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# DECARBONISING HEAT IN BUILDINGS

## PUTTING CONSUMERS FIRST

APRIL 2021

# FOREWORD

As a nation, we are fast approaching a crunch point, with Net Zero and associated policies leading the pull away from fossil fuels. When discussing decarbonisation with friends and at work, I am struck by how often heat in homes is omitted from the conversation, and when it is remembered, by how much the peak heat demand in winter is underestimated. I therefore very much welcome the thoughtful contributions this report provides.

Clearly heat pumps have a huge role to play in the transition to low carbon heat in homes. Indeed, there is a temptation to assume we can rely on them exclusively. After all, they are available now and can be delivered house by house, while other solutions such as hydrogen must take place at the community or street scale, which introduces a whole new set of barriers to overcome, including finding new low carbon ways to scale up hydrogen production.

It is however, as this report highlights, much more complicated than simply switching from boilers to heat pumps, not least due to the unsuitability of some homes for heat pumps, but also because it appears that delivering peak heat to homes in winter may be an insurmountable challenge for all electrically delivered heat. Thus, alternative, and complimentary approaches are needed, to align with practical constraints of people's homes and deliver huge swings in demand and service peak heat, which is perhaps the brightest feather in the hydrogen's proponents cap.

Where the balance lies between combinations of these, and other technologies identified in this report, is not yet known. It will depend on many factors, not least the success of any future national domestic retrofit campaigns, consumer acceptance of different technologies, the speed of the decarbonisation of electricity and the emergence of new solutions like house batteries and energy storage.

It is a cliché to say there is no silver bullet to low carbon heating, but this document provides tangible evidence to inform policy decisions around the scale, speed and direction of future low carbon heating in UK homes. It presents a refreshingly accessible and pragmatic evaluation of low carbon heating options from the point of view of one of the most important stakeholders, who are -sadly - often excluded from discussions and decision making associated with decarbonising heat in homes: householders like you and me.

Dr David Glew,
Head of Energy Efficiency and Policy at the Leeds Sustainability Institute

# EXECUTIVE SUMMARY

From an evaluation of the GB housing stock, it is clear that a mosaic of low carbon heating technologies will be needed to reach net zero. While heat pumps are an important component of this mix, our analysis shows that it is likely to be impractical to heat many GB homes with heat pumps only.

A combination of lack of exterior space and/or the thermal properties of the building fabric mean that a heat pump is not capable of meeting the space heating requirement of 8 to 12m homes (or 37% to 54% of the 22.7m homes assessed in this report) or can do so only through the installation of highly disruptive and intrusive measures such as solid wall insulation. Hybrid heat pumps that are designed to optimise efficiency of the system do not have the same requirements of a heat pump and may be a suitable solution for some of these homes. This is likely to mean that decarbonised gas networks are therefore critical to delivery of net zero.

3 to 4m homes[1] (or 14% to 18% of homes assessed in our analysis) could be made suitable for heat pump retrofit through energy efficiency measures such as cavity wall insulation. For 7 to 10m homes there are no limiting factors and they require minimal/no upgrade requirements to be made heat pump-ready.

Nevertheless, given firstly the levels of disruption to the floors and interiors of homes caused by the installation of heat pumps, and secondly the cost and disruption associated with the requirement to significantly upgrade the electricity distribution networks to cope with large numbers of heat pumps operating at peak demand times - combined with the availability of a decarbonised gas network which requires a simple like-for-like boiler replacement - is likely to mean that many of these 'swing' properties will be better served through a gas based technology such as hydrogen (particularly when consumer choice is factored in) or a hybrid system. A recent trial run in winter 2018-19 by the Energy System Catapult revealed that all participants were reluctant to make expensive investments to improve the energy efficiency of their homes just to enhance the performance of their heat pump. They were more interested in less costly upgrades and tangible benefits, such as lower bills or greater comfort.

This means that renewable gases including hydrogen as heating fuels are a crucial component of the journey to net zero and the UK's hydrogen ambitions should be reflective of this.

The analysis presented in this paper focuses on the external fabric of the buildings, further analysis should be undertaken to consider the internal system changes that would be required for heat pumps and hydrogen boilers, for example BEIS Domestic Heat Distribution Systems: Gathering Report from February 2021 which considers the suitability of radiators for the low carbon transition.

1 The analysis takes into account the number of energy efficiency measures that have already been installed in GB homes.

# THE CHALLENGE OF DECARBONISING HEAT

Near-full decarbonisation of heat for buildings is one of the biggest challenges in reducing emissions from the energy system to net zero by 2050.

To date much of the success in reducing emissions has come from the power sector, with more recent successes in the transport sector. Having plucked the low hanging fruit, we now need to work on reaching the harder to decarbonise areas, and in particular heat in buildings.

In 2019, the residential sector emitted 65.2 Mt of carbon dioxide emissions ($CO_2$), accounting for 19 per cent of all $CO_2$[2]. The main source of emissions in the residential sector is the use of fossil fuels (mainly natural gas) for heating and cooking.

Currently 85% or 23 million homes are connected to the gas grid with the remaining 15% or 4 million using oil or LPG as their main heating fuel or electric heating. In the next 10 to 15 years, the majority of these systems will need to be replaced with low-carbon alternatives if the UK is to meet its net zero target.

Compared to decarbonisation of the power sector, where emission reductions were delivered without shifts required in consumer behaviour, reducing emissions from buildings need support from consumers and access to their homes.

This means it is also critical to consider what the consumer experience of the transition to low carbon heat  feels like and how this might affect preferences.

## A COMBINATION OF LOCALITY-SPECIFIC SOLUTIONS WILL DELIVER HEAT DECARBONISATION IN HOMES

Residential building emissions can be reduced through a combination of switching to low-carbon sources and energy efficiency improvements. However, the heterogeneity of the UK building stock means that heating decarbonisation will not be through a single nationwide solution and will likely require a mix of locality-specific solutions tailored to the opportunities, requirements and constraints of each location.

The two primary routes to reducing emissions in buildings are electrification of heat using heat pumps and/or to repurpose gas distribution grids to carry hydrogens rather than natural gas. A mix of electric and low-carbon gas technologies are expected to be predominantly used.

Other solutions such as biomethane, heat networks, hybrid heat pumps and direct electric heating are also expected to be part of the mosaic of technologies needed to deliver heat decarbonisation in different locations.

## ENERGY EFFICIENCY WILL BE CRUCIAL TO ACHIEVE NET ZERO

Reducing underlying energy demand through increasing energy efficiency will be critical. Installing energy efficiency measures in homes and buildings has an upfront cost but reduces energy demand and carbon emissions. Some energy efficiency measures are simple to install and pay for themselves quickly, these should be installed in combination with any heating system replacement. For example, thermostatic radiator valves, smart thermostats and draughtproofing interventions fall into this category.

Insulation is a more tricky case, some types of insulation are relatively cheap and easy to install, whereas others can be highly disruptive. Insulation of cavity walls falls into the first category, as it is a non-intrusive measure which has a major impact on heat lost through the walls[3]. Over two-third of homes in the GB were built with cavity walls, and in nearly 65% of these, or 11.2[4] million homes, there is evidence of insulation being installed. Insulation of the remaining ~4,8 million homes that have unfilled walls should be a priority.

Meanwhile, nearly one third of homes in the GB were built with brick and stone solid walls, most of which remain uninsulated due to the costs and disruption caused by the installation of solid wall insulation. This typically involves either installing cladding on the exterior of the building, which fundamentally changes the aesthetic of the property and may require planning permission, or installing insulation on the interior face of the walls which is highly disruptive and reduces interior floor area as well as requiring redecoration works, floor insulation installation also follows a similarly disruptive process[5]. For this reason, it is likely to be highly challenging to make the case for these types of measures to be installed in significant numbers.

2 BEIS (2020). UK Greenhouse gas emissions, provisional figures 2019.
3 Loft insulation also falls into this category
4 Estimates based on sample of 22.7m properties used in this analysis. For further details on the methodology, please see section 'Housing stock analysis'
5 New technology solutions such as Q-Bot can be less disruptive

## CUSTOMER EXPERIENCE IS KEY

Heat and comfort are necessities for life. And as the decarbonisation of heat will require changes to people's homes, the consumer needs to be bought into the process and actively participate. Therefore, in transitioning to a zero-carbon future it is imperative that firstly the quality of these services is maintained or improved and secondly that they are inclusive and accessible to all customer types, not just a subset.

Different heating technologies have different impacts on customer experience, both in terms of the enduring interaction with the product and also of the installation itself.

## THE ENDURING EXPERIENCE OF DIFFERENT TECHNOLOGIES WILL SUIT DIFFERENT TYPES OF CONSUMERS

On the enduring experience, it is important to recognise that heat pumps tend to produce heat at lower temperatures to hydrogen boilers, meaning they are more suited to maintaining relatively static room temperatures and require larger surface areas for heat dissipation, making them highly suitable for underfloor heating, or otherwise requiring relatively larger radiators than boilers.

Heat pumps are also not suitable for replacing combi boilers for instantaneous production of hot water, instead requiring a hot water storage tank. Again the temperature output of heat pumps means this tank needs to run more continuously given the longer time required to heat the water.

## THE INSTALLATION OF DIFFERENT HEAT TECHNOLOGIES WILL SUIT DIFFERENT TYPES OF PROPERTIES

The majority of homes in Great Britain are heated by either a natural gas or other fossil fuel boiler system. Replacing a boiler with a heat pump has a number of key challenges.

# INSTALLING A HEAT PUMP IN EXISTING HOMES

For heat pumps to work effectively as the sole heating source, the buildings need to be thermally efficient. Heat pumps typically require both internal and external space as well as changes to internal systems such as radiators which can cause disruption to consumers.

# INSTALLING A HYDROGEN-READY BOILER IN EXISTING HOMES

The installation of a hydrogen boiler is a like-for-like replacement for a conventional heating system which does not need to be supported by the interventions needed to fit a heat pump in a home. There is also no requirement in this case for exterior or additional interior space in the home. This can also be the case for some compact hybrid systems.

KEY ☆ New

### THERMAL PROPERTIES

Buildings need to be thermally efficient in order for heat pumps to be a viable heating technology. As building regulations have evolved over the last century, the thermal properties of new builds have improved - however this means that there is a wide range of thermal characteristics depending on a properties age. In general, the older the property, the worse the thermal efficiency and hence the greater level of intervention required to make the property suitable for retrofit. As discussed above, while some insulation measures are entirely rational, others may well be impractical. This means there is likely to be a correlation between the construction date of a property and its applicability for heat pumps.

### HEATING SYSTEMS

Heat pumps produce lower output temperatures than boilers meaning that the internal heating systems of properties need to be altered. Depending on the floor construction and covering, an underfloor heat distribution system may be most suitable alternatively, new, larger radiators may need to be added or replaced. The cost and disruption of changing internal systems mean that customer preference will play a role in uptake of different technologies.

### SPACE REQUIREMENTS

There are interior and exterior space requirements for the installation of a heat pump. Storage cylinders for hot water are required [and are typically larger than those required for boilers]. Aside from the necessity of hot water storage, the heat pump itself requires equipment to be installed both on the exterior of the property and the interior. Whilst the internal equipment is similar in footprint to a boiler, the necessity of availability of exterior space can be a constraint especially in more densely populated areas and may also feature in consumer preference decisions.

On the other hand, the installation of a hydrogen boiler is a like-for-like replacement for a conventional heating system which does not need to be supported by the interventions needed to fit a heat pump in a home. There is also no requirement in this case for exterior or additional interior space in the home. This can also be the case for some compact hybrid systems.

Experience from schemes that require work to be carried out in the home such as the smart meter roll out or the energy company obligation (ECO) show that consumers are generally reticent to what are perceived to be enforced changes within their homes. Both of these schemes have ultimately underdelivered against expectations and they only required relatively small interventions. It is likely to be politically and practically challenging to impose obligations on householders to install highly intrusive and disruptive measures.

This has been evidenced in early heat pump retrofit trials, where even proactive consumers that were interested in heat pump installation have dropped out of the schemes once the scale of associated works to the home became apparent.

## IT IS IMPORTANT TO CONSIDER THE REALITY NOT THE ABSTRACT

When considering the likely technology mix it is crucial to examine the actual make up of the housing stock, both in terms of the age and therefore thermal properties and the archetype and therefore likely availability of space. It is also imperative to consider consumer preference given the scale of challenge and need to engage with them.

Heat pumps are expected to be the most suitable technology to decarbonise heat in a number of situations. However, in other cases with less potential for electrification, low-carbon gas-based solutions will be the optimal solution. Examples of where heat pumps may be an optimal solution and where they may not be suitable are discussed next based on property archetypes.

# LOW CARBON HEATING OPTIONS

## HEAT PUMPS

Heat pumps are an established technology that can immediately and substantially reduce emissions from heating and hot water consumption. A heat pump uses the heat in the air or the ground as the main source of energy and requires electricity to operate. For every unit of electricity that is put in, the technology has the potential to produce 3 to 4 units of heat, depending on the type of heat pump.

Running costs will depend on heat demand, system efficiency and electricity prices. Depending on the heating fuel that it replaces, it can lead to energy bill savings. A heat pump operates at higher efficiencies at low flow temperatures which means that in buildings that are poorly insulated, the technologies is less efficient. Therefore, in order to make heat pumps viable, buildings need to be highly thermally efficient.

A report[6] prepared for BEIS in 2018 found the costs of the work involved to install an air-source heat pump to be between £8,750 and £21,550 depending on the heat pump size and interventions required. Meanwhile, the same report found the costs of the work involved to install a ground-source heat pump to be between £13,200 and £27,350, depending on the heat pump size and interventions required. Ground-source heat pumps may be more suitable for communal heating.

In 2019, heat pumps represented two per cent of the heat market.

## HYDROGEN BOILERS

Hydrogen boilers can replace conventional gas boilers on a like-for-like basis and has the potential to eliminate carbon emissions from heating completely, with water as the only by-product. Hydrogen-ready boilers are being developed by UK leading boiler manufacturers in the UK. Two UK boiler manufacturers are currently involved in the Government's Hy4Heat programme that looks at the technical and safety challenges of replacing conventional appliances with hydrogen-ready ones. One of the workstreams of the programme focuses on development of consumer ready and fully certified prototype hydrogen boilers to be installed in consumer homes. The programme has already reported on the technical details of the technologies and more information will be made available in the annual report to be published in December. It is expected that hydrogen-ready boilers will be available to consumer at no or small additional cost to methane boilers.

'Green hydrogen' can be produced through a process that makes use of electricity - if the electricity comes from renewable sources such as wind, solar or hydro, then the hydrogen is effectively green. In the production of 'blue hydrogen', the gas is produced by steam methane reformation and the emissions are curtailed using carbon capture and storage.

## HYBRID HEAT PUMPS

Hybrid heat pump systems combine a boiler and a heat pump to meet a building's space heating and hot water requirements. Hybrid heat pumps are a low-carbon heating solution that can deliver emission savings that vary depending on the overall efficiency of the system that in turn is determined by the mode of operation. Hybrids can be run such that the boiler meets the entire heat demand at times when the heat pump is unable to operate ('switch' mode) or such that the heat pump contributes to meeting the space heating demand and the boiler provides the remaining heat required for the water to reach the right temperature at all times ('parallel' mode).

Hybrid heat pumps can either be installed alongside existing high temperature emitters or with low temperature emitters. In contrast to electric heat pumps, relying on high temperature emitters is possible because the boiler component is capable of meeting the peak heat demand with higher flow temperatures, ensuring comfort can be achieved. Costs for installation are similar to heat pump only systems, on a £/kW basis though the heat pump size will be lower due to the hybrid nature of the system.

## BIOMETHANE

Biomethane is a green gas chemically identical to methane that can be injected in the gas grid and deliver immediate carbon emission savings, without the requirement from consumers to change existing appliances.

Production of biomethane is based on anaerobic digestion of waste organic material through the breakdown of organic material by micro-organisms in the absence of oxygen to produce biogas. The biogas is then refined to produced biomethane.

The technology to produce biomethane is a commercially available solution. Until recently, installations have been supporting the injection of biomethane in the gas distribution network. In July 2020, National Grid connected a biomethane production facility (a farm) to the National Transmission System (NTS), injecting biomethane in the grid for the first time. The plant will support up to 15,000 cubic metres per hour of biogas flows which is enough renewable gas to supply ten  households every hour.

The total potential supply of biomethane from waste in the UK will be limited by the amount of waste that can be cost-effectively accessed.

6 Delta-ee (2018). The Cost of Installing Heating. Measures in Domestic Properties. The findings are also reported in the fourth Environmental Audit Committee report on energy efficiency of existing homes.

# HOUSING STOCK ANALYSIS

## We have carried out an analysis of the GB housing stock based on the challenges discussed above.

Property archetypes are defined by their type and age. Data published in the National Energy Efficiency Data-Framework (NEED) Multiple Attributes Tables[7] is used to define the size of each archetype segment. This dataset, compiled in 2020, uses all properties contained on the 2019 VOA council tax database in Great Britain[8], where the property is assessed to have valid gas or electricity consumption. The dataset covers 82%[9] of properties registered to pay council tax in England and Wales[10] and 65%[11] in Scotland[12]. Building insulation and thermal elements are sourced from the English Housing Survey[13] from England and Wales[14] and from the House Condition Survey for Scotland[15,16].

While decarbonising heat will require a mosaic of solutions, our analysis focuses on the suitability of different building archetypes to the installation of an electric heat pump as the sole decarbonisation solution. We have considered heat pump suitability for each property archetype, focusing on the properties thermal efficiency, space availability and period features. When heat pump is not found to be a likely solution for the property archetype, a gas-based heating solution needs to be considered. Gas-based solutions include a range of options such as hydrogen boilers, hybrid heat pumps and biomethane injection into the grid. This approach allows us to establish whether network infrastructure to deliver gas-based solutions to consumer homes is requirement to deliver the country decarbonisation goals or whether the same objective can be achieved without it.

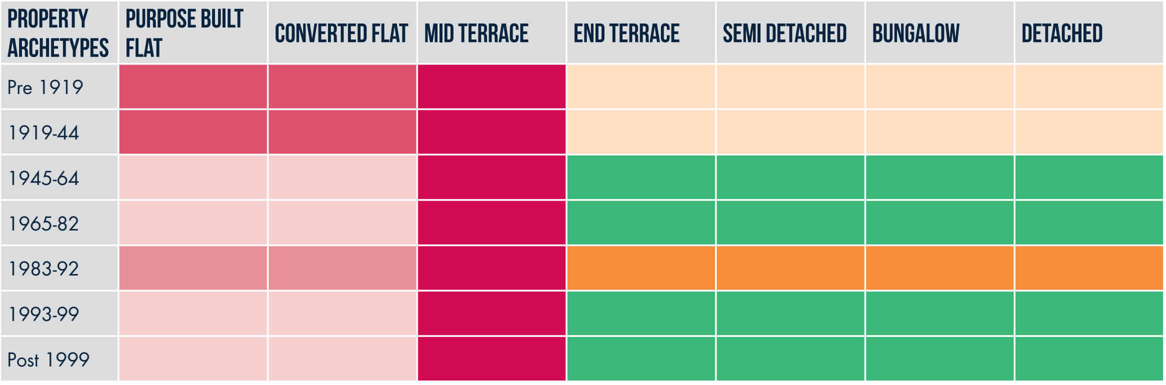
The results of this analysis are presented using a RAG assessment[17]. Based on their score against thermal efficiency and space availability metrics, each property archetype is considered as either:

- Likely suitable for a heat pump: these property archetypes require minimal or no energy efficiency upgrades and are not space-constrained;
- Possibly suitable for a heat pump: these property archetypes are either space-constrained or require energy efficiency and heating system upgrades;
- Not suitable for a heat pump: these property archetypes require significant energy efficiency and heating system upgrades, such as solid wall or underfloor insulation and/or are space-constrained.

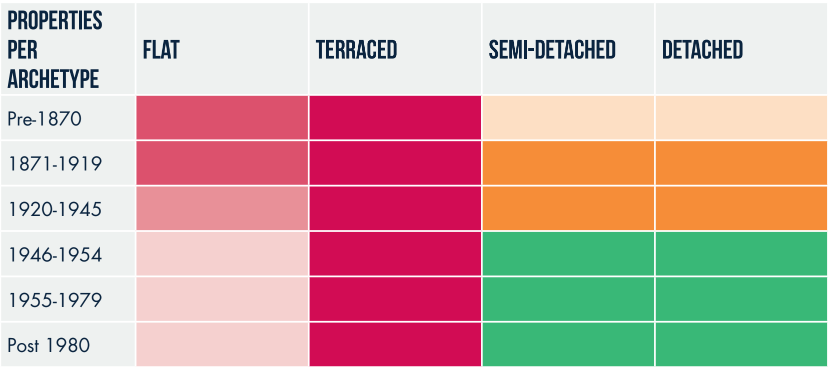
The score and suitability to a heat pump for each archetype is assigned based on the features of the typical property in each segment and on the overall number of properties that would require interventions in each group. The analysis of the estimated number of properties that may be suitable/possibly suitable/not suitable that is presented in the next section, takes into account the actual number of properties in each segment, the type of wall[18], and the number of energy efficiency upgrades that have been completed to date.

7 Multiple Attributes Table 2018 and Scotland Multiple Attribute Table 2018
8 The VOA database only covers properties that are registered to pay council tax. There are properties not included due to an inability to accurately match the property to an ordnance survey UPRN. The VOA dataset used for Scotland is based on 2014 data.
9 21.1 million
10 Coverage is limited by availability of information on electricity or gas consumption
11 1.57 million
12 Coverage is limited by availability of information on electricity or gas consumption.
13 DA6201: insulation - dwellings
14 Insulation and thermal properties of properties in Wales assumed to be the same as in England.
15 For Scotland, we used the wall type and insulation estimates published in the House Condition Survey as starting point. The percentage of homes with cavity walls and with insulation reported in the survey is broadly in line with the estimates reported for England. Given the lack of data on wall type and insulation by type and age for Scotland, we have assumed the same distribution observed for homes in England.
16 The percentage of homes build with solid walls assumed to be insulated is 8%, in line with the estimated published by the Climate Change Committee in 'Annex 2. Heat in UK buildings today'.
17 Please see appendix - RAG Assessment for the complete RAG assessment
18 For example, while the majority of properties built before 1940 were built with solid walls, some properties in this archetype were built with cavity walls. This is reflected in the analysis, as well as the number of energy efficiency interventions that has already been installed.

## OVERALL SUITABILITY OF PROPERTIES IN ENGLAND AND WALES TO A HEAT PUMP[19]




## OVERALL SUITABILITY OF PROPERTIES IN SCOTLAND TO A HEAT PUMP[20]




### KEY

- Possibly suitable for communal heat pump with solid wall insulation/ not suitable
- Possibly suitable for communal heat pump with cavity wall insulation/ not suitable
- Possibly suitable for communal heat pump/ not suitable
- Possibly suitable for heat pump with cavity wall insulation
- Likely suitable for a heat pump
- Possibly suitable for heat pump with solid wall insulation
- Not suitable

## Based on this analysis it is likely that heat pump only systems will be unsuitable for 37% to 54% of the existing housing stock.

While 14 to 18% could be practically adapted to be made suitable, consumer and societal choice will need to be factored in to determine whether this is the optimal technology solution.

**There are limiting factors to installing a heat pump which means that the technology is highly unlikely to be suitable solution for 8 to 12m of homes** or 37% to 54% of the properties considered in this analysis. These buildings include properties that were built with solid brick walls, uninsulated and/or space constrained e.g., flats and mid-terrace buildings as well as high rise buildings that would require non-standard insulation measures. There is likely to be variation among properties in the purpose-built flat and converted flat segments (some of these flats will be space constrained, others will not). This uncertainty is captured by the range estimate of properties considered to be unsuitable to a heat pump.

Hybrid heat pumps that are designed to optimise efficiency of the system do not have the same requirements of a heat pump and may be a suitable solution for some of the homes where a heat pump cannot work effectively as the sole heating source. Compact hybrids may be suitable for properties with space constraints.

**Our analysis suggests that 3 to 4m homes or, 14% to 18% of homes considered in this paper could be made suitable for a heat pump following some energy efficiency improvements such as insulation of cavity walls.** This includes detached, semi-detached, bungalow and end-terrace properties built with cavity walls. There is likely to be variation among properties in the purpose-built flat and converted flat segments (some of these flats will be space constrained, others will not). This uncertainty is captured by the range estimate of properties considered to be potentially suitable to a heat pump.

**Our analysis suggests that 7 to 10m homes including detached, semi-detached, bungalow, end-terrace properties could be suitable for a heat pump** given the limited space constraint and thermal efficiency of the buildings.

19 While the RAG assessment for mid terrace houses is the same as the assessment for flats, the installation of communal heat pump is not considered a potential solution for mid-terrace buildings given the buildings layout.

20 The assessment of terrace properties will vary depending on whether the properties are assumed to be mid-terrace or end-terrace houses. 70% of terrace properties in England are mid-terraces, the same assumption is made for Scotland, hence the table shows the assessment using this assumption. Our range captures the uncertainty in this variable.

# CASE STUDIES

# PRE-WAR MID-TERRACE

For nearly 1.6 million homes  a combination of lack of exterior space and the thermal properties of the building fabric mean that a heat pump is not capable of meeting the space heating requirement of the property or can do so only through the installation of highly disruptive and intrusive measures.

Mid terraced houses are one of the most popular forms of housing in GB. There are 3.9 mid-terraced properties in GB[21] and 1.7 million were built pre 1930s, using solid bricks, the majority of which remains uninsulated

Several improvements to these properties would be required to make them suitable for a heat pump and lack of exterior space could make the installation challenging.

Insulating the envelope of the building is key to reduce the heat loss of the property. In addition to insulating the walls, a combination of roof, ceiling and/or floor insulation is likely to be necessary to reduce the heat loss to a level that can guarantee the efficient operation of the heat pump.

Replacement of existing radiators is likely to be needed to ensure the heat pump can operate at a low flow temperature. Alternatively, underfloor heating pipes may need to be installed.

Some of these interventions can be intrusive and disruptive to the householder. In addition, mid-terraced houses often lack the exterior space that is necessary to install the heat pump.

Another consideration is the period features of these properties which may be impacted by the interventions required to make them heat-pump ready and may reduce their value.

Overall, the building fabric requirements necessary for the efficient operation of a heat pump and the lack of exterior space means that the technology will not be the optimal solution to reduce emissions from heating from these properties.

## DECARBONISING HEAT EMISSIONS FROM PRE-WAR MID-TERRACES

There are 1.8m mid-terrace houses in the UK that were built pre-war, using solid bricks. To be made heat-pump ready, a combination of the following interventions is likely to be required:

- Insulation of solid wall
- Insulation of ceiling and floor
- Replacement of radiators or installation of underfloor heating

These measures can cause significant disruption to the consumer. Even with these interventions, the installation of a heat pump may not only be challenging due to the disruptive improvements required but also impractical given the space constraint.

Given these barriers, decarbonisation of pre-war mid-terraced houses through a heat pump may be impractical. **A hydrogen boiler or compact hybrid is likely to be the most suitable and practical solution in this case.**

21 These estimates are based on a sample of 22.7m properties used in this analysis.

# CONVERTED FLATS

## For nearly 520,000 converted flats, a heat pump is not likely to be the optimal decarbonisation solution, due to the thermal properties of the buildings and space constraints.

Nearly 850,000 homes in the GB are converted flats, 60% of them built with uninsulated solid walls[22].

Several improvements are likely to be required to make the properties suitable for a heat pump.

The building envelope will require insulation. In addition to walls, ceiling and or floor will need to be insulated. Radiators or underfloor heating may need to be added or replaced to allow the heating system to operate optimally. These interventions can be intrusive and cause significant disruption to the householder.

In addition, converted flats could have limited exterior space and can be space constrained, particularly in dense urban areas. The space constraint combined with the thermal characteristics of converted flats means that a heat pump is not likely to be the optimal solution for the majority of converted flats.

### DECARBONISING HEAT EMISSIONS FROM CONVERTED FLATS

There are 520,000 converted flats in GB that were built using solid bricks and that have not been insulated.

To be made heat-pump ready, a combination of the following interventions is likely to be required:

- Insulation of solid wall
- Insulation of ceiling/floor
- Replacement of radiators or underfloor heating

These measures can cause significant disruption to the end-user. Even with these interventions, the installation of a heat pump may still be impractical due lack of exterior and interior space for the installation of the technology.

Given these constraints, decarbonisation of converted flats through heat pump may not only be challenging due to the disruptive improvements required but also impractical. **A hydrogen boiler or compact hybrid is likely to be the most suitable and practical solution in this case.**

22 These estimates are based on a sample of 22.7m properties used in this analysis.

# POST-WAR SEMI-DETACHED

For nearly 2.3m semi-detached properties built between 1945 and 1980s with cavity walls, heat pumps could be a suitable solution due to the thermal characteristics of the buildings and availability of both exterior and interior space. However, in some cases refurbishment work may still be required.

There are nearly 3.2 million semi-detached homes in GB[23], built between 1945 and 1980s with cavity walls. There is evidence of insulation in 2.3 million of these homes.

There properties are likely to be suitable for a heat pump, however some of them will require refurbishment work to ensure the heat loss is minimised. In addition, these buildings have no exterior or interior space constraints.

There is evidence that nearly 70% of semi-detached properties have filled cavity walls, however heating system upgrades such replacement or installation of radiators and underfloor heating may still be required.

Semi-detached properties are not space constrained, hence heat pumps could be fitted easily outside the property and a hot water cylinder and radiators be installed within the home.

Overall, heat pumps are likely to be a plausible solution for semi-detached homes with filled cavity walls, after small improvements to the properties.

## DECARBONISING HEAT EMISSIONS FROM POST-WAR SEMI DETACHED HOMES

There are nearly 2.3 million semi-detached properties built between 1945 and 1964 with filled cavity walls.

These properties are likely to be suitable for a heat pump, however some of them will require refurbishment work, such as replacement of radiators or underfloor heating.

**There less likely to be exterior or interior space constraints, hence a heat pump is likely to be a suitable solution, equally consumers may prefer a hydrogen boiler or hybrid system.**

23 These estimates are based on a sample of 22.7m properties used in this analysis.

# MODERN DETACHED

For nearly 720,000 detached properties in GB heat pumps are likely to be the optimal heating solution due to thermal characteristics of these buildings and availability of both exterior and interior space.

There are nearly 720,000 detached properties in the GB that were developed after 1999[24].

A heat pump is likely to be the optimal solution for detached properties built in the last two decades. There are no thermal insulation barriers and detached homes usually have both exterior and interior space.

With the tightening of building regulations, the majority of homes built after 1996 are assumed to have filled cavity walls.

Detached properties have adequate exterior space for the installation of a heat pump and sufficient interior space for heating system upgrades such as the installation or replacement of radiators, where that is a requirement. Overall, a heat pump is likely to be the optimal solution for these homes.

## DECARBONISING HEAT EMISSIONS FROM MODERN DETACHED HOUSES

There are nearly 720,000 detached properties built in recent years.

The majority of properties built after 1996 are assumed to have filled cavity walls.

**No major intervention is expected to be required in these homes to make them suitable for the installation of a heat pump, the optimal solution may however be driven by consumer preference.**

24 These estimates are based on a sample of 22.7m properties used in this analysis.

# FINDINGS

- Heat decarbonisation will require a mix of locality-specific solutions tailored to the needs of the housing stock and other geographical features. The best solution for each home will depend on a number of factors including the thermal insulation, space constraints, housing density, availability and capacity of energy infrastructure and whether the home is existing or new build. It is expected that both heat pumps and decarbonised gases amongst others will play a crucial role in the transition to Net Zero.
- However, there is no practical way of heating the majority of UK homes with heat pumps only. For 8 to 12m homes a combination of lack of exterior space and/or the thermal properties of the building fabric mean that a heat pump is not capable of meeting the space heating requirement of the property or can do so only through the installation of highly disruptive and intrusive measures such as solid wall insulation. Hybrid heat pumps that are designed to optimise efficiency of the system do not have the same requirements of a heat pump and may be a suitable solution for some of these homes. This is likely to mean that decarbonised gas networks are therefore critical to delivery of net zero.
- 3 to 4m homes could be made suitable for heat pump retrofit through energy efficiency measures such as cavity wall insulation.
- Nevertheless, given firstly the levels of disruption to the floors and interiors of homes caused by the installation of heat pumps and secondly the cost and disruption associated with the requirement to significantly upgrade the electricity distribution networks to cope with large numbers of heat pumps operating at peak demand times combined with the availability of a decarbonised gas network, many of these 'swing' properties will be better served through a gas-based technology (particularly when consumer choice is factored in).
- The analysis presented in this paper focuses on the external fabric of the buildings, further analysis should be undertaken to consider the internal system changes that would be required for heat pumps and hydrogen boilers, for example BEIS Domestic Heat Distribution Systems: Gathering Report from February 2021 which considers the suitability of radiators for the low carbon transition.
- In some cases, the best solution may be a combination of electrification and hydrogen. This would be delivered by hybrid heat pumps that combine a hydrogen boiler with an electrically driven heat pump, where the hydrogen boiler meets the winter peak and the heat pump provides the base heat demand.
- The UK gas transportation infrastructure can be converted incrementally from natural gas to hydrogen to support the switchover with limited disruption to the consumer. A number of trials focused on hydrogen as a potential option for decarbonising heat have already demonstrated the technical and economic feasibility of the conversion.
- This means that hydrogen as a heating fuel alongside renewable gases more broadly are a crucial component of the journey to net zero and the UK's hydrogen ambitions should be reflective of this.

# APPENDIX

## RAG ASSESSMENT - SUITABILITY OF PROPERTIES IN ENGLAND AND WALES TO A HEAT PUMP

| PROPERTY ARCHETYPES | PURPOSE BUILT FLAT | | CONVERTED FLAT | | MID TERRACE | | END TERRACE | | SEMI DETACHED | | BUNGALOW | | DETACHED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constraints | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties |
| Pre 1919 | Not suitable | Not suitable | Not suitable | Not suitable | Not suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable |
| 1919-44 | Not suitable | Not suitable | Not suitable | Not suitable | Not suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable |
| 1945-64 | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |
| 1965-82 | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |
| 1983-92 | Not suitable | Possibly suitable | Not suitable | Possibly suitable | Not suitable | Possibly suitable | Likely suitable | Possibly suitable | Likely suitable | Possibly suitable | Likely suitable | Possibly suitable | Likely suitable | Possibly suitable |
| 1993-99 | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |
| Post 1999 | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |

## RAG ASSESSMENT - SUITABILITY OF PROPERTIES IN SCOTLAND TO A HEAT PUMP

| PROPERTY ARCHETYPES | FLAT | | TERRACED* | | SEMI-DETACHED | | DETACHED | |
|---|---|---|---|---|---|---|---|---|
| Constraints | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties | Space constraints | Thermal properties |
| Pre-1870 | Not suitable | Not suitable | Not suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable |
| 1871-1919 | Not suitable | Not suitable | Not suitable | Not suitable | Likely suitable | Not suitable | Likely suitable | Not suitable |
| 1920-1945 | Not suitable | Possibly suitable | Not suitable | Possibly suitable | Likely suitable | Possibly suitable | Likely suitable | Possibly suitable |
| 1946-1954 | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |
| 1955-1979 | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |
| Post 1980 | Not suitable | Likely suitable | Not suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable | Likely suitable |

*end-terrace properties will not be space constrained. It is assumed the majority of properties in this segment are mid-terrace.

**KEY**

- Not suitable
- Possibly suitable
- Likely suitable
- Space constraints
- Thermal properties