Cambridge Centre for Housing & Planning Research

Places for People

Net zero ready new build housing: benefits and barriers to delivery

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1. Executive summary

The UK government intends to reduce greenhouse gas emissions by 100% relative to 1990 levels by 2050. To achieve this, cutting carbon emissions from the built environment, and in particular from residential buildings, is a key priority as the built environment in the UK is responsible for approximately 40% of all greenhouse gas emissions. In addition, given the rapidly increasing cost of living, especially with regard to energy costs, the transition to a net zero carbon future and reduced dependence on non-renewable energy, through the adoption of cost effective solutions to heating and powering homes, is becoming ever more important.

To meet the UK's legally-binding climate change targets, the Climate Change Committee (2019) and the Sixth Carbon Budget (2020) propose that all new residential buildings should be zero carbon-ready from 2025. Building the zero carbon ready homes required means fundamentally changing the way that we design and build homes in the UK. This research investigates how housebuilders in the affordable housing sector can plan effectively for a zero carbon future by exploring the main challenges and opportunities in delivering net zero carbon ready new build housing in the affordable housing sector.

Drawing on current policies and relevant literature, the report sets out some of the net zero carbon definitions before discussing how net zero carbon is expected to be achieved in new homes. Net zero carbon ready homes are those that are built with high energy efficiency and use low carbon technologies (e.g., heat pumps or other forms of electric heating instead of gas boilers) that will become net zero carbon when the national electricity grid is decarbonised. These homes will not need retrofitting in the future in order to have net zero carbon emissions from their regulated operational energy.

To achieve net zero carbon in new homes, using the fabric first approach to maximise the performance of the components and materials that make up the building fabric itself appears to be key to reducing the initial need for energy consumption. The inclusion of renewable technologies can further help to provide clean heat and energy for the new homes. However, the report identifies some gaps in the take up of the technologies, for example, the low uptake of heat pumps, despite the availability of the technology and its high uptake in other countries. It also discusses some of the implications of not having a holistic approach to designing net zero carbon new homes. UK policies and regulations have a strong focus on achieving zero carbon targets for buildings and are less concerned with the design of the wider site or the environment. Neither the siting and orientation of buildings, their built form and layout, nor the role of the external environment in enhancing the energy and environmental performance of a building, have received sufficient attention in the current discussions about net zero carbon homes.

The report identifies a number of barriers to implementing net zero housing at the pre-construction stage, construction stage and post-construction stage. At the pre-construction stage, gaps in policy and regulation for delivering net zero carbon homes, the additional capital costs of building net zero carbon homes and the lack of financial incentives and funding to cover part of those costs are some of the barriers. At the construction stage, there is currently a lack of net zero carbon skills and capacity within the supply chain which is likely to reduce construction quality, make delivery more challenging and increase performance gaps. Procuring net zero carbon products at scale within the supply chain is a significant barrier faced by housebuilders and has a direct impact on their ability to build net zero carbon homes. At the post-construction stage, the impact of consumer behaviour, the constraints within energy systems and the challenge of delivering or upgrading necessary infrastructure, are identified as potential barriers. Housing associations and others with stewardship responsibilities will perhaps need to change the ways in which they repair and maintain their housing stock as housing design and energy systems change.

The report also provides an overview of some of the benefits of delivering net zero carbon homes for the environment and for residents and social landlords, including housing associations. Some of these benefits include reduced emissions and increased resilience to climate change, the possibility of reduced utility bills and improvements to the comfort and health of residents, and the possibility of financial and reputational gains for housing associations and housing providers.

Nonetheless there are trade-offs that social landlords might face in implementing net zero carbon ready new homes. One of the main trade-offs is between the additional cost associated with building net zero carbon homes and the viability and/or profitability of development. There is a cost premium for the early adoption of new zero carbon technologies and designs, and those additional costs may affect the affordability and viability of the units constructed. In addition, the social housing sector faces other pressing priorities and there are also trade-offs to be made between building net zero carbon homes and addressing, for example, fire safety, the needs of the ageing population, the rising cost of living, and homelessness.

In addition, housebuilders face a range of dilemmas primarily relating to the adoption, use and maintenance of new low carbon technologies. There is no clear guidance on which technology to use to provide, for example, green heating for homes. It is not clear which technology is cheaper, greener and more customer friendly. It is challenging to know which of these products to adopt and how their use can be brought into the mainstream and used consistently across the design and delivery of new build homes.

Finally, the report sets out a series of recommendations to address some of the barriers in delivering net zero carbon new homes. These are summarised here, and explained in more detail in section 7 of this report:

- The necessity of providing greater clarity over the policy, regulations and standards that housebuilders should comply with and the expected timeframes, clarity on the role of planning, and clarity on the definitions commonly used by the government.
- Incorporating sustainability objectives into the design of not only the buildings but the site and its surroundings in order to achieve net zero carbon targets and improve the quality of life for residents. Gains will be lost if homes are designed to net zero standards but developments are not well connected to sustainable transport networks and do not promote sustainable lifestyles.
- To mitigate risks for the pioneers of building net zero carbon ready new homes, the formation of strong collaborations and partnerships within the sector, between the housing sector and other related sectors (e.g., suppliers, skills bodies, and planners), and between the housing sector and the government is recommended.
- There is a need for more research to develop a robust evidence base to support the development of more net zero carbon homes. The housing sector and the research community need to work together to create an evidence base of what works, to share best practice, and the learning from what does not work.
- We recommend engaging with residents of new net zero carbon homes post-occupancy to inform them about how the new homes work. Post occupancy evaluation to collect robust data on net zero carbon homes can help to better understand how the adopted technologies and designs perform in practice and how they can be improved. In addition, exploring the greater use of sensors and digital technologies may help to collect data to improve designs and develop an evidence base about the performance and use of new homes.
- Financial incentives including the allocation of upfront grants, removal or reduction of VAT for all low regret technologies options and for the labour cost associated with their installation. Further research and evidence on how other countries' financial and policy incentives have facilitated their transition

to greater use of net zero carbon home technologies would be beneficial to inform the development of incentives in the UK.

- Providing training and upskilling for the workforce across the supply chain to support the transition to a net zero carbon future is very important. Instead of demand-led skills development in the construction sector, we suggest that training provision is planned and actively managed in advance as the current levels of demand-led training will not be sufficient.
- The transition to electric heating and increased use of electric vehicles will increase the UK's reliance on electricity. There is a need for OFGEM, BEIS and network operators to work together to identify solutions that will avoid intermittent and erratic supply by the national electricity grid.

2. Introduction and context

2.1. Background

In June 2019, the UK Parliament passed legislation requiring the government to reduce the UK's net emissions of greenhouse gases by 100% relative to 1990 levels by 2050 (HM Government, 2021a). To achieve this, cutting carbon emissions from the built environment, and in particular from residential buildings, is a key priority as the built environment in the UK is responsible for approximately 40% of all greenhouse gas emissions (UKGBC, n.d.).

Most of the emissions in buildings are direct greenhouse gas emissions resulting primarily from the use of fossil fuels, mainly gas, for heating. In the UK, 85% of domestic heating systems run on gas because of the access to the relatively cheap gas from North Sea gas fields (Eunomia & CITB, 2021, p.5). The Climate Change Committee (CCC), the UK government's adviser on emissions targets, warns that the UK's legally-binding climate change targets will not be met without the near-complete elimination of greenhouse gas emissions from UK buildings (CCC, 2019).

The Climate Change Committee (2019) and the Sixth Carbon Budget (2020) both propose that, for the UK to reach net zero carbon emissions by 2050, all direct, regulated emissions from buildings must be eliminated by 2048. To achieve this, they propose that all new residential buildings should be zero carbon-ready from 2025. The government has announced that by 2025, all new homes will be banned from installing gas boilers and will instead be heated by low-carbon alternatives.

The government has amended the Building Regulations to ensure that new homes built in England will emit around 30% less carbon, when the requirements come into effect from 15 June 2022. The introduction of the Future Homes Standard in 2025 will ensure that an average home will produce at least 75% lower CO_2 emissions than one built to current energy efficiency requirements (MHCLG 2021).

Building the zero carbon ready homes required by the Future Homes Standard means fundamentally changing the way that we design and build homes in the UK. Given the aim of building 300,000 homes per year and the currently low number of new build net zero carbon developments, there are concerns and uncertainties about how the industry is going to achieve this target and what the implications will be for the industry and for home occupants.

2.2. Research aim

The aim of this research is to investigate how Places for People and other large-scale property owners and developers in the affordable housing sector can plan effectively for a zero carbon future. In this research, we explore the main challenges and opportunities in delivering 'net zero carbon ready' new build housing in the affordable housing sector, whilst putting the needs and aspirations of the residents of affordable housing at the centre of changes.

This research is intended to inform Places for People's net zero strategy for the delivery of net zero ready new homes, as a leading developer in the social housing sector, as well as providing evidence for the wider industry on how to plan effectively for a zero carbon future by delivering net zero carbon ready new build developments.

Whilst only new build housing is within the scope of this research, we note that there are cross overs between building net zero new build and retrofitting the existing housing stock. However, the attention of this report is on new build.

2.3. Research methods

The primary research method was a desk-based internet search for existing evidence and publications about the construction of net zero ready new homes in the UK. The main sources of data were published government regulations and policies, reports, and industry guidelines (for example, UKGBC's Net Zero Carbon Buildings: A Framework Definition, RIBA's 2030 Climate Challenge, LETI's Climate Emergency Design Guide).

In order to develop a better understanding of and insights into the challenges that the industry faces in achieving a net zero future, we discussed some of the operational challenges with Places for People.

2.4. About this report

This report presents the findings of our analysis in the following sections:

Section 3: What is net zero and how will it be achieved?

This section sets out some of the net zero carbon definitions, discusses how net zero carbon is expected to be achieved, provides an overview of some of the low carbon technologies, and explores the gaps identified in the approaches to achieving net zero.

Section 4: Barriers to the building of net zero carbon homes

This section discusses potential barriers to the implementation of net zero carbon ready new homes at the pre-construction, construction and post-construction stages.

Section 5: Benefits of implementing net zero carbon homes

This section provides an overview of some of the benefits of delivering net zero carbon homes for the environment, residents, and social landlords, including housing associations.

Section 6: Trade-offs

This section looks at some of the trade-offs and dilemmas that social landlords might face in implementing net zero carbon ready new homes.

Section 7: Recommendations

This section sets out the recommendations of this report to overcome the barriers in delivering net zero carbon new homes.

3. What is net zero and how will it be achieved?

3.1. Definitions

3.1.1. What does 'net zero carbon' mean?

Net zero carbon (or net zero, as commonly used) refers to achieving a balance between the amount of greenhouse gas emissions produced and the amount removed from the atmosphere. There are two different routes to achieving net zero carbon which work in tandem: reducing existing emissions and actively removing greenhouse gases from the atmosphere (Institute for Government, 2020).

A *gross* zero target means reducing all emissions to zero. As this is not possible, the *net* zero target recognises that there will be some emissions which will need to be fully offset, predominantly through natural carbon sinks (e.g., trees) (Institute for Government, 2020). Where the amount of carbon emissions produced are cancelled out by the amount removed or offset, it can be said that a net zero emission is achieved. The lower the emissions, the easier this becomes.

3.1.2. Net zero carbon homes

The UK Green Building Council (UKGBC, 2019) sets out its net zero carbon framework for buildings around two approaches:

- Net zero carbon construction: the amount of carbon emissions associated with a building's production and construction stages up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy (UKGBC, 2019, p.6);
- Net zero carbon operational energy: the amount of carbon emissions associated with a building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly energy efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance being offset (UKGBC, 2019, p.6).

To go one step beyond net zero carbon in the construction and operation of a building, the UKGBC proposes a whole life net zero carbon assessment which calculates whether the amount of carbon emissions associated with a building's embodied and operational impacts over the life of the building, including its disposal, are zero or negative (UKGBC, 2019, p.12). However, net zero whole life carbon is not proposed as an approach at present due to current limitations in the reporting of carbon emissions from the maintenance, repair, refurbishment and end-of-life stages of a building's lifecycle (UKGBC, 2019, p.12).

A net zero carbon new home has net zero carbon emissions in both the construction process and its in-use operational energy.

Net zero carbon ready homes are those homes that are built with high energy efficiency and using low carbon technologies (e.g., heat pumps or other forms of electric heating instead of gas boilers) that will become net zero carbon when the national electricity grid is decarbonised (CIH, 2021). These homes will not need retrofitting in the future in order to have net zero carbon emissions from their regulated operational energy.

3.1.3. Glossary of commonly used terminologies

- Greenhouse gases (GHG): the gases in the Earth's atmosphere, including carbon dioxide and methane, which have a heating effect when released into the atmosphere. GHG is often simplified to 'carbon'.
- Upfront carbon: the total GHG emissions associated with materials and construction of a home up to practical completion.
- Embodied carbon: the total GHG emissions and removals associated with the materials and construction processes throughout the whole lifecycle of a home.
- Operational energy: the GHG emissions arising from all energy consumed by a home, in use, over its lifecycle. The operational energy comprises of regulated and unregulated energy consumption. The regulated energy is building energy consumption resulting from the specification of controlled, fixed building services and fittings, including space heating and cooling, hot water, and ventilation while the unregulated energy is the energy consumption that is not controlled by Building Regulations, including, but not limited to, energy consumption from IT equipment, lifts, and appliances (BRE, 2018).
- Whole life carbon: the total of all the GHG emissions and removals in the construction, operation and demolition of buildings and infrastructure.
- Sequestered carbon: carbon dioxide removed from the atmosphere and incorporated in biomass such as timber.
- Circular economy: a non-linear model of economic development based upon elimination of waste and pollution, keeping products and materials in use and regenerating natural systems.

- Net biodiversity gain: weaving nature more effectively in and around developments, not only to improve quality of life but also to reverse wider biodiversity loss.
- Performance gap: a performance gap is a disparity that is found between the regulated energy use predicted and carbon emissions in the design stage of buildings and the energy use of those buildings in operation.

3.2. Policy and regulation

Several strategy and policy documents have been recently released by the government and these set out a general plan for achieving the UK's net zero agenda. These include, but are not limited to:

Energy White Paper: Powering Our Net Zero Future (HM Government, 2020a)

Chapter 4 of the White Paper concerns buildings and sets out the key commitments of the government in facilitating the growth in new green technologies. These include increasing the installation of electric heat pumps, working with industry to evaluate hydrogen as an option for heating, increasing the proportion of biomethane in the national gas grid, consulting on the role of hydrogen as a source of energy, and the commitment to fund a new Heat Network Transformation Programme.

Net Zero Strategy: Build Back Greener (HM Government, 2021a)

The Net Zero Strategy sets out policies and proposals for decarbonising all sectors of the UK economy in order to meet the net zero target by 2050.

Heat and Buildings Strategy (HM Government, 2021b)

The Heat and Buildings Strategy sets out how the UK will decarbonise homes, and commercial, industrial and public sector buildings, as part of setting a path to net zero by 2050.

For new-build homes, the government previously introduced the Zero Carbon Homes Standard and the Code for Sustainable Homes to help assess and certify the sustainable design and construction of new homes. However, the Zero Carbon Homes Standard was scrapped in 2015 and the Code for Sustainable Homes was relaxed in 2015, becoming voluntary. This has created a lack of long-term policy certainty for the development of sustainable new homes.

Building Regulations 2010, first introduced in 1965, is a suite of building standards which set the standards in England for the design, construction and alteration of buildings. On 15 December 2021, the Department for Levelling Up, Housing and Communities (DLUHC) announced further changes to the Building Regulations which will come into effect on 15 June 2022. To pave the way for the Future Homes Standard in 2025, the changes to the Building Regulations provide for a new way of measuring energy efficiency, change the way on-site electricity generation systems are regulated, introduce regulations for overheating mitigation, and make provision for ventilation standards (DLUHC, 2021b).

Alongside amendments to the Building Regulations, DLUHC has published Approved Document L: Conservation of fuel and power, of which Volume 1 covers dwellings; Approved Document F: Ventilation, of which Volume 1 covers dwellings; and an entirely new Approved Document O covering overheating, which applies to new residential buildings.

As well as setting out measures for the 2021 uplift to the Building Regulations, the government response to the Future Homes Standard consultation also sets out plans for the implementation of the Future Homes Standard from 2025. The Future Homes Standard intends to ensure that all future homes are net zero carbon ready and will not need retrofitting. However, the Future Homes Standard is concerned only with emissions from regulated operational energy and does not regulate the embodied carbon associated with the materials and construction processes.

3.3. How to achieve net zero carbon in housing?

The UK's government's approach to net zero carbon homes is three-fold:

- adopting a 'fabric first' approach to achieve a minimum Fabric Energy Efficiency Standard;
- then adopting on-site zero carbon technologies and ceasing the installation of gas boilers in new homes;
- and finally, using off-site measures to deal with any remaining emissions.

3.3.1. Fabric first approach

A 'fabric first' approach to building design involves maximising the performance of the components and materials that make up the building fabric itself, before considering the use of mechanical or electrical building systems. Buildings designed and constructed using a fabric first approach aim to minimise the need for energy consumption through methods such as:

- maximising air-tightness;

- increasing the levels of insulation;
- optimising solar gain through the provision of openings and shading;
- optimising natural ventilation;
- using the thermal mass of the building fabric.

Reducing the energy demand through a fabric first approach results in reducing the need for on-site and off-site renewable energy. Without improving building fabric, the amount of renewable energy that will be needed to supply all the homes will be enormous and the amount of renewable energy generated on-site will be limited (Designing Buildings Wiki, 2021).

Homes built to the Passivhaus Standard are examples of adopting a fabric first approach to energy efficiency. They are designed to use very little energy for heating and cooling, with a design characterised by high levels of fabric efficiency and airtightness as well as measures to address overheating risks.

3.3.2. Zero carbon technologies and innovations

Decarbonising buildings requires the adoption of new technologies and practices to provide heat and energy for new build housing. Using a combination of energy efficient, low carbon technologies to minimise carbon emissions and maximise the energy performance of a building, thereby achieving the best environmental impact rating possible for that building, will help the UK to achieve the net zero carbon homes target.

The Heat and Buildings Strategy (HM Government, 2021b, pp. 59- 75) sets out some of the key technologies, highlighting some of their benefits and opportunities, risks and barriers. Chapter 4 of the Energy White Paper, Powering our Net Zero Future (HM Government, 2020a), also provides an overview of some of the currently available clean heat technologies as well as the government's transition plans.

This section sets out an overview of some of the technologies available to heat homes from 2025, when gas boilers will no longer be installed in new homes; alternative fuels to gas include on site renewable electricity, ventilation and smart home control systems.

Heating homes: heat pumps

Heat pumps are considered as one of the established forms of heating technology that is able to immediately deliver zero emissions from homes (Greenpeace UK, 2021). A heat pump is a system designed to heat an enclosed space by transferring thermal energy from the outside environment (air, ground, or a water source) to the inside space. Heat pumps use electricity rather than fossil fuels for power, thus they do not produce carbon emissions at the point of use. In time, as the national electricity grid decarbonises further, the delivered electricity used to power heat pumps will be net zero carbon.

Common heat pump types are air source heat pumps and ground source heat pumps. An air source heat pump (ASHP) absorbs heat energy from air blown across a heat exchanger by fans (Energy Saving Trust, n.d.). A ground source heat pump (GSHP) gathers heat energy from water circulating in underground pipes, which is pumped to a heat exchanger inside the house (Energy Saving Trust, n.d.).

The Climate Change Committee expects that the vast majority of homes will need to be heated by pumps in the future (CCC, 2020, p.42). However, in the UK, heat pumps have a relatively small share of the market, especially when compared to the rest of Europe and the USA. According to Greenpeace UK (2021), the rate of heat pump units sold in the UK in 2020 was 1.3 heat pumps per 1,000 households, far behind the rate in other European countries, particularly Scandinavian countries and Estonia (Greenpeace UK, 2021).

In general, heat pumps have a higher upfront cost compared to gas boilers and, as heat pumps rely on electricity, the cost of running them might be higher than gas heating. In addition, with the inevitable higher pressure on the national grid, it is possible that the electricity supply could be more intermittent and expensive in future (BEIS, 2020).

Heating homes: heat networks (district heating)

After heat pumps, the Climate Change Committee (CCC, 2020, p.42) considers district heating to be the next low carbon heating option for UK homes. Heat networks use piped hot water to deliver heating (and in some cases cold water for cooling) from a centralised heat source. Low carbon heat sources for heat networks can include waste heat sources, low carbon fuels (e.g., biomass boilers and hydrogen boilers), combined heat and power systems, and low carbon nuclear reactors.

District heat networks, which connect multiple buildings in a local area, can be complex and expensive to build. They typically require an organisation to promote and install them and are not normally initiated by individual building owners (HM Government, 2021b, p.67).

These systems lend themselves particularly well to densely populated towns and cities. Around half a million households in the UK take heat and hot water from shared heat networks (BEIS, 2020, p. 114).

Alternative fuels: hydrogen

Hydrogen is being explored as a low carbon alternative to natural gas as it does not release CO_2 when burned and can be produced through a range of low carbon methods (HM Government, 2021b, p.68). The government's analysis suggests that 20-35% of the UK's energy consumption by 2050 could be hydrogen-based (BEIS, 2021). However, a significant programme of work is needed to ensure that hydrogen is cost-effective, safe, feasible, and compatible with net zero carbon strategies (HM Government, 2021b, p.68).

Low carbon hydrogen boilers are likely to display similar variation to natural gas boilers; they could be standalone or combined with a hot water tank, they could differ in size to supply a range of heat demands, they could be combined with heat pumps to create a hybrid system (HM Government, 2021b, p.68).

Alternative fuels: bioenergy

Bioenergy refers to electricity and gas generated from organic matter, known as biomass. This can be anything from plants and timber to agricultural and food waste. The Heat and Building Strategy (HM Government, 2021b, pp.69-70) identifies three types of bioenergy:

- Biogas and biomethane (produced through gasification or anaerobic digestion);
- Bioliquids (such as BioLPG, an ecopropane);
- Solid biomass (such as wood chippings).

Biomass systems burn wood pellets, chips or logs to heat a room or to power central heating and hot water boilers. Burning the wood does emit carbon dioxide, but at a lower level than coal or oil, provided the fuel is sourced locally (Energy Saving Trust, 2021). Although biomass is considered as a sustainable fuel option by the UK government, there are concerns about the sourcing of large quantities from distant locations (e.g., Canada) and the emissions associated with its transport (ONS, 2019), as well as the adverse air quality impacts of biomass burning (Air Quality Expert Group, 2017).

Onsite renewable electricity: photovoltaic (PV) panels

Solar, or photovoltaic (PV), cells convert sunlight directly into electricity. PV panels generate renewable electricity onsite, reducing demand on the electricity grid. The latitude of the site, the direction that the panels face, and the tilt angle of the panels play a part in the amount of energy that the panels can produce. If a power system is grid-connected, the electricity grid can provide a normal supply to the premise when there is insufficient photovoltaic generation, and electricity not used on site can be exported back to the national grid and sold to the energy supply company.

Ventilation: mechanical ventilation with heat recovery (MVHR)

MVHR systems are used to remove stale air from a building and replace it with fresh air. Traditionally buildings were ventilated largely by natural ventilation, with fresh air entering through windows, doors or gaps in the fabric of the building. However, as buildings become more air-tight, ventilation is increasingly provided mechanically. To reduce the heat lost to the outside as a result of mechanical ventilation, mechanical ventilation with heat recovery (MVHR) systems are used.

With an MVHR, air is continually extracted from rooms that might be warm and humid, such as bathrooms and kitchens, passing through a heat exchanger in the heat recovery unit, where waste heat is recovered from the air before it is returned to the outside. The heat exchanger uses the recovered heat to temper incoming fresh air that is used to supply the non-humid habitable rooms, such as bedrooms and living rooms. Tempering the incoming air reduces the need for heating and so reduces energy use. The heat exchanger can be by-passed in warmer conditions so that the fresh supply air remains cool (Designing Buildings Wiki, 2020).

Having MVHR in the building involves installing ductwork to each room, typically in ceiling voids, and running these ducts to a heat recovery unit, something which needs to be considered in building design. Typically, filters will be included in the system to remove potential pollutants such as pollen and dust from the supply air. Regular maintenance is required to ensure that fans are operating correctly and filters remain clean.

Smart home control systems

Smart gas and electricity meters help to deliver accurate bills and enable pre-paying customers to track and top-up their credit. The consumption and price data recorded by smart electricity meters enables innovative smart tariffs which can vary the cost of electricity – rewarding consumers with a cheaper rate if they use electricity at off-peak times or when there is excess clean electricity available (HM Government, 2021b, p.72-73).

Home energy management systems can be controlled remotely or automatically to optimise energy use and to minimise costs to consumers (HM Government, 2021b, p.73). Smart appliances, including heating appliances, are able to respond to price signals such as those from smart tariffs, or from national or local flexibility markets (HM Government, 2021b, p.73).

3.4. Gaps in approaches to achieving net zero carbon in housing

To reach net zero carbon in new homes, using the fabric first approach to maximise the performance of the components and materials that make up the building fabric itself appears to be key to reducing the initial need for energy consumption. The incorporation of renewable technologies can further help to provide clean heat and energy for the new homes. However, there are some gaps and areas of confusion in the current approaches. This section identifies some of the gaps in the take up of the technologies and also discusses some of the implications of not having a holistic approach in designing net zero carbon new homes.

3.4.1. Gaps in technologies

Some of the new technologies lack a robust evidence base, and it is therefore challenging to make investment decisions about their use. From 2025 gas boilers will not permitted to be installed in new build homes and new technologies are required to be adopted in the next few years. Some of the available technologies for net zero carbon homes have been used in residential buildings for a while now and are perceived as being successful and effective but their take up is still low in the UK. For example, heat pumps, despite the availability of the technology and its high uptake in other countries, are not widely installed in UK homes. In 2020, around 32,000 heat pumps were installed in the UK, while France saw the installation of 394,000 heat pumps and Italy the installation of 233,000 (European Heat Pump Association, 2020).

BEIS (2021b) cites six barriers to the widespread adoption of heat pumps in the UK, including cost (the higher cost of buying a heat pump compared to a boiler and a higher fuel bill), disruption (linked to installation), noise (as generated by air-source heat pumps), thermal comfort (heat pumps are slower to reach room temperature than traditional gas boilers), space constraints, and aesthetics (BEIS, 2021, cited in MCS, 2021). CCC (2019, p.11) perceived that the low uptake in the UK is symptomatic of low awareness of the technology, financial constraints, concerns around disruption, and difficulty in finding trusted installers with the right skills.

There are concerns about the uptake of other technologies in the UK. For example, PV panels have been steadily adopted in the UK. In 2018, the UK was the third highest adopter of solar capacity in Europe, after Germany and Italy, increasing its solar capacity through PV systems (Green Match, 2021a). However, there are concerns around the environmental impact of the panels, their capacity to generate energy, their life expectancy, and the environmental impact of their disposal (Maani et al., 2020; Centre for Alternative Technology, n.d.; Green Match, 2021a and 2021b).

There are some harmful chemicals involved in the production of PV panels, including cadmium and lead-based solder (Maani et al., 2020). Cadmium is an extremely toxic metal, and the use of lead-based solder leads to pollution if landfilled or incinerated (ibid). Given that the life expectancy of PV panels is 25 years (ibid), making good collection and recycling plans for the redundant PVs is important.

In addition, it is understood that PVs have a limited capacity to produce electricity. If the goal is to reduce home energy bills, installing solar panels can be an option. In general, an average UK home consumes between 3kWh and 6kWh of energy daily. To provide this level of energy through PV panels, 12 (to produce 3kWh) to 24 (to produce 6kW) solar panels are required for each home, which will need an estimated surface area of 19.2m^2 to 38.4 m^2 (Green Match, 2021b). This means that to be able to rely on the energy generated from PV panels, a large surface area will be required for each home.

Solar battery storage is required to store the generated energy; this is still expensive and has environmental impacts in its manufacture and disposal (Centre for Alternative Technology, n.d.). Households who install solar panels with battery storage use about 80% of the energy they generate, while households without battery storage use only 40% of energy they generate (Green Match, 2021b).

In addition, PV panels need a site that is largely free of shade, particularly between spring and autumn. They perform well if facing anywhere between south-east and south-west, at an angle of 20 to 50 degrees. A PV array that faces due east or west will give about 20% less energy than one facing due south (Centre for Alternative Technology, n.d.).

3.4.2. Gaps in approaches

In addition to gaps in the technologies, there are gaps in the current approaches to achieving net zero. As discussed before, UK policies and regulations have a stronger focus on achieving zero carbon targets for buildings and are less concerned with the design of the wider site or the environment. Neither the siting and orientation of buildings, their built form and layout, nor the role of the external environment in enhancing the energy and environmental performance of a building have received sufficient attention in the current discussions about net zero carbon homes.

In terms of building orientation, a building needs to be within 30° of south to maximise its access to solar radiation and daylight. Thus, roads should ideally run east-west to facilitate south-facing front or rear housing layouts (Green Spec, n.d.). However, if a home is oriented with its main windows facing west, it will experience more unwanted solar gains from low-level sun in the evenings and is more prone to overheating (NHBC Foundation, 2012). Some building typologies such as terrace housing and blocks provide more efficient envelopes than semi-detached and detached houses.

The landscaping of trees plays an important role in optimising solar gain and reducing the impact of cold winds: south-facing windows should not be overshadowed by trees, and trees should be planted in such a way as to provide shelter from cold winter winds and mitigate excessive summer heat (Green Spec, n.d.). However, attention should be paid to the risk of overheating whilst thinking about the building's fabric, insulation, and orientation to optimising solar gains. NHBC Foundation (2012) highlights some strategies for managing this and references ventilation strategies, window design and shading devices as useful features for avoiding overheating in new build homes.

Paying attention to the site design at the masterplan level can make a substantial contribution to delivering low carbon residential developments. UKGBC's (2022) report presents the findings of reducing embodied carbon of a residential development - Trumpington South in Cambridgeshire - by undertaking a range of masterplan-level design interventions. Their findings show that design interventions at masterplan level can reduce the embodied carbon by 20.3% by reducing grey infrastructure on site (e.g., roads and hard surfaces), and the number of homes can be increased by 5.3% if parking provision per home is reduced, as this frees up land.

3.5. Net zero new build pilots

There is no robust data source about the number of net zero homes or developments. According to the Guardian (2021) currently there are about 30,000 net zero carbon housing development projects in the pipeline. This section summarises some of these housing projects to highlight examples of net zero carbon ready new homes. The examples are chosen to showcase the diversity of approaches used but do not represent all the approaches and techniques currently being used. As these projects are new, there is little evaluation available about their performance and the examples below are descriptive and based on the information available about them on the internet. Further in-depth evaluation of these or similar projects would provide a much needed evidence base to inform the scaling up of net zero carbon home construction.

3.5.1. Solar Avenue, Leeds

Solar Avenue in Leeds consists of 60 low-energy homes. The developer behind this project is Citu, based in Leeds. The homes in Solar Avenue are made from super-airtight timber panels built in a local factory (Citu Works). The intention of using Citu Works was to maintain more control of quality and the supply chain while minimising transport, wastage and ultimately cost (Wilson, 2019).

The airtight timber panels are filled with wood-fibre insulation. The windows are triple-glazed, and solar panels are installed on the roof. The heating demand of the houses is so low that they create excess electricity that is fed into a community grid and used to charge shared electric cars. Each home was erected in less than a week (The Guardian, 2021).

The development is car-free and is located close to the city centre. It has a green landscape with planted trees and herb gardens. All the houses own their own rain gardens to store rainwater running off the roof terrace.

The Solar Avenue project is part of a larger development called the Climate Innovation District with 1000 homes, combined with facilities such a primary school, a care home, an office building, as well as other facilities. The architect behind this project is White Arkitekter with experience of delivering sustainable urban developments in Scandinavia and knowledge of off-site timber-framed construction.[1]

3.5.2. Fen Road and Ditton Fields, Cambridge

Fen Road and Ditton Fields homes are a pilot of Passivhaus social housing in Cambridge. They are 18 homes designed by Pollard Thomas Edwards architect practice for the Cambridge Investment Partnership and will be 100% affordable rent. For these homes, in addition to adopting a fabric first approach, air source heat pumps, PV solar panels with additional thermal storage and wastewater heat recovery technologies are used. Prefabricated timber panels are used for construction. The project retains existing mature trees and will provide a biodiversity uplift of 20%.

These homes are planned to be completed in 2022 and the lessons learned will help the council to build up confidence in delivering Passivhaus, which has now become a city-wide commitment for all new council housing in Cambridge.[2]

There are other net zero carbon projects underway in Cambridge, including: the Knights Park neighbourhood, providing 249 homes by housebuilder Hill and architects at Pollard Thomas Edwards and Alison Brooks Architects[3]; Marleigh Active Homes, providing 1300 homes of which 5 prototype houses are active homes by housebuilders Hill and Marshall and architects

[1] For more information about Solar Avenue project see:
https://citu.co.uk/citu-places/solar-avenue
https://www.architectsjournal.co.uk/buildings/leeds-green-blueprint-climate-innovation-district-by-white-arkitekter

[2] For more information about Fen Road and Ditton Fields project see: https://kb.goodhomes.org.uk/case-study/fen-road-and-ditton-fields/

[3] For more information about Knights Park project see: https://kb.goodhomes.org.uk/case-study/knights-park/

at Pollard Thomas Edwards[4]; and Juniper Place in East Cambridge, providing 30 net zero modular homes developed by Etopia[5].

3.5.3. Gascoigne Estate, London

The third phase of the Gascoigne Estate project is part of a larger project to regenerate the 1960s Gascoigne Estate in Barking. Providing 226 new homes, this development will be the first net zero carbon development to be delivered by Be First, Barking and Dagenham's development company. 55 percent of these homes are affordable homes.

Pitman Tozer Architects is the architect of the project and Turkington Martin designed the public realm. These homes have a high performing building fabric, minimising both heat loss and heat gain; green roofs and rain gardens as part of the Sustainable Urban Drainage Strategy; connection to an existing local heat network; and PV panels on roofs.[6]

3.5.4. Various sites, Exeter

Exeter City Council has been building zero carbon homes for the last decade, with more than 200 council houses built so far to the Passivhaus Standard, and 1,000 more in the pipeline (The Guardian, 2021). The initial intention of the council was to address fuel poverty and they built their first three Passivhaus homes in 2009 (ibid). The council is now on the seventh generation of its low-energy house design (ibid).

Silverberry Close, Barberry Close and Reed Walk are three sites with 20 social housing homes designed by Gale & Snowden architects for the city council. These houses were completed in 2015. These homes are built with dense concrete blockwork walls, wrapped with high levels of external wall insulation and colourful render. The combination of high internal thermal mass, insulation, thermal-bridge-free design, and exceptional airtightness results in very low energy bills for occupiers. Mechanical ventilation with heat recovery (MVHR) is also used in these homes to maintain the air quality.[7]

3.5.5. Additional examples

In addition to the above examples, there are others to note:

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[4] For more information about Marleigh project: https://www.hill.co.uk/partnerships/joint-venture-partnerships/new-town-marshall
[5] For more information about Juniper Place project see: https://www.pbctoday.co.uk/news/mmc-news/zero-carbon-housing/91644/
[6] For more information about Gascoigne project see: https://befirst.london/east-london-estate-sets-new-green-standards/ and https://nla.london/projects/gascoigne-east-plot-j
[7] For more information about Exeter examples see:
https://www.ecodesign.co.uk/project/tempor-incididunt-5/
https://news.exeter.gov.uk/why-exeter-is-a-leading-uk-city-for-building-design/

- Norwich City Council's 100 Passivhaus homes designed by Mikhail Riches Architects, awarded the RIBA Stirling prize[8];
- York City Council's seven sites to provide 600 zero carbon homes, designed by Mikhail Riches Architects[9];
- Milton Keynes Council's 115 zero carbon dwellings to be constructed between 2022-2024, designed by Mikhail Riches Architects and Mole and landscape architects URBED[10];
- Somerset West and Taunton Council's 54 new zero carbon in operation homes, designed by Mitchells/APG Architecture[11].

As mentioned before, this section presented some of the net zero carbon new home examples. More examples are available[12] and the number of case studies is growing fast. However, evidence-based research to evaluate the achievements and outcomes of these projects is not yet available.

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[8] For more information about Norwich City Council's zero carbon homes see:
http://www.mikhailriches.com/project/goldsmith-street/#slide-1
https://www.theguardian.com/artanddesign/2019/jul/16/norwich-goldsmith-street-social-housing-green-design
[9] For more information about York City Council's zero carbon homes see:
http://www.mikhailriches.com/project/city-of-york/#text
[10] For more information about Milton Keynes project see: https://kb.goodhomes.org.uk/case-study/love-wolverton/
[11] For more information about Somerset West & Taunton Council project see: https://kb.goodhomes.org.uk/case-study/seaward-way/
[12] For more examples see Good Homes Alliance website: https://kb.goodhomes.org.uk/case-studies/

4. Barriers to the building of net zero carbon homes

This section discusses the identified potential barriers to the implementation of net zero carbon ready new homes. A survey undertaken by LETI (2021, p.17) indicates that the biggest barriers to achieving net zero carbon projects are:

- a lack of knowledge and awareness
- high construction costs
- insufficient built precedents/benchmarks
- insufficient technology
- high design costs
- a lack of industry commitment and focus
- net zero carbon criteria are not included in project briefs, and net zero carbon performance is not set as a target for projects.

In this report we identify a number of barriers to implementing net zero housing at the pre-construction stage, construction stage and post-construction stage.

4.1. Barriers at the pre-construction stage

At the pre-construction, or planning, stage, there are a number of barriers to the realisation of a net zero new housing project, including gaps in policy and regulation, additional costs and lack of funding, and viability and affordability.

4.1.1. Gaps in policy and regulation

In order to achieve net zero ready new homes by 2025, having policies and standards that are adequate, clear and enforceable is key. The Climate Change Committee, in their 'UK housing: Fit for Future?' report (CCC, 2019), is of the opinion that the technology and knowledge to create high quality low carbon homes exists, but that current policies and standards are not sufficient or ambitious enough to encourage and enforce the implementation of net zero carbon homes.

CCC believes that weakening or withdrawing key policies like the Zero Carbon Homes Standard and the Code for Sustainable Homes has led to many new homes only being built to minimum standards for water and energy efficiency, and to a low uptake of heat pumps and other low carbon heating systems (CCC, 2019, p.11). Furthermore, the CCC (2019, p.11) believes that building regulations are not sufficiently ambitious, are overly complex, and that compliance is poor.

The role of the planning system in facilitating the delivery of net zero carbon developments is not yet fully clear, but it is possible that the issue will be addressed as part of wider planning reforms (First Plan, 2021). According to the Town and Country Planning Act 1990, in some circumstances, homes can be built subject only to the standards in place at the date at which planning permission was granted, even though this may be a number of years ago. This means that new homes are being built which do not meet the *current* minimum standards (CCC, 2019, p.12).

The National Planning Policy Framework (2021) provides some positive clarifications on how to address overheating and flooding. However, subsequent revisions have removed the requirement for local authorities to give active support in favour of energy efficiency improvements to existing buildings, and have failed to clarify how far local and regional authorities are permitted to go in setting their own tighter standards for new build homes (CCC, 2019, p.12).

The National Audit Office's report, 'Local government and net zero in England', suggests that there is considerably more work to do to further align the planning system with net zero carbon in the forthcoming planning reforms (NAO, 2020). There is a need for practical advice and support for local authorities on how to reduce carbon emissions through planning, both strategically, to consider spatial patterns of development and associated infrastructure requirements, and at the site level, to provide sustainable flood management, green infrastructure and nature recovery (LUC, 2021).

4.1.2. Additional costs and lack of funding

In their Building the Case for Net Zero Carbon report, the UKGBC (2020) presents the findings of a feasibility study that shines a light on the implications for achieving new net zero carbon buildings. They calculated the capital cost for two net zero design scenarios based on future net zero performance targets[13]. In an 'intermediate scenario', which uses net zero targets for 2025 to represent residential buildings that are in, or will soon be in, design, the cost uplift is calculated as 3.5% when compared to a baseline scenario which represents business as usual. The cost uplift for a 'stretch scenario', which uses net zero targets for 2030, is calculated to be 5.3% for residential buildings as the net zero targets for 2030 are

[13] Based on targets for embodied carbon and operational energy published (UKGBC, 2020), Climate Emergency Design Guide (LETI, 2020) and 2030 Climate Challenge (RIBA, 2019).

substantially more demanding and the marketplace is not yet geared up to delivering them at scale (UKGBC, 2020).

Given the lack of financial assistance for new build homes from the government to cover some or all of these additional costs, the land buying and development processes may be affected which can, in turn, affect the viability of a development. Financial incentives for new build homes - such as grants, the removal of VAT on net zero technologies, interest-free or low-cost loans for installation - are some of the reasons why other European countries have a higher uptake of some zero carbon technologies, e.g., heat pumps (Greenpeace UK, 2021).

4.1.3. Viability and affordability

Industry research shows that 145,000 affordable homes - including 90,000 for social rent - should be built each year for at least the next 10 years to address the acute need for affordable homes (NHF, 2021). One of the potential barriers of constructing net zero carbon homes is the effect that this transition to net zero carbon might have on the affordability of affordable housing schemes.

In addition to the cost uplift in achieving the net zero targets set out by UKGBC (2020), LETI (2020), and RIBA (2019), which can in turn affect the feasibility of the project, there are other considerations to bear in mind when thinking about a project's viability. There are no conclusive studies available to determine the full implications that building a net zero carbon project has on cost or affordability. However, it has been argued that adopting a fabric first approach and including different or new technologies can affect the design and footprint of a building which will determine the number of units on a site, affecting its capacity (Baily Garner, 2021). Baily Garner's (2021) report discusses the need for more space for MVHR units and associated ducting, the installation of heat pump condensing units, and the thicker external walls required to achieve the new net zero building standards. It concludes that all these technologies impact the number of units which can be planned on a given site area (Baily Garner, 2021).

Figure 1 shows the potential effect of improving the U-values[14] of external walls on site capacity. Improving the U-values of the external walls means that both the overall wall thickness and building footprint will become larger and the internal ground floor area is reduced when compared to sites designed to 2013 U-values. This may decrease the buildability (the total area that can be built up and used) of the site and is likely to reduce the number of units built, particularly where the homes to be built are semi-detached or in terraces.

[14] A U-value is a sum of the thermal resistances of the layers that make up an entire building element

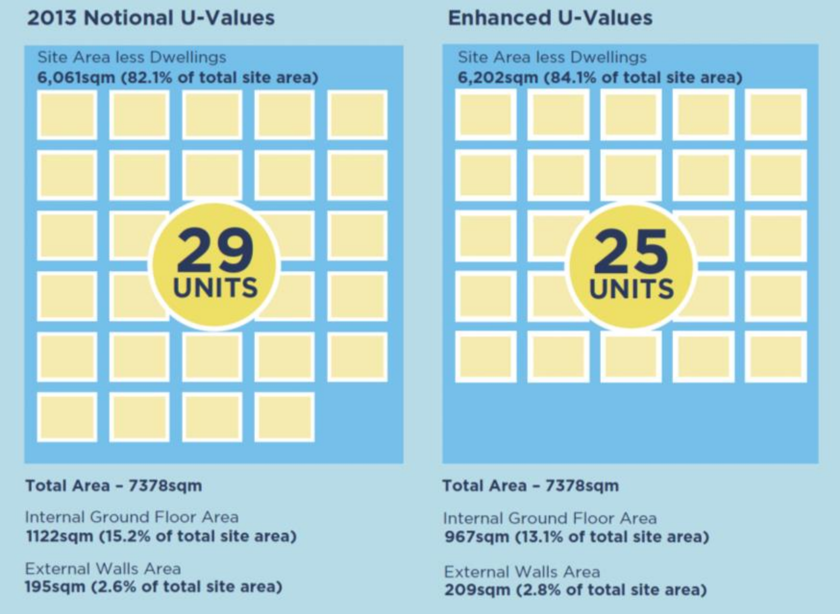

Figure 1- Potential effect of enhanced U-values on site capacity (Baily Garner, 2021, p.9)

The potential decrease in the area that can be built-up and used in the site and reduction on the number of units may affect the affordability of units in two ways: fewer units will be delivered on a site, and the delivered units may be more expensive.

4.2. Barriers at the construction stage

4.2.1. Skills gap

The delivery of net zero carbon new homes requires a highly skilled workforce, with project managers, engineers, technicians and builders all with experience of, and a willingness to use, net zero carbon building construction skills. At present, there is a significant lack of net zero carbon skills, and this is likely to reduce construction quality and increase performance gaps between how homes are designed and how they perform (LETI, 2021, p.23).

According to a survey for the Construction Industry Training Board (Eunomia & CITB, 2021), the construction sector recognises that there is a decarbonisation skills gap: 78% of surveyed participants believed that there is a skills gap in their occupation/profession for decarbonisation work (Eunomia & CITB, 2021, p.126). The most significant reasons for this gap in the construction industry were listed as a lack of training, a lack of funding for training, regulation changes and a lack of standards (ibid). Although the survey demonstrates that there is an appetite for retraining and upskilling in the industry (approximately 90% of the participants surveyed by Eunomia & CITB (2021) stated they would be willing to re-train), the industry suffers from an insufficient skilled net zero carbon workforce.

4.2.2. Supply chain issues

The net zero technologies and methods in use today are being used in discrete pockets and these technologies and methods are not yet being used in combination or at scale (Future Homes Task Force, 2021, p.21). Shortages in materials to build net zero carbon homes leads to delay in construction on site, and delays in the construction stage and slippage in the critical path programme can lead to increased cost and affect project viability (LETI, 2021, p.23).

Procuring a provider who can produce net zero carbon products at scale is one of the most significant barriers faced by housebuilders and has a direct impact on their ability to build net zero carbon homes.

4.3. Barriers at the post-construction (operational) stage

4.3.1. Consumer behaviour

The Committee for Climate Change (2020) estimates that 62% of the actions required to achieve net zero carbon targets will involve some element of societal or behavioural change. According to Ofgem (2020), there are a host of actual and perceived barriers that may impede the pace of behavioural change. As new low carbon technologies are in their infancy, many consumers are unaware of their options or, even when they know the options available to them, prefer to stick to what they are familiar with (Ofgem, 2020). One of the reasons that the take-up of heat pumps and other low carbon technologies has been slow is that householders prefer familiar gas heating (Carmichael, 2019).

In addition to this, consumers have different and evolving needs and capabilities. New technologies require occupiers to consider how they operate their home heating systems and perhaps adapt their behaviours to maximise the potential of a new approach. However, not all consumers will be equally capable of contributing towards reducing the carbon intensity of their energy usage (Ofgem, 2020) or of behaving in the way that the designers and providers of buildings and technologies had in mind at the point of design and construction. It is argued that providing information to consumers can support decision-making and behavioural change, but information alone is rarely sufficient to change behaviour as human decision-making processes are very complex (Ofgem, 2020).

4.3.2. Energy systems and infrastructure

The core element of the net zero carbon strategy for homes is switching their energy supply from gas to electricity. In time, when the electricity grid is decarbonised and fuelled by renewable sources, the UK's energy supply will be net zero carbon (Future Homes Task Force, 2021). However, there will be a number of issues to navigate on the way.

Widespread electric heating, electric vehicles and on-site renewables will all put additional pressure on the electricity grid, which may result in more intermittent and inconsistent generation and supply (Future Homes Task Force, 2021). In addition to this, the current cost of electricity is five times higher than that of gas[15] and the price difference presents a significant barrier to the UK's decarbonisation via electrification (Eunomia & CITB, 2021, p.5).

It is believed that diversification of supply through site renewable generation, bioenergy and hydrogen can alleviate some of the pressure on the grid. The role of hydrogen and other energy sources in providing electricity is still uncertain (Future Homes Task Force, 2021).

4.3.3. Maintenance

Using new technologies, materials and designs may mean that housing associations and other housing providers with long term stewardship responsibilities need to change the way they repair and maintain their housing stock. They will need an appropriately trained workforce for the repair and maintenance of their net zero carbon stock and a new schedule for maintenance work. For heat pumps and other similar technologies (Renewable Energy Hub UK, 2021), the maintenance procedure might be similar and require a yearly service, but for others like MVHR (Paul Ventilation Services, n.d.), more frequent and different service plans may be required.

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[15] According to Eunomia & CITB (2021) each kWh of energy supplied in the UK will cost 14-15p if delivered through electricity and less than 3p by gas

5. Benefits of building net zero carbon homes

It is argued that there are multiple benefits in building net zero carbon ready new homes, which include reduced emissions and increased resilience to climate change, the possibility of reduced utility bills, and improvements to comfort, health and the natural environment (CCC, 2019, p.16). According to the CCC (2019, p.16), when properly planned and used, net zero homes can lower carbon emissions, be more comfortable to live in and be better for occupants' health; they may also be more affordable to run.

This section provides an overview of the benefits of implementing net zero carbon homes for the environment, the users and occupants of the buildings, and social landlords, including housing associations.

5.1. Environmental benefits

Net zero carbon new homes, if planned and used properly, will produce significantly lower levels of CO_2. In the UK, heating and hot water for homes make up 25% of total energy use and 15% of greenhouse gas emissions (CCC, 2019). A further 4% of greenhouse gas emissions are the result of electricity used in the home for appliances and lighting (ibid). As announced by the government in the UK's Sixth Carbon Budget, the target is to reduce emissions by 78% by 2035 compared to 1990 levels (CCC, 2020). The housing industry has a significant role to play in achieving this target and in reducing the adverse impacts of climate change, by reducing the risk of flooding, heat-related health impacts and cold-related deaths (CCC, 2019).

5.2. User benefits

As discussed in the previous chapter, there are ambiguities around how consumer behaviour can impact upon the effectiveness of the benefits of net zero carbon homes. The most readily promised benefits of net zero ready new homes for their future occupants are the reduction of operational running costs and improvements to health and wellbeing, but they can only be achieved with the right policy interventions and approach. Although fuel poverty among social housing residents almost halved from 2010 to 2019, 18.4% of housing association residents still live in fuel poverty (NHF, 2021, p.9). Decarbonisation has the potential to be an opportunity to eliminate fuel poverty by delivering lower bills alongside more comfortable homes (NHF, 2021, pp. 8,9).

It is argued that net zero ready homes will have a higher building performance if a fabric first approach is properly adopted and used. Closing the performance gap between how homes are designed and how they perform when built can generate savings for annual bills. Depending on the type of house, closing the performance gap could deliver annual energy bill savings of £70-£260 for households (CCC, 2019, p.12). If new technology is used effectively, it will be possible to deliver homes with a high level of thermal efficiency which stay warm in winter and cool in summer, and are moisture-safe, with healthy indoor air quality (CCC, 2019, p.47).

However, it is not necessarily appropriate to expect to see some of these benefits across all households. For example, a study (Savage et al., 2022) on the impact of heat pumps on social inequality shows that in the UK, whilst heat pumps would reduce carbon emissions, it is predicted that they would increase fuel costs. The study argues that by transitioning to using heat pumps instead of gas boilers, both local and regional areas of high fuel poverty would experience the largest increase in fuel costs, increasing existing regional inequalities (Savage et al., 2022).

5.3. Benefits for registered providers of social housing

The construction of net zero ready homes can bring long term benefits, despite the need for extensive changes in the way that housing associations build and manage their housing stock. Legislative compliance, reputation and legacy, as well as long term financial benefits can all be gained by future proofing new housing stock and negating the need to retrofit new build homes in the near future.

Constructing net zero ready new homes may add to the capital cost of a building. However, it is argued that, if life cycle costing[16] is used instead of one-dimensional capital cost metrics, the long-term financial savings of building net zero carbon homes can be considerable (LETI, 2021, p.22). The additional upfront cost of building net zero carbon ready homes is likely to be offset by other benefits, including lower offset costs, and lower operating and life cycle costs (LETI, 2021, p.20). Additionally, getting the design right from the outset is vastly cheaper than retrofitting later (CCC, 2019).

In the UK government's Net Zero Strategy, no-regret actions are introduced which are cost-effective now and will continue to prove beneficial in the future (HM Government, 2021a). For new home construction, fabric-first approaches are recognised as no-regret options for improving building thermal efficiency through insulation and draught-proofing, as well as

[16] This method reviews costs during the development, construction, and operational phases of a project.

increasing the energy performance and capability of products and appliances (HM Government, 2021a).

In addition, it is likely that the early adoption of net zero approaches for building new homes can bring reputational benefits for those housebuilders who wish to be industry leaders. People are concerned about the future of the environment. In October 2021, ahead of the COP26 UN Climate conference in Glasgow, three-quarters (75%) of adults in Great Britain said they were worried about the impact of climate change (ONS, 2021). It is inevitable that housebuilders are going to have to adapt housing designs, energy systems and construction approaches in light of the realities of climate change, it is a strategic organisational decision as to how fast they do so.

6. Trade-offs

In building net zero carbon ready homes, there are trade-offs to be recognised and considered. The main trade-off is that between the additional cost associated with building net zero carbon homes and the viability and/or profitability of development and possibly the affordability of those homes. There is a cost premium for early adoption of new zero carbon technologies and designs, and how the additional cost will affect the affordability and viability of the units constructed should be considered in the early stages of planning. It is important to establish who will pay for the additional cost and whether there are any financial mechanisms available to cover that additional cost, other than charging a higher rent or a premium to live in a net zero carbon home.

The number of housing units delivered may be another trade-off when building net zero carbon homes. As discussed in chapter 4, site capacity might be affected if the new build homes are built with an enhanced u-value, and additional on-site space could be required to accommodate the adoption of low zero carbon technologies (e.g., space for MVHR ducts). Creating scenarios will enable stakeholders to consider to what extent the number of units on a given site will be affected and how the number of units can be recovered through changes to the layout, density and type of the buildings on site.

The social housing sector faces other pressing priorities and there are also trade-offs to be made between building net zero carbon homes or addressing, for example, fire safety, the needs of the ageing population, housing need or homelessness.

In addition to the trade-offs mentioned above, housebuilders face a range of dilemmas primarily relating to the adoption, use and maintenance of new low carbon technologies. There is no clear guidance on which technology to use to provide, for example, green heating for homes. It is not clear which technology is cheaper, greener and more costumer friendly: air source heat pumps, ground source heat pumps or hydrogen boilers? It is challenging to know which of these products to adopt and how their use can be brought into the mainstream and used consistently across the design and delivery of new build homes.

All of these trade-offs and dilemmas will lead to discussions that influence a series of critical decisions that housebuilders will need to make which will form, or be informed by, the overall organisational strategy. Some of the questions that organisations will need to consider in building net zero carbon ready new homes will be as follows:

- Does the organisation wish to deliver net zero carbon ready homes ahead of the legislative timetable to avoid future new build retrofit and other costs?
- How can the organisation cover the additional construction costs so the projects will be viable but the additional costs are not passed on to the occupants?
- Can the organisation accommodate the current cost premium of early adoption?
- Is the organisation ready and able to maintain these types of properties and energy systems?
- Which technologies are the organisation and its residents likely to accept, and how much risk in terms of adoption or non-adoption is the organisation willing to accept?
- Will the homes produced be affordable to heat and cool for residents?
- Will the homes produced be used in the way intended by residents to prevent performance gaps? Will they be acceptable to and desirable for residents? What role do housebuilders and housing associations have in shaping consumer and resident behaviour?
- What role can housebuilders and housing associations play in creating a stronger evidence base about new designs and technologies, for example, how can post occupancy evaluation be successfully implemented and the data usefully shared?

The strategic choices that housebuilders (especially in the social housing sector) make will have an impact on all stages of construction and management of housing units, and will require revisions to design briefs, procurement strategies, development pipeline activities, asset management and maintenance.

7. Recommendations

This report presented some of the key discussions around the delivery of net zero carbon new homes. First, it set out some of the net zero carbon definitions, discussed how net zero carbon is expected to be achieved, overviewed some of the low carbon technologies, and explored gaps in the current approaches. Then the report identified the potential barriers to the construction of net zero carbon new homes at the pre-construction, construction, and post-construction stages. The benefits of delivering net zero carbon homes for the environment, residents, and social landlords were also discussed.

This report also discussed that in building net zero carbon new homes, there are trade-offs to be recognised and considered by housebuilders. These trade-offs include viability and affordability of net zero carbon projects, decisions on what low carbon technologies and approaches to use and how to adapt to new regulations to future proof what is in the development pipeline now or in the near future.

This section sets out a number of recommendations to overcome the barriers to delivering net zero carbon new homes. There is a vast array of recommendations provided by various stakeholders on how to facilitate decarbonisation of buildings in the UK (e.g., NHF, 2021; Cambridgeshire & Peterborough ICC, 2021; CCC, 2019; CITB & Eunomia, 2021; Future Homes Task Force, 2020; Greenpeace, 2021); the following points derive from this project and, wherever possible, integrate suggestions from existing reports in order to substantiate our recommendations.

7.1. Recommendation 1: greater clarity from national government

Our first recommendation is about the necessity of providing greater clarity over the regulations and standards that housebuilders should comply with and the expected timeframes, clarity on the role of planning, and clarity on the commonly used definitions by the government.

7.1.1. Clarity on regulations and policies

The government has set targets and deadlines for the housing industry to decarbonise and adapt to new regulations. However, in some cases the details of the proposed regulation are not fully clear which makes it difficult for housebuilders to adjust to new rules. Changes to the Standard Assessment Procedure (SAP) is an example of a change which needs further clarity from the government, as recommended by Etude (2021). We recommend that the government provides clear roadmaps and supplementary documents to clarify what the expectations are and how they expect the housing industry to respond to those expectations. These clarifications, we recommend, need to be published in a timely manner so that the industry will have sufficient time to adapt.

7.1.2. Clarity on the role of planning

The planning system should reflect the government's climate targets and ambitions but there are some conflicts between the government's approach in its Environmental Bill and in its Planning Bill. At present, the NPPF (2021) has no specific mention of net zero carbon requirements. However, some local authorities or combined authorities have set their own targets and strategies. For example, the Greater London Authority (GLA) in the London Plan (2021) imposes more rigorous low carbon policies, with major developments expected to achieve net zero carbon, as displayed through a detailed energy strategy.

For housing associations and other housebuilders who operate in various local authorities, a greater consistency and clarity is needed to reduce the risk of the planning application process being delayed which can affect the speed of the housing delivery.

We recommend that the government clarifies the role of planning in the transition towards the net zero carbon future and ensures some level of consistency across the country. The government's planning reforms should lead to an overarching national system which facilitates the delivery of sustainable, well connected, and attractive housing developments. The high-level national policies then will need to be considered in local plans to connect the national sustainability policies to local circumstances.

7.1.3. Clarity on definitions

In addition, we recommend that the government releases an agreed set of definitions for the industry to set out the meaning of the frequently used terms. For example, it is expected that all new homes should be net zero carbon ready by 2025. However, there is a lack of consensus over what net zero carbon ready means in practice and what it entails.

7.2. Recommendation 2: well-designed net zero carbon new developments and homes

Incorporating sustainability objectives into the design of not only the buildings but the site and its surroundings is recommended in order to achieve net zero carbon targets and improve the quality of life for residents.

7.2.1. Site design

The UK's policies and regulations have a strong focus on buildings in achieving zero carbon targets with less attention being paid to the design of the wider site and environment. Gains will be lost if homes are designed to net zero standards but developments are not well connected to sustainable transport networks and do not promote sustainable lifestyles.

We recommend the adoption of a comprehensive approach to the design of new developments by incorporating site design and the wider natural and built environment into the planning and design stages.

To achieve this, we recommend that new developments are sited in locations where infrastructure is sufficient and low carbon transport is available. This should incorporate both walking and cycling infrastructure to promote active modes of transport, and access to wider public transport infrastructure.

We recommended that all new residential developments have access to green space and nature, and that developers identify biodiversity assets and enhance these where possible.

7.2.2. Building layout, density and type

We recommend that the layout, density and type of homes are designed to maximise energy and environmental performance. The orientation and layout of the buildings should maximise access to solar radiation and daylight in winter and mitigate excessive summer heat. Measures should be in place (e.g., tree planting) to provide proper shelter for the buildings from cold winter winds. Consideration should be given to the performance of different building typologies when designing the project as some typologies like terraces provide more efficient envelopes than, for example, detached houses.

We recommend the development of scenario modelling for different housing types and layouts using the standard assessment procedure (SAP). Adding different technologies and levels of air tightness will help to understand the implications of each scenario (see for example: Baily Garner's 'A Practical Toolkit Towards Net Zero'). This will help an organisation to make an informed decision about what scenario to follow.

7.2.3. Design of the homes

The transition to a net zero carbon future needs to be as seamless as possible for the occupants. We recommend that the homes are designed to be desirable, affordable to run, and not challenging and daunting to 'use' for tenants.

7.2.4. Building standards

We recommend that all new buildings be net zero ready as soon as possible, and before the implementation of the Future Homes Standard to avoid the need for expensive retrofitting at a future date.

We recommend that no regret actions are prioritised in the construction of new homes now. These actions include the adoption of a fabric first approach to increase the energy efficiency of the building's envelope, including the proper insulation of walls and ceilings, and triple glazed windows, all of which are well known and available.

7.3. Recommendation 3: collaboration and evidence base

The pioneers in building net zero carbon ready new homes in the housing industry are inevitably exposed to risk. To mitigate those risks, we recommend the formation of strong collaborations and partnerships within the sector, between the housing sector and other related sectors (e.g., suppliers, skills bodies, and planners), and between the housing sector and the government.

We recommend collaboration across the housing industry in order to share data, experience of successes and failures, evidence from pilot projects and case studies through various industry publications, workshops and working groups. Collaboration will allow pioneers to share some of the risks they face. The Future Homes Consortium[17] and the Future Homes Hub[18] are two examples of existing collaborations within the industry and between the industry and other related sectors, central government and other agencies.

The Future Homes Consortium, established in 2021 by David Cowans, Places for People's former chief executive, is an example of collaboration between housing associations who are members of the consortium. The consortium focuses on sharing practical ideas and initiatives on sustainability and building safety in new build and in retrofitting existing stock. It looks at best practice to create synergies in resources that each organisation is already deploying on studying challenges in sustainability and building safety in their existing stock.

We recommend further collaboration within the housing sector to reduce the risks associated with adopting new technology. Ordering products at scale should lead to lower unit costs, with the added benefit of inducing the market to meet increased demand. Pooling

[17] https://placesforpeople.co.uk/news/all-news/2021/05/the-group-joins-industry-leaders-to-create-the-future-homes-consortium
[18] https://www.futurehomes.org.uk/

technical capacity can also support smaller businesses to develop innovations and find solutions to industry-wide problems.

There is a need for more research to develop a robust evidence base to support the development of more net zero carbon homes. The housing sector and the research community need to work together to create an evidence base of what works, to share best practice, and the learning from what does not work. Systematic data capture and evidence collection of new ways of designing, building and heating homes, are needed to create a strong evidence base of the benefits of such a shift.

7.4. Recommendation 4: engaging residents

We recommend engaging with residents of new net zero carbon homes post-occupancy to inform them about how the new technologies and unfamiliar features of their homes work. This is important and will reduce the performance gap (the gap between design and operational performance).

We also recommend that mechanisms are put in place for post occupancy evaluation to collect robust data on net zero carbon homes. This can help to better understand how the adopted technologies and design perform in practice and how they can be improved. The collected data can help to show the impacts on emissions and energy savings to make a stronger business case and make the homes attractive for residents.

To monitor the ongoing performance of new housing stock, we recommend exploring the greater use of sensors and digital technologies, including digital twin technology. Sensors and digital technologies can help to collect data to improve designs and develop an evidence base about the performance and use of new homes.

7.5. Recommendation 5: incentives, subsidies and funding

We recommend that the government plays an active role in financing zero carbon new homes through the allocation of upfront grants to pioneering housebuilders who are taking the risk of transiting to build net zero carbon ready new homes ahead of the deadline. It is understood that financial support from the government may be relatively modest given the scale of change needed, but additional funding may incentivise those housebuilders who are inclined to transform their development pipeline.

There are existing examples of successful funding schemes for the retrofitting of housing stock, including the Social Housing Decarbonisation Fund, which is available to social landlords carrying out energy efficiency upgrades, and the Home Upgrade Grant scheme which is available to local authorities supporting low-income households to carry out property upgrades. More schemes are underway to encourage energy efficient retrofits (e.g., the Boiler Upgrade Scheme). We further recommend that the government expands its funding schemes to new build homes.

Italy and Germany have a range of tax incentives and loan mechanisms to facilitate the uptake of low carbon technologies (Green Finance Institute, 2020). We call for further research and evidence on how other countries' financial incentives have facilitated their transition to the net zero carbon future. This research can help us to learn about the approaches taken in other countries to drive the greater provision of net zero homes and technologies and whether they can be adopted in the UK.

7.6. Recommendation 6: training and upskilling for a resilient supply chain

It is recommended to provide training and upskilling for the workforce to support the transition to a net zero carbon future. Currently, skills development in the construction sector is demand-led (CITB & Eunomia, 2021), however, we suggest that training provision is planned and actively managed as the current levels of demand-led training will not be sufficient.

If the provision of training is not supported in advance, the demand for skilled workers will increase as the deadlines for decarbonisation get closer, and there will be a lag in the supply of skilled workers, causing a delay to the net zero carbon implementation plan. It is recommended to forecast what skills will be required in order to ensure that resources are in place ahead of demand (CITB & Eunomia, 2021). It is recommended that a working group of stakeholders (including, government, CITB, training providers) is convened to revise existing training course content and propose new courses (CITB & Eunomia, 2021).

In addition to developing skills training programmes, we recommend that some or all of the cost of the training be covered to incentivise workers to participate, and that attendees receive an accredited qualification at the end of the course. We recommend that the costs of training should be met by large organisations across their supply chains where possible. This will benefit those organisations by building supply chain resilience and will support smaller suppliers.

7.7. Recommendation 7: improving energy systems and infrastructure

As highlighted by the government's Energy White Paper, to deliver energy reliably, while ensuring fair and affordable costs and accelerating the transition to clean energy, the government need to create investment opportunities across the UK to enable a smarter, more flexible energy system, which harnesses the power of competition and innovation to the full (HM Government, 2020a, p.64).

The transition to electric heating and increased use of electric vehicles will increase the UK's reliance on electricity. We recommend that Ofgem, BEIS and network operators work together to identify solutions that will avoid intermittent and erratic supply by the national electricity grid.

It is also recommended that the regulations around electricity pricing are reformed in order to ensure that using electric heating systems such as heat pumps does not lead to higher bills for consumers (NHF, 2021). This may be achievable by promoting greater innovation and competition in networks, and in national and local energy markets (HM Government, 2020a, p.64).

8. Conclusions

This report presented some of the key discussions around the delivery of net zero carbon new homes. It set out some of the net zero carbon definitions and discussed how net zero carbon is expected to be achieved. It also reviewed some of the low carbon technologies available and explored gaps in the current approaches. The report identified the potential barriers and benefits of delivering net zero carbon homes. The report also discussed that, in building net zero carbon new homes, there are trade-offs to be recognised and considered by housebuilders. Finally, a number of recommendations to overcome the barriers to delivering net zero carbon new homes were discussed.

To conclude the report, this section offers some brief reflections on the net zero carbon discussion. The first reflection is the need for a systems-based approach to achieve net zero carbon in the housing sector. Housing is a complicated and inter-connected system and net zero is unlikely to be achieved if the focus is on individual components within the system, on specific targets, on particular technologies, or in isolated silos.

The UK's policies lack system thinking in achieving net zero targets as the focus is on the carbon emissions of operational energy use of individual buildings rather than thinking about the buildings as part of their wider environment, their location, the availability of infrastructure to support sustainable travel such as public transportation, and broader water management and waste collection. The Future Homes Standard does not regulate the embodied carbon associated with construction and does not take a whole lifecycle approach.

The second reflection is on the multiple pressures that housing associations and other actors in the housing industry face. As discussed, housing associations face several urgent and competing priorities, and there are trade-offs to be made between building net zero carbon homes and addressing other significant issues, for example, fire safety, the needs of the ageing population, the rising cost of living, or homelessness. Achieving net zero is an additional delivery challenge for housing associations and housebuilders, and there are no simple solutions.

The third reflection is the ambiguity of current policy. Without knowing clearly what is expected from housing associations and housebuilders, it is difficult to adjust business models and strategies to respond effectively.

However, as we acknowledge the urgency of the climate emergency, the transition has to begin despite the lack of certainty around policy or technologies. The pioneers in building net zero carbon ready new homes are inevitably exposed to risk, and more could be done to help mitigate those risks. As pilots of new home designs and energy systems emerge in greater number, we must do more to work together to collect the evidence about what works, and just as importantly, about what does not work. Greater collaboration between organisations, including with research organisations, will help us to provide the evidence base needed to show how the housing sector can respond to the climate change emergency in the most effective ways.

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9. References

Air Quality Expert Group (2017) The potential air quality impacts from biomass combustion. Available at https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf. Accessed 16/03/22.

Baily Garner (2021) The Future Homes Standard A Practical Toolkit Towards Net Zero. Available at https://indd.adobe.com/view/e9d0acad-8b02-4bb5-86cc-bc7c8f161c28. Accessed 20/12/21.

BEIS (2020) Energy White Paper, Powering our Net Zero Future. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf. Accessed 23/12/21.

BEIS (2021) UK government launches plan for a world-leading hydrogen economy. Available at https://www.gov.uk/government/news/uk-government-launches-plan-for-a-world-leading-hydrogen-economy. Accessed 23/12/21.

BRE (2018) Home Quality Mark One, Technical Manual. Available at https://www.homequalitymark.com/wp-content/uploads/2018/09/HQM-ONE-Technical-Manual-England.pdf. Accessed 16/03/22.

Cambridgeshire & Peterborough ICC (2021) Fairness, nature and communities: addressing climate change in Cambridgeshire and Peterborough. Available at https://f.hubspotusercontent40.net/hubfs/6985942/FINAL%20CLIMATE%20REPORT%20LOW%20(002).pdf. Accessed 16/01/2022.

Carmichael, R. (2019) Behaviour change, public engagement and Net Zero. A report for the Committee on Climate Change. Available at https://www.theccc.org.uk/publications/ and http://www.imperial.ac.uk/icept/publications/. Accessed 06/01/2022.

Centre for Alternative Technology (n.d.) Photovoltaic (PV) Solar Panels. Available at https://cat.org.uk/info-resources/free-information-service/energy/solar-photovoltaic/. Accessed 19/01/22.

CIH (2021) Zero carbon ready from2025. Available at https://www.cih.org/blogs-and-articles/zero-carbon-ready-from-2025-a-look-at-the-future-homes-standard-and-future-building-standard. Accessed 09/02/22.

Committee on Climate Change (CCC) (2019a) UK housing: Fit for the future? Available at https://www.theccc.org.uk/2019/02/21/uk-homes-unfit-for-the-challenges-of-climate-change-ccc-says/. Accessed 06/01/2022.

Committee on Climate Change (CCC) (2019b) Behaviour change, public engagement and Net Zero. Available at https://www.theccc.org.uk/wp-content/uploads/2019/10/Behaviour-change-public-engagement-and-Net-Zero-Imperial-College-London.pdf. Accessed 20/01/2022.

Committee on Climate Change (CCC) (2020) the Sixth Carbon Budget. Available at https://www.theccc.org.uk/publication/sixth-carbon-budget/. Accessed 20/1/2022

Construction Leadership Council (2021) Carbon Reduction Code for the Built Environment. Available at https://www-smartinfrastructure.eng.cam.ac.uk/files/carbonreductioncode_issue_2021-2_november_1_2021.pdf. Accessed 30/03/2022.

Designing Buildings Wiki (2020) Mechanical ventilation with heat recovery. Available at https://www.designingbuildings.co.uk/wiki/Mechanical_ventilation_with_heat_recovery_MVHR. Accessed 23/12/21.

Designing Buildings Wiki (2021) Fabric first. Available at https://www.designingbuildings.co.uk/wiki/Fabric_first. Accessed 23/12/21.

DLUHC (2021a) Press release: New homes to produce nearly a third less carbon. Available at https://www.gov.uk/government/news/new-homes-to-produce-nearly-a-third-less-carbon. Accessed 06/01/2021.

DLUHC (2021b) Building (Amendment) Regulations 2021: circular 01/2021. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1040800/Circular.pdf. Accessed 06/01/2021.

Energy Saving Trust (n.d.) In-depth guide to heat pumps. Available at https://energysavingtrust.org.uk/advice/in-depth-guide-to-heat-pumps/. Accessed 22/12/21.

Energy Saving Trust (2021) A quick guide to low carbon heating. Available at https://energysavingtrust.org.uk/a-quick-guide-to-low-carbon-heating/. Accessed 22/12/21.

Etude (2021) Making SAP and RdSAP 11 fit for Net Zero. Available at https://www.etude.co.uk/wp-content/uploads/2021/06/Making-SAP-and-RdSAP-11-fit-for-Net-Zero-Full-report.pdf. Accessed 09/02/22.

Eunomia & CITB (2021) Building Skills for Net Zero. Available at https://www.citb.co.uk/media/kkpkwc42/building_skills_net_zero_full_report.pdf. Accessed 06/01/2022.

European Heat Pump Association (2020) Market Data. Available at https://www.ehpa.org/market-data/. Accessed 19/01/22.

First Plan (2021) Net Zero Strategy: What's the Plan for Planning? Available at https://www.firstplan.co.uk/news/net-zero-strategy-whats-the-plan-for-planning/. Accessed 20/01/22.

Future Homes Task Force (2021) Future Homes Delivery Plan. Available at https://www.futurehomes.org.uk/delivery-plan. Accessed 20/12/21.

Greenpeace UK (2021) The UK's poor record on heat pumps. Available at https://www.greenpeace.org.uk/wp-content/uploads/2021/09/Briefing-heat-pumps-9Sept-4.pdf. Accessed 19/01/22.

Green Finance Institute (2020) Financing zero carbon heat: turning up the dial on investment. Available at https://www.greenfinanceinstitute.co.uk/wp-content/uploads/2020/12/Financing-zero-carbon-heat-turning-up-the-dial-on-investment_Green-Finance-Institute.pdf. Accessed 01/02/22.

Green Match (2021a) UK Solar Capacity: Is the Future of Solar Cloudy? Available at https://www.greenmatch.co.uk/blog/2019/09/uk-solar-capacity. Accessed 19/01/22.

Green Match (2021b) A Guide to Calculating Your Solar Panel Size. Available at https://www.greenmatch.co.uk/blog/how-many-solar-panels-do-i-need. Accessed 19/01/22.

Green Spec (n.d.) Passive solar design: Siting and Orientation. Available at https://www.greenspec.co.uk/building-design/solar-siting-orientation/. Accessed 19/01/22.

HM Government (2020a) Energy White Paper: Powering Our Net Zero Future. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf. Accessed 25/01/20220

HM Government (2020b) The Government Response to the Committee on Climate Change's 2020 Progress Report to Parliament. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928005/government-response-to-ccc-progress-report-2020.pdf. Accessed 25/01/2022.

HM Government (2021a) Net Zero Strategy: Build Back Greener. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf. Accessed 25/01/2022.

HM Government (2021b) Heat and Buildings Strategy. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044598/6.7408_BEIS_Clean_Heat_Heat___Buildings_Strategy_Stage_2_v5_WEB.pdf. Accessed 25/01/2022.

HM Government (2022) Spring Statement 2022. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1062708/Spring_Statement_2022_Print.pdf. Accessed 30/03/2022.

Institute for Government (2020) UK net zero target.
Available at https://www.instituteforgovernment.org.uk/explainers/net-zero-target. Accessed 20/01/2022.

LETI (2020) Climate Emergency Design Guide. Available at https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_3b0f2acf2bb24c019f5ed9173fc5d9f4.pdf. Accessed: 04/01/22.

LETI (2021) LETI Client Guide for Net Zero Carbon Buildings. Available at https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_779b2a7276684247821fea72a30fd3a8.pdf. Accessed 04/01/22.

LUC (2021) Updated NPPF: Does it reflect the climate emergency? Available at https://landuse.co.uk/updated-nppf-framework-climate-emergency/. Accessed 25/01/22.

Maani, T., Celik, I., Heben, M., Ellingson, R., Apul, D. (2020) Environmental impacts of recycling crystalline silicon (c-SI) and cadmium telluride (CDTE) solar panels. Science of The Total Environment, Volume 735. https://doi.org/10.1016/j.scitotenv.2020.138827. Accessed: 31/01/22.

MCS (2021) Addressing the key barriers to widespread heat pump adoption: a response to BEIS. Available at https://mcscertified.com/wp-content/uploads/2021/10/BEIS-Heat-Pump-Response.pdf. Accessed 19/01/22.

MHCLG (2021) The Future Homes Standard: 2019. Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings. Summary of responses received and Government response. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956094/Government_response_to_Future_Homes_Standard_consultation.pdf. Accessed 06/04/22.

MHCLG (2021a) The National Planning Policy Framework. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005759/NPPF_July_2021.pdf. Accessed 15/01/22.

NAO (2020) Local government and net zero in England. Available at https://www.nao.org.uk/wp-content/uploads/2021/07/Local-government-and-net-zero-in-England-Summary.pdf. Accessed 19/01/22.

NHBC Foundation (2012) Understanding overheating- where to start: An introduction for house builders and designers. Available at https://www.zerocarbonhub.org/sites/default/files/resources/reports/Understanding_Overheating-Where_to_Start_NF44.pdf. Accessed 16/03/22.

NHF (2021) Decarbonisation: a guide for housing associations. Available at https://www.housing.org.uk/resources/decarbonisation-guide-for-housing-associations/. Accessed 19/12/21.

Ofgem (2020) The role of the consumer in achieving net zero. Available at https://www.ofgem.gov.uk/news-blog/our-blog/role-consumer-achieving-net-zero. Accessed 25/01/22.

ONS (2021) Three-quarters of adults in Great Britain worry about climate change. Available at https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/articles/threequartersofadultsingreatbritainworryaboutclimatechange/2021-11-05. Accessed 01/02/22.

ONS (2019) A burning issue: biomass is the biggest source of renewable energy consumed in the UK. Available at https://www.ons.gov.uk/economy/environmentalaccounts/articles/aburningissuebiomassisthebiggestsourceofrenewableenergyconsumedintheuk/2019-08-30#:~:text=Biomass%20can%20be%20considered%20a,soil%2C%20trees%20and%20other%20vegetation. Accessed 16/03/22.

Paul Ventilation Services (n.d.) Maintenance Service for MVHR Systems. Available at https://www.paulheatrecovery.co.uk/services/maintenance/#:~:text=It%20is%20recommended%20that%20MVHR,working%20as%20it%20should%20be.&text=%E2%80%93%20Check%20your%20external%20terminals%20for,it%20or%20poke%20into%20it. Accessed 26/01/2022.

RIBA (2021) 2030 Climate Challenge. Available at https://www.architecture.com/about/policy/climate-action/2030-climate-challenge. Accessed 19/01/22.

Savage, T., Akroyd, J., Mosbach, S., Hillman, M., Seilker, F., Kraft, M. (2022) Universal Digital Twin – the impact of heat pumps on social inequality. Available at https://www.sciencedirect.com/sdfe/reader/pii/S2666792421000718/pdf. Accessed 20/01/22.

The Renewable Energy Hub UK (2021) Heat Pump Maintenance. Available at https://www.renewableenergyhub.co.uk/main/heat-pumps-information/maintenance-of-heat-pumps/. Accessed 19/01/22.

UKGBC (n.d.) Climate Change. Available at https://www.ukgbc.org/climate-change-2/. Accessed 06/01/2022.

UKGBC (2019) Net Zero Carbon Buildings: A Framework Definition. Available at https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2019/04/05150856/Net-Zero-Carbon-Buildings-A-framework-definition.pdf. Accessed 22/12/2021.

UKGBC (2020) Building the Case for Net Zero Carbon report. Available at https://www.ukgbc.org/wp-content/uploads/2020/09/Building-the-Case-for-Net-Zero_UKGBC.pdf. Accessed 22/12/2021.

UKGBC (2022) Building the case for net zero: a case study for low carbon residential developments. Available at https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2022/03/08122558/UKGBC-Masterplan-Report-version-2.pdf. Accessed: 30/03/2022.

Wilson, R. (2019) Leeds' green blueprint: Climate Innovation District by White Arkitekter, Architects' Journal. Available at https://www.architectsjournal.co.uk/buildings/leeds-green-blueprint-climate-innovation-district-by-white-arkitekter. Accessed 10/02/22.