off-site manufacture in factories [51] show how to reduce waste by tighter control of materials from design to final construction.

## 6.2 Reducing Operational Carbon

There are two strategies for reducing operational carbon emissions from buildings, reducing the building demand, and decarbonising the energy supply to the building.

### 6.2.1 Reducing Building Demand

Reducing the building energy demand is all about eliminating inefficiency; whether in the building fabric or in the way the building operates.

#### 6.2.1.1 Reducing Consumption

The two key strategies for reducing consumption are:

- Demand-side response – providing financial signals to encourage users to use less electricity, particularly at peak times [52].
- Demand reduction – replacing older lighting, motors, refrigeration systems etc, with more efficient devices, and encouraging user behaviours that reduce consumption [53].

Both rely on accurate information and precise control. This leads to the concept of smart buildings, where sensors and control strategies can optimise consumption.

#### 6.2.1.2 Improving the Efficiency of the Building Envelope.

The other way to reduce building energy demand is to improve the efficiency of the outer envelope. To prevent heat transfer across the envelope that requires additional heating or cooling, prevent excessive solar gain, and manage ventilation to provide an adequate and controlled flow of fresh air to maintain a healthy and comfortable environment without increasing the energy demand.

For new-build, an efficient building envelope should be a basic requirement and a solved problem. The design criteria are well understood and supported by established standards, such as BREEAM Outstanding, LEED Platinum, and Passivhaus [54, 55]. Despite knowing in principle how to deliver efficient building fabric, the reality is an enormous gap between performance as designed and performance in use. In a series of experiments funded by

Innovate UK, new-build non-domestic buildings used 3.6 times more energy than predicted by their designers [56], and domestic new-build used 2.6 times the design intent [57].

There are many reasons for this performance gap. The Better Buildings Partnership points the finger at a 'design for compliance' culture instead of 'design for performance' [58]. Buildings designed to comply with the rules, not meet the customer and user requirements. The problem is exacerbated in domestic retrofit by subsidy programmes that encourage installation of energy efficiency measures at the lowest cost, regardless of real-world performance.

Even if an effective low or zero-carbon design can be produced, delivering the design performance is still difficult. Poor communication between the many participants in typical construction projects leads to misunderstandings and errors. Lack of training and unfamiliarity with the demands of net-zero construction and installation leads to a leaky building envelope that does not perform well. Add to that the innate conservatism of many construction specialists, and the performance gap becomes very difficult to bridge.

A building designed and constructed for good efficiency can still struggle when handed over to its intended users. Increased sophistication in building design and operation throws up issues of skill gaps throughout the design and commissioning of buildings. “Soft Landings” is a framework to ensure that the development of a building continues right through the handover phase and assures good performance [59].

We understand how to design, construct and operate energy-efficient buildings but consistently fail to do so. Innovations in materials and components would help, reducing cost and complexity whilst making it easier to deliver buildings right first time and right every time. However, the core problem with new-build is less technology and more policy and customer demand.

Despite the challenges, there are many case studies available of successful low-carbon and zero-carbon new-build projects. The difficulty is making this approach mainstream in a commercial market.

The situation for retrofitting existing buildings is similar. We understand the changes that must be made to improve a building envelope to where the use of decarbonised energy can deliver net-zero. Since 80% of the buildings standing today will still be in use in 2050 [60], retrofitting existing buildings to the required standard is essential for a net-zero transition.

The PAS 2035 standard for domestic retrofit [61] and draft PAS 2038 standard for non-domestic buildings [62] provide detailed guidance. BREEAM, LEED and Passivhaus Enerphit all provide both a strategic approach and certification of projects.

We also have a large collection of national and international demonstrator projects that have shown the feasibility of upgrading both domestic and non-domestic buildings to high levels of energy efficiency [63-68]. The UK Green Building Council publishes guidelines for commercial retrofit projects [69]

Retrofitting existing buildings is more complex than creating energy-efficient new-build. Buildings may be in a poor state of repair. Design and construction decisions were made with other targets than energy efficiency, locking in poor performance. Levels of refurbishment required for energy efficiency may be too disruptive or not economically viable. Finally, the market is diverse. Virtually every building that has been in use for some years will be changed and will now be unique. This keeps the cost and complexity of retrofit projects high.

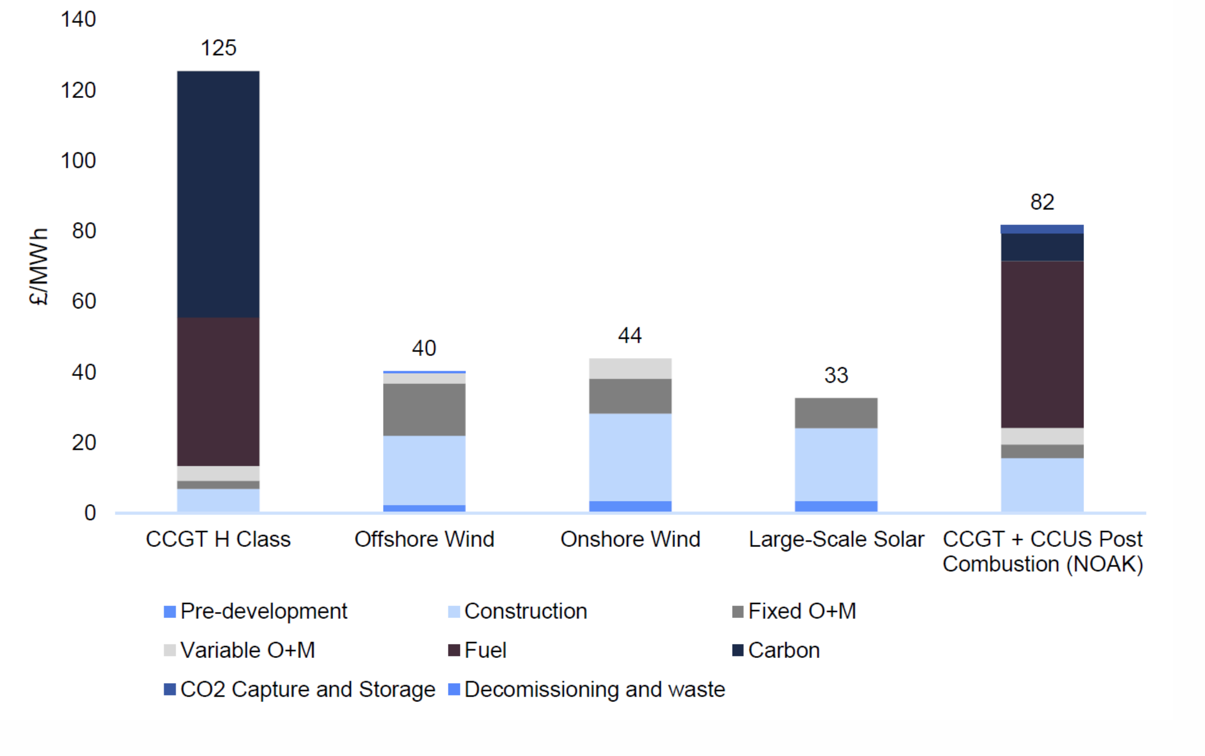
Although the principle of whole building lifecycle assessment and costing is well established, it is difficult to do and rarely practised [12]. A decision to retrofit a building or to demolish and rebuild is not often based on a proper evaluation of the likely carbon impacts. Lack of data, skills and tools prevents a proper analysis.

### 6.2.2 Decarbonising the Energy Supply

#### 6.2.2.1 Net-Zero Electricity

The electricity grid is rapidly decarbonising, both in the UK and across the globe [70] [71]. The transition to net-zero electricity grids is happening worldwide [72] [73], driven by falling costs of renewable energy compared to fossil fuel generation.

For example, this chart shows levelised cost estimates for electricity generation projects commissioning in 2050 in the UK. New wind capacity, both offshore and onshore, and large-scale solar will be much cheaper than combined-cycle gas turbine generation, even ignoring carbon price [74]. Although the difference is not as significant, the Government projects new wind and solar installations to be cheaper than gas turbines by 2025.




*Levelised cost estimates for generation projects commissioning in 2050 £/MWh at real 2018 prices [74]*

Already, renewables are the lowest-cost source of new energy generation capacity for two-thirds of the globe [75]. In 2022, over 40% of UK electricity came from renewables [76].

Cost data on new nuclear for the UK has not been updated since 2016 [77]. At that time, new nuclear was cheaper than any fossil-fuel system with CCS, but more expensive than all renewables except offshore wind, where costs were similar. Since then, cost estimates for renewables have fallen further and those for nuclear are static. However, a recent report argues that the LCOE for extending the life of existing nuclear capacity is comparable with renewables, and that nuclear for baseload has a significant role to play in decarbonisation [78].

With developments in storage technology, integrating large amounts of intermittent renewable energy into the grid is being solved. Net-zero renewable electricity is available today and will become the dominant form of grid energy by 2030.

#### 6.2.2.2 Net-Zero Heat

Approximately three-quarters of building emissions in the UK are direct emissions, burning fossil fuels for space and water heating. We can cut these emissions with interventions that reduce building demand, but what remains must be zero-carbon heat.

The Committee on Climate Change has looked at how we can supply heat to our buildings [15, 79, 80]. Their scenarios for low carbon domestic heat expect:

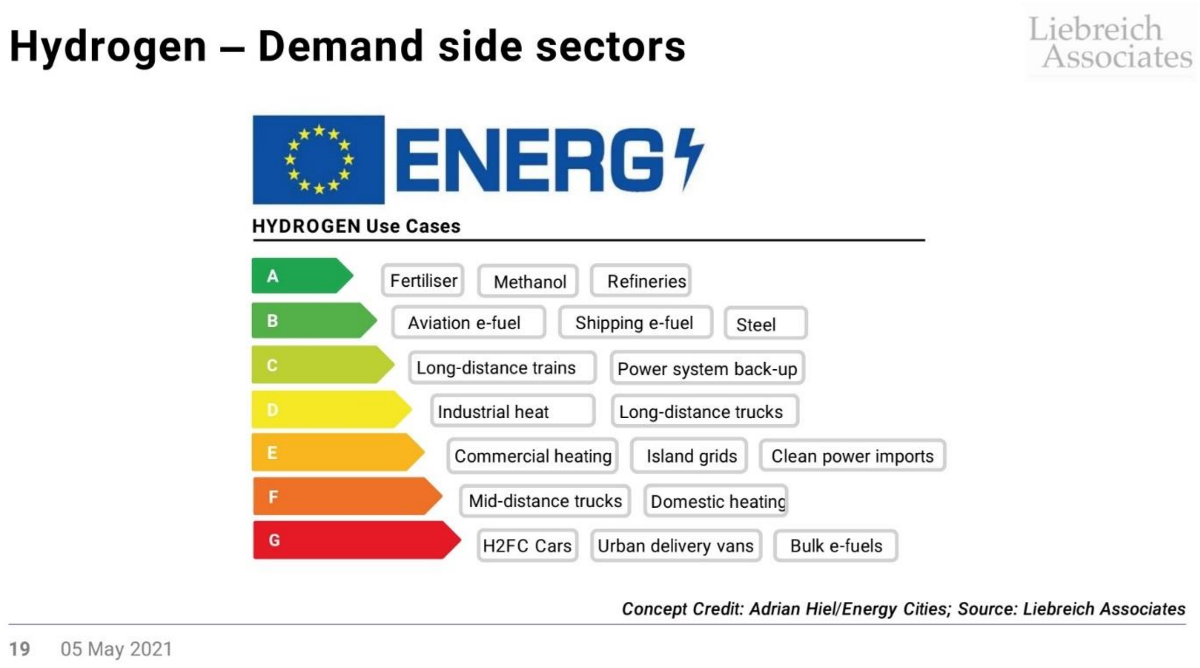
- Low-carbon district heating for 5.5m existing homes
- Heat pumps for 21m existing homes (including 5m in a hybrid configuration with some using hydrogen backup)
- Direct electric heating for 2m homes

The main operating assumption is that heat pumps represent the most effective way to decarbonise heating, except where zero-carbon district heating is practical. However, heat pumps are not yet a complete solution. A recent BEIS webinar reviewed some barriers faced by heat pumps [81], including:

- High costs – air-source heat pumps cost £7k - £14k. Ground source £15k - £35k. Incorrectly installed or in poorly insulated buildings, they can increase fuel costs.
- Low temperature output – this may require increasing the size of pipework and radiators to create the required heat flows. This means increased cost and disruption, and also slower warm up times.
- Space requirement - heat pumps require sufficient space externally for installation, and also a properly sized hot-water tank and buffer tank. Many homes do not have enough space (only 1/3 of current homes have a hot water tank).
- Noise and aesthetics – air-source heat pumps have fans that can produce noise levels sufficient to break permitted development rules, and some consumers find the external equipment of heat pumps unsightly.
- Supply chain capacity and capability – most heat pumps are imported and domestic production is low. There are few qualified installers. Since boiler replacement is often a distress purchase, delays in being able to get and install heat pumps are a significant barrier.

Hydrogen has been regularly proposed to extend the life of gas distribution networks and existing infrastructure. However, experts from BloombergNEF have argued that we lack sources of green hydrogen, and given the fundamental round trip inefficiency of converting renewable electricity to hydrogen and then to heat, heating buildings is not the priority use for a limited resource [82, 83]. They have created a use-case cascade that suggests using green hydrogen for building heating gives a poor return compared to using it in industrial processes and for synthetic fuels where electric motive power cannot be used.

A recent meta study also suggests that a future role for hydrogen in heating is unlikely except for a few limited scenarios [84].



# 7 Market Trends – Positive and Negative

We need low-carbon and net-zero buildings to meet the UK's 2050 targets. It is technically possible to deliver net-zero buildings today, both for new-build and retrofit. However, it is not happening at the speed and scale required.

There are significant barriers to wider deployment of net-zero building solutions, but there are also positive trends that are beginning to shift the market.

Barriers to rapid deployment of net-zero solutions have been widely researched and debated for some time. The core challenges are well understood and have not changed significantly for many years. They seem to apply equally to domestic and non-domestic buildings, to new-build and retrofit, and both in the UK and internationally [20, 63, 64, 85-90].

The key reported barriers are:

- Lack of customer demand – in the absence of regulatory mandates, net-zero is a 'nice to have' option for customers, rather than a priority requirement for many. The perception that the cost accrues to the individual, but the benefits to society, does not help.
- Lack of strong government policy – whilst most governments accept the threat of climate change and the need to transition to a net-zero economy, there is a general reluctance to mandate the changes to building design, construction and operation required to achieve it.
- Perceived or actual cost – costs, particularly up-front capital costs, can be a significant barrier to net-zero building adoption.
- Perceived or actual risk – as with any innovative construction methods and technologies, there is a risk they will not deliver as promised. For long-life high capital investments, this increases the reluctance of customers, suppliers and sources of finance to take on that additional perceived risk.
- A lack of trusted evidence and information – the construction sector is awash with claims and counterclaims about how to deliver net-zero buildings. Evidence for many approaches is limited and fragmentary. This encourages both suppliers and customers to lean on traditional approaches.
- Lack of supply chain capacity and skills – transitioning to net-zero buildings requires a transformation in the way buildings are designed, constructed, and operated. The necessary skills are in limited supply, particularly in retrofit.
- Inadequate technical solutions – for some key challenges, the available technical solutions fall short in performance or economic viability.
- Lack of financing – it continues to prove difficult to raise financing for serious investment in a net-zero building transition, whether for retrofitting an owner-occupied home or building a new office block.

There are also positive market trends:

- Tenants and users of non-domestic properties are increasingly demanding low-carbon and net-zero building, driven in part by Environmental, Social and Governance (ESG) policies. In turn, this is driving developers and managers to specify net-zero construction and to upgrade their property portfolio [91].

- There is progressively increasing pressure on UK domestic rentals, both private and social, to improve the stock and cut carbon emissions [21].
- There is a gradual shift in the UK public's perception of the risks of climate change and the importance of a shift to net-zero [92]. Around 80% of the population are concerned about climate change and the same proportion are supportive of a net-zero transition. Three-quarters believe a move to net-zero will bring health and well-being benefits and half that the switch will strengthen the economy. These long-awaited shifts in public perception will encourage owner-occupiers to improve their properties, providing costs are acceptable.
- The economic potential of reducing emissions from buildings has become a hot topic as more countries attempt to wean themselves off fossil fuels. A recent EU study observed that driving for net-zero in buildings will increase GDP by 1%, create 1.2 million new jobs, cut heating bills, reduce $NO_x$ emissions by 90%, and dramatically reduce natural gas imports [93]. UK studies make the same point [10, 37].
- Increasing interest in reducing energy consumption and cost, and increasing energy security, is driven by the recent invasion of Ukraine by Russia.

# 8 Policy Expectations

An essential requirement for tackling decarbonisation of the built environment is a stable policy framework. The UK Government and the Devolved Administrations have not given a clear and consistent policy lead on the importance of decarbonising the built environment. Various policy initiatives have been started, but frequently changed or abandoned before they can produce the required changes. This does not encourage the various players to commit the time and resources needed to effect change at the speed required. The history of policy declarations followed later by policy changes has damaged industry confidence in the commitment to radical reduction. The challenge is now to convince industry, owners and tenants that investment in developing and implementing net-zero solutions will be repaid.

The recently published Government strategy documents “Net Zero Strategy: Build Back Better” [94], and “Heat and Buildings Strategy” [21], recognise the importance of heat and buildings in a net-zero transition. The key policies are:

- We need to take a whole-buildings and whole-system approach to minimise costs of decarbonisation.
- Innovation is essential to driving down costs, improving options, and informing future decisions.
- In parallel, we need to accelerate ‘no- and low-regrets’ action now.
- We will balance certainty and flexibility to provide both stability for investment and an enabling environment for different approaches to be taken to address different buildings.
- Government will target support to enable action for those in most need.

However, these policy directions are not backed up with sufficient resources to shift the market quickly enough.

The history of such strategies is not encouraging.

In 2006, the Code for Sustainable Homes was published. This envisaged progressively tightening standards for carbon emissions in new homes, and that by 2016, all new homes would be net-zero. This lead to the setting up of an industry led body, the Zero-Carbon Hub, and the development of technical guidance [95]. A great deal of work was done by industry to solve the technical and commercial problems. But suddenly in 2015, the target was abandoned.

Similarly, the Green Deal was a scheme that ran from 2012 to 2015. It provided a Government supported up-front loan for energy efficiency measures for existing homes, to be paid back through the energy bill. Since the energy bill would be reduced by the retrofit measures, householders would find this a painless way of financing the upgrades. In reality, the results were disappointing. The scheme never really gained momentum because was largely unknown to its target users, complex, and carried a relatively high interest rate. The National Audit Office reported that it was poor value for money, and criticised a lack of clarity of purpose, poor engagement with the target audience, and lack of a long-term vision [96].

The Green Homes Grant scheme ran for a very brief period between September 2020 and March 2021. It provided grants covering two-thirds of the cost of insulation or low-carbon heating systems, up to a maximum of £5,000. For households receiving certain benefits, 100% of the costs could be covered up to £10,000. The House of Commons Public Accounts Committee found the scheme was poorly thought through, rushed, and badly implemented. The Government did not consult sufficiently with consumers or industry, and as a result there was very little take up and the scheme had to close early [97].

The required policies are well understood in industry. The UK Green Building Council has published a Net Zero Whole Life Carbon Roadmap for the built environment in the UK [98]. It lays out the type of policy required to support the industry to the point where net-zero becomes the norm.

Government policy should be:

- Clear.
- Outcome focused – specifying targets, not solutions, to allow room for the necessary innovation.
- Consistent – stable for a long time.

UK Government policy on the decarbonisation of buildings has been subject to constant tinkering. Often rapidly introduced without proper preparation, or becoming bogged down in complexity. Rarely has a policy in this sector been sustained long enough to drive the desired changes.

The evidence from other countries is that successful decarbonisation programmes have long-term goals, stable structures and full engagement between government and industry [63, 99].

The UK Government has demonstrated the capability to dramatically change industries through consistent policy and targeted investment. The cost of offshore wind has dropped to one third of what it was ten years ago, and is now the cheapest form of new energy capacity [100]. This has been driven by policy.

The UK Government needs the same kind of long-term vision to decarbonise the built environment.

# 9 Engineering Opportunities

The engineering profession can be at the heart of punching through the logjam and smoothing the path to net-zero.

Their influence will be strongest where new design and technology come together to reduce the barriers and support positive market trends. Areas such as:

- innovating to reduce cost and risk.
- simplifying to overcome problems with skills and capacity.
- innovating to provide better solutions to specific challenges.
- improving buyer confidence through better performance evidence and information.
- reducing energy demand through better design.

There are two potential areas of engineering opportunity:

- technological innovation, improving individual components and subsystems
- a systems approach providing integrated solutions

## 9.1 Technological Innovation

There is a strong consensus that we do not need radical technological innovation. We have the technologies required to decarbonise the built environment, but there is substantial room for incremental improvement. Engineers can take existing technologies and:

- Reduce cost
- Improve performance
- Improve manufacturability and reliability
- Tackle ease of installation, use and maintenance
- Design for remanufacture and recycling

Examples of current innovation and demonstration activities are listed in the following sub-sections. These examples suggest topics for further technological development.

### 9.1.1 Energy efficient building envelope

It is easier to decarbonise a building if you have already minimised the energy demand. An efficient building envelope cuts demand, and places less stress on the electricity grid as we move towards the electrification of heat, and away from burning fossil fuels.

An important trend is the industrialisation of construction, using factory built components (also known as modern methods of construction, MMC). The UK Government funded Transforming Construction programme has supported innovation towards industrialising construction. This reduces costs, time to build, waste, and reduces the accumulation of errors that can lead to a gap between the real-life performance and the design. 84 stories of projects from this program are available through a website [101]. Several of the stories address modern methods of construction. For example, the AIMCH project successfully scaled up MMC for new homes. Offsite manufacturing coupled with new designs & materials, and digital planning, modelling & scheduling, can eliminate any additional costs from building efficient homes.

Industrialisation can also help retrofit existing buildings. Prefabricated components have been used by Energiesprong to improve the energy efficiency of homes, whilst cutting cost, time and disruption [102].

Disruption to residents is a major problem, particularly when retrofitting existing buildings. Insulating suspended wooden floors is a good example of the problem. Normally this requires emptying the room and lifting floorboards. Q-bot is a small robot that can be lowered into the underfloor cavity through a small slot. Once there, it can crawl around the space, spraying foam insulation to the underside of the floor and joists [103]. This is faster, cheaper, and much less disruptive to any residents.

An energy efficient building envelope implies high levels of airtightness. This means controlled ventilation is essential to preserve the building fabric and the indoor air quality. The Covid-19 pandemic has increased the focus on the ventilation challenge, and new research is exploring how we should change building ventilation to maintain energy efficiency whilst preventing viral transmission and enhancing air quality and well-being [104].

### 9.1.2 Heating systems

We are witnessing a transformation in approaches to providing space, water heating and cooling in buildings. The Climate Change Committee and the UK Government both assume heating and cooling will in future be largely electrical, although they believe there is a role for hydrogen and district heat systems [15, 21].

One of the key challenges in decarbonising heating is the familiarity, performance and convenience of existing solutions, such as gas boilers. Heat pumps are the preferred solution, expected to account for the majority of homes and non-domestic properties. However, they work in a very different way to conventional boilers and need changes in how buildings operate.

There is an urgent need to improve the consumer appeal of heat pumps. They need to be as convenient as gas, but cheaper and better performing. Practical problems, including size, noise, low output temperatures and costs, all need to be tackled for widespread deployment [81].

An option for heating and energy systems in buildings is the use of green hydrogen powered fuel cells. These have the capacity to produce both electrical power and heat [105]. However, many experts think that with green hydrogen in limited supply for the foreseeable future, there are more important uses, such as steel-making and long distance transportation [82, 83].

Direct electric heating and modern storage heaters are also considered, but have an inferior performance to heat pumps.

A significant part of the energy consumption in buildings is the provision of hot water. A number of companies are supplying systems that use excess electricity from solar PV or off-peak electricity to power heat stores that can be used to provide hot water on-demand. Heat can be stored in thermal masses, or more compactly in phase-change materials [https://sunamp.com/, https://tepeo.com/, https://www.caldera.co.uk/]. Lacking at the moment are systems that can make efficient use of low-grade heat.

We can also use sunlight to generate heat directly. One of the most interesting innovations entering the market is a hybrid system from Naked Energy [https://www.nakedenergy.co.uk/]. This combines solar PV with solar thermal, producing both electricity and heat. Carbon savings are claimed to be 3.5 times solar PV on its own.

### **9.1.3** Energy systems

In addition to work on decarbonising the electricity grid, there is a great deal of interest in self-generation of electricity by individual buildings and small communities. Through a combination of efficient buildings, local generation and energy storage, it is possible to make buildings energy positive, generating more power than they need for their operations [106, 107]. The excess can be redistributed via the electricity grid.

Alternatively, renewable energy assets can be shared with neighbours to create larger net-zero energy spaces. Reducing the overall costs by increasing utilisation.

An example of this approach is the Johan Cruijff Arena in Amsterdam [108].


This football stadium has 4200 solar panels on the roof, and they store electricity from these in 148 second-life Nissan LEAF batteries. This 3 MW energy system can power the stadium, charge cars in the car park, or share with other commercial buildings and homes nearby. Electric vehicles can be connected in Vehicle-to-Grid mode, where vehicle batteries can supply energy to the local grid as well as drawing energy.

Several companies are developing integrated 'energy pods' that provide low carbon heating & cooling, electrical & thermal energy storage, hot & cold water and ventilation all in one box. These fit particularly well with the Energiesprong approach to domestic retrofit [https://es.catapult.org.uk/case-study/ventive/, https://factoryzero.nl/producten/]. Energy pods speed up installation, both for new build and retrofit, and ensure all the systems work together effectively.

An increasing number of experts are questioning the conventional approach to power in buildings where electricity distribution is through AC current at various voltages. With many renewable energy sources intrinsically DC, and with the growth of low voltage DC equipment in buildings, there is no logic to supplying AC throughout buildings and then converting to the required DC at the point of use [109]. The IET is currently converting part of their offices at Futures Place in Stevenage to DC as an experiment.

In the longer term, DC is expected to dominate many types of electricity generation, transmission and use.

### 9.1.4 Digital everything

Like many other industries, the construction sector has a lot to gain from deploying digital technologies at every stage of a building's life from initial design, through construction & use, to eventual demolition & disposal.

Digital advances are built into 68 of the 84 case studies from the Transforming Construction programme [101]. Digital techniques can ensure efficient design, speed up construction, reduce costs, and cut waste.

Applications include:

- Design tools for energy efficient buildings
- Building information management (BIM), digital twins and other modelling techniques for integrating information across the building lifecycle
- Support to offsite manufacturing
- Improved logistics and traffic control on site
- Smart buildings and improved building controls
- Use of augmented reality for communication and management

Another interesting development is the rapid surveying and monitoring of buildings and urban environments using remote sensing. This is critical to understanding the existing conditions of both individual buildings and their surroundings. Research groups like the Sheffield Urban Flows Observatory are developing powerful capabilities to rapidly and non-intrusively gather information on urban spaces [110].

There are still substantial opportunities in the deployment of digital technologies for the construction sector. The sector still lags adoption in comparison with many other industries. Digital solutions will be key to delivering decarbonisation of the built environment quickly and cost-effectively.

#### **9.1.5** Embodied carbon

Key construction materials are cement, steel, glass and timber. Cement, steel and glass are the products of energy-intensive industries. These industries are obvious targets for decarbonisation, and a great deal of work has already been carried out to develop pathways to net zero. Their future success depends on it.

Identified changes could cut emissions from the cement industry by 75% by 2050 [44]. However, many of the solutions are still in development and are not yet commercially viable. The glass industry has published a 2050 strategy for a transition both to net-zero and a circular economy [46]. A route being actively explored for the steel industry is to replace blast furnaces with direct reduction and electric arc furnaces [45].

Reuse and recycling are other options for minimising embodied carbon. Concrete can be recycled as aggregate, and glass and steel and other metals recycled by melting and remanufacture. A more efficient process is to reuse the materials directly without remanufacture. Several long-running programs have evaluated the potential of reusing structural steelwork recovered from demolished buildings in new buildings. The challenges are reducing the cost of testing recovered components, transportation logistics, and constructing a new supply chain and business model [111].

Timber and other bio-based materials can lock up carbon for relatively long periods of time when used in construction. Timber frame domestic buildings are well established, but recent experiments have extended the use of timber as a structural component.

The Mjøstårnet building in Norway is the world’s tallest timber building, at 85.4 meters [112]. At the other end of the scale, Agile Properties and Homes are developing smaller homes using timber structures and straw-bale insulation to Passivhaus standards of energy efficiency [113]. They take full advantage of offsite construction methods and are targeting affordable homes and difficult to use sites in cities.

Another approach to reducing embodied carbon is reducing carbon emissions in the construction process itself. This involves converting all equipment on site to clean electricity, efficient management of logistics and materials to reduce waste, and increasingly digital techniques such as augmented reality. Two pilot project sites are the Royal Botanic Garden in Edinburgh [114], and Olav V Gate in Oslo [115].

## 9.2 Systems Approach

A constant theme that has come through in preparing this report is that decarbonising the built environment is not mainly a technology problem, it is a systems problem. We have the core technologies required for full decarbonisation. Those technologies can be improved, made more efficient and reliable, with lower upfront and operational costs. But that is not the main barrier to wider deployment. Our core problem is creating the integrated systems that will improve efficiency and cut carbon emissions. We have the individual pieces of solutions. The problem is putting them together effectively.

This challenge has been recognised by the Royal Academy of Engineering, who stress the importance of systems thinking and systems engineering in delivering net zero and decarbonising the built environment [116, 117].

Decarbonisation of the built environment requires managing complex interactions at every level, from individual buildings to neighbourhoods, cities and regions.

As an example, heat pumps are seen as one of the key technologies for reducing the carbon impact of heating in homes. However, the heat pump is not a plug-in replacement for the existing boiler. Because of their different heat generation characteristics and profiles, when you switch from a conventional boiler to a heat pump, every part of the heating system may change.

- Upgrading the energy efficiency of the building envelope through additional insulation can have a profound effect on the sizing and effectiveness of the heat pump.
- Heat pumps have lower output temperatures and lower return temperatures. The design and operation of heat pump systems is different to boilers.
- Particularly in retrofit, it may be necessary to resize both pipework and radiators to take full advantage of heat pump characteristics.
- Instantaneous hot water is typically not available. To produce hot water for a family, an insulated hot water tank is necessary. This takes up space which may not be available in a smaller property, and may require an additional immersion heater to raise the temperature in the hot water tank periodically to kill off Legionella organisms.
- Heat pumps respond more slowly than conventional boilers. This means the optimum pattern for use is different. Control systems need to take this into account, and users must learn new patterns of operation.

There are concerns that we currently lack the supply chain capable of designing and implementing effective heat pump systems in the numbers required. Histories of heat pump systems that did not deliver, spread rapidly amongst users, increasing resistance and further delaying deployment.

There is a real risk of specific point solutions to decarbonisation having significant unintended consequences [118]. These include:

- Problems with indoor air quality.
- Increased risk of summer overheating.
- Poorly installed upgrades leading to increased condensation, mould growth and damage to the building fabric.
- Energy consumption increases due to ‘take-back’ and rebound effects.
- Potential for increased heat island effects in urban areas.

It is vital that we do not tackle the problem immediately in front of us, but also consider the system impacts of the proposed solutions.

The construction and operation of buildings, and the way they integrate with local infrastructure, has developed over many years into a number of discrete specialisations. This brings efficiency, through specialisation and division of labour, but also creates technological silos. These silos are well entrenched, and make it harder to take the necessary systems view.

For example, looking at a single property in a terrace, the sensible route to decarbonisation may be improved insulation and an air source heat pump. However, for the whole terrace, street or estate to be upgraded, installing bulky and potentially noisy heat pumps on each property could be a poor solution. It may be better to use a large community ground source heat pump, or district heating scheme if a suitable source of heat is available.

At a larger scale, planning decisions about the distribution, type and purpose of buildings can have a profound effect on the overall emissions from transport [119]. The history, layout and characteristics of different urban areas provide natural laboratories for testing different approaches [120].

Buildings are places for people to use, and the way in which they use them will affect the success or failure of decarbonisation strategies. Behavioural science can contribute to understanding how people use buildings, what the implications for energy consumption and carbon emissions are, and what changes will support people to use buildings in a low carbon way [121]. Recently, the Energy Systems Catapult conducted consumer trials of ‘heat-as-a-service’ [122]. The concept was based on the way mobile phone contracts work. Consumers pay for a certain base level of comfort for a fixed fee, with additional ‘bolt on’ services available if required. The model was attractive to consumers because they could understand what they were buying. Not kWh, but a certain guaranteed level of comfort.

There are several steps that can be taken to encourage and support greater levels of systems thinking in construction, from individual buildings to neighbourhoods and cities.

Systems thinking and systems engineering are better established in other industries; for example, energy, automobiles and some aspects of transport. We need a transfer of knowledge into the construction sector, adapting it to the specific needs.

There is a need for a new breed of designers, engineers and installers who understand the new technologies required for decarbonisation, and how they go together. This implies a substantial upgrade to skills in the sector, but also a more multidisciplinary approach [18].

The existing business models within the sector are a barrier to a holistic systems approach. Fragmentation is a constant problem with not enough people looking across the whole of the building and how it integrates into its surroundings. Procurement methods, the practice of contracting and subcontracting, and the way responsibility and liability is managed throughout a construction project, all contribute to making a systems approach difficult. The Better Building Partnership has drawn attention to the problem of ‘design for compliance’ instead of ‘design for performance’ [58]. Coupled with the tendency of individual specialisations to carry out value engineering that compromises the design intention, the ambitions of clients and users are often not met in practice.

An example of an attempt to tackle this problem by changing the business model is the role of the retrofit coordinator in PAS 2035 [62]. PAS 2035 is a UK standard governing domestic retrofit projects. The retrofit coordinator has overall responsibility for a retrofit project. They have a duty to ensure the various requirements of the standard are met. For example:

- A whole house design is developed based on a detailed assessment of the property.
- The design adopts a ‘fabric first’ philosophy, making sure the building envelope is efficient before focusing on low-carbon energy and heat.
- A medium-term plan is developed showing which order to install different energy efficiency measures if it is not possible to complete the retrofit in one job. This is to avoid single point solutions which may be regretted investments at a later date.
- All installers are properly qualified and hold the correct certifications.
- Monitoring and evaluation is carried out after retrofit completion to make sure the design outcomes are achieved.

The standard emerged from studies of failed retrofit projects, identifying the common failings and developing processes to minimise these risks. The same approach can be deployed for new build and retrofitting non-domestic buildings.

Any attempt to introduce greater systems thinking into construction requires changes to information flows. The existing fragmentation and specialisation within construction has acted as a profound block to open and effective information exchange between participants in construction projects. BIM and digital twins are tools that can help information to flow again.

The construction sector is capable of taking a systems approach. This is mostly seen in large-scale new build projects when masterplans are developed to show how an entire neighbourhood, city or region will function. The challenge is to apply the same level of sophistication and detailed thinking to smaller projects involving only a few buildings. How can we masterplan when we are not masterplanning?

# 10 Recommendations

There are many opportunities to develop new solutions for net-zero buildings, and many actions that can be taken to accelerate the transition. In this section, we have grouped these into five broad recommendations. Areas for action.

A longer list of specific opportunities and actions can be found in Appendix 1.

## 10.1 Overarching recommendation

Few actions for decarbonising the built environment can be delivered by one player alone. Progress on decarbonisation relies on breaking down the walls between existing silos and reconfiguring relationships across many specialist sectors that have traditionally operated with a great deal of autonomy. Routes to decarbonisation create new connections between subsystems that must be accounted for in new ways. For example, building fabric, ventilation, energy use and user habits affect each other in very different ways for a low-carbon or net-zero building. The existing traditional breakdown of tasks and responsibilities is no longer viable.

Therefore, an overarching recommendation is that:

**Decarbonising the built environment requires new relationships and understanding between the groups involved in creating, using, and disposing of buildings. Trade and professional organisations have a key role in fostering a fresh approach. They must show leadership and drive the change. Government, innovation funders and the education base should support them.**

## 10.2 Policy

The Government should set a clear policy for the transition of the built environment to net-zero by 2050. The policy should be:

- Consistent and long-term – it should not undergo constant change.
- Outcome oriented – the policy should describe the desired outcome and how it should be measured. It should not specify the solutions so there is space for unexpected innovation.

The Government needs help in developing the policy from:

- Trade and professional associations and the research base.

## 10.3 Technological innovation

There are still plenty of opportunities for innovation in approaches to decarbonising the built environment. In most areas, we understand what needs to be done. What is required now is innovation to render those solutions practical and cost-effective. Areas ripe for innovation include:

- Packages of technologies that work together effectively – we need people working on specific technologies to collaborate with others to create integrated solutions. Too often, a technology does not deliver as promised because of how it interacts with the rest of the system. The new types of integrator mentioned under 'new business models' could play a key role in creating these packages.
- Improvement of existing technologies to deliver:
    - Easier installation.
    - Easier operation and maintenance.
    - Lower cost.
    - Reduced hassle for buyers and users.
- Fully exploiting the digital revolution – the construction sector has been slow to exploit the latest digital technologies. At every level, from initial design, through construction to operation, digital technologies can improve carbon efficiency. Known technologies need adapting to the needs of the construction sector. These solutions should be actively promoted.
- Scaling down powerful solutions – at every level, we have technological solutions that can only be used for large projects; typically new build. These solutions provide lower costs, faster delivery and improved performance. We need to make BIM, BMS, building modelling and smart systems viable for every project, from a domestic retrofit to a major new office block. For example, in the master planning of major new developments, we think about and how it integrates into the local and national infrastructure – transport, energy, water, waste, etc. How do we scale this down? How do we masterplan when we are not masterplanning?

Innovation can be supported by:

- Government – providing development funding and ensuring the policies and rules they develop do not hinder innovation.
- Innovation funding agencies – supporting both early stage R&D and commercialisation.
- The research base actively looking for commercialisable solutions.
- Intermediate agencies – acting as midwives to new approaches.
- Professional and trade associations – promoting the opportunities, providing appropriate CPD and linking users, innovators and funding sources.
- Innovators and entrepreneurs – responding to the opportunities with practical solutions.

### 10.4 New business models

The existing business models in the construction industry promote silos and can be a profound barrier to information flow and collaboration. The challenge of a decarbonised built environment requires us to rethink this.

There are a number of opportunities, some of which have already been explored:

- The emergence of new types of integrator at different levels within the overall structure.
    - People who can pull together packages of technologies that work together to deliver net-zero in a single building. Some of this thinking can be seen in domestic retrofit through the requirements of the PAS 2035 standard.

    - People who understand how to link groups of buildings together to take maximum advantage of their individual resource generation capabilities and needs. Extending that thinking into clusters of clusters, neighbourhoods, cities and ultimately nations and global regions.
- Learning more effectively from other industries. Early work on Modern Methods of Construction has begun the industrialisation of the construction sector, but take-up is slow. Current business models are a definite barrier. Much more can be achieved in reducing embedded carbon, construction costs & waste, ensuring buildings are efficient and perform as designed.
- Designing new ways of paying for the benefits of the built environment. The idea of heat or comfort as a service has been explored in the Energiesprong approach and in the Smart Systems and Heat demonstrator programme. Changing the way we pay for the services the built environment provides could unlock low carbon opportunities.

The development of new business models should be:

- Encouraged and supported by government policy – the role of the regulators is vital.
- Encouraged and supported by the professional and trade organisations – alerting innovators to the opportunities while ensuring their own rules and practices are not barriers.
- Explored by the research base.
- Supported by pump-priming funding by government and innovation agencies.

### 10.5 Marketing and information

With multiple interlocking changes to design, materials and components, everyone involved in the design, construction and use of buildings needs to understand how they work. For example, designers, installers and customers all need to understand that a heat pump is not a gas boiler. It behaves differently and should be installed and operated differently.

If we don't communicate these differences effectively, buildings will not deliver their promise to the buyers and users.

In addition, there is a need for trusted information on the performance of different solutions and how to integrate them.

All relevant professional and trade associations should come together to collate and spread this information. The Construction Leadership Council could act as the focal point. This is not only a technical task; it is a marketing task to reach all the interested parties.

### 10.6 Skills and education

Every aspect of the built environment is touched by the transition to net-zero. It changes the design (including how they integrate into local and national infrastructure), the materials and components, the methods of construction, and the way buildings are operated. The current reductionist approach allows different specialist teams to make assumptions about what is happening in the rest of the building. That cannot continue.

The education system with the professional and trade associations should work together to encourage systems thinking at every level. Suppliers and installers need to understand how their components and subsystems fit into efficient operation of the building. Building designers and planners need to understand how the building will integrate into local and national infrastructure. For example, is there the potential for a local electricity microgrid, or can a local heat network be developed?

We must develop a workforce that can lift its eyes to wider horizons.

# 11 References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# 12 Appendix 1 – Specific Opportunities

A wider list of opportunities and possible actions uncovered in the development of this report.

**Policy**

- Trade and professional organisations should work together to eliminate silos. Recognising each other's qualifications and promoting shared training.
- Encourage the establishment of a single recognition scheme for all installers. A 'Certified Low-Carbon Installer' to match the widely understood 'Gas-Safe' scheme.
- Government to develop a roadmap and policy for the journey to net-zero by 2050. Policy should:
    - Receive cross-party support to avoid constant tinkering.
    - Be long term and set out a clear roadmap with increasingly stringent targets.
    - Develop a regulatory framework that can last until 2050.
    - Be outcome oriented and not prescribe specific solutions.
    - Be based on actual building performance measured in use.
- Further develop standards for low-carbon buildings to encompass all building types, both new-build and retrofit.
- Structurally encourage the reuse of existing buildings where possible to avoid unnecessary embodied carbon and construction emissions.
- Remove financial barriers to creating and using low-carbon buildings, making them more investable.
- Provide secure sources of low-cost funding for low-carbon buildings.
- Encourage the large-scale demonstration of low-carbon construction and buildings.

**Technological innovation**

- Heating systems with consumer appeal – "better than what we have now".
    - Low-carbon heat systems, such as heat-pumps, deliver heating in a very different way to gas-boilers. Consumers miss the 'instant response' of current systems and this is a barrier. We need improved performance and smart controls to increase consumer attractiveness.
- Industrialised insulation systems – offsite manufactured and robot installed.
    - Current retrofit insulation systems are expensive and slow to deliver. In one study 40% of the cost of external wall insulation was the scaffolding. We need industrial approaches to make insulation faster, cheaper and less disruptive.
- Intrinsic design of ventilation – post-Covid.
    - Proper ventilation that can reduce infection rates from airborne diseases such as Covid-19 needs to be designed into buildings from conception. Viable retrofit solutions are needed.
- Improved MVHR and HVAC – lower cost, improved installability, improved usability.
    - For energy efficient but liveable buildings we need improved MVHR and HVAC. MVHR in residential is a particular problem as both installers and users are unfamiliar with the technology, yet it is critical to the 'build tight, ventilate right' philosophy.

- Heat storage systems.
    - Systems that can take 'excess' heat produced at times of low carbon intensity and release it during times when carbon cost would be higher. For example:
        - Solar thermal heat generated during daylight stored until the hours of darkness.
        - Heat produced by off-peak electricity to reduce consumption when carbon intensity of the grid increases.
- IR Heating.
    - As an alternative high-efficiency way to use electricity for heating.
- Fuel cells for combined heat and power.
    - Using hydrogen fuel cells as an alternative to hydrogen boilers to generate both heat and electricity.
- Improved heat pumps – higher output temperature, higher reliable COP, lower cost.
    - Heat pumps are seen as a poor alternative by many target customers. How do we improve them to provide better performance at lower cost?
- Hybrid heat pumps/boilers.
    - Often seen as a solution to perceived poor performance of heat pumps, combining heat pump and fossil fuel burning for situations where the heat pump cannot deliver.
- Improved batteries and controls for domestic micro-generation.
    - Storage is essential to get the best out of building mounted solar PV.
- Improved building controls and smart buildings.
    - Improved building controls can significantly reduce a building's energy demand. How can this be achieved in a low-cost and user-friendly way?
- Better building analytics.
    - Understanding the way in which buildings are using energy allows demand reduction whilst providing users with all the comfort and convenience they desire. How can we make advanced building analytics standard?
- Improved outcome modelling.
    - Improving the performance of buildings relies on modelling the impact of various design choices, particularly in retrofit projects. How can we improve the speed, flexibility and reliability of building modelling?
- Rapid surveys
    - Associated with better modelling is the need to provide good survey information about building design, manufacture and condition. With so many buildings to upgrade it is impossible to do this in the traditional way. It is too slow and too costly for the number of buildings to be upgraded.
- Energy pods
    - For retrofit, a number of companies produce 'energy pods'. Complete energy systems that can be rapidly installed, internally or externally, and quickly connected to the building services. Standardisation and mass production techniques bring lower costs and faster and easier installation.
- Low disruption retrofit
    - A major barrier to retrofitting to decarbonise buildings is the disruption and hassle caused to the owners and users. Can we develop retrofit strategies that reduce disruption to a minimum?
- Solutions for hard-to-treat homes.

  - In England 16 million homes have an energy efficiency lower than EPC C.
  - 8 million homes have solid walls.
  - Improved solutions for insulating hard-to-treat homes are required.
- Realising the energy saving potential of DC homes.
  - With increasing deployment of PV and use of electronic equipment of all types, there are gains to be made from switching to DC supplies in buildings. How can we facilitate a transition?
- Low-carbon construction sites.
  - By 2050 half the lifetime carbon emissions from a building may be due to embodied carbon. Can we use industrialisation techniques to minimise embodied energy in buildings, minimise waste and energy consumption during the construction phase.
- Developing ‘kits’ of subsystems that can be demonstrated to work effectively together. Simplify the specification of a low-carbon building.

**New business models**

- New types of integrator that can pull together a complete low-carbon building design.
- New ways of funding the costs of low-carbon buildings – long term green bonds.
- Transferring methods from other industries.
  - Wider use of modern methods of construction.
  - Managing on-site logistics and operations using techniques from mass customisation.
  - Using construction approaches that eliminate rework and snagging.
- New ways of paying for low-carbon buildings.
  - Heat as a service.
  - Shared benefits as with power purchase agreements. Installation of low carbon measures with guaranteed reduced costs for the user.
- Integration of individual buildings into the energy grid.
  - Local micro-grids.
  - Peer-to-peer energy trading.
- Insurance products to cover risk of poor performance of low-carbon installations.

**Marketing and information**

- Explain the benefits of low-carbon buildings to users to build market pull.
  - Do not sell on cost-saving but on increased comfort and utility.
  - Make low-carbon aspirational.
  - Make sure users understand many low-carbon technologies need to be operated in a different way for best effect; for example, Passivhaus designs.
- Create a reliable and trusted ‘one-stop shop’ for information on low-carbon solutions.
- Ensure performance-in-use data is collected and available for different building types, technologies and use cases.
- Consolidate certification schemes to create a simpler story, both for technologies and providers.
- Promote standards for low-carbon construction and buildings.

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**Skills and education**

- Increasing the numbers of low-carbon heating engineers.
    - The transition to a low-carbon economy requires converting millions of existing buildings and new designs for all new buildings. How can we ramp up the number of designers and engineers to meet the need?
- Train and support designers and installers to understand how low-carbon features and technologies interact to avoid problems.
- Government supported/mandated training for all installers.
    - This was done in the Netherlands with the introduction of condensing gas boilers to ensure there were no future problems due to untrained installers.
- Increasing the awareness of architects and designers about the challenges and benefits of low-carbon buildings.
- Change undergraduate, postgraduate and professional training to promote systems thinking and support the breaking down of professional silos.
- Expand the vision of professionals beyond a single building into groups of buildings, communities, towns, cities and regions.