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Reductions in maximum flow temperatures in Scottish domestic heating

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1 Executive summary

1.1 Background

Decarbonisation of domestic heating systems is crucial for achieving the Scottish Government's ambitious climate change targets of net zero emissions by 2045. The transition to zero direct emissions heating systems (e.g., heat pumps, district heating) will require a suite of changes to the Scottish housing stock, including preparing it to operate at lower flow temperatures than the current majority of 70-80°C. Flow temperature is the temperature a wet heating system warms water to before sending it to radiators in different areas of a building.

This study summarises the current evidence for flow temperature reduction in hot water (wet) systems and considers how this might be applied to the Scottish housing stock. Suitability is defined as a dwelling's ability to reach thermal comfort for a range of external temperature test criteria. We assess the suitability of the present housing stock as it is today and then with two different cost levels of retrofit. The assessment method includes a literature review, stakeholder interviews and scenario modelling to test different temperature cases.

1.2 Findings

We have found that most of the Scottish housing stock is currently unsuitable for flow temperature reduction to 55°C or below on a winter peak day (see Figure 1).

Many dwellings in Scotland could reach suitability for 55°C flow temperatures after the inclusion of retrofit(s). Effective retrofit measures include efficiency measures such as wall and/or loft insulation, upgrading radiators or a combination of smaller efficiency measures such as hot water tank insulation, draughtproofing and reduced infiltration measures.

In our higher cost retrofit scenario, 76% of homes become suitable for a flow temperature of 55°C on a winter peak day (see Figure 2). This could prepare the housing stock to be ready for zero direct emissions systems without requiring gas boilers to be removed from homes immediately.

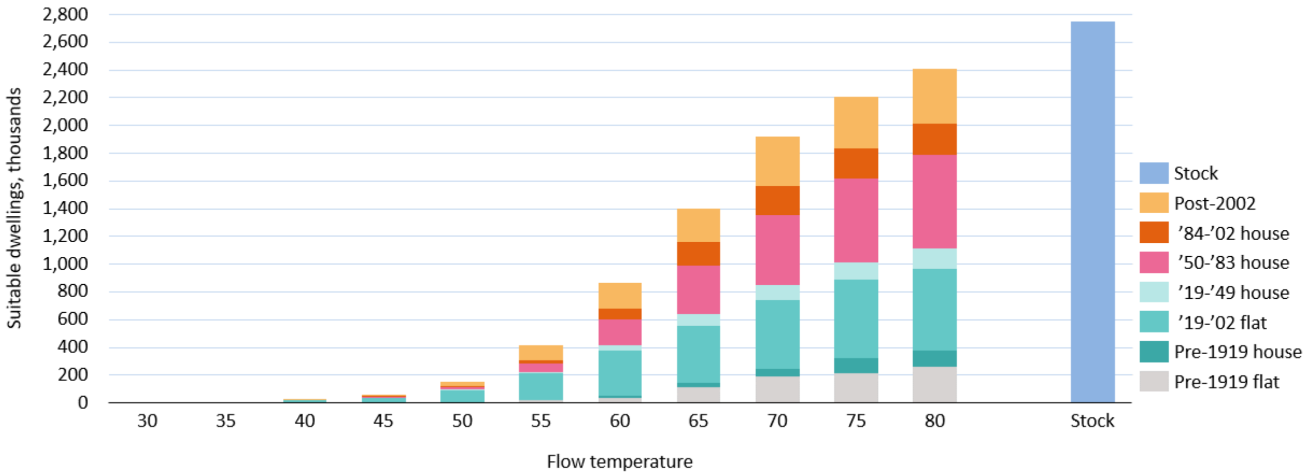

Figure 1 Absolute number of dwellings suitable to meet thermal comfort at each flow temperature (°C) on a winter peak day with no retrofits

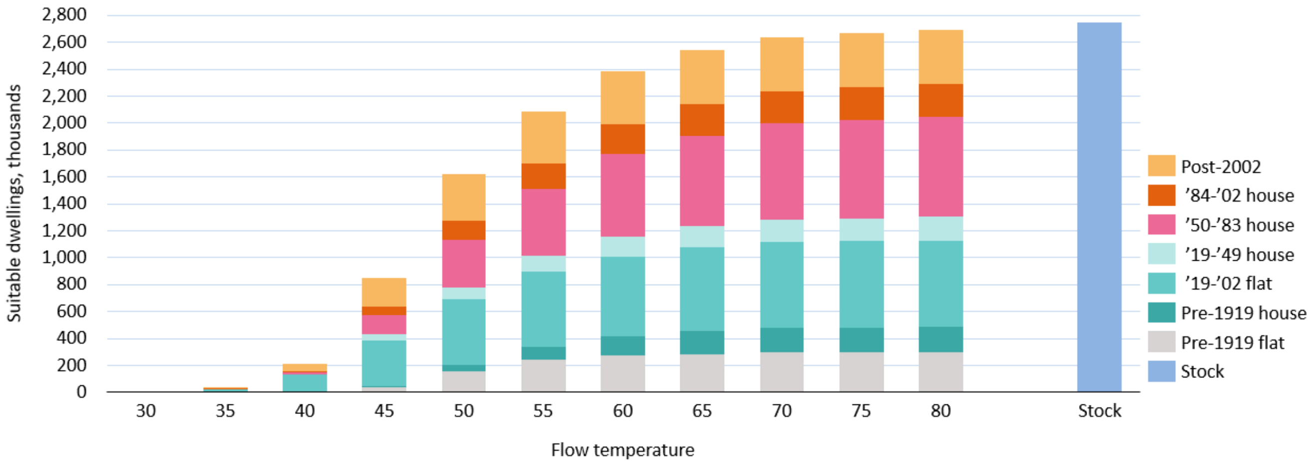

Figure 2 Absolute number of dwellings suitable at each flow temperature (°C) on a winter peak day with more extensive, higher cost, retrofits

We find that 30% of the overall housing stock is unsuitable for a flow temperature below 75°C, and 20% require a flow temperature above 75°C. This suggests these dwellings are either running at temperatures higher than 75°C or are currently unable to reach thermal comfort during periods of peak demand.

Fuel bill savings and emissions reduction from reducing flow temperature is significant and range from £151m to £501m in the stringent external temperature test cases. The associated greenhouse gas emission savings are estimated to be 6.17–10.18 $MtCO_2$ equivalent per year, depending on external temperature cases and retrofit scenarios. Exploring the potential for varying flow temperatures throughout the year could be one way to increase savings.

The most important factor when assessing suitability for flow temperature reduction is in setting temperature criteria that captures the needs of occupants. We used particularly stringent criteria in our assessments, requiring a dwelling to be heated to 20°C during the coldest hour of an average or 20-year winter peak. This may not reflect the reality of how heating systems should be, or are currently, expected to perform but it was selected to ensure the heating needs of the most vulnerable households were considered.

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2 Technical Glossary

Flow temperature	The temperature at which water or another heat transfer medium in a heating system is warmed to before being sent to heating emitters such as radiators in different areas of a building.
Heating emitter	A product that sends out heat, used to distribute heat around a building, e.g. radiators.
Thermal comfort	The condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.
Building envelope	The physical separator between the conditioned and unconditioned environment, typically including the building's floors, walls, windows, and roofing.
Draughtproofing	Measures to reduce airflow, such as applying physical fillers and sealants, around doors and windows.
Reduced infiltration measures	Measures to reduce airflow throughout the dwelling – this is like draughtproofing measures but is applied to other points of airflow throughout the dwelling.
Peak (or peak heating hour)	The calendar hour with the highest measured demand for heating in the previous calendar year, or the timespan being measured if otherwise specified.
Shoulder season	The period between typical warming seasons and cooling seasons. This typically refers to spring and autumn when lower demands for heating are observed. The November average is used in this report.
1-in-20 peak (historic cold snap)	The peak heating hour as measured over the previous 20 calendar years. This metric is often used to capture "historic" weather events such as cold snaps and heat waves.
Oversizing factor	The ratio of peak radiator capacity to peak energy demand in a building.
U-value	The U-value, also called thermal transmittance, measures how well a building element conducts heat. It quantifies the heat transfer rate, with lower values indicating better insulation. It is measured in $W/(m^2 \cdot K)$.
Specific heat loss	Specific heat loss refers to the rate of heat loss from a building at a given temperature differential between internal and external conditions. This is measured in W/m^2 of building envelope and is dependent on the U-value of the building envelope.

3 Introduction

Domestic heating system decarbonisation is crucial for achieving the Scottish Government's ambitious climate change targets of 75%, 90% and net zero emissions, relative to 1990, by 2030, 2040 and 2045 respectively. The transition to zero direct emissions heating (ZDEH) systems will require changes to the Scottish housing stock. This will potentially including preparing the building stock to operate at the lower flow temperatures that ZDEH options such as heat pumps operate.

Currently, the majority (approximately 85%) of dwellings in Scotland are heated by water based (wet) boiler systems, which typically operate at flow temperatures between 70-80°C. The remaining dwellings are heated by a mix of communal, heat pump, electric and off-grid systems. Flow temperature reduction has the benefit of reducing the energy required to meet the same internal room temperature, thus leading to reduced emissions and fuel bill costs in gas boiler and ZDEH systems alike.

We summarise the current evidence base for reducing flow temperature in the existing housing stock. We consider how flow temperature reduction might be applied to Scottish housing by modelling a range of lower flow temperature and assessing the potential suitability with varying degrees of retrofits.

4 Findings from literature review and stakeholder interviews

4.1 Range of temperatures for consideration

4.1.1 Evidence base for 55°C

According to the Heat Pump Association (see Appendix 8.1), 55°C is considered the "target" temperature for transitioning existing residential heating systems to lower-flow temperature systems. This is because it is an effective and relatively feasible "middle ground" between flow temperatures of current residential gas boiler currently (>70°C) and the direction of travel towards ZDEH technologies such as heat pumps (which operate optimally between 30-55°C).

At 55°C, most condensing boilers will run more efficiently (because more latent heat can be transferred from the flue gases at lower return temperatures) and there will be a reduction of wear and tear caused by cycling at current flow temperatures. Heat pumps, on the other hand, will reach the limits of their peak efficiency at approximately 55°C; at higher flow temperatures, efficiency will drop below quoted performance.

We found wide agreement in the stakeholder interviews (see Appendix 8.1 for stakeholder engagement overview) that most homes in the UK, and most homes in Scotland, will be able to run heating systems at 55°C without significant retrofitting. According to the CCC (2022), based on a report conducted by Nesta and Cambridge Architectural Research (2022), approximately 27% of homes in the UK currently are suitable for flow temperature reduction based on assumed ancillary attributes (namely radiator and pipework suitability). It is our understanding that a property assessment was not undertaken as part of the Nesta/Cambridge work. This estimate is about half of that found in previous research (Element Energy, 2021), which found that 53% of the UK stock was able to run at 55°C on a typical winter day (the percentage is reduced to 10% to reach thermal comfort on a winter peak day).

It was the opinion of our interviewed stakeholders that most homes in Scotland can successfully be run at 55°C, and that there were few attributes that would rule out this flow temperature (see Appendix 8.4).

4.1.2 Potential for further reduction

It is difficult to transition the housing stock to even lower flow temperatures below 55°C. The proportion of homes which are suitable without any works (or without major works) is significantly lower. Stakeholders suggested that some homes may not be suitable at all, but it is unclear if there was any tangible evidence or guidelines this was based on.

Our previous work (Element Energy, 2021) showed that the percentage of stock suitable for reduced flow temperatures reduces from 53% to 25% at 50°C, 6% at 45°C and <1% at 40°C. On a winter peak day (with an assumed external temperature almost 10°C lower) these proportions of houses suitable reduce to 3% at 50°C, 1% at 45°C and <1% at 40°C.

At lower flow temperatures, the specific heat loss of a property becomes increasingly important. Specific heat loss, in practice, is an indicator of how much heat will be required to maintain thermal comfort. Heat loss tends to have an inverse relationship with efficiency – a home with a low specific heat loss rate will be highly efficient, while homes with a high heat loss rate tend to be less efficient.

This is an important consideration when assessing the suitability of reducing flow temperature because in a home without retrofitting, a reduced flow temperature will decrease the amount of heat delivered to a room. If a room is difficult to heat because the home has a high heat loss rate, it becomes increasingly difficult to reach the desired temperature of that room because the system cannot adequately deliver or retain heat.

In this situation, one or both of the following paths can be taken to make a home suitable for a lower flow temperature:

Increase delivered heat. To do this, specific components of the heat system may need to be replaced or adjusted. The two key components are pipework, which impacts the flow rate of water through the system; and radiators, which emit heat transferred from the water. Existing pipework may need to be replaced to allow for a higher flow rate (which would help move more heat through the radiator in a given time period). Radiators could be replaced with larger units, which will allow more heat to be emitted due to an increase in absolute surface area. One or both options will increase delivered heat.

Decrease specific heat loss. To do this, a home needs to become more efficient through retrofitting to increase efficiency and airtightness. The two most important retrofits that can be undertaken are insulation (loft or wall) and window glazing. In addition, draughtproofing can be applied to windows and doors. These measures will lead to a higher rate of heat retention, meaning the absolute amount of heat that needs to be transferred to reach thermal comfort in a home is decreased.

4.2 Building envelope measures to increase suitability for flow temperature reduction

Increasing the efficiency of the building envelope decreases specific heat loss, thus supporting flow temperature reduction. Stakeholder interviews emphasised the importance of home retrofitting and maintenance, especially where homes are poorly insulated, as it also leads to heat demand reduction.

4.2.1 Home insulation

In general, more insulated homes will be more suitable for lower flow temperatures, due to the lower heat demand to reach thermal comfort. It is unlikely that there is a situation in which a home is "too insulated", except if this insulation does not allow for moisture to be driven from the masonry.

Interviewed stakeholders considered insulation as one of the most influential aspects for suitability to operate at lower flow temperatures. Despite a general concern that traditionally built homes were unlikely to be suitable for a lower flow temperature, one stakeholder suggested loft and wall insulation is likely to be sufficient. It makes little difference if the loft is used as a room (CCC, 2022), as insulating in either case will decrease the home's heat loss, but additional care should be taken due to the likely increased cost.

4.2.2 Window glazing

Similar to insulation, improving window glazing to double glazing or secondary glazing, is always beneficial for increasing the suitability of homes for reduced flow temperatures because they reduce the specific heat loss of a property. While triple glazing may offer benefits, it can introduce ventilation concerns and results in a lower marginal efficiency gain for flow rates compared to the adoption of double glazing.

Both double glazing and secondary glazing can effectively lower heat loss, but double glazing is a more expensive process and involves replacing entire units. Replacing existing windows with double glazed windows may be more difficult or restricted in traditional homes due to conservation/listed building status or for aesthetic reasons. Care should also be taken to balance ventilation requirements with increased glazing.

4.3 Ancillary components for the reduction of flow temperature

Ancillary components are key to effectively increasing delivered heat and/or decreasing specific heat loss. The overall efficiency of the heating system and, more generally, home energy efficiency will increase the suitability for flow temperature reduction. Some ancillary components are particularly important to a home's suitability, and these are discussed in the following sections.

4.3.1 Radiators

When radiators are fitted, the size of radiator suitable for a home is determined with consideration to the flow temperature the heating system runs at, alongside flow rate, to determine an adequate size to meet thermal comfort. If all else remains constant but the flow temperature is reduced, it is possible that the heat transferred to the radiator will not be sufficient. To mitigate this, existing radiators can be replaced with larger units which can transfer more heat, but this may be more expensive than other retrofit measures.

4.3.2 Pipework

Pipework is likely to be a key attribute for suitability of a home to increase the flow rate of the heating system. Like radiators, piping tends to be sized for the heating distribution system. Pipework may need to be replaced to account for a lower flow temperature, but our previous work (Element Energy, 2021) and stakeholders consulted had mixed opinions as to whether increased flow rate was an effective counterbalance to reduced flow temperature, and whether it would be required.

During our engagement with Renewable Heat (see Appendix 8.1, it was suggested homes were built or had heating system replacements between the 1980s and 2002 are more likely to require pipework replacements. During this period, a copper shortage led to smaller piping instalments across the industry. Due to an update to buildings regulations in 2002 this is not an issue for newer builds.

Pipework, compared to other ancillary components, is particularly susceptible to maintenance problems leading to inefficiencies. For example, past analysis (Element Energy, 2021) found that efficiency reductions due to sludge (15%), hydraulic imbalance (10%), air (6%) and limescale (15%) can impact the ability for a heating system to reach thermal comfort.

4.3.3 Other considerations

The efficiency improvements possible for pipework highlight the importance of regular maintenance for heating systems. Heat distribution systems should have annual maintenance servicing, but our recent analysis (Element Energy, 2021) found that currently only 20% currently participate in this. Proper maintenance would increase overall system efficiency, thus making reaching thermal comfort at lower flow temperatures more feasible.

4.4 Key risks to reducing flow temperature

4.4.1 Thermal comfort (human and fabric)

Reaching adequate thermal comfort is the goal of assessing the feasibility of lowered flow temperatures. There are clear guidelines (British Gas, 2022) set by knowledgeable bodies (including the Lullaby Trust, Energy Savings Trust, World Health Organisation and Age UK) for temperatures homes should be heated to depending on the occupant, including:

- Homes with new-borns should be heated between 16–20°C
- Homes with healthy occupants should be heated to 18°C
- Homes with occupants which are old, young or unwell should be heated to 20–21°C (some recommendations state homes can be warmed to 18°C as long as the main living space of the older occupant is heated to 21°C)

In practice, there are many instances where these temperature thresholds are not met, for technical and behavioural reasons. This complicates suitability assessments, because setting the above thresholds may require heating systems to perform to temperatures that are not used in practice. Some behavioural reasons homes are not heated to the above thresholds may include:

- Turning heating on/off in bursts, instead of maintaining a constant temperature
- Regularly keeping heating at a comfortable temperature below the guideline temperature (for example, 18°C instead of 21°C)

- Refraining from heating despite discomfort (often associated with fuel poverty)

The disconnect between recommended thermal comfort and behavioural practice makes assigning a temperature threshold for lowered flow temperature complex, but previous reports and stakeholders generally agree a reasonably lower flow temperature will not cost consumers' thermal comfort. It should be noted that special care may need to be taken for identified vulnerable consumers.

Nesta and The University of Salford (2022) suggests lower flow temperatures may lead to longer warming times, if flow rate and radiator size are not changed at the same time, due to the decrease in transferable heat. The acceptability of increased warming times would likely require a behavioural study.

Reduced flow temperature could also mean that room temperature cannot reach thermal comfort guidelines. It is not clear by how much and if this would cause a reduction from current practice. In the Nesta and The University of Salford (2022) study, homes with boilers and reduced flow temperature were able to reach within 0.5–2°C of thermal comfort (set at 21 °C in the living room, 22°C in the bathroom and 18°C in all other zones) on an average heating day, which is likely to be sufficient for most homes with healthy consumers.

Similarly, reduced flow temperature may make reaching thermal comfort on peak heating days more difficult. Further testing is likely to be required to better understand the impact of heating during periods of lower external temperatures. It could be the case that systems with reduced flow temperatures are within 2°C of thermal comfort on these peak days, which may be acceptable to occupants, but this is masked by the binary threshold of reaching thermal comfort.

Stakeholders agreed that buildings generally do not suffer from damp, moisture, and mould when the home is heated to human thermal comfort levels. Ensuring thermal comfort for humans is likely to provide adequate heating and avoid impacts on the building structure as well.

4.4.2 Unsuitable ancillary components

In many homes, reducing flow temperature without also retrofitting (e.g., adding insulation, replacing pipework, upgrading radiators) may cause the system to under-perform. The home would not reach thermal comfort due to the reduction of transferable heat and unimproved specific heat loss or system efficiency. Conversely, if the heating system is replaced before the home is retrofitted (insulation and window glazing, for example) the heating emitter could be oversized, causing increased cycling or inefficiency. To ensure this is not the case, retrofitting measures should be implemented before or in tandem with reducing flow temperature for an individual property.

Concerning the building masonry, the level of energy efficiency retrofitting should be balanced against the need to ventilate the home properly and drive moisture out of the walls to avoid deterioration of the home's exterior. This is a particular concern in older dwellings but should be considered for all dwellings. One stakeholder suggested approximately 100mm of wall insulation would be a good balance, but previous analysis suggests this may not be adequate insulation for energy efficiency. More research may be needed to understand this balance better.

4.4.3 Costs incurred by significantly lower temperatures

The Heat Pump Association suggests homes which are not properly retrofitted to increase heat delivery or decrease specific heat loss could be required to heat their homes for significantly longer periods of time, and thus higher overall energy consumption. This, in turn, would lead to an increase in both energy usage and the absolute value of energy bills.

Our engagement with the Heat Pump Association suggested that lower temperatures will require increasingly airtight, well-insulated homes with larger radiators to ensure the heat loss doesn't rise above 150W/m^2. For most homes, a flow temperature reduction to 45°C should not incur significant financial costs. To reduce flow temperatures further, homes must be increasingly efficient and airtight, potentially with larger radiators. These costs are likely to be prohibitive for many without financial support.

4.5 Key benefits to reducing flow temperature

4.5.1 Energy savings

When combined with required retrofits, reducing flow temperatures is expected to reduce energy use significantly. Previous work suggests savings are roughly correlated to the degree of change between the baseline temperature and new flow temperature. There are continued savings to be achieved by lowering flow temperature below 55°C.

Nesta and the University of Salford (2022) found 16–23% energy savings in gas used for heating when flow temperatures as low as 48.2°C were tested. This correlates to roughly 12–17% of overall gas savings at household level (assuming heating accounts for 75% of gas use in residential buildings). At low flow temperatures, care must be taken to ensure a boiler's intended operating regime is maintained, for example maintaining efficiency of a condensing boiler.

These energy savings will lead to savings in in fuel bill costs at the household level, due to the lowered energy required to heat the distribution system. The level of fuel bill savings will depend on a combination of flow temperature and fuel prices.

Emissions savings will also be a result of flow temperature reduction. Most homes in Scotland are heated with natural gas, so the direct reduction in natural gas use will reduce emissions. For homes heated with electricity, reducing electricity use on a grid that is not completely zero carbon will have indirect emissions reductions.

4.5.2 ZDEH readiness

The Salford Energy House (2022) study shows that even homes using boilers can benefit from reduced flow temperatures. The retrofits and system upgrades required for such a switch are often "no regret" decisions, no matter what future heat source the home will use (whether it be natural gas, hydrogen, electricity or district heating) because these changes improve the overall efficiency of the homes.

In general, low carbon heating systems run on lower temperatures, so all ancillary works, maintenance and upgrades will smooth the transition to a low carbon heating system across all home archetypes. There was agreement amongst stakeholders that ancillary works and reducing flow temperatures prepare houses for ZDEH systems. Systems with lower flow temperatures (including those currently using gas) use less overall energy to meet demand because the whole home system is more efficient.

5 Methodology for assessing flow temperature reduction

5.1 Overview

This study seeks to model the suitability for potential flow temperature reduction in heating systems in Scottish homes. The ideal methodology for an assessment of flow temperature reduction potential would include a property-specific heat loss calculation. In lieu of this, our method uses heat demand and property characteristics as a proxy for current ability to meet demand.

Property characteristics including levels of insulation, current heat distribution systems and heat demand was provided by the Home Analytics Scotland (HAS, 2022) dataset. The HAS dataset provides characteristics of the Scottish housing stock based on a compilation of datasets and modelling. This dataset is the result of whole-stock modelling conducted by the Energy Saving Trust. It should be noted that there is a discrepancy between the number of properties modelled as part of the work in this report (2,747,067 dwellings) and data in the Scottish House Condition Survey (Scottish Government, 2021) which accounts for approximately 10% less homes. We believe this is due to the modelling method used by Home Analytics Scotland.

Our assessment of suitability was led by stakeholder interviews and previous work (Element Energy 2020b, 2021). The previous work developed a suitability assessment for the UK housing stock based on dwellings' current oversizing factor.

Retrofit options were modelled using prices for materials and labour for individual retrofits taken from previous work for the CCC (Element Energy, 2020a).

Results from suitability modelling were then translated into energy demand reduction using heat demand profiles from the National Energy Efficiency Data-Framework (NEED), Scottish weather data and heat system efficiencies. Cost and emissions savings were calculated using up-to-date fuel prices and emissions data from recent Element Energy analysis.

5.2 Modelling approach

5.2.1 Defining suitability

The first step in this study's methodology was defining suitability, which considered both internal temperature and external temperature. Both sets of temperatures were based on previous work commissioned by BEIS (Element Energy, 2021).

The target internal temperature was 20°C, which is the lower end of the World Health Organisation's (WHO) recommended internal temperature range for dwellings with vulnerable occupants. While not every home has vulnerable occupants, there is no robust way to predict what homes will be occupied by vulnerable consumers, and as such an internal temperature target was chosen which could meet the needs of any consumer at any hour of a given year. This temperature is also aligned with the Microgeneration Installation Standard (MIS) 3005 (MCS, 2019), which recommends living zones maintain a temperature of 18–22°C.

We tested a dwelling's ability to reach thermal comfort (20°C) at various external temperature cases:

- **Winter peak**, our central case which tests suitability during the peak heating hour of an average year.
- **20-year peak**, which tested a dwelling's ability to reach thermal comfort during the peak heating hour of a historic cold snap. Also referred to as a **historic cold snap**.
- **Winter average**, which tested a dwelling's ability to reach thermal comfort during an average heating hour in an average winter (as opposed to the peak heating hour in the winter peak).
- **November average**, which tested a dwelling's ability to reach thermal comfort during an average heating hour in an average "shoulder season" (the heating hour used in this study is taken from an average November).

Suitability at a set internal and external temperature test case was measured based on the dwelling's oversizing factor, which is the ratio of peak radiator capacity to peak demand. See Appendix 8.2 for more information on why oversizing factors were used in lieu of specific external temperatures. Based on this oversizing factor, we know what minimum flow temperature each dwelling can operate at and still meet thermal demand. Oversizing factor ranges are set out in the BEIS study (Element Energy, 2021). Oversizing factors of between 1.00 and 1.20 suggest a dwelling's radiator capacity is adequately sized for the dwelling, while an oversizing factor under 1.00 suggests a heat distribution system will not be able to reach thermal comfort and a factor of over 1.20 suggests a heat distribution system is larger than required for the dwelling at a given flow temperature.

5.2.2 Archetyping and radiator mapping

The housing stock was aggregated into seven archetypes with the aim of modelling the suitability and impact of flow temperature reduction for a set of "average" homes. These archetypes were primarily based on stakeholder insights on the key determinates of flow temperature reduction based on their experience (age and house type). These were compared to the archetype design of the BEIS study, which used similar archetypes. The seven archetypes were:

- Pre – 1919 flats (approximately 10% of stock)
- Pre – 1919 houses (approximately 7%)
- 1919 – 2002 flats (approximately 23%)
- 1919 – 1949 houses (approximately 6%)
- 1950 – 1983 houses (approximately 27%)
- 1984 – 2002 houses (approximately 10%)
- Post – 2002 dwellings (flats and houses) (approximately 14%)

All dwellings in the HAS database were assigned an archetype, which was used for energy demand reduction, fuel bill and emissions savings calculations. We then assigned oversizing factors. Extrapolation of BEIS (Element Energy, 2021) survey data to the entire UK housing stock provided a distribution pattern across archetypes. This was used to assign oversizing factors for Scottish dwellings across the archetypes. Dwellings surveyed in the BEIS study were assigned archetypes from the above list and reassigned a proportion of the archetype stock that they represented based on extrapolation from the original study which maintained the robustness of the original study's housing stock mapping.

The clearest relationship observed in this data was that between building footprint and radiator capacity, with larger dwellings tending to have larger capacities. Dwellings in the BEIS survey and HAS dataset were ordered by archetype and building footprint. The radiator size, building peak demand and oversizing factors were assigned to dwellings from smallest to largest building footprint, maintaining the correct proportions in the housing stock. For example, if the smallest surveyed home in the pre-1919 flats archetype was found to represent 2.7% of the stock, this dwelling's data was assigned to the smallest 2.7% of HAS dwellings in the same archetype, and so on. This allowed the data to maintain the same oversizing factor distribution.

5.2.3 Suitability modelling

The suitability of the current housing stock portfolio was modelled based on the minimum flow temperatures each HAS dwelling could operate at using the oversizing factor. Retrofit packages were assigned to dwellings based on their archetype and existing levels of insulation. Two retrofit scenarios were modelled:

- The **Lower cost retrofit scenario**, where retrofit package costs could total approximately £2000 per dwelling, and
- The **Higher cost retrofit scenario**, where retrofit package costs could total up to 10% of the cost of a whole-home renovation. To determine this cost, the average price of a whole home renovation was taken for an "average" home, which was then scaled up or down for each archetype. This led to a range of costs between £6,000 - £12,000 (see Table 1 for these costs).

	Flats	Mid Terrace	End Terrace	Semi Detached	Detached	Bungalow
Maximum cost (£/dwelling)	6,123	7,459	9,106	10,670	13,585	11,143

Table 1 Retrofit costs for dwellings in the Higher cost retrofit scenario, by dwelling type

Dwellings were assigned retrofit packages based on the specific dwelling attributes in the HAS dataset. Because these attributes are in the original dataset, retrofit packages were assigned regardless of what external temperature case or radiator sensitivity was being tested.

Each dwelling was assigned two packages, one for each retrofit scenario (see Appendix 8.3 for list of retrofits). In both scenarios, most homes are assigned standard energy efficiency measures and/or radiator upgrades (75% and 71% in the Lower and Higher cost retrofit scenarios, respectively, see Figure 3 below). For many dwellings, additional insulation measures are required based on current level of insulation modelled by HAS. In some of these cases, dwellings can be insulated within the approximately £2000 price bracket, while other homes are more expensive to insulate. In these situations, the cost to insulate falls within the more expensive retrofit scenario.

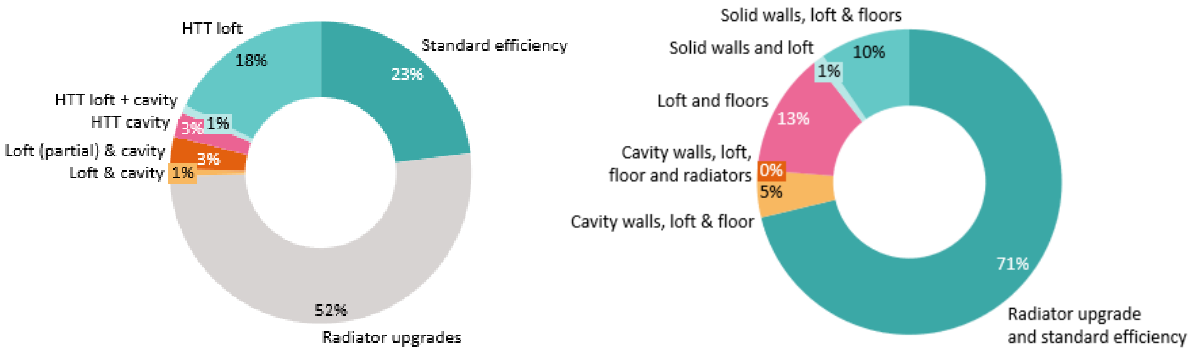

Figure 3 (Left) Retrofit packages assigned to the Scottish housing stock (Lower cost retrofit scenario); (Right) Retrofit packages assigned to the Scottish housing stock (Higher cost retrofit scenario)

Retrofit packages took a fabric first approach, prioritising measures with higher efficiency gains (mostly wall and loft insulation), then measures with lower-efficiency gains (increased draughtproofing, reduced infiltration measures and hot water tank insulation) and finally radiator upgrades where applicable. See Appendix 8.3 for details.

After a retrofit package was assigned to all dwellings in each retrofit scenario, the efficiency increases are applied to the dwellings assigned oversizing factors. This study assumed a direct relationship between energy efficiency increases and demand reduction, so an efficiency increase of 18% was applied by reducing the oversizing factors by 18%. These new oversizing factors were used to reassign dwellings to minimum flow temperatures. In practice, this may not reflect how efficiency increases are observed in dwellings, but an implementation-based study would be required to accurately capture this.

5.2.4 Fuel bill and emissions modelling

Results were aggregated at archetype level and used to find archetype-level energy demand reduction for fuel bill and emissions savings modelling. To calculate energy demand reduction at the archetype level, the average energy demand was calculated from the NEED (BEIS, 2022). Hourly energy demand profiles were calculated using the Watson method (Watson et al., 2019). We assumed all dwellings currently operate at 75°C flow temperature. The difference between 75°C flow temperature and lower temperatures (down to 50°C) was calculated based on the proportion of the stock which could support this for different external temperature case and retrofit scenarios. All dwellings suitable at temperatures below 50°C were modelled using 50°C savings, due to uncertainty over some boiler’s efficiency at lower temperatures. The cost and emissions modelling outputs were expected to be conservative estimates for fuel bill and emissions savings, due to not capturing the potential savings from 85°C to 75°C and temperatures under 50°C.

To calculate fuel bill savings, two fuel prices (representing a historic average and more recent fuel costs) were used to give a range of savings based on the energy demand reduction on national, archetype and archetypal individual dwelling levels.

To calculate emissions savings, the average natural gas emissions in Scotland were applied to the energy demand reduction on national, archetype and archetypal individual dwelling levels. In this calculation, all dwellings were modelled as gas boilers due to the overwhelming majority of boilers in the breakdown of heat distribution systems in the Scottish housing stock. Only 15% of homes do not currently use gas boiler systems, instead running on electricity or off-grid heating systems. Due to higher price per kWh for electricity, we expect these modelled results to be conservative estimates.

5.2.5 Method limitations

This study sets out to model flow temperature reduction suitability, for which practical research has not been conducted previously on Scottish housing stock. Our study aggregated several data sources and relied on previous research to assess suitability in lieu of property-by-property heat loss calculations and real time case studies for retrofitting and monitoring. As such, the method has several limitations that should be acknowledged when considering findings and conclusions (see Table 2 below for an overview of these limitations).

Limit	Rationale	Impact
Mapping radiator capacity, heat demand from BEIS (Element Energy 2021) study	UK/Scottish subset were reasonably aligned; allowed bigger spread of radiator capacity	This means a key element of the suitability criteria is modelled based on UK stock when ideally, we would have data from Scottish property surveys. In addition, this may predispose certain archetypes to being unfairly penalised or rewarded in the suitability modelling based on the smaller sample of dwellings surveyed as part of the BEIS study. This may be the case for the pre-1919 houses, for example, which are difficult to make suitable.
Lack of available data on ancillaries such as pipework	Data not available, so modelling would not have been robust	This factor for flow temperature reduction could not be assessed at present. Stakeholders provided useful insights and guides for further study. We confirmed that pipework was not an essential upgrade to meet the suitability levels we modelled but could be an additional factor to further increase proportions of stock that are suitable.
Thermal comfort was set at 20°C for all scenarios	We felt it was important to keep conservative estimates for internal temperature (led by WHO health standards for vulnerable occupants)	The use of a relatively high internal temperature target risks unfairly comparing dwellings with lower flow temperatures to a counterfactual that does not exist (because homes are often not heated to 20°C, and many homes are currently unsuitable for this level of heating).
Assume all current flows are 75°C in cost and emissions modelling	No reliable data to allow us to assign a proportion of the stock to higher flow temperatures	This may give a conservative estimate to fuel bill and emissions savings (because it captures the change from 75°C to X°C, so the additional savings from 85°C to 75°C are not accounted for).
All costs are set at 2022 prices (adjusted from 2019 data)	Lack of more up to date data with the same level of robustness	Does not consider inflation in future years (a retrofit package in 2024 may be pushed into a higher cost bracket by inflation or other market pressures in future years).

Table 2 Summary of method limitations and key assumptions with rationale and impact

6 Modelling results

6.1 Overview

We find that the majority of Scottish housing stock is currently unsuitable for flow temperature reduction to 55°C or below on a winter peak heating hour. However, more than half (60%) of the stock is suitable for a flow temperature reduction during the less stringent test case using the winter average. Both retrofit scenarios considered increase suitability for flow temperature reduction across all external temperature cases and home types. With Higher cost retrofits, between 64% (winter peak) and 97% (November average) of homes become suitable for a flow temperature of 55°C or below.

	Suitability now (2022)	Suitability with lower cost retrofits	Suitability with higher cost retrofits
Winter peak	15%	55%	76%
20-year peak	7%	41%	64%
Winter average	60%	85%	94%
November average	80%	92%	97%

Table 3 Suitability for Scottish housing stock for flow temperatures of 55°C for different temperature cases

6.2 Winter peak

The winter peak temperature case measures a heat system's ability to maintain thermal comfort during the peak heating hour in an average year.

Before Retrofit

Without retrofits, 15% of the housing stock (approximately 410,000 dwellings) in Scotland are suitable for flow temperature reduction to 55°C (See Figure 4 and Figure 5). Most of these dwellings are flats and post-2002 properties. 30% of post-1919 flats are suitable for flow temperature reduction, and 27% of post-2002 flats and houses. Combined, these two archetypes represent 75% of the suitable stock, and 11% of the overall stock. These two archetypes also capture the portions of the stock that can reduce to the lowest flow temperature without retrofits. In both archetypes, a small subset of homes is suggested to be suitable at a 40°C flow temperature without retrofits (7% of suitable post-1919 flats and 1% of suitable post-2002 flats and houses).

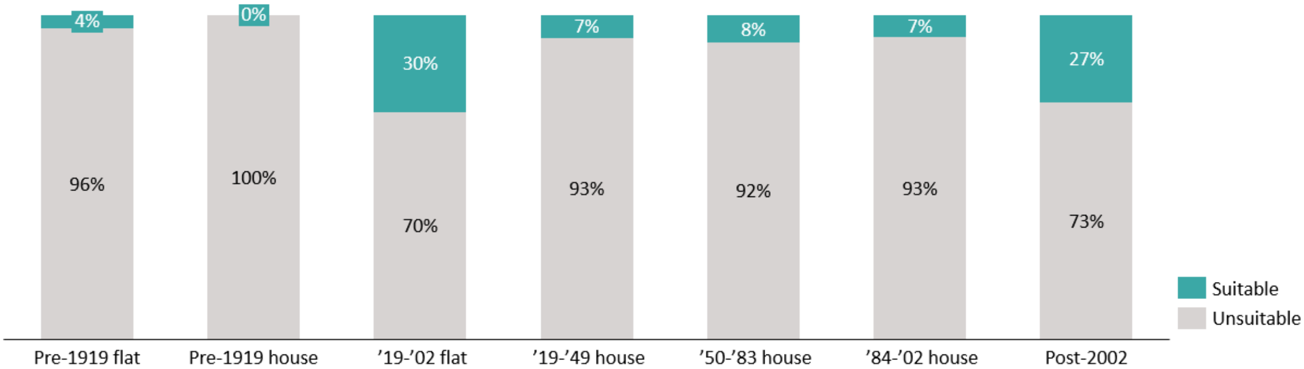

Figure 4 Proportion of stock suitable for 55°C, by archetype (no retrofit scenario)

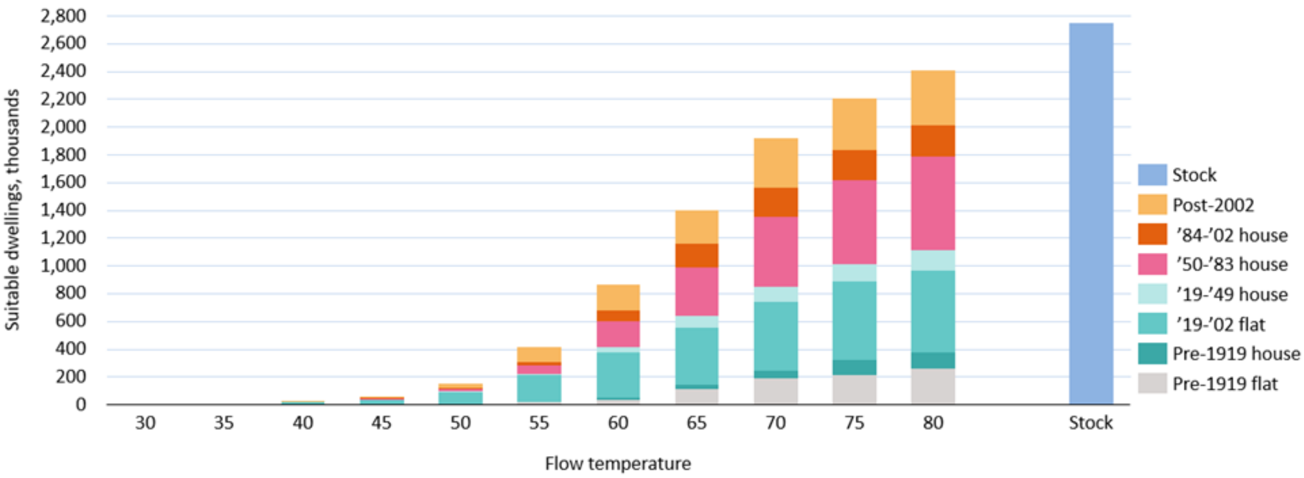

Figure 5 Dwellings suitable for each flow temperature (cumulative, no retrofit scenario)

Pre-1919 houses and flats and mid/late-century houses (1919-2002) are least suitable for 55°C flow temperatures, all having less than 10% of the archetype stock suitable. The majority for each archetype would be able to reduce flow temperature below 75°C (Figure 5). For example, among pre-1919 flats, 58% of homes are suitable for flow temperatures between 60°C and 70°C.

Pre-1919 houses are not suitable for flow temperatures of 55°C. This result is directly related to the archetype's lower proportion of adequately sized radiators from the mapping exercise and may also be related to the high heat loss rates in these dwellings. This archetype will require more significant energy demand reductions for homes to reach lower flow temperatures. Despite this, there is a proportion of the stock suitable for a more modest flow temperature reduction, with 30% of the stock being suitable to reduce to flow temperatures between 60°C and 70°C.

30% of Scottish housing stock is currently unsuitable for flow temperature below 75°C. 20% of the stock may also be unsuitable to run at 75°C. This suggests these dwellings are either running at temperatures higher than 75°C or are currently unable to reach thermal comfort during periods of peak demand.

6.2.1 Lower cost retrofit scenario

Lower cost retrofit packages are effective in increasing the proportion of homes suitable at a range of lower flow temperatures. After retrofits of around £2k, the proportion of homes suitable for 55°C increases to 55%. In addition to homes being suitable for 55°C, 36% of homes are suitable for lower flow temperatures.

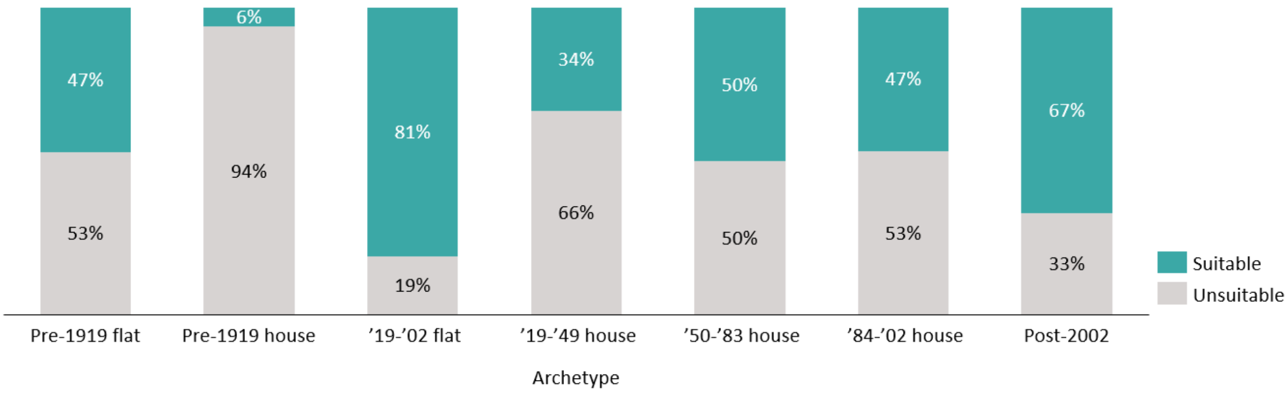

Figure 6 Proportion of stock suitable for 55°C, by archetype (Lower cost retrofit scenario)

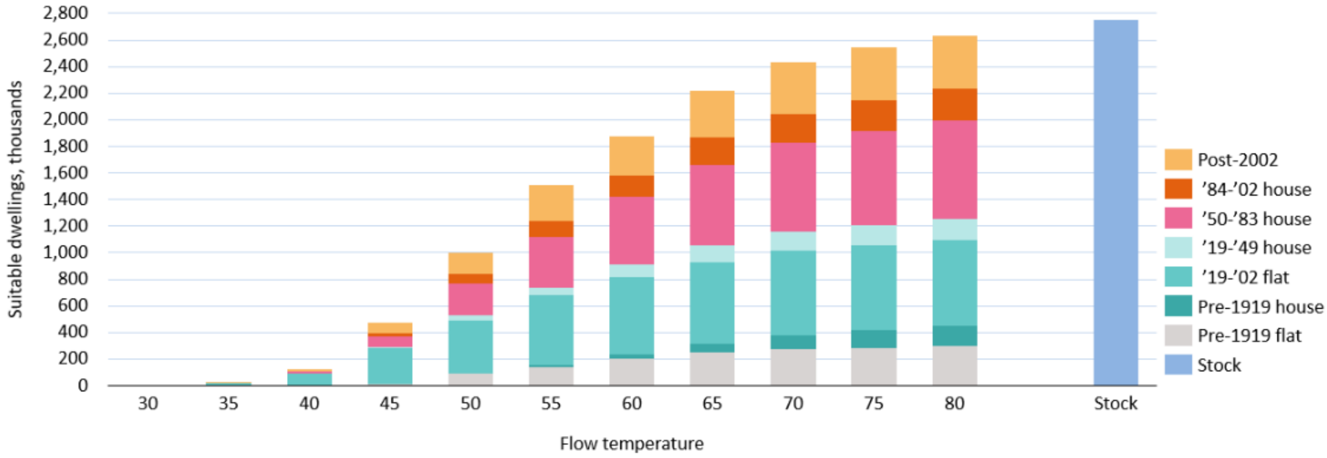

Figure 7 Dwellings suitable for each flow temperature (cumulative, Lower cost retrofit scenario)

Post-1919 flats and post-2002 archetypes continue to be most suitable, while the pre-1919 flats and houses and mid/late century (1919-2002) house archetypes had lower suitability, see Figure 6 and Figure 7. While the archetypes maintained the same relative standing, there are large differences in terms of proportions of the archetype stock that become suitable at lower flow temperatures.

The biggest beneficiaries of lower cost retrofits are the 1919-2002 house archetypes and the pre-1919 flat archetype. The absolute value of suitable homes increased between factors of 5x and 11x (pre-1919 flats and 1919-1949 houses, respectively).

Before retrofits are applied, older dwellings are generally less suitable for lower flow temperatures (see Figure 4). When retrofits are applied, the age of a dwelling appears to matter less than dwelling type (flat or house) with the suitability of pre-1919 flats being similar to houses built from 1950-2002.

The large proportion of the stock that becomes suitable after lower cost retrofits suggests that many dwellings in Scotland may be close (in monetary terms) to suitability for flow temperatures of 55°C. If 55°C is chosen as a "target" temperature, this suggests many homes in Scotland could achieve this target, even with stringent suitability criteria, for a relatively small amount of money. One or two larger efficiency measures (wall and/or loft insulation), an ancillary upgrade (radiators) or three smaller efficiency measures (hot water tank insulation, draughtproofing and reduced infiltration measures) would be required.

6.2.2 Higher cost retrofit scenario

After more extensive retrofits, 76% of the housing stock reaches suitability for reduced flow temperatures of 55°C. Similar, to the base and lower cost retrofit scenario, the post-1919 flats and post-2002 dwellings have the highest rates of suitability (see Figure 8). All archetypes other than pre-1919 houses are above 66% suitability for 55°C flow temperatures within their respective archetype stocks. The archetype with the largest change between scenarios is the pre-1919 homes, with suitability increased by a factor of over seven. In this scenario, almost half of the stock in this archetype reaches suitability (46%).

More homes in this scenario can reach even lower flow temperatures (i.e., flow temperatures between 30°C and 50°C). However, the lower cost retrofits changed the proportion of suitability for 55°C for a higher absolute number of homes than the higher cost retrofits (an additional ~1 million homes suitable, compared to an additional ~600,000 homes).

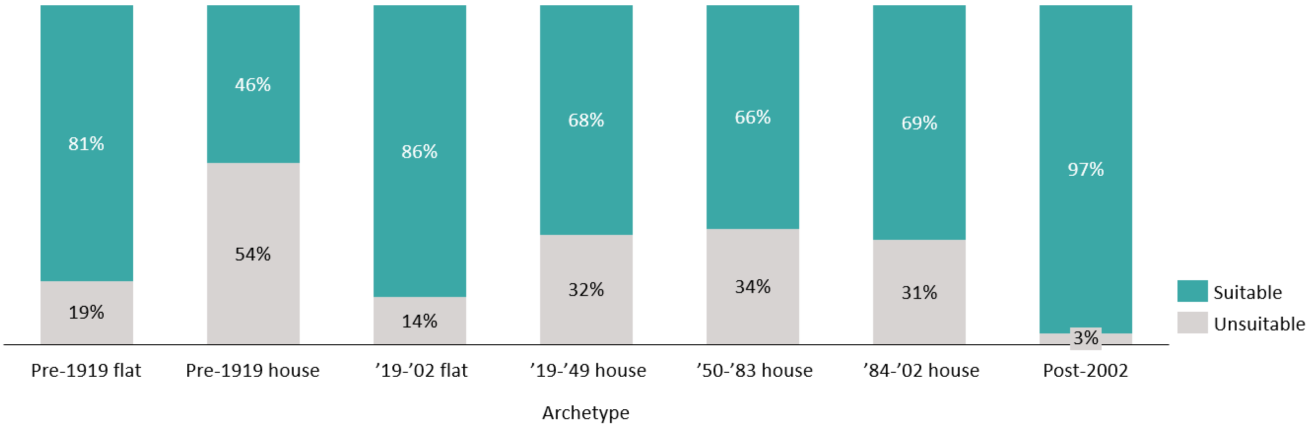

Figure 8 Proportion of stock suitable for 55°C, by archetype (Higher cost retrofit scenario)

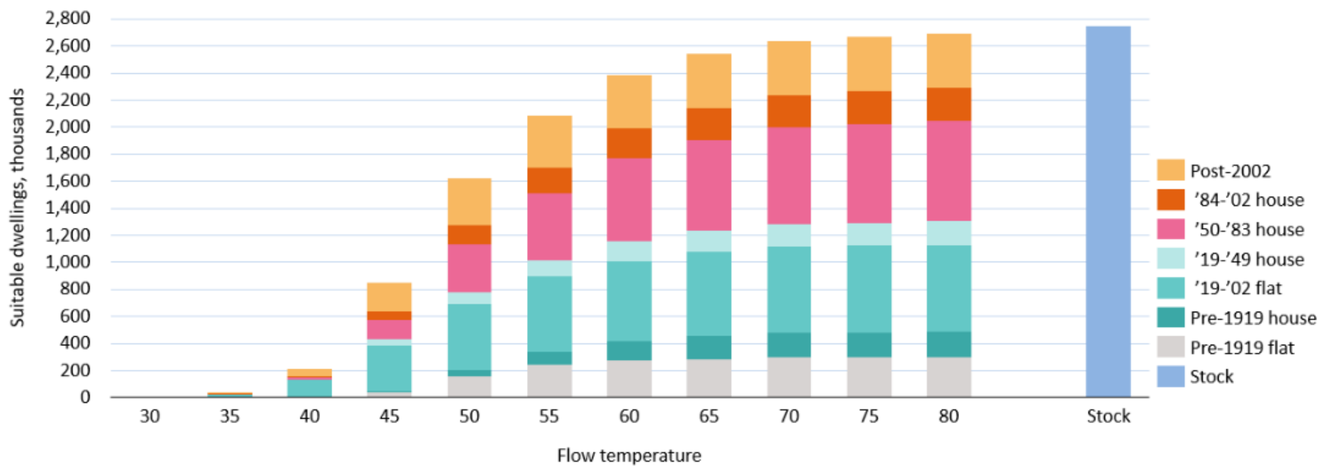

Figure 9 Dwellings suitable for each flow temperature (cumulative, Higher cost retrofit scenario)

6.3 20-year peak (historic cold snap)

The 20-year peak temperature case is our most stringent external temperature case, testing the ability for a dwelling to meet thermal comfort in a historic cold snap (the coldest day recorded in a given postcode for the past 20 years).

Without retrofits, the proportion of homes suitable to reduce to a flow temperature of 55°C include is only 7% of the stock (see Figure 10 and Figure 11), mostly consisting of post-1919 flats (4%) and post-2002 houses and flats (2%).

Some housing remains suitable for a flow temperature reduction below 75°C. Most suitable homes are post-1919 flats (15%), 1950-1983 houses (11%) and post-2002 flats and houses (10%).

In this case, over half (52%) of dwellings cannot meet thermal comfort below 75°C. In addition, 33% of the stock is not suitable for 75°C and is either currently operating at a higher flow temperature or would be unable to meet thermal comfort during a 20-year peak/historic cold snap.

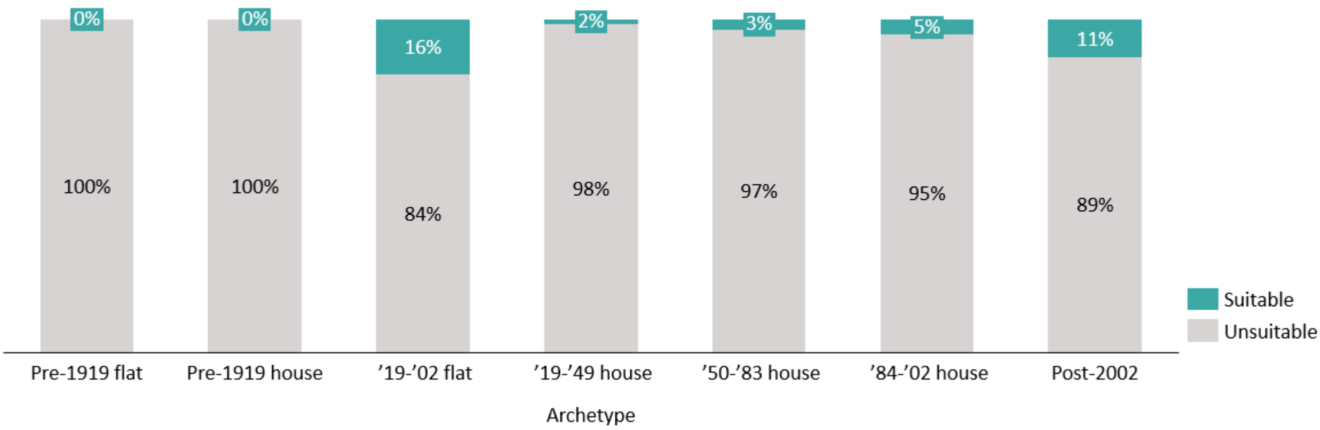

Figure 10 Proportion of stock suitable for 55°C, by archetype (no retrofit scenario)

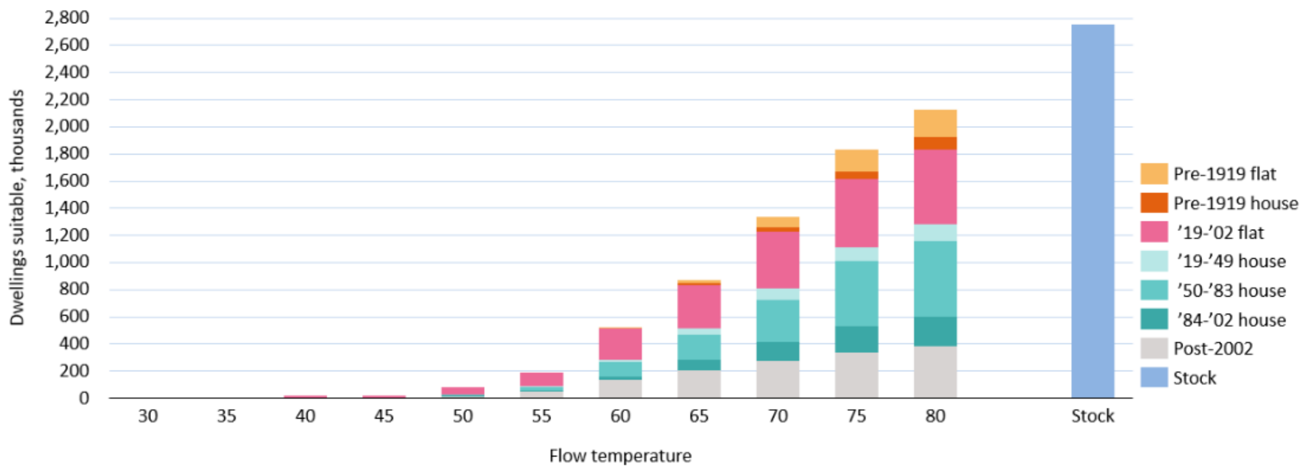

Figure 11 Dwellings suitable for each flow temperature (cumulative, no retrofit scenario)

6.3.1 Lower cost retrofit scenario

The application of lower cost (~£2k) retrofits also brings a significant portion of the housing stock to suitability for 55°C flow temperatures. 40% of the total housing stock could reach suitability even during a 20-year peak/historic cold snap (see Figure 12 and Figure 13).

Post-1919 flat and post-2002 dwellings archetypes continue as most suitable archetypes, both increasing by just over a factor of four. Combined, the suitable stock in these two archetypes represents almost one quarter of the total housing stock (23%).

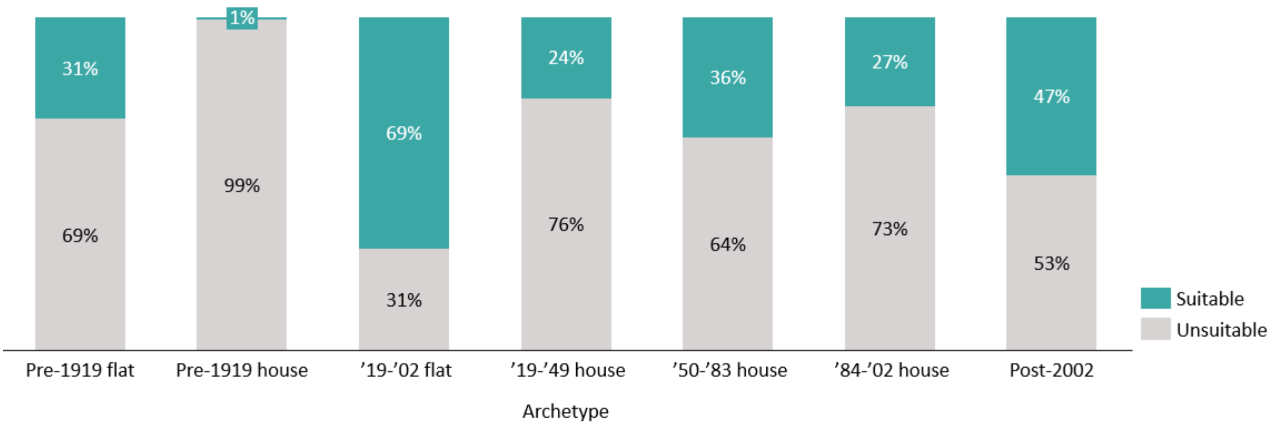

Figure 12 Proportion of stock suitable for 55°C, by archetype (Lower cost retrofit scenario)

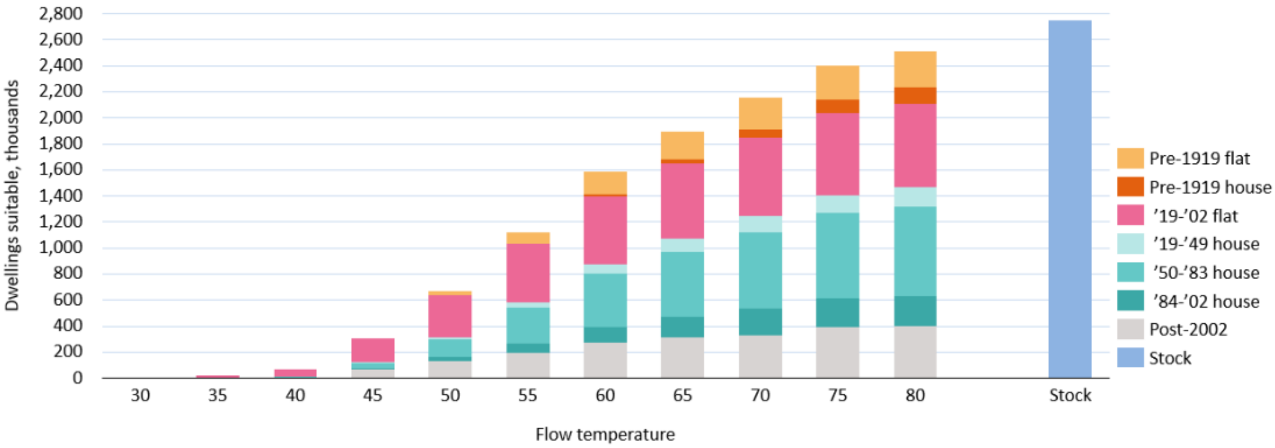

Figure 13 Dwellings suitable for each flow temperature (cumulative, Higher cost retrofit scenario)

Before retrofits, a correlation between age and suitability could be observed, with newer homes having slightly higher rates of suitability. After retrofits, the 1919-1949 homes and 1984-2002 houses have similar rates of suitability (24% and 27% respectively), while 10% more houses in the 1950-1983 archetype are suitable (36%). This suggests more houses in this archetype had oversizing factors on the higher end of each range, thus the same retrofit measure could have transitioned one home to 55°C and a house from one of the other archetypes to only 60°C. It could also suggest that more houses in this archetype required wall or loft insulation, and thus benefited more than other archetypes which received smaller energy efficiency uplifts from the "standard" measures.

6.3.2 Higher cost retrofit scenario

The archetypes with the highest proportions of suitability continue to be the post-1919 flats and post-2002 dwellings (78% and 92% of their respective stocks, and 32% of the total stock, see Figure 14 and Figure 15). All archetypes other than pre-1919 houses improve suitability for 55°C flow temperatures to above 51% of their respective archetype stock. In total, 64% of the stock becomes suitable after more extensive retrofits.

The change in suitability across the archetypes between the lower and higher cost retrofits are larger than in the winter peak case. Therefore, if the 20-year peak was chosen as the external temperature case to assess dwelling suitability, higher cost retrofits would be required achieve a high degree of suitability for lower flow temperatures. The absolute number of stock suitable would still be lower than in the other external temperature cases considered.

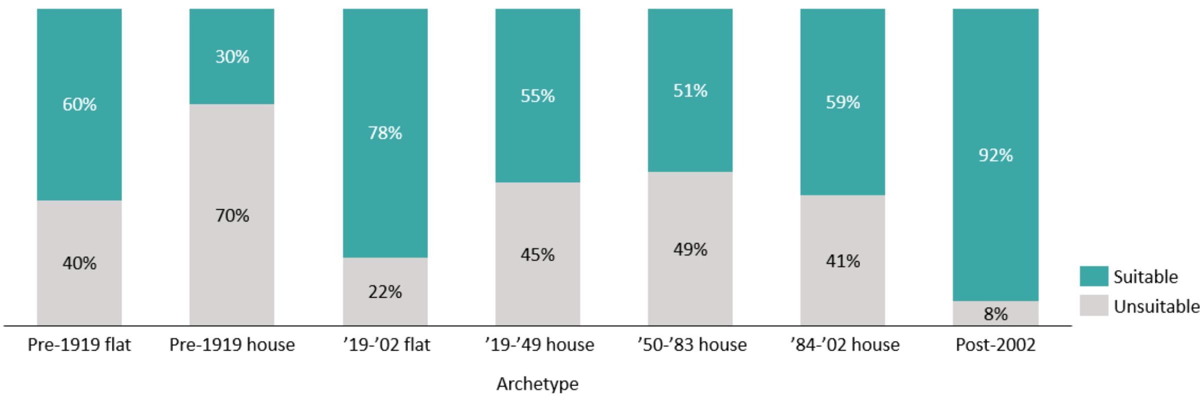

Figure 14 Proportion of stock suitable at 55°C, by archetype (Higher cost retrofit scenario)

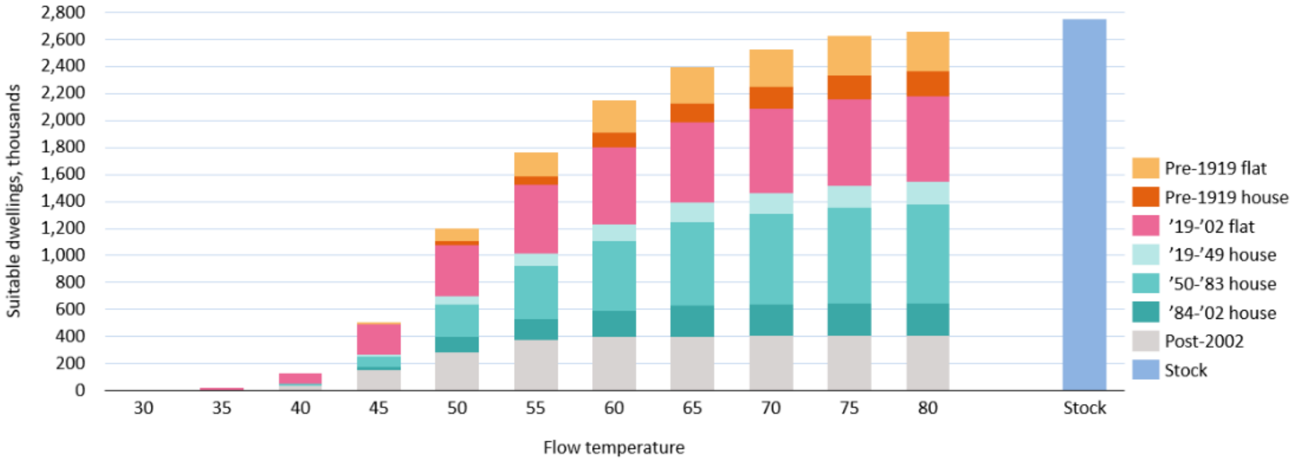

Figure 15 Dwellings suitable for each flow temperature (cumulative, Higher cost retrofit scenario)

6.4 Average external temperature cases

The two 'average temperature' cases (winter average and November average) were tested to gauge the suitability of dwellings under less stringent criteria. The results show that with less stringent criteria, much larger proportions of the stock are already, or can be made suitable, for 55°C and lower flow temperatures. See Appendix 8.5 for full archetype results.

The results show that 60-80% of homes are already suitable for 55°C flow temperatures for these less stringent external temperature cases. Lower cost retrofits increase this to 85-92% (for winter average and November average respectively). Higher cost retrofits result in almost all homes being suitable for 55°C (94-97%).

6.5 Importance of radiator upgrades

In half of the model runs, we investigated a reduced potential for radiator upgrades in all dwellings. The intention was to model the potential for flow temperature reduction when there were significant barriers to radiator upgrades (which could be caused by impracticalities or aesthetics).

In the winter peak cases, reducing radiator uptake decreases the suitability of the stock at every flow temperature tested. This demonstrates that upgrading radiators could be a key retrofit measure for facilitating flow temperature reduction.

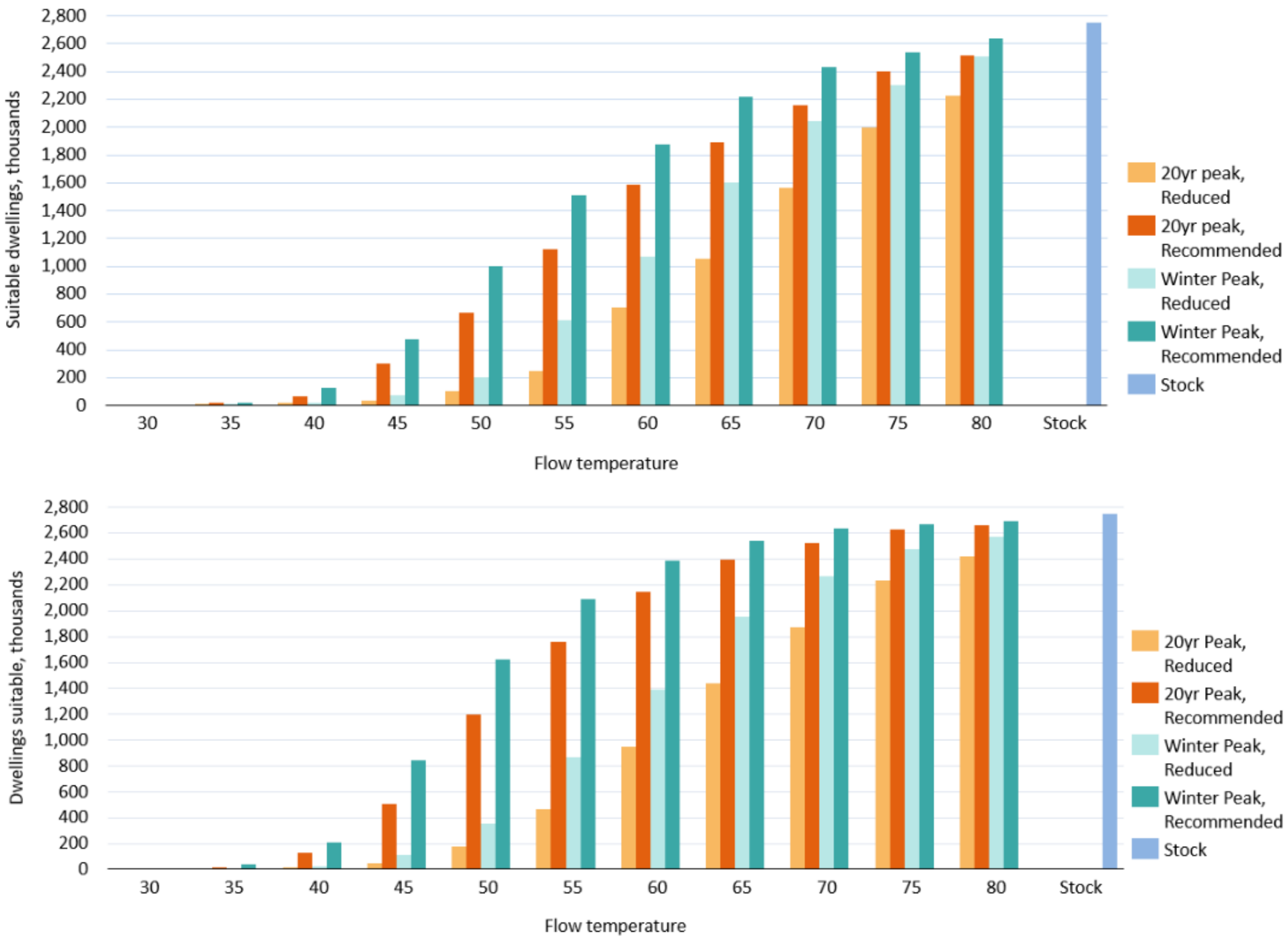

Figure 16 Comparison of dwellings suitable at each flow temperature (cumulative) when reduced and recommended rates of radiator uptake are tested in peak external temperature cases, Lower cost retrofit scenario (above) and Higher cost retrofit scenario (below)

6.6 Fuel bill and emissions modelling

The final step in this study is translating energy demand reductions from lower flow temperatures into fuel bill and emissions savings estimates by archetype.

6.6.1 Fuel bill modelling

At a flow temperature of 55°C, dwellings can save between £50 and £300 per year depending on the archetype and fuel cost scenario. The ranges for each archetype are set by applying low and high fuel costs to the archetype's average annual heat demand from the NEED database (BEIS, 2022). As such, this is reflective of the archetype's average energy demand patterns as opposed to being reflective of anything tested or modelled in the suitability assessment detailed above. Based on the NEED data, the flat archetypes and 1984-2002 houses will potentially save the most in fuel bills on a per dwelling basis (see Figure 17).

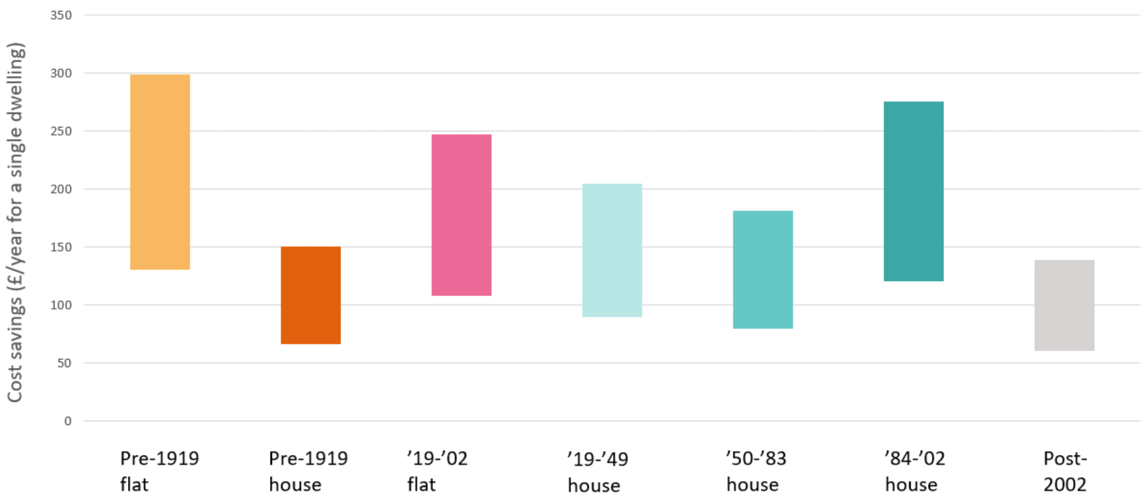

Figure 17 Cost savings when moving from 75°C to 55°C (showing cost range from 4.5p/kWh and 10.3p/kWh)

When aggregated, the potential for fuel bill savings is significant (Table 4). At the lower fuel price, savings range from £151m-£249m depending on the temperature case and retrofit scenario. Higher fuel prices increase this to £345m-£624m.

	Lower cost retrofits		Higher cost retrofits	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Winter peak	£181m	£414m	£219m	£501m
20-year peak	£151m	£345m	£198m	£454m
Winter average	£233m	£580m	£244m	£624m
November average	£244m	£558m	£249m	£570m

Table 4 Aggregated total fuel bill savings per year for all temperature cases and retrofit scenarios (at both fuel prices)

Table 5 shows the potential savings if all dwellings' flow temperatures are reduced as low as they are suitable higher cost retrofits are applied at archetype level. In this temperature case, highest savings come from the post-1919 flats and the 1950-1983 houses.

The winter peak temperature case results in higher savings than the 20-year peak. This is due to a higher absolute number of suitable homes at increasingly lower flow temperatures in the winter peak case, which uses less stringent suitability criteria.

Savings per year, by archetype (£m)	Winter peak		20-year peak	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	34.58	79.16	30.40	69.59
Pre-1919 house	9.19	21.03	7.16	16.39
1919-2002 flat	64.40	147.40	60.70	138.94
1919-1949 house	12.95	29.63	11.38	26.04
1950-1983 house	47.85	109.52	41.44	94.85
1984-2002 house	26.01	59.54	23.62	54.06
Post-2002	23.92	54.75	23.48	53.75

Table 5 Potential for fuel bill savings (£m/yr) in peak external temperature cases when all suitable dwellings reduce flow temperatures to 55°C, aggregated to the archetype level (Higher cost retrofit scenario)

		Savings per year, by dwelling (£)			
		Winter peak		20-year peak	
	Average cost to retrofit	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	£1331	117.43	268.78	103.23	236.28
Pre-1919 house	£4831	45.27	103.62	35.29	80.78
1919-2002 flat	£754	99.76	228.35	94.04	215.24
1919-1949 house	£2354	72.09	165.00	63.35	145.00
1950-1983 house	£2600	63.35	145.01	54.87	125.59
1984-2002 house	£2404	96.39	220.63	87.52	200.31
Post-2002	£396	59.89	137.08	58.79	134.57
Average	£2096	£79.68	£182.39	£72.14	£165.13

Table 6 Potential for fuel bill savings in peak external temperature cases when all suitable dwellings reduce flow temperatures to 55°C, on a per dwelling basis (Higher cost retrofit scenario)

When assessed on a per dwelling basis (see Table 6), the archetypes with the highest fuel bill savings include the pre-1919 flats, post-1919 flats and 1984-2002 houses. These all have the highest rates of savings per dwelling as a direct result of their archetypes' NEED data. The other archetypes have similar savings per archetype, and the pre-1919 houses have the lowest potential savings at the household level.

Table 7 shows the impact of reducing flow temperatures a further 5°C, to 50°C. Estimates for total fuel bill savings are given. Dwellings suitable for reduction beyond 55°C are assigned savings from reducing to 50°C. The range of savings is increased to £181m-£802m (from £151-£624m at 55°C) depending on the temperature case and retrofit scenario.

Savings per year	Lower cost retrofits		Higher cost retrofits	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Winter peak	£227m	£519m	£291m	£666m
20-year peak	£181m	£414m	£251m	£575m
Winter average	£318m	£728m	£350m	£802m
November average	£347m	£795m	£363m	£831m

Table 7 Aggregated total fuel bill savings per year for all temperature cases and retrofit scenarios (at both fuel prices) when all suitable dwellings reduce flow temperatures to 50°C

6.6.2 Emissions modelling

At 55°C, dwellings can save between 2.5 $kgCO_2$/year and 5.5 $kgCO_2$/year depending on the archetype. The emissions saving estimate for each archetype is set by applying the archetype's average annual heat demand to the carbon intensity of natural gas used for residential heating in Scotland. Based on this, the flat archetypes and 1984-2002 houses have the highest potential emissions savings (see Figure 18).

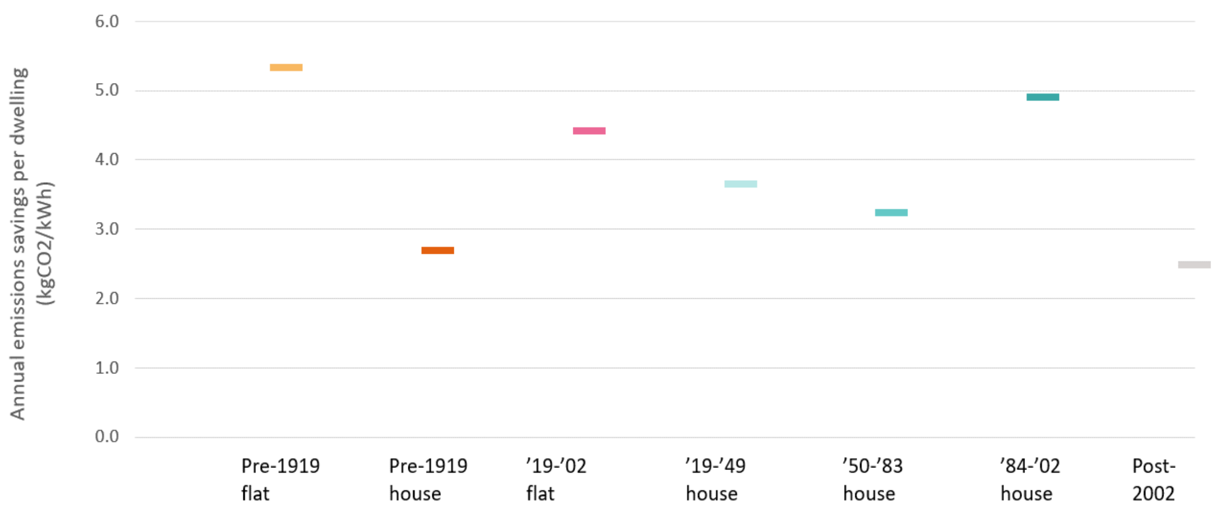

Figure 18 Emission savings when moving from 75°C to 55°C - showing emissions based on 0.184 $kgCO_2$/kWh for natural gas

When aggregated to the archetype level, the potential for emissions savings ranges from 8.10 $MtCO_2$/yr in the 20-year peak to 8.95 $MtCO_2$/yr in the winter peak for higher cost retrofits. The November average and winter average result in higher emissions savings than the winter peak and 20-year peak temperature case (see Table 8). This is expected due to the increasingly stringent suitability criteria meaning that more homes are suitable for reduced flow temperatures in the average cases compared to peak cases. Lower cost retrofits also reduce potential emissions savings, with a range of 6.17 $MtCO_2$/yr (in the 20-year peak temperature case) to 9.96 $MtCO_2$/yr (November average temperature case).

Total savings per year ($MtCO_2/yr$)	Lower cost retrofits	Higher cost retrofits
Winter peak	7.40	8.95
20-year peak	6.17	8.10
Winter average	9.54	10.00
November average	9.96	10.18

Table 8 Potential emissions savings across all temperature cases and retrofit scenarios when all suitable dwellings reduce flow temperatures to 55°C

Table 9 shows the potential savings if all dwellings' flow temperatures are reduced as low as they are suitable after higher cost retrofits are applied. Most savings come from the post-1919 flats, followed by the 1950-1983 houses and pre-1919 flats.

Savings per year, by archetype ($MtCO_2/yr$)	Winter peak	20-year peak	Winter average	November average
Pre-1919 flat	1.41	1.24	1.56	1.57
Pre-1919 house	0.38	0.29	0.49	0.51
1919-2002 flat	2.63	2.48	2.82	2.84
1919-1949 house	0.53	0.47	0.62	0.64
1950-1983 house	1.96	1.69	2.33	2.40
1984-2002 house	1.06	0.97	1.19	1.23
Post-2002	0.98	0.96	0.99	0.99

Table 9 Potential emissions savings in peak external temperature cases when all suitable dwellings reduce flow temperatures to 55°C, aggregated to the archetype level (Higher cost retrofit scenario)

Table 9 shows the breakdown of the emissions savings by archetype for all temperature cases with higher cost retrofits. The pre-1919 house archetype has the lowest potential savings at archetype level while post-1919 flats and 1950-83 houses provide the highest emissions savings.

Table 10 shows the impact of reducing flow temperatures a further 5°C, to 50°C. Dwellings suitable for reduction beyond 55°C are assigned savings from reducing to 50°C. This shows that emissions savings increase at the lower flow temperature.

Savings per year, by archetype ($MtCO_2/yr$)	Lower cost retrofits	Higher cost retrofits
Winter peak	9.27	11.90
20-year peak	7.39	10.27
Winter average	13.01	14.33
November average	14.19	14.85

Table 10 Potential emissions savings in all external temperature cases and retrofit scenarios when all suitable dwellings reduce flow temperatures to 50°C

7 Conclusions

7.1.1 The evidence base for flow temperature reduction

This study finds a strong theoretical case for broad flow temperature reduction in heating systems and suggests that 55°C is a suitable temperature target, which could result in reductions in energy demand and emissions at individual dwelling level.

While previous work and stakeholders suggest many dwellings will be able to run at 55°C without significant retrofitting, we note the importance of assessing suitability with property-by-property specific heat loss calculations. Our study and others use a variety of factors including ancillary component characteristics, building insulation levels and oversizing factors as proxies for a dwelling's suitability. However, minimum flow temperature potential should be based on a property-level assessment where possible.

7.1.2 Suitability of the Scottish housing stock

This study has found a lower current level of suitability than suggested through the literature review and stakeholder engagement process. We found 15% of the current housing stock would be suitable for reduced flow temperature at present in our winter peak temperature case, which decreases to 7% in the 20-year peak case.

Suitability increases significantly after retrofits, reaching 55% and 76% of the total stock in the winter peak case after lower cost and higher cost retrofits, respectively. In the 20-year peak case, overall stock suitability rises to 41% to 64% after lower cost and higher cost retrofits, respectively.

There is also potential for dwellings to lower flow temperatures below 55°C, potentially into the 30–50°C range (60% of dwellings in the winter peak, higher cost retrofit scenario), given the heat distribution system's operating regime is properly maintained and sufficient retrofits are undertaken. This may be more straight forward in some dwelling types than others, particularly flats and recent properties.

The most important factor when assessing suitability for flow temperature reduction is setting suitability criteria that adequately captures the needs of occupants. Our two key temperature cases use particularly stringent criteria, requiring that dwellings should be heated to 20°C during the coldest hour of an average or historic year. This is an ambitious goal and not one currently being met by many heating systems operating between 70°C–80°C, as evidenced by the significant portion of homes that could not meet thermal comfort while operating at 75°C in the scenarios modelled in this study. Care should be taken to ensure that suitability is sufficiently, but not overly, stringent.

The other temperature cases tested in this study (winter average and November average) test a dwelling's ability to meet suitability during a heating hour in average winter temperatures. Significantly larger proportions of dwellings are suitable for low flow temperatures in these cases suggesting that for most of the year, many homes are suitable to run at lower flow temperatures than in our stringent test cases. Exploring the potential for varying flow temperatures throughout the year could be one way to increase the fuel bill and emissions savings overall, only increasing the flow temperature when heat distribution systems need to meet thermal comfort in peak hours.

Varying internal temperatures may also bring more homes into suitability for lower flow temperatures but this was not modelled in this study. If the internal temperature was lowered (for example to 18°C, which is in the healthy living range for healthy, not vulnerable, occupants) during peak heating hours, more homes could be made suitable. In practice, this would imply an acceptance that domestic heating systems are not expected to meet the higher end of thermal comfort during peak heating hours, which is already the case in many dwellings.

Our study suggests some dwelling archetypes will have higher proportions of the stock already suitable at lower temperatures and that these archetypes will also likely be easier to retrofit for flow temperature reductions. These dwellings tended to include flats and post-2002 dwellings. This could be due to multiple factors, including building footprint in the case of the flats and better building regulations which mandate higher levels of efficiency in the newer dwellings.

Conversely, some dwellings are likely to be harder to prepare for flow temperature reduction and will have a smaller proportion of the stock able to transition without retrofits. This study showed the difficulty in transitioning the pre-1919 houses, which are currently unsuitable for 55°C. These are larger, built with solid walls and tend to have undersized heating systems. This means more expensive retrofits will likely be required to support these dwellings in transitioning to lower flow temperatures. Our modelling identifies that after higher cost retrofits than for other dwelling types, almost half of homes in this archetype can reach suitability for reduced flow temperatures to 55°C.

7.1.3 Retrofitting the housing stock

A consistent finding from this study is that across archetypes and scenarios, retrofits significantly improve the proportion of the housing stock suitable for flow temperature reduction. We have found that building envelope retrofits (insulation, window glazing) and ancillary upgrades (pipework, radiators) are complementary in the transition to ZDEH systems. This means that building retrofits could be a reliable way to increase suitability for reduced flow temperatures and, at a later date, ZDEH systems.

To prepare a dwelling for lower flow temperatures, we suggest that building envelope measures are prioritised to reduce the overall energy demand of the home. Where this is not possible (because dwellings are not adequately insulated, for example) ancillary upgrades should be implemented. Radiator upgrades could be implemented, and the same goal of flow temperature reduction could be achieved but this does not improve energy efficiency in the domestic heating system.

Increased budgets for retrofits lead to increased gains in fuel bill and emissions reductions by allowing dwellings to achieve lower flow temperatures. Even the lower cost retrofit packages resulted in significant fuel bill savings (£151m–£580m depending on temperature case and fuel cost) and potential emissions savings (6.17–9.96 $MtCO_2$/year depending on temperature case).

7.1.4 Benefits to flow temperature reduction

Our findings indicate that there is potential for fuel bill and emissions savings across all archetypes. With higher cost retrofits, fuel bill savings from transitioning the stock to lower flow temperatures could total between £198m and £501m depending on the winter temperature case. Emissions savings are suggested to follow the same trends, with potential to save between 8.10 MtCO_2/year and 10.18 MtCO_2/year (depending on the winter temperature case).

The fuel bill savings and emissions reduction modelling undertaken in this work supports the view that any flow temperature reduction, whether around 55°C or lower, will bring benefits.

8 Appendices

8.1 Stakeholder engagement summary

Targeted stakeholder engagement was carried out to source further quantitative information and qualitative insights from industry experts. Stakeholders were selected due to their expertise on specific areas of interest and practical experience in this area. A summary of the relevance of the organisation and topics discussed for each stakeholder organisation is shown below.

Organisation: Historic Environment Scotland

Relevance: Knowledgeable government agency

Topics discussed:

- Thermal comfort of occupants and building fabric (with an emphasis on maintaining enough ventilation in the dwelling to avoid moisture build-up, resulting in damp and mould).
- Potential to reduce the flow temperature in historically built dwellings (in our study, this means the pre-1919 flats and houses) and what insulation measures might best support this aim.
- Suitability for historically built dwellings to maintain lower internal temperatures than occupants can safely live in, thus suggesting internal temperature is not a concern for the health of the building envelope.
- Potential difficulty in renovating historically built homes, particularly challenges around floor insulation and double/triple window glazing.
- Benefits to lowering flow temperatures and heating the house more gradually.

Organisation: Heat Pump Association

Relevance: Industry organisation

Topics discussed:

- Confirmation of HPA's assertion that 55°C is the "target" flow temperature for all dwellings, and reasoning behind this (discussion around 55°C as the "compromise" between the increased efficiency of boilers at lower flow temperatures and heat pumps' ability to operate efficiently at up to approximately this temperature).
- The trade-off between benefits of reduced flow temperature and increasingly stringent requirements for air tightness and increased energy efficiency measures in the dwelling, which also played a role in HPA's selection of a "target" flow temperature.
- Discussion of risks of legionella, and components of heat pumps which will guard against legionella risk (including a broader discussion on factors causing legionella).

Organisation: Renewable Heat

Relevance: Heat pump installation specialists

Topics discussed:

- Potentially for the Scottish housing stock to reduce flow temperature, based on experience and monitoring efforts by renewable heat (this include a conversation regarding how to best consider whether dwellings might be suitable for flow temperature reduction based on their type and age, then being further segmented by insulation measures and specific heat loss rates).
- Discussion around credibility of HPA's target flow temperature across homes, which Renewable Heat thought was a generally sound target.
- Discussion around potential to reduce flow temperature beyond 55°C, and the difficult of preparing the housing stock for temperatures this low, including what potential considerations may need to be taken for various dwellings, particularly the historically built dwellings.
- Rules of thumbs for what heat loss rates are required for reducing the flow temperature in 5°C increments, and at what point underfloor heating would be required regardless of building envelope and a low heat loss rate, based on the company's installations.
- Potential for pipework replacement required as part of ancillary upgrades to the dwelling due to pipes with smaller diameters being common in the late 20th century (this would be relevant if the flow rate of the heat distribution system needed to be increased to improve heat transfer).

Organisation: Ovo Energy

Relevance: Energy company, heat pump trial participant

Topics discussed:

- Potential for boiler and heat pump systems to reach flow temperatures of 55°C or lower, and the difference in low temperature versus high temperature units.
- Impact of refrigerant type on heating system performance.
- Importance of prioritising building envelope retrofits to increase energy efficiency as a means of overall energy use reduction.
- Potential oversizing of radiators in the housing stock today.
- Importance of retrofitting the dwelling before/as the heat system or ancillary components are being replaced, to avoid an unnecessarily large oversizing factor.
- Ability for homes with heat pumps and lower flow temperatures to meet thermal comfort, with discussion of case studies in cold-weather climates (i.e., Scandinavia).

Organisation: Energy Saving Trust

Relevance: Knowledgeable company

Topics discussed:

- Validation of topics discussed in above stakeholder engagement.
- Potential oversizing of radiators in the housing stock today.
- Building envelope efficiency measures versus ancillary component (mainly radiators) upgrades for flow temperature reduction.
- Importance of prioritising overall energy efficiency over ancillary upgrades as a means of overall energy use reduction (and the importance of preparing the stock for flow temperature reduction as a means of achieving other goals such as overall energy reduction, decarbonisation, etc.).

8.2 Peak external temperature cases

In this study, we used external temperature cases assigned to specific properties from previous analysis for BEIS (Element Energy, 2021) to inform oversizing factors for heating systems. Oversizing factors for properties, which included the relationship between peak external temperature and radiator capacity, were used instead of assigning specific peak external temperatures to each home. Homes are not explicitly assigned peak external temperatures because this would require granular data about the heat system capacity of individual homes, which was not available in the HAS data.

The temperatures in the original modelling (Element Energy, 2021) are more akin to Scottish central belt temperatures. The external temperatures from the original study would not be an accurate reflection of average Scottish temperatures across the whole country, so were not used in this work. Instead, we extrapolated the relationship between external temperature and the ability for heat systems to meet demand in homes.

These temperatures, and the distribution of homes they were applied to in the original BEIS modelling, were used with other factors, e.g., heat system capacity, to determine oversizing factors under different external temperature cases to determine suitability for lower flow temperatures.

Although specific external temperatures were not used directly in this work, the approximate temperatures represented by the four external temperature cases would be in the order of:

- **Winter peak**: around 0 to -10°C
- **20-year peak**: around -10 to -20°C
- **Winter average**: around 1 to 3°C
- **November average**: around 3 to 5°C

8.3 Retrofit package data

Retrofit Package	Average cost (£, flat)	Efficiency increase	Cost per marginal increase to efficiency (£/% efficiency gained)	Average cost (£, houses)	Efficiency Increase	Cost per marginal increase to efficiency (£/% efficiency gained)
Loft and cavity wall insulation	£1003.48	35%	£28.67	£1521.65	24%	£63.40
Loft (partial) and cavity wall insulation	£1003.48	23%	£43.63	£1521.65	17%	£89.51
Hard to treat (HTT) cavity wall insulation	£1989.30	28%	£71.05	£3427.56	19%	£180.40
HTT loft and cavity wall insulation	£1529.81	35%	£43.71	£1751.11	22%	£79.60
HTT loft insulation	£1100.20	23%	£47.83	£1174.38	14%	£83.88
Standard efficiency measures*	£176.20	13%	£13.55	£361.88	10%	£36.19
Radiator upgrades (<90m)	£2206.10	Oversizing factor doubles	-	£2206.10	Oversizing factor doubles	-
Cavity wall, loft and floor insulation	£3924.94	45%	£87.22	£4323.97	33%	£131.03
Cavity wall, loft and floor insulation with radiator upgrade	-	-	-	£7633.16	24%+ Oversizing factor doubles	£318.05
Loft and floor insulation	£3495.33	29%	£120.53	£5410.75	24%	£225.45
Solid wall and loft insulation	£2979.05	37%	£80.51	£5766.00	28%	£205.93
Solid walls, loft and floor insulation	£5900.51	48%	£122.93	£8253.73	37%	£223.07

* Note "Standard efficiency measure" includes draughtproofing, reduced infiltration and hot water tank insulation. All packages except radiator upgrades in the Lower cost retrofit case include standard efficiency measures.

8.4 Building-envelope led method for suitability assessment

A central finding from our stakeholder engagement is the estimation of a dwelling's suitability based on a combination of the dwelling's building envelope (i.e., levels of various insulation) and peak heat demand. This approach is based on the following principle:

- In pre-1919 dwellings (flats and houses), operating at 55°C is possible with double/triple window glazing, loft insulation of at least 100mm and draughtproofing measures.
- In flats, operating at 55°C is possible with double/triple window glazing and wall insulation. These conditions are the same to operate at 50°C (only achievable in homes built after 1984) and 45°C (only achievable in homes built after 1992).
- In houses, operating at 55°C is possible with double/triple window glazing, loft insulation of at least 100mm and wall insulation. To run at lower temperatures, houses must have 250mm of loft insulation and floor insulation. Temperatures below 45°C are not suitable without underfloor heating or a heat demand threshold below $45Wm^2$.

Based on this, dwellings could be roughly designated a minimum flow temperature based on their archetype and insulation levels. See below for an estimate of what dwellings are considered always suitable (green - always), suitable depending on insulation measures (yellow - depends) and unsuitable without underfloor heating or peak heat demand below $45W/m^2$ (red - unsuitable).

	55°C	50°C	45°C	40°C	35°C
Pre-1919 flat	sometimes	unsuitable	unsuitable	unsuitable	unsuitable
Pre-1919 house	sometimes	unsuitable	unsuitable	unsuitable	unsuitable
'19-'02 flat	sometimes	sometimes	sometimes	unsuitable	unsuitable
'19-'49 house	sometimes	sometimes	sometimes	unsuitable	unsuitable
'50-'83 house	sometimes	sometimes	sometimes	unsuitable	unsuitable
'84-'02 house	sometimes	sometimes	sometimes	unsuitable	unsuitable
Post-'02 flats and houses	always	always	sometimes	unsuitable	unsuitable

The results of our modelling generally agree with the finding that all dwelling types could, in theory, reach lower flow temperatures (45 - 55°C). Our study additionally finds that many dwellings in all archetypes, after some level of retrofits, could operate at even lower flow temperatures (35 - 45°C). This contrasts the stakeholders' assumptions that for older dwelling types these low temperatures may not be attainable. It is important to note that while this approach was discussed with us by stakeholders with ample experience in home retrofitting, it is not backed by any quantitative study and as such may best be considered as "robust rules of thumbs". In practice, dwelling suitability should be based on a quantitative assessment undertaken at the property level.

8.5 Detailed results – suitability modelling

Winter peak – suitability now (all winter peak scenarios)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	-	-	-	-	-
40°C	-	-	13,129	-	-	-	555
45°C	-	-	34,106	-	5,140	6,127	7,851
50°C	-	-	86,664	2,740	17,290	6,127	38,145
55°C	12,515	-	193,456	12,718	63,901	18,180	107,716
60°C	34,830	13,479	323,560	40,452	184,780	74,660	188,503
65°C	105,485	35,131	409,306	87,930	347,068	167,539	246,342
70°C	183,445	60,266	494,218	108,147	505,634	204,541	358,035
75°C	212,125	102,801	566,410	129,864	601,460	216,426	375,979
80°C	253,320	122,005	589,514	144,744	670,749	229,331	392,185
85°C	273,917	154,294	608,833	152,820	712,624	241,216	392,185
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter peak – Lower cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	13,929	-	-	-	448
40°C	-	-	85,543	-	17,960	286	17,143
45°C	6,350	-	268,355	14,754	79,266	17,672	85,326
50°C	88,836	1,837	396,258	38,466	236,930	72,603	158,850
55°C	138,703	12,591	522,090	60,495	377,385	126,057	267,161
60°C	200,687	33,866	575,252	100,921	502,890	162,693	294,799
65°C	244,355	63,463	611,965	129,972	609,035	206,203	349,079
70°C	272,197	104,343	631,749	146,453	670,055	214,351	390,531
75°C	279,739	130,707	640,352	154,715	705,860	227,956	397,162
80°C	291,369	156,971	643,239	162,089	737,202	241,242	399,267
85°C	292,231	178,000	644,254	170,539	748,796	241,553	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter peak – Higher cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	21,939	-	-	3,962	7,703
40°C	-	-	126,863	3,765	14,154	10,084	53,145
45°C	35,813	7,774	338,881	46,074	139,737	64,469	211,578
50°C	150,202	45,992	487,979	89,093	351,768	145,208	350,313
55°C	239,712	94,330	555,898	121,505	497,471	186,626	386,730
60°C	269,706	143,666	592,894	146,453	611,384	221,411	396,474
65°C	278,537	169,788	627,336	159,300	667,660	236,768	398,483
70°C	291,168	181,024	637,547	167,637	714,021	240,638	399,009
75°C	293,226	184,379	640,342	171,366	729,163	245,907	399,398
80°C	294,362	186,921	642,979	175,204	743,553	246,189	399,419
85°C	294,373	188,866	643,767	177,725	744,431	247,343	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter peak – Lower cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	1,329	-	-	-	-
40°C	-	-	14,037	-	-	286	715
45°C	-	-	42,023	-	5,392	6,127	12,162
50°C	2,370	-	104,575	3,997	25,527	10,324	49,899
55°C	18,455	5,567	221,982	21,846	110,092	55,507	178,177
60°C	57,730	23,398	363,690	65,526	240,279	103,306	207,535
65°C	123,510	51,429	431,606	103,900	417,431	176,704	294,268
70°C	192,207	90,725	508,913	125,326	544,019	205,708	368,677
75°C	223,714	122,276	571,891	138,338	627,757	227,956	383,521
80°C	268,439	148,540	594,523	153,263	703,624	241,242	393,314
85°C	275,900	173,013	612,117	161,749	715,272	241,553	393,466
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter peak – Higher cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	6,987	-	-	-	1
40°C	-	-	15,849	87	913	2,165	593
45°C	1,063	2,492	70,646	1,592	12,615	7,618	16,437
50°C	16,556	17,687	154,457	13,474	65,705	22,975	56,313
55°C	50,676	45,554	276,700	38,557	191,423	77,426	183,423
60°C	92,093	79,999	418,668	84,958	353,694	140,440	219,451
65°C	182,336	113,544	497,086	116,029	526,282	202,213	313,225
70°C	220,030	142,140	562,040	134,671	623,564	212,776	367,606
75°C	261,756	156,948	592,909	149,802	681,262	233,959	392,427
80°C	277,857	173,271	602,469	157,048	719,032	242,036	392,448
85°C	284,142	181,786	617,125	166,516	725,504	243,190	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

20-year peak – suitability now (all 20-year peak scenarios)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	-	-	-	-	-
40°C	-	-	13,129	-	-	-	555
45°C	-	-	14,444	-	-	-	555
50°C	-	-	54,596	-	5,140	6,127	8,406
55°C	-	-	105,604	2,740	22,542	12,254	45,441
60°C	12,515	-	228,970	20,739	107,372	23,603	128,535
65°C	22,315	17,972	316,995	45,930	187,124	80,295	197,983
70°C	76,024	30,638	417,764	82,508	307,202	142,242	272,028
75°C	158,415	55,772	500,781	106,332	481,949	193,477	329,359
80°C	199,611	94,005	550,970	122,626	563,482	217,446	375,979
85°C	248,888	118,332	578,322	135,690	634,460	229,331	375,979
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

20-year peak – Lower cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	12,037	-	-	-	448
40°C	-	-	57,454	-	4,059	-	555
45°C	-	-	180,145	6,081	43,583	6,127	61,474
50°C	25,738	1,837	322,225	23,349	131,382	33,777	123,861
55°C	89,909	1,837	447,529	43,689	272,703	71,987	189,548
60°C	169,371	20,207	524,233	67,770	410,699	118,243	269,896
65°C	206,907	31,536	580,993	98,510	502,766	155,102	311,011
70°C	245,626	62,757	604,261	124,745	588,437	206,869	322,107
75°C	261,437	98,199	631,868	139,249	656,151	222,692	385,489
80°C	277,752	126,318	639,831	150,072	692,811	229,368	391,736
85°C	281,481	142,554	641,828	156,617	723,820	230,006	399,205
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

20-year peak – Higher cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	13,024	-	-	-	554
40°C	-	-	76,118	1,872	10,598	4,485	29,868
45°C	15,146	1,829	221,053	15,637	78,297	20,744	147,464
50°C	91,229	25,806	380,846	62,467	237,061	121,390	273,859
55°C	177,740	60,940	505,511	98,484	388,291	159,045	368,331
60°C	241,697	105,701	570,990	124,025	518,556	189,663	394,570
65°C	271,720	139,737	589,884	148,256	615,544	227,994	397,189
70°C	277,320	164,168	622,390	158,597	665,440	236,466	398,256
75°C	291,154	179,683	637,448	165,030	706,443	240,775	399,159
80°C	293,143	183,872	639,035	169,908	726,531	243,417	399,353
85°C	293,277	185,024	642,234	172,430	742,425	246,180	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

20-year peak – Lower cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	609	-	-	-	-
40°C	-	-	13,265	-	-	-	555
45°C	-	-	19,145	-	664	6,127	1,007
50°C	-	-	66,232	592	7,764	6,137	20,206
55°C	3,443	-	127,154	6,816	39,808	12,969	53,236
60°C	19,352	13,183	254,896	31,096	142,446	51,201	184,041
65°C	48,638	22,914	354,533	63,779	242,819	97,188	217,794
70°C	128,226	50,723	438,192	100,538	391,214	172,370	280,139
75°C	181,741	84,581	514,346	116,896	523,864	207,288	365,533
80°C	211,104	117,796	557,819	133,644	601,360	220,725	378,095
85°C	255,227	134,123	583,512	144,201	671,898	230,006	385,564
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

20-year peak – Higher cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	956	-	-	-	-
40°C	-	-	13,864	-	256	523	555
45°C	-	-	29,249	367	6,682	6,643	985
50°C	3,876	9,876	85,108	4,348	29,327	11,702	31,235
55°C	19,995	22,538	197,209	18,427	86,152	28,297	86,749
60°C	59,090	55,685	291,025	46,036	216,619	84,547	191,293
65°C	94,107	79,360	409,352	84,303	361,875	150,122	256,425
70°C	181,119	107,924	477,443	108,119	510,680	199,635	282,937
75°C	215,638	138,819	551,689	130,257	591,746	221,428	376,509
80°C	258,269	155,035	581,920	142,190	665,691	231,469	376,703
85°C	268,436	162,505	606,729	150,866	710,271	234,232	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter average – suitability now (all winter average scenarios)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	13,129	-	-	-	555
40°C	-	-	43,403	-	5,140	6,127	8,406
45°C	-	-	164,293	2,740	22,542	12,254	92,631
50°C	22,315	13,479	345,944	38,691	178,163	74,660	188,503
55°C	158,415	39,624	471,833	100,071	413,283	177,603	286,237
60°C	212,125	89,893	559,845	128,103	590,790	204,541	375,979
65°C	261,403	125,677	592,248	142,005	670,749	229,331	392,185
70°C	282,000	158,787	608,833	160,114	717,763	241,216	399,419
75°C	282,000	179,230	628,152	172,008	723,294	247,343	399,419
80°C	294,515	182,903	638,938	172,008	729,351	247,343	399,419
85°C	294,515	187,396	645,503	176,840	744,016	247,343	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter average – Lower cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	5,832	-	-	-	-
35°C	-	-	76,561	-	4,059	-	16,578
40°C	16,985	-	319,867	17,798	86,087	21,162	92,186
45°C	134,034	3,467	481,831	44,556	320,833	79,733	206,680
50°C	208,772	28,919	586,587	98,834	494,791	151,135	294,401
55°C	259,944	77,714	630,357	133,708	638,844	209,884	383,903
60°C	281,481	126,350	640,332	152,426	700,839	218,527	390,948
65°C	292,111	152,714	643,667	163,833	742,252	241,242	399,373
70°C	293,420	182,550	644,688	171,069	749,369	245,613	399,419
75°C	294,515	186,111	645,302	176,277	751,508	247,343	399,419
80°C	294,515	190,566	645,503	178,506	752,960	258,925	399,419
85°C	294,515	190,566	645,503	179,383	753,762	258,925	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter average – Higher cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	11,499	-	-	-	-
35°C	-	-	102,461	1,872	10,755	4,754	43,940
40°C	55,082	14,483	363,366	50,096	175,705	95,833	240,776
45°C	211,162	73,999	537,510	108,094	434,246	157,876	368,809
50°C	271,410	136,115	594,714	145,663	609,595	218,739	396,551
55°C	291,030	171,706	629,353	161,994	682,087	237,154	398,847
60°C	293,143	183,798	639,544	169,888	725,973	243,416	399,398
65°C	294,362	188,456	642,917	176,031	743,553	246,180	399,419
70°C	294,427	192,752	645,020	177,831	745,902	247,343	399,419
75°C	294,515	195,843	645,503	178,463	750,535	257,387	399,419
80°C	294,515	197,806	645,503	179,108	752,284	257,475	399,419
85°C	294,515	197,868	645,503	179,580	754,121	258,921	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter average – Lower cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	13,352	-	-	-	555
40°C	-	-	54,024	-	5,426	6,127	19,022
45°C	13,786	47	184,797	6,992	71,422	13,954	111,278
50°C	50,503	20,297	385,831	64,137	227,471	91,748	207,137
55°C	180,248	64,096	487,289	109,501	490,093	187,461	329,092
60°C	225,456	116,055	566,399	134,879	614,570	209,884	377,307
65°C	275,780	144,283	597,323	151,238	703,643	241,242	393,420
70°C	283,309	175,894	612,551	165,419	719,769	245,613	399,419
75°C	284,404	181,357	629,704	172,987	726,006	247,343	399,419
80°C	294,515	187,396	639,442	175,216	732,190	247,343	399,419
85°C	294,515	187,396	645,503	177,454	744,437	247,343	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

Winter average – Higher cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	37	-	-	-	-
35°C	-	-	14,310	-	413	792	555
40°C	3,876	3,733	74,968	2,427	16,336	8,802	23,910
45°C	38,788	29,944	235,488	26,544	132,227	39,012	116,727
50°C	103,542	75,549	420,488	84,111	346,882	141,440	219,528
55°C	209,225	120,491	535,920	118,723	559,708	209,292	367,444
60°C	268,302	156,367	592,111	145,215	664,080	226,177	376,748
65°C	284,131	171,250	611,969	157,875	719,032	242,027	399,419
70°C	284,196	184,342	629,838	168,989	726,975	247,343	399,419
75°C	294,515	189,058	639,745	173,226	735,245	247,343	399,419
80°C	294,515	192,983	645,503	177,165	745,039	247,431	399,419
85°C	294,515	193,045	645,503	177,637	746,876	248,877	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

November average – suitability now (all November average scenarios)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	-	-	-	-	-
35°C	-	-	13,849	-	-	-	555
40°C	-	-	86,664	-	5,140	6,127	38,145
45°C	22,315	8,986	261,790	20,739	134,879	57,977	188,503
50°C	150,332	35,131	469,099	87,930	408,143	183,027	255,822
55°C	232,722	94,195	571,037	128,103	590,790	204,541	375,979
60°C	269,486	125,677	608,833	148,264	700,473	241,216	392,185
65°C	282,000	171,255	614,226	163,199	723,294	241,216	399,419
70°C	294,515	182,903	638,938	172,008	729,351	247,343	399,419
75°C	294,515	187,396	645,503	176,840	737,959	247,343	399,419
80°C	294,515	187,396	645,503	176,840	744,016	247,343	399,419
85°C	294,515	187,396	645,503	179,580	749,721	247,343	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

November average – Lower cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	11,984	-	-	-	448
35°C	-	-	151,542	3,765	18,624	6,127	58,345
40°C	88,836	1,837	415,895	34,983	220,724	67,864	151,771
45°C	192,928	21,839	567,126	80,194	452,326	140,407	282,866
50°C	259,944	77,581	620,344	132,779	618,576	209,823	384,278
55°C	281,481	129,106	640,332	153,575	703,684	222,459	392,421
60°C	292,231	164,426	643,687	168,170	743,641	241,242	399,419
65°C	293,420	183,421	645,302	175,048	749,764	247,343	399,419
70°C	294,515	189,267	645,503	176,521	752,199	258,925	399,419
75°C	294,515	190,566	645,503	179,307	753,730	258,925	399,419
80°C	294,515	191,371	645,503	179,580	754,709	258,925	399,419
85°C	294,515	192,752	645,503	179,580	755,251	258,971	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

November average – Higher cost retrofit scenario

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	11,846	-	-	-	554
35°C	8,717	-	191,671	9,096	53,444	16,839	112,958
40°C	159,005	41,003	495,297	82,547	334,873	143,283	367,608
45°C	268,029	122,898	586,338	136,328	568,203	209,701	395,204
50°C	290,106	170,085	628,649	160,424	678,752	236,134	398,847
55°C	293,143	183,900	640,931	170,718	728,989	245,881	399,398
60°C	294,373	188,828	642,991	176,284	744,024	246,189	399,419
65°C	294,515	192,778	645,023	178,117	747,483	257,387	399,419
70°C	294,515	195,843	645,503	178,942	751,827	257,475	399,419
75°C	294,515	197,868	645,503	179,580	754,120	258,921	399,419
80°C	294,515	198,036	645,503	179,580	755,251	258,972	399,419
85°C	294,515	198,432	645,503	179,580	755,251	262,795	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

November average – Lower cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	556	-	-	-	-
35°C	-	-	17,237	-	664	6,127	1,007
40°C	2,370	-	103,816	4,167	13,449	12,299	49,933
45°C	40,879	14,815	298,689	43,596	177,161	73,365	195,602
50°C	173,946	63,963	484,267	105,530	470,477	190,966	329,467
55°C	242,251	118,811	575,934	136,028	617,415	213,816	378,780
60°C	282,120	155,995	611,550	157,415	714,411	241,242	393,466
65°C	283,309	180,168	617,706	169,398	724,262	247,343	399,419
70°C	294,515	186,097	639,442	173,231	731,429	247,343	399,419
75°C	294,515	187,396	645,503	177,378	739,587	247,343	399,419
80°C	294,515	188,201	645,503	177,651	745,384	247,343	399,419
85°C	294,515	189,582	645,503	179,580	750,957	247,389	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

November average – Higher cost retrofit scenario (reduced radiators)

Number of dwellings suitable at each flow temperature, by archetype							
	Pre-1919 flat	Pre-1919 house	1919-2002 flat	1919-1949 house	1950-1983 house	1984-2002 house	Post-2002
30°C	-	-	384	-	-	-	-
35°C	-	-	19,069	87	5,312	6,143	971
40°C	18,216	14,694	151,171	12,497	58,928	21,050	56,091
45°C	81,548	65,841	388,607	64,348	268,811	106,725	191,927
50°C	208,301	118,870	532,422	117,153	546,140	205,234	367,444
55°C	268,302	158,015	593,498	146,045	671,635	228,642	385,410
60°C	284,142	173,340	612,043	163,855	719,503	242,036	399,419
65°C	284,284	185,993	639,265	172,880	728,556	247,343	399,419
70°C	294,515	191,020	645,503	175,165	736,537	247,431	399,419
75°C	294,515	193,045	645,503	177,637	746,875	248,877	399,419
80°C	294,515	193,213	645,503	179,580	751,960	248,928	399,419
85°C	294,515	195,337	645,503	179,580	755,251	249,955	399,419
90°C	294,515	202,925	645,503	179,580	755,251	269,874	399,419

8.6 Detailed results – fuel bill modelling

Winter average – suitability now

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	28.40	64.99	96.41	220.68	29.79	68.19	101.16	231.55
Pre-1919 house	6.14	14.07	30.28	69.31	6.57	15.04	32.38	74.12
1919-2002 flat	58.97	134.97	91.35	209.09	76.92	176.07	119.17	272.76
1919-1949 house	11.40	26.10	63.49	145.33	13.07	29.91	72.76	166.53
1950-1983 house	45.28	103.63	59.95	137.22	52.06	119.16	68.93	157.78
1984-2002 house	24.95	57.11	92.46	211.63	29.26	66.98	108.43	248.19
Post-2002	21.44	49.07	53.68	122.87	26.94	61.66	67.45	154.38
Total/Average (archetype/dwelling)	196.58	449.95	71.56	163.79	234.62	537.02	85.41	195.49

Winter average – Lower cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	36.34	123.38	83.17	282.39	49.42	113.11	167.79	384.05
Pre-1919 house	8.29	40.83	18.96	93.45	9.20	21.06	45.34	103.77
1919-2002 flat	68.95	106.82	157.82	244.49	99.40	227.51	153.98	352.45
1919-1949 house	13.60	75.73	31.13	173.34	17.85	40.86	99.40	227.51
1950-1983 house	55.31	73.24	126.60	167.63	74.15	169.73	98.18	224.73
1984-2002 house	27.12	100.51	62.08	230.05	35.85	82.06	132.84	304.06
Post-2002	23.80	59.58	54.47	136.38	32.39	74.13	81.09	185.61
Total/Average (archetype/dwelling)	233.41	580.09	98.26	194.48	318.26	728.45	115.85	265.17

Winter average – Higher cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	38.19	129.66	87.40	296.77	55.19	126.33	187.40	428.93
Pre-1919 house	12.00	59.14	27.47	135.37	16.31	37.33	80.36	183.94
1919-2002 flat	68.88	106.71	157.66	244.24	99.75	228.31	154.53	353.69
1919-1949 house	15.21	84.71	34.82	193.90	21.48	49.16	119.59	273.73
1950-1983 house	56.94	75.40	130.33	172.57	80.16	183.47	106.13	242.93
1984-2002 house	29.15	108.00	66.71	247.20	41.78	95.62	154.80	354.32
Post-2002	24.23	60.67	55.47	138.88	35.80	81.95	89.64	205.18
Total/Average (archetype/dwelling)	244.60	624.29	101.17	203.81	350.46	802.16	127.58	292.01

Winter peak – suitability now

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	9.17	20.98	31.12	71.23	9.17	20.98	31.12	71.23
Pre-1919 house	1.47	3.36	7.23	16.55	1.47	3.36	7.23	16.55
1919-2002 flat	35.59	81.46	55.13	126.19	40.09	91.75	62.10	142.14
1919-1949 house	4.85	11.11	27.03	61.87	4.97	11.38	27.69	63.37
1950-1983 house	18.92	43.30	25.05	57.34	19.58	44.81	25.92	59.33
1984-2002 house	12.07	27.62	44.72	102.35	12.42	28.43	46.03	105.35
Post-2002	12.42	28.42	31.08	71.15	13.53	30.96	33.87	77.52
Total/Average (archetype/dwelling)	94.49	216.25	34.39	78.82	101.23	231.67	36.85	84.33

Winter peak – Lower cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	26.40	60.42	89.63	205.14	31.96	73.16	108.52	248.40
Pre-1919 house	3.03	6.94	14.95	34.21	3.09	7.08	15.23	34.87
1919-2002 flat	62.18	142.32	96.32	220.48	82.75	189.40	128.19	293.41
1919-1949 house	9.13	20.89	50.83	116.35	10.78	24.68	60.04	137.43
1950-1983 house	40.79	93.35	54.00	123.61	49.81	114.01	65.95	150.95
1984-2002 house	20.38	46.65	75.53	172.87	24.57	56.25	91.06	208.42
Post-2002	19.13	43.80	47.91	109.65	23.77	54.41	59.51	136.21
Total/Average (archetype/dwelling)	181.04	414.37	65.90	150.84	226.73	518.99	82.53	188.91

Winter Peak – Higher cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype		Dwelling		Archetype		Dwelling	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	34.58	79.16	117.43	268.78	44.00	100.70	149.38	341.92
Pre-1919 house	9.19	21.03	45.27	103.62	10.64	24.36	52.44	120.03
1919-2002 flat	64.40	147.40	99.76	228.35	89.73	205.37	139.00	318.16
1919-1949 house	12.95	29.63	72.09	165.00	16.78	38.40	93.42	213.82
1950-1983 house	47.85	109.52	63.35	145.01	61.24	140.18	81.09	185.61
1984-2002 house	26.01	59.54	96.39	220.63	34.40	78.73	127.46	291.74
Post-2002	23.92	54.75	59.89	137.08	34.14	78.15	85.48	195.65
Total/Average (archetype/dwelling)	218.9	501.03	79.68	182.39	290.93	665.89	105.90	242.40

Winter peak – Lower cost retrofit scenario (reduced radiators)

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	10.91	24.98	37.06	84.83	11.06	25.32	37.56	85.98
Pre-1919 house	2.36	5.40	11.63	26.63	2.36	5.40	11.63	26.63
1919-2002 flat	38.55	88.23	59.71	136.68	43.97	100.65	68.12	155.92
1919-1949 house	6.29	14.39	35.01	80.14	6.46	14.78	35.97	82.33
1950-1983 house	23.11	52.89	30.60	70.03	24.08	55.12	31.88	72.98
1984-2002 house	14.72	33.70	54.56	124.88	15.32	35.07	56.77	129.93
Post-2002	14.97	34.27	37.49	85.81	16.43	37.61	41.13	94.15
Total/Average (archetype/dwelling)	110.91	253.87	40.38	92.41	119.69	273.95	43.57	99.72

Winter peak – Higher cost retrofit scenario (reduced radiators)

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	15.91	36.43	54.04	123.68	16.95	38.80	57.56	131.74
Pre-1919 house	5.74	13.13	28.27	64.72	6.30	14.41	31.03	71.03
1919-2002 flat	44.71	102.34	69.26	158.54	52.73	120.69	81.68	186.96
1919-1949 house	7.63	17.46	42.47	97.20	8.21	18.78	45.69	104.59
1950-1983 house	30.66	70.18	40.60	92.93	33.16	75.91	43.91	100.51
1984-2002 house	17.59	40.25	65.16	149.15	18.91	43.29	70.08	160.40
Post-2002	15.52	35.53	38.86	88.95	17.17	39.29	42.98	98.37
Total/Average (archetype/dwelling)	137.76	315.31	50.15	114.78	153.42	351.17	55.85	127.83

20-year peak – suitability now (all 20-year peak scenarios)

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	2.84	6.49	9.63	22.04	2.84	6.49	9.63	22.04
Pre-1919 house	4.42	10.11	21.76	49.81	4.42	10.11	21.76	49.81
1919-2002 flat	26.03	59.57	40.32	92.29	28.86	66.06	44.71	102.34
1919-1949 house	2.82	6.45	15.69	35.90	2.82	6.45	15.69	35.90
1950-1983 house	10.51	24.05	13.91	31.84	10.70	24.50	14.17	32.43
1984-2002 house	6.51	14.91	24.13	55.24	6.87	15.72	25.45	58.24
Post-2002	8.62	19.72	21.58	49.38	8.86	20.29	22.19	50.79
Total/Average (archetype/dwelling)	61.73	141.30	22.47	51.44	65.36	149.61	23.79	54.46

20-year peak – Lower cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	21.45	49.09	72.83	166.69	23.06	52.78	78.30	179.22
Pre-1919 house	1.59	3.63	7.82	17.90	1.65	3.77	8.11	18.56
1919-2002 flat	56.76	129.92	87.94	201.28	73.49	168.21	113.85	260.58
1919-1949 house	6.88	15.75	38.32	87.71	7.89	18.05	43.91	100.50
1950-1983 house	33.02	75.58	43.72	100.07	38.02	87.03	50.35	115.24
1984-2002 house	15.24	34.87	56.45	129.22	17.19	39.34	63.68	145.76
Post-2002	15.87	36.32	39.73	90.93	19.48	44.59	48.77	111.64
Total/Average (archetype/dwelling)	150.80	345.17	54.90	125.65	180.77	413.76	65.81	150.62

20-year peak – Higher cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	30.40	69.59	103.23	236.28	36.12	82.67	122.64	280.70
Pre-1919 house	7.16	16.39	35.29	80.78	7.98	18.26	39.31	89.98
1919-2002 flat	60.70	138.94	94.04	215.24	80.47	184.19	124.66	285.34
1919-1949 house	11.38	26.04	63.35	145.00	14.06	32.19	78.31	179.23
1950-1983 house	41.44	94.85	54.87	125.59	50.47	115.52	66.82	152.95
1984-2002 house	23.62	54.06	87.52	200.31	30.63	70.10	113.49	259.76
Post-2002	23.48	53.75	58.79	134.57	31.47	72.04	78.80	180.36
Total/Average (archetype/dwelling)	198.18	453.62	72.14	165.13	251.20	574.96	91.44	209.30

20-year peak – Lower cost retrofit scenario (reduced radiators)

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	5.23	11.96	17.75	40.62	5.23	11.96	17.75	40.62
Pre-1919 house	1.16	2.65	5.71	13.07	1.16	2.65	5.71	13.07
1919-2002 flat	28.86	66.06	44.71	102.34	32.30	73.93	50.04	114.53
1919-1949 house	3.83	8.77	21.34	48.85	3.86	8.83	21.48	49.17
1950-1983 house	13.88	31.76	18.37	42.05	14.17	32.44	18.76	42.95
1984-2002 house	8.46	19.37	31.36	71.79	8.82	20.19	32.68	74.80
Post-2002	9.97	22.81	24.95	57.11	10.56	24.16	26.43	60.49
Total/Average (archetype/dwelling)	71.39	163.39	25.99	59.48	76.09	174.16	27.70	63.40

20-year peak – Higher cost retrofit scenario (reduced radiators)

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	9.85	22.55	33.45	76.56	10.09	23.10	34.27	78.44
Pre-1919 house	3.90	8.92	19.20	43.94	4.21	9.63	20.74	47.47
1919-2002 flat	34.57	79.12	53.55	122.56	38.98	89.23	60.39	138.23
1919-1949 house	5.07	11.61	28.24	64.63	5.26	12.03	29.28	67.02
1950-1983 house	20.48	46.88	27.12	62.08	21.60	49.44	28.60	65.46
1984-2002 house	12.16	27.84	45.07	103.17	12.84	29.39	47.58	108.90
Post-2002	11.36	26.01	28.45	65.12	12.27	28.10	30.73	70.34
Total/Average (archetype/dwelling)	97.39	222.92	35.45	81.15	105.26	240.92	38.32	87.70

November average – suitability now

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	34.45	78.85	116.97	267.74	43.87	100.41	148.95	340.94
Pre-1919 house	8.94	20.47	44.08	100.89	10.06	23.02	49.55	113.42
1919-2002 flat	65.06	148.91	100.79	230.69	89.41	204.64	138.51	317.03
1919-1949 house	13.34	30.53	74.28	170.02	17.12	39.19	95.34	218.21
1950-1983 house	53.36	122.13	70.65	161.70	68.90	157.70	91.23	208.81
1984-2002 house	27.59	63.16	102.25	234.04	38.16	87.35	141.41	323.67
Post-2002	23.65	54.14	59.22	135.54	31.12	71.22	77.91	178.32
Total/Average (archetype/dwelling)	226.40	518.20	82.41	188.64	298.63	683.54	108.71	248.82

November average – Lower cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	37.70	86.30	128.02	293.01	53.99	123.57	183.32	419.59
Pre-1919 house	10.61	24.29	52.30	119.70	13.07	29.91	64.39	147.38
1919-2002 flat	69.46	159.00	107.61	246.31	101.66	232.70	157.49	360.49
1919-1949 house	14.88	34.05	82.84	189.60	20.58	47.12	114.63	262.37
1950-1983 house	58.07	132.92	76.89	176.00	81.63	186.84	108.08	247.39
1984-2002 house	28.76	65.82	106.55	243.89	40.87	93.55	151.45	346.64
Post-2002	24.10	55.16	60.34	138.11	35.31	80.83	88.41	202.36
Total/Average (archetype/dwelling)	243.58	557.54	88.67	202.96	347.12	794.51	126.36	289.22

November average – Higher cost retrofit scenario

Savings, by archetype (£million) and by dwelling (£)	Reduction to 55°C				Reduction to 50°C			
	Archetype (£m)		Dwelling (£)		Archetype (£m)		Dwelling (£)	
	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price	Lower fuel price	Higher fuel price
Pre-1919 flat	38.33	87.72	130.13	297.86	56.50	129.33	191.85	439.12
Pre-1919 house	12.46	28.52	61.40	140.55	17.84	40.84	87.92	201.24
1919-2002 flat	69.46	158.99	107.61	246.30	102.09	233.67	158.16	362.00
1919-1949 house	15.68	35.89	87.32	199.86	22.58	51.68	125.73	287.78
1950-1983 house	58.72	134.40	77.75	177.96	84.57	193.57	111.97	256.30
1984-2002 house	30.12	68.95	111.62	255.50	43.76	100.16	162.14	371.13
Post-2002	24.25	55.50	60.70	138.94	35.88	82.13	89.84	205.63
Total/Average (archetype/dwelling)	249.02	569.98	90.65	207.49	363.22	831.38	132.22	302.64

8.7 Detailed results – emissions modelling

Winter average – suitability now

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.16	3.94	1.22	4.14
Pre-1919 house	0.25	1.24	0.27	1.32
1919-2002 flat	2.41	3.74	3.15	4.87
1919-1949 house	0.47	2.60	0.53	2.97
1950-1983 house	1.85	2.45	2.13	2.82
1984-2002 house	1.02	3.78	1.20	4.43
Post-2002	0.88	2.19	1.10	2.76
Total/Average (archetype/dwelling)	8.04	2.93	9.59	3.49

Winter average – Lower cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.49	5.04	2.02	6.86
Pre-1919 house	0.34	1.67	0.38	1.85
1919-2002 flat	2.82	4.37	4.06	6.30
1919-1949 house	0.56	3.10	0.73	4.06
1950-1983 house	2.26	2.99	3.03	4.01
1984-2002 house	1.11	4.11	1.47	5.43
Post-2002	0.97	2.44	1.32	3.32
Total/Average (archetype/dwelling)	9.54	3.47	13.01	4.74

Winter average – Higher cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.56	5.30	2.26	7.66
Pre-1919 house	0.49	2.42	0.67	3.29
1919-2002 flat	2.82	4.36	4.08	6.32
1919-1949 house	0.62	3.46	0.88	4.89
1950-1983 house	2.33	3.08	3.28	4.34
1984-2002 house	1.19	4.42	1.71	6.33
Post-2002	0.99	2.48	1.46	3.67
Total/Average (archetype/dwelling)	10.00	3.64	14.33	5.22

Winter peak – suitability now

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.37	1.27	0.37	1.27
Pre-1919 house	0.06	0.30	0.06	0.30
1919-2002 flat	1.46	2.25	1.64	2.54
1919-1949 house	0.20	1.11	0.20	1.13
1950-1983 house	0.77	1.02	0.80	1.06
1984-2002 house	0.49	1.83	0.51	1.88
Post-2002	0.51	1.27	0.55	1.38
Total/Average (archetype/dwelling)	3.86	1.41	4.14	1.51

Winter peak – Lower cost retrofit scenario

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.08	3.66	1.31	4.44
Pre-1919 house	0.12	0.61	0.13	0.62
1919-2002 flat	2.54	3.94	3.38	5.24
1919-1949 house	0.37	2.08	0.44	2.46
1950-1983 house	1.67	2.21	2.04	2.70
1984-2002 house	0.83	3.09	1.00	3.72
Post-2002	0.78	1.96	0.97	2.43
Total/Average (archetype/dwelling)	7.40	2.69	9.27	3.37

Winter peak – Higher cost retrofit scenario

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.41	4.80	1.80	6.11
Pre-1919 house	0.38	1.85	0.38	2.14
1919-2002 flat	2.63	4.08	3.67	5.68
1919-1949 house	0.53	2.95	0.69	3.82
1950-1983 house	1.96	2.59	2.50	3.32
1984-2002 house	1.06	3.94	1.41	5.21
Post-2002	0.98	2.45	1.40	3.50
Total/Average (archetype/dwelling)	8.95	3.26	11.85	4.33

Winter peak – Lower cost retrofit scenario (reduced radiators)

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.45	1.52	0.45	1.54
Pre-1919 house	0.10	0.48	0.10	0.48
1919-2002 flat	1.58	2.44	1.80	2.79
1919-1949 house	0.26	1.43	0.26	1.47
1950-1983 house	0.94	1.25	0.98	1.30
1984-2002 house	0.60	2.23	0.63	2.32
Post-2002	0.61	1.53	0.67	1.68
Total/Average (archetype/dwelling)	4.54	1.65	4.89	1.78

Winter peak – Higher cost retrofit scenario (reduced radiators)

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.65	2.21	0.69	2.35
Pre-1919 house	0.23	1.16	0.26	1.27
1919-2002 flat	1.83	2.83	2.16	3.34
1919-1949 house	0.31	1.74	0.34	1.87
1950-1983 house	1.25	1.66	1.36	1.80
1984-2002 house	0.72	2.66	0.77	2.87
Post-2002	0.63	1.59	0.70	1.76
Total/Average (archetype/dwelling)	5.63	2.05	6.27	2.28

20-year peak – suitability now (all 20-year peak scenarios)

Savings, by archetype ($MtCO_2$/yr) and by dwelling (tCO_2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.12	0.39	0.12	0.39
Pre-1919 house	0.18	0.89	0.18	0.89
1919-2002 flat	1.06	1.65	1.18	1.83
1919-1949 house	0.12	0.64	0.12	0.64
1950-1983 house	0.43	0.57	0.44	0.58
1984-2002 house	0.27	0.99	0.28	1.04
Post-2002	0.35	0.88	0.36	0.91
Total/Average (archetype/dwelling)	2.52	0.92	2.67	0.97

20-year peak – Lower cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.88	2.98	0.94	3.20
Pre-1919 house	0.06	0.32	0.07	0.33
1919-2002 flat	2.32	3.60	3.00	4.66
1919-1949 house	0.28	1.57	0.32	1.80
1950-1983 house	1.35	1.79	1.55	2.06
1984-2002 house	0.62	2.31	0.70	2.60
Post-2002	0.65	1.62	0.80	1.99
Total/Average (archetype/dwelling)	6.17	2.24	7.39	2.69

20-year peak – Higher cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.24	4.22	1.48	5.01
Pre-1919 house	0.29	1.44	0.33	1.61
1919-2002 flat	2.48	3.85	3.29	5.10
1919-1949 house	0.47	2.59	0.57	3.20
1950-1983 house	1.69	2.24	2.06	2.73
1984-2002 house	0.97	3.58	1.25	4.64
Post-2002	0.96	2.40	1.29	3.22
Total/Average (archetype/dwelling)	8.10	2.95	10.27	3.74

20-year peak – Lower cost retrofit scenario (reduced radiators)

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.21	0.73	0.21	0.73
Pre-1919 house	0.05	0.23	0.05	0.23
1919-2002 flat	1.18	1.83	1.32	2.05
1919-1949 house	0.16	0.87	0.16	0.88
1950-1983 house	0.57	0.75	0.58	0.77
1984-2002 house	0.35	1.28	0.36	1.34
Post-2002	0.41	1.02	0.43	1.08
Total/Average (archetype/dwelling)	2.92	1.06	3.11	1.13

20-year peak – Higher cost retrofit scenario (reduced radiators)

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	0.40	1.37	0.41	1.40
Pre-1919 house	0.16	0.78	0.17	0.85
1919-2002 flat	1.41	2.19	1.59	2.47
1919-1949 house	0.21	1.15	0.21	1.20
1950-1983 house	0.84	1.11	0.88	1.17
1984-2002 house	0.50	1.84	0.53	1.95
Post-2002	0.46	1.16	0.50	1.26
Total/Average (archetype/dwelling)	3.98	1.45	4.30	1.57

November average – suitability now

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.41	4.78	1.79	6.09
Pre-1919 house	0.37	1.80	0.41	2.03
1919-2002 flat	2.66	4.12	3.66	5.66
1919-1949 house	0.55	3.04	0.70	3.90
1950-1983 house	2.18	2.89	2.82	3.73
1984-2002 house	1.13	4.18	1.56	5.78
Post-2002	0.97	2.42	1.27	3.19
Total/Average (archetype/dwelling)	9.26	3.37	12.21	4.45

November average – Lower cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.54	5.23	2.21	7.50
Pre-1919 house	0.43	2.14	0.53	2.63
1919-2002 flat	2.84	4.40	4.16	6.44
1919-1949 house	0.61	3.39	0.84	4.69
1950-1983 house	2.37	3.14	3.34	4.42
1984-2002 house	1.18	4.36	1.67	6.19
Post-2002	0.99	2.47	1.44	3.62
Total/Average (archetype/dwelling)	9.96	3.63	14.19	5.17

November average – Higher cost retrofit scenario

Savings, by archetype (MtCO2/yr) and by dwelling (tCO2/yr)	Reduction to 55°C		Reduction to 50°C	
	Archetype	Dwelling	Archetype	Dwelling
Pre-1919 flat	1.57	5.32	2.31	7.84
Pre-1919 house	0.51	2.51	0.73	3.59
1919-2002 flat	2.84	4.40	4.17	6.47
1919-1949 house	0.64	3.57	0.92	5.14
1950-1983 house	2.40	3.18	3.46	4.58
1984-2002 house	1.23	4.56	1.79	6.63
Post-2002	0.99	2.48	1.47	3.67
Total/Average (archetype/dwelling)	10.18	3.71	14.85	5.41

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