

Balancing investment in clean heat and energy efficiency in Scottish housing retrofit

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1 Executive summary

The Scottish Government has statutory commitments to achieve net zero and to eradicate fuel poverty. This study reviewed the existing evidence base on the benefits and trade-offs of installing energy efficiency measures alongside clean heat in Scottish homes. It also provides evidence to support the development of the Heat in Buildings Delivery Plan.

A fabric first approach, which prioritises maximising a building's thermal performance through improved insulation, for example, has traditionally been advocated across the retrofit sector. Indeed, the Scottish Government's Heat in Buildings Strategy supports such an approach to underpin the roll-out of low and zero emissions heating. However, energy efficiency improvements alone will not deliver net zero emissions. Many industry stakeholders argue that only basic fabric measures are required to enable cost-effective decarbonisation, when combined with clean heat upgrades. But it is also necessary to consider the wider impacts of retrofit and heating upgrades on health, wellbeing, and household finances.

1.1 Aims

This study aimed to ascertain whether there is consensus on an optimal balance between fabric efficiency and clean heat solutions for Scottish homes. The balance must deliver concurrently on the cross-sector agendas of net zero, fuel poverty, and public health.

The analysis was primarily carried out via a literature review. In addition, surveys were conducted with key stakeholders to explore health, wellbeing and socio-economic impacts. Recognising that data gaps were present in the existing literature, the study also proposes a brief for further modelling work to address these.

1.2 Findings

There is conflicting information on the desirable level of fabric performance for a home to be considered suitable for clean heat. Some studies look at a system's capability to maintain a desired indoor temperature during the coldest expected weather conditions. Others consider running cost implications, with the aim of avoiding increased heating costs

compared to the existing home heating system. Studies found optimal solutions are often different in UK housing archetypes compared to Scottish ones. Climate and property characteristics of Scotland must be considered to fully understand efficiencies and costs.

Improving a home's fabric can reduce peak heating loads and therefore help improve heating system efficiencies and reduce running costs. The literature also suggests other options to achieve cost effective clean heat given potential property constraints, including:

- Radiator upgrades
- High temperature heat pumps
- Demand shifting using Time-of-Use tariffs
- Self-generation of power via solar energy
- Different heat pump systems (e.g. hybrid heat pumps or air to air heat pumps).

The cost-effectiveness of measures will vary by tenure, and the viability of various options will depend on the circumstances:

- Owner-occupiers may prefer solutions with a better whole-life cost
- Renters may favour options that do not increase ongoing energy bills
- For others, minimising disruption or space loss may be a priority
- For social landlords, economies of scale may have the biggest influence.

There has been limited exploration of the specific impact of the fabric versus clean heat balance on fuel poverty. No research appears to have assessed impacts following the Scottish Government's approach to assessing fuel poverty statistics. Retrofit also offers opportunities to improve household health and wellbeing, as well as tackling high energy bills and reducing fuel poverty risk. Many homes and households at risk of fuel poverty or with particular health needs may require more extensive retrofit measures.

Retrofit opportunities noted by stakeholders, included:

- Using 'trigger points' for retrofit measures when other home upgrade or renovation works are undertaken can be more practical and cost-effective.
- Raising awareness of the health and comfort benefits of retrofit could be more motivational than carbon or cost arguments.
- A stronger focus on commissioning and aftercare with new clean heat systems could improve system efficiencies and end user satisfaction and may negate the need for more extensive measures to deliver acceptable heating running costs.

1.3 Recommendations

- Policies should remain flexible and avoid prescribing a single retrofit pathway across all homes.
- Those in fuel poverty, or significantly at-risk, should be supported with more extensive retrofit measures to reduce running costs and improve comfort.
- Therefore, a modelling exercise should be undertaken to investigate the extent of measures likely to be required to remove Scottish homes from fuel poverty (or at least close the gap) while decarbonising.

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2 Glossary/Abbreviations table

ASHP	Air Source Heat Pump
BREDEM	BRE Domestic Energy Model
CODE	Cost-Optimal Domestic Electrification (project)
COP	Coefficient of Performance
CWI	Cavity wall insulation
DEEP	Demonstration of Energy Efficiency Potential (project)
EESSH	Energy Efficiency Standard for Social Housing
EPC	Energy Performance Certificate
ETICS	External Thermal Insulation Composite System
EWI	External wall insulation
HWS	Health, wellbeing and socio-economic
IAQ	Indoor air quality
IEQ	Indoor environmental quality
IWI	Internal wall insulation
LZE	Low and Zero Emission
MEES	Minimum Energy Efficiency Standards
NHS	National Health Service
PV	Photovoltaic (system)
RdSAP	Reduced Data Standard Assessment Procedure
SCOP	Seasonal Coefficient of Performance
SHCS	Scottish House Condition Survey
SHS	Scottish Household Survey
SWI	Solid wall insulation
ToU	Time of Use (tariff)

3 Introduction

This study reviews the existing evidence base on the benefits and trade-offs of installing energy efficiency measures alongside clean heat in Scottish homes. The Scottish Government has statutory commitments to achieve net zero and to eradicate fuel poverty. This research examines trade-offs between fabric efficiency improvements and clean heat investments to support the development of policies addressing net zero, fuel poverty, and public health objectives. It aims to support a balanced, evidence-driven approach in the Heat in Buildings Delivery Plan.

4 Background and research scope

Emissions from houses will need to be reduced to contribute towards Scotland's 'net zero' by 2045 target. This is required via the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019. The Heat in Buildings Strategy (Scottish Government, 2021) sets the framework for decarbonising homes, outlining a pathway to eliminating direct emissions from homes by 2045. This includes improving fabric thermal efficiency to underpin the roll-out of clean heating and to address commitments made under the Fuel Poverty (Targets, Definition and Strategy) (Scotland) Act (2019). A Scottish household is in fuel poverty if:

- They need to spend more than 10% of their adjusted net income (after housing costs) on fuel to achieve a satisfactory heating regime, and
- The remaining income is insufficient to maintain an acceptable standard of living.

To support the delivery of the Strategy, the forthcoming Heat in Buildings Bill will set out laws on how buildings will be heated and meet required energy performance standards. The bill will place a focus on reducing costs for people alongside decarbonisation.

The independent Green Heat Finance Taskforce report (April 2025) stated that the cost of heating homes in Scotland is having a negative impact on health outcomes. It proposed that transforming how buildings are heated can deliver multiple social, economic and environmental benefits. Housing is linked to health in various ways, as set out in the 'Healthy housing for Scotland' briefing paper by Public Health Scotland (2021). This includes the impact of physical conditions such as damp and mould on ill health. It also highlights the impacts of fuel poverty and affordability on mental health. Policy decisions on approaches to housing retrofit can therefore have a significant impact on health and wellbeing. These factors will also need to be taken into consideration alongside net-zero and fuel poverty agendas.

The UK Government's recently published Warm Homes Plan aims to improve energy efficiency in UK homes, reduce household energy bills and reduce fuel poverty. Specific retrofit grants outlined in the plan will apply only to England. Compared to previous initiatives, the Plan adopts a more technology-led approach, promoting clean heat technologies and electrification measures alongside insulation improvements. The Plan places less emphasis on extensive fabric retrofit measures such as solid wall insulation, citing cost and supply chain constraints.

The aim of this research is to ascertain whether there is consensus on an optimal balance between fabric efficiency and clean heat solutions for Scottish homes.

Scope: This study focusses primarily on the interrelationships and trade-offs between energy efficiency measures and clean heat. Other renewable energy sources (not related to space heating) were considered only where they were integral to the case being made for fabric or clean heat respectively. Heat networks were also out of scope for this study.

5 Methodology

The objectives of this study were primarily delivered via a literature review. In addition, a number of surveys were conducted with key stakeholders. These specifically explored the implications of the potential fabric/clean heat balance on health, wellbeing and socio-economic (HWS) impacts. Recognising that data gaps were present in the existing literature, the study also proposes a brief for further modelling work to address these. The approach to tasks is discussed further in Appendix A, with a brief summary given below.

Literature review: A desk-based evidence review sought information from academic articles and grey literature. A selection of initial search terms were used, followed by a cascade approach to identify further references cited in relevant articles. Inclusion/exclusion criteria were set, including a focus on domestic properties, material linking both energy efficiency and clean heat, prioritising experience of relevance to the Scotland stock. References to HWS effects were also identified alongside energy/net zero impacts.

Stakeholder interviews: Seven expert interviews were held to gather insights into wider HWS impacts of installing fabric and clean heat improvements from the perspective of different groups. These included representatives from third sector organisations, academic and independent research organisations with particular interests in fuel poverty and/or healthy homes. Most were specifically concerned with the situation in Scotland, while some represented a UK-wide view. An interview topic guide was developed that served as the basis for consistent semi-structured interviews. Common themes were identified and compared with the findings of the literature review.

Developing the scope of a future modelling project: Data gaps and recommendations emerging from the evidence review were collated. A workshop with Scottish Government officials informed recommendations for future modelling. Based on the feedback, the research team proposed modelling approaches to address these needs.

6 Characteristics of the Scottish housing stock

Data from the Scottish House Condition Survey (SHCS) indicates that there were 2.55 million occupied dwellings in Scotland in 2024 (Scottish Government, 2025a) (all data mentioned below is from SHCS 2024 unless otherwise referenced). These cover a diverse range of property types with varying characteristics. Key trends include:

- 56% of homes are rated EPC C or above (compared to 53% of homes in England, (ONS, 2025). Dwellings with lower energy efficiency (i.e. EPC bands F and G) are disproportionately represented in rural areas. It is recognised that retrofitting rural homes in Scotland often incurs a significant cost premium due to logistical challenges and property characteristics, such as age, size and construction.
- 28.7% of homes (732,000 households) were in fuel poverty in 2024, which occurred across all tenures. 14% (357,000) were in extreme fuel poverty. 42% of fuel-poor homes used electricity for heating. Households in remote/rural areas have higher rates of fuel poverty. The high proportion of low energy efficiency homes in such areas noted above will be a driver for this.
- Approximately 23% of Scottish homes are social rented properties (Scottish Government, 2026) (compared to 16% in England (MHCLG, 2025b). Scottish Government regulates standards for social homes, so has significant influence over this sector. Social housing offers opportunities for economies of scale in retrofit, where landlords often address multiple, often similar, properties. Cost reduction opportunities could potentially influence the optimal choice of measures for homes, since optimality will be sensitive to capital costs. 49% of fuel-poor homes were in the social rented sector.
- Tenements make up 23% of the Scottish housing stock, of which 30% were built before 1919 (of the type common in Edinburgh and Glasgow). However, 70% of tenements are rated EPC bands A, B, or C, suggesting most are relatively energy efficient. Combined with other types of flats, they represent 35% of Scottish dwellings. By comparison, flats and apartments make up only approximately 21% of English dwellings (MHCLG, 2025a). Tenements and other multi-unit blocks with shared ownership can present challenges to traditional fabric retrofit due to the need to secure collective consent for works. However, the high rate of flats and tenements offers greater potential for communal systems and heat networks as clean heat solutions, if challenges relating to the coordination of works can be overcome.
- Approximately 13% of Scottish homes are privately rented properties (Scottish Government, 2026). 37% of households in the private rented sector (PRS) were in fuel poverty. 40% of homes in the sector were built before 1919 (approximately 128,000 homes). Due to their age, these homes will typically be of solid wall construction, for which installing wall insulation is more technically challenging and can be costly. Some may therefore be exempt from having to undertake such measures under proposed future Minimum Energy Efficiency Standards (MEES) for the PRS. This may be on grounds of negative impacts on the fabric or structure, or due to upgrade works exceeding the cost cap (Scottish Government, 2025b). Cheaper, alternative measures in support of decarbonisation and mitigating fuel poverty may therefore be required for this portion of the private rented sector.

7 Strategies for competing objectives

7.1 The 'fabric first' approach to retrofit

A fabric first approach prioritises improving the thermal performance of the building fabric before deploying low carbon heating systems or renewable technologies. The logic is that this sequencing reduces the heating system capacity and subsequent energy demand that needs to be met by these systems. Supporters of this approach note that it offers the best chance of achieving energy cost reductions for households and reducing fuel poverty (Existing Homes Alliance Scotland, 2019; National Energy Action, 2024). This method is well established, widely recognised within the retrofit sector and firmly integrated into building standards. The Scottish Government's Heat in Buildings Strategy supports a fabric first approach to underpin the roll-out of low and zero emissions heating (Scottish Government, 2021).

Main benefits/opportunities of this approach include:

- Generally 'fit and forget' measures, that permanently reduce heat demand and peak heating loads.
- Can reduce running costs and fuel poverty risk regardless of heating system type.
- May improve comfort even in under-heated homes by enabling warmer conditions at similar running costs.
- Improved insulation and ventilation can reduce risks associated with damp, condensation and mould.

Main issues/challenges of this approach:

- Fabric measures do not address the carbon intensity of heating energy use. The amount of greenhouse gas emissions (measured in carbon dioxide equivalent, CO_{2e}) associated with heating energy depends on the heating system, heating demand and fuel source used in a home. While fabric measures can reduce demand, it will be necessary to move away from heating with fossil fuels to ultimately decarbonise heat. The UK and Scotland carbon budgets, discussed in Section 8.2, both assume a far lower contribution to overall emissions reductions from homes from energy efficiency measures than from low-carbon heat.
- With many homes having adopted basic fabric measures (loft insulation, cavity wall insulation), further improvements, as required in a deep retrofit, tend to be more costly and disruptive (e.g. other wall insulation approaches, floor insulation). Deeper fabric measures are therefore currently occurring at a relatively slow rate.
- Inappropriate or poor-quality fabric installations can lead to undesirable unintended consequences. Costs may be expected to increase for some fabric measures where additional quality control and assurances are needed to ensure appropriate installation quality to help avoid mistakes experienced in some previous schemes (discussed further in section 7.4.2). Perception of elevated risk may make consumers resistant to deeper retrofit measures.

- Practical, technical and/or heritage constraints mean that not all homes are equally suited to a fabric first strategy. Real-world situations and opportunities can influence the sequence that retrofit measures are carried out, which may move away from a fabric first ideology. For example, when other non-energy-related works or upgrades are taking place, new heating or renewable energy upgrades may become more cost-effective. Prioritising decarbonisation of heat

7.2 Decarbonisation of heat

Decarbonisation of heat is a transition from fossil fuel-based heating systems to low or zero emission (clean heat) heating systems. Clean heat systems can often be installed without extensive fabric retrofit measures, although this may have implications for efficiency, comfort and running costs. This will directly contribute to decarbonisation, although it will not necessarily reduce the heating energy requirements.

Main benefits/opportunities of prioritising decarbonisation:

- Electrification of heat is expected to make the greatest contribution towards achieving zero emissions targets in homes, as the electricity grid decarbonises further over time.
- Despite electricity prices typically being higher than other fuel sources (particularly mains gas) cost savings can sometimes be achieved by switching from a traditional heating system with no other measures. For example, one study estimates that around a third of households in England would see reduced energy bills if switching from a gas boiler to a heat pump. This generally occurs in homes with the oldest and least efficient gas boilers (e.g. back boilers) (Leather and Marshall, 2025).

Main issue/challenges with decarbonisation:

- The Climate Change Committee (CCC) 2025 progress report (CCC, 2025c) indicated that decarbonisation of heat was happening too slowly. In particular, there were insufficient policy plans in place for 14% of emissions, partly due to a lack of programmes and funding towards heat pumps. There is concern that requirements for implementing fabric measures before installing clean heat systems is hindering progress. There is also evidence that suggests that clean heat systems can operate without deep retrofit in many homes, although additional fabric measures may still be important to improve affordability and comfort. (Eyre, N. *et al.* 2023).
- While clean heat systems may be technically viable in poorly insulated homes, acceptable running costs and comfort levels may still require additional measures. While the Leather and Marshall study noted above (2025) estimated that around a third of households would see bills reduce when switching from a gas boiler to a heat pump, the other two thirds would see bills increase. In many cases, the increase would be modest (around £32 per year). However, 22% of those switching from mains gas would see bills increase by over £100 per year. This could be a particular concern for low-income households or those in, or at risk of, fuel poverty. In such cases, fabric improvements or some other mitigation would be required to prevent bill increases. Other approaches may include capitalising on savings from off-peak tariffs or utilising 'social tariffs' for vulnerable households (National Energy Action (NEA), 2023; Leather and Marshall, 2025).

- Systems may be oversized if/when building fabric is later upgraded. This may not necessarily be an issue for efficient operation. However, it may mean that a more expensive system cost was incurred compared to if the system were sized after fabric measures (Nesta, n.d.).
- The Electrification of Heat demonstration project carried out by Energy Systems Catapult found that heat pumps can be used efficiently in a wide variety of buildings (ESC, 2024). A large number of the test homes in the study were in Scotland. While this is positive, it was found that installation quality can have a notable impact on achieved system efficiency. In most cases, heat pump efficiency was lower in practice than quoted at the design stage. This will have implications on expected running costs. However, impact on running costs was not an apparent focus of the trial.
- Unlike the 'fit and forget' nature of fabric measures, heating systems have to be maintained and replaced at the end of their lifespans. Hence there will be maintenance costs and replacement costs to consider. This is true of any type of heating (with greater or less frequency). However, capital costs can be higher with systems such as heat pumps than with other traditional heating systems.

7.2.1 Impact of heat decarbonisation on the electricity grid

A transition to increased use of electric heating will increase electricity demand, potentially aligning new peaks with periods of already high demand. This raises concerns for the electricity network. Fabric efficiency measures can help reduce peak electricity demand, though flexible operation of electric heating systems and Time-of-use tariffs could be an alternative strategy to help mitigate impacts on the electricity network. This can also bring savings to consumers, which can be enhanced if PV and battery storage is also employed (Rosenow and Lowes, 2023; Moss *et al*, 2024; Nesta, 2025a). Rosenow *et al* (2020) observed that network reinforcement costs could be deferred where technically difficult through short term hybrid approaches and by capitalising on flexibility.

An earlier study for BEIS suggested that 84% of rural homes in England and Wales could be electrified at then-current (2018) levels of insulation. This considered expected loads on the low voltage network relevant to average peak winter day temperatures. This increased to 93% of rural homes if all those suitable had loft and wall insulation installed. However, the proportion of homes the current low voltage network can support dropped considerably when a 1 in 20-year winter peak scenario was considered. Peak demand shifting, as noted above, and/or thermal stores or battery storage are noted as helping to reduce constraints on the low voltage network (Myers *et al*, 2018).

7.3 Forms of clean heat

The clean heat technologies most often discussed for heat decarbonisation in the UK are:

- Various types of heat pumps
- Other electric heating (electric boilers, panels heaters, storage heaters)
- District heating networks (with low or zero carbon sources) (out of scope for this study)

All systems have their associated risks and typical suitability.

Heat pumps (e.g. air source, ground source, air-to-air, etc): As set out later, these are generally considered to be technically suitable for most buildings (particularly Air Source Heat Pumps (ASHPs), due to their cost and flexibility). They are an existing, known technology, and are therefore the main form of heating assumed in domestic decarbonisation trajectories (CCC, 2025b). Some types can face issues in relation to space and noise constraints that can influence selection. Many may require associated works, such as changes to pipework or emitters.

Hybrid heat pumps: These combine a heat pump with another heat source (such as a gas boiler), and associated controls to optimise efficiency and running costs. They can offer an interim solution to full decarbonisation in homes where installing just a heat pump would be unfavourable. This may include older properties with high heat demand where fabric efficiency measures are impractical or excessively costly. (EHAS, 2019). Hybrids could also help reduce the impact on the electrical network of increased peak demands that may be presented by a significant roll out of traditional heat pumps without any integrated flexibility.

Direct electric heaters: This can include wall mounted electric radiators, storage heaters, infra-red heaters, electric boilers and similar. These are generally affordable to buy and relatively easy to install. However, they tend to have higher running costs compared to heat pumps, because the efficiency with which they deliver heat cannot exceed 100%. (Direct electric heaters are 100% efficient at converting electricity into heat. Meanwhile, heat pumps use electricity to upgrade heat from the air or ground via a compressor, meaning they can achieve efficiencies of 250-400%.) Running costs may be acceptable in smaller and/or highly energy efficient homes, or where occupied hours are low or highly intermittent.

Solar thermal systems: Solar thermal systems capture sunlight to produce heat. These were not a significant focus of this study, largely because hot water provision was not central to balancing fabric efficiency and clean heat measures. PV systems, which instead convert sunlight into electricity, were more commonly discussed in the literature in relation to reducing the running costs of electrified heating.

Biomass/bioenergy heating: Biomass heating systems are not generally considered a mainstream solution due to constraints on sustainable fuel supply and competing demand from other sectors (Foster *et al.* 2020). Despite this, they may remain relevant in some properties with limited suitability for electrified heating systems. As with other heating types, fabric improvements can help reduce energy demand and running costs.

7.4 Associated health, wellbeing and socio-economic impacts of retrofit

7.4.1 Impact on the National Health Service

Improving poor housing is predicted to have significant benefits on occupant health, comfort and wellbeing. BRE research on the cost of poor housing in England found that mitigating hazards (which include excessive cold and damp as well as other hazards) could save the NHS over £1 billion per year (Garrett, 2023).

A Climate Services for a Net Zero Resilient World (CS-N0W) study simulated health impacts of retrofit measures alongside energy and carbon impacts (Symonds *et al.* 2025). It found that full fabric retrofit of homes in England could provide NHS cost savings of around £0.26 billion over 25 years. The addition of a heat pump to that scenario was forecast to potentially save the NHS around £1.3 billion in total over a 25-year modelling period. This is because a 1°C increase in average internal temperature was assumed from continuous, lower temperature operation of the heating. (This phenomenon had been witnessed in studies of ASHP use, though was acknowledged as a 'behavioural' factor rather than inherent to the technology.) A further £0.5 billion in NHS savings over 25 years was predicted by also switching to electric cookers. This would reduce indoor air pollution, which would benefit cardiovascular and respiratory conditions.

A cost analysis for Scotland by the University of Glasgow estimated that annual NHS costs associated with poor housing in Scotland was around £530 million (Boyd *et al.* 2025).

7.4.2 Reported health, wellbeing and socio-economic benefits and risks with fabric measures

Homes that do not have an energy efficient building fabric can experience a poor internal environment, including damp, mould and reduced indoor air quality. Heating costs may not be affordable for households if energy demand is too high. When fabric energy efficiency measures are implemented in a retrofit, it can improve these HWS aspects by making a home easier/cheaper to heat. Increased temperatures help to combat damp and mould, and better ventilation provision can improve air quality. Improved warmth and physical environment can contribute to improved cardiovascular and respiratory health. Improvements in all of these factors can reduce stress, leading to improved mental and social outcomes (Public Health Scotland (PHS), 2021; BEIS, 2020).

However, there have been reported failings with fabric retrofit due to poor design and installation quality, and inadequate ventilation provision (National Energy Action, 2025; National Audit Office, 2025). These can undermine the intended HWS and energy benefits, leading to localised increased heat loss, condensation and mould, and in severe cases, physical damage to the building. Overheating can also potentially be a risk in highly insulated homes, which can be exacerbated by a lack of adequate ventilation (PHS, 2021; BEIS, 2020).

The DEEP project (Glew, 2024) specifically assessed overheating risk associated with retrofit interventions. It found that retrofitting can help reduce overheating risk, but it depended on what measures were installed. Improved airtightness, loft and floor insulation typically led to marginally increased risk. This was a result of reduced beneficial summer air changes, and reduced heat exchange with adjacent colder spaces respectively. Room-in-roof and solid wall insulation reduced overheating risk by fundamentally limiting transfer of heat into spaces. However most homes, even those with beneficial retrofits, were found to fail overheating criteria when 2050 weather scenarios were considered.

In some retrofit cases, energy savings may be short-lived or not in line with expectations due to 'rebound effects', particularly if homes were previously underheated (Peñasco and Díaz Anadón, 2023). A rebound effect is when expected energy savings are not delivered in practice due to changes in occupant behaviour.

However, rebound effects may still represent positive outcomes in terms of home health and comfort. A retrofit may therefore be considered successful if occupants are able to achieve a warmer and healthier home at a similar running cost (Nesta, n.d.).

7.4.3 Reported health, wellbeing and socio-economic benefits and risks with clean heat measures

Electric-based heating systems are 'clean' at the point of use (and are expected to completely decarbonise as the electrical grid does so). It is typically assumed that if homes switch to clean heating, they will most likely also switch to electric cooking. This would allow complete removal of the need for a secondary fuel source, which would save money on separate bill standing charges. This would also further reduce risk of internal air quality detriment from the burning of fossil-fuels indoors.

However, clean heat systems may fail to achieve quoted efficiency or running costs if they are poorly installed and/or commissioned (ESC, 2024). This can lead to higher energy bills than expected, which is particularly detrimental to households with limited budgets and can increase risk of fuel poverty.

Intermittent high temperature heating patterns, typical of traditional heating systems, can lead to suboptimal heat pump operation, resulting in lower system efficiency and reduced thermal comfort. Heat pumps generally operate most efficiently with continuous heating schedules and limited difference between setback temperatures (i.e. backstop temperatures typically set when a home is unoccupied) (Palmer and Terry, 2023).

Studies suggest that maintaining more stable indoor temperatures may also support improved health outcomes. Specifically, raising backstop temperatures from 16°C to 18°C was found to cost only a relatively small amount extra in a typical home (with gas heating). However, the lower temperature can potentially lead to significant negative health impacts (NEA, 2024a). Therefore, where heat pump systems are able to operate affordably at a relatively constant temperature, this could deliver improved comfort, beneficially impacting the health of occupants. The Scottish Fuel Poverty (Targets, Definition and Strategy) (Scotland) Act 2019 and Regulations 2020 recognises extended heating requirements for some households, including older people, young children, and those with health conditions. Such heating regimes may facilitate more efficient heat pump operation. The extent to which the Act's enhanced temperature regime could be efficiently delivered by clean heat systems does not appear to have been specifically explored in the literature.

While heat pumps typically operate most efficiently at low circulation temperatures, the disruption of replacing emitters/radiators to accommodate this can be off-putting. However, adopting a high temperature heat pump could avoid the need to replace emitters and allow a heat pump to remain a cost-effective solution (Palmer and Terry, 2021).

8 Evidence related to the optimal balance of fabric efficiency measures and clean heat in retrofit

Rosenow & Hamels (2023) considered numerous stock and system level modelling studies from across Europe. They summarise that decisions on the optimal balance of fabric measures and clean heat would depend on various perspectives, in particular:

- Individual building owner versus stock and energy system level optimisation.
- Concern for the total cost of measures (capital and operational) versus either capital or operational/running costs separately (e.g. owner occupiers, landlords, rental tenants).
- Whether also focussing on addressing wider health, wellbeing and socio-economic outcomes, including fuel poverty risk.
- The timeframe considered for assessment (i.e. short versus long term costs and impacts).

These factors were borne out in the present study. Differing perspectives arise from the literature depending on whether system level (i.e. electricity grid) impacts are considered for example. In addition, determination of an optimal balance between fabric and clean heat measures varies depending on whether the focus is on:

- The technical viability of clean heat operation in isolation of running costs.
- Assessment of total cost of ownership, with potential trade-off between up-front costs and ongoing costs.
- Avoiding increased running costs (particularly to avoid risk of worsening fuel poverty).

8.1 Sensitivity to energy pricing

All studies generally cite the sensitivity of their recommendations to the relative prices of gas and electricity. Electricity is currently more expensive than mains gas, which makes delivering an equivalent amount of heat more costly when electrifying from gas. Some studies quote the electricity to gas ratio recently reducing to approximately 4:1 (e.g. Nesta, n.d). However, the ratio in Scotland in February 2026 was 4.7-4.8:1 (Ofgem, n.d).¹ Minimising the impact of a fuel switch on energy bills relies heavily on enhancing the building fabric and/or deploying clean heating systems with higher efficiencies. As heat pumps can operate at efficiencies around 300% (indicated by their coefficient of performance, i.e. COP = 3), they can help to close the running cost gap in homes where they are suitable. Recent trials of heat pumps found in-use seasonal performance factors to average just below 3 (ESC, 2024).

¹ The January to March 2026 Ofgem price cap rates per kWh for direct debit single rate electricity were 27.83p for southern Scotland and 28.36p for northern Scotland. The direct debit rates for gas were 5.89p per kWh for all of Scotland.

Time of Use (ToU) tariffs and smart controls are examined in some studies. Shifting heating periods to times of low pricing can help to reduce running costs.

Energy pricing is largely outside the Scottish Government's control (it is a UK Government reserved issue). Some studies have explored the potential influence of changing energy prices. However, policy decisions will likely need to be based on conservative assumptions in line with the status quo.

8.2 Assumptions for carbon budgets for the UK and Scotland

The Climate Change Committee (CCC) has developed the seventh carbon budget for the UK (2025a) and a Carbon Budget for Scotland (2025b). Both budgets are based on decarbonisation in homes via electrification of heat, primarily through the adoption of heat pumps. At a UK level, half of homes are expected to run on clean heat by 2040. Scotland's pathway indicates 40% of homes should have a low-carbon heating system by 2035. The Scottish carbon budget acknowledges that for tenement buildings, heat networks or communal heat pumps (including high temperature systems) are likely to be most suitable.

With many homes still relying on fossil fuels to 2035/2040, improving home efficiency is expected to help reduce emissions in the short term. However, these fabric efficiency improvements will only deliver 14% of the planned emissions reduction from residential buildings in the Scottish carbon budget in 2035. This compares with 54% emissions reductions expected to be achieved through low-carbon heating. Equivalent figures for the UK carbon budget, to 2040, are 10% emissions from energy efficiency and 66% from low-carbon heating. Both carbon budgets assume most homes would install 'small' cost effective energy efficiency measures in this time. This includes draught-proofing and hot water cylinder insulation. It is acknowledged that the majority of homes with lofts or cavity walls are already insulated to varying standards. In the UK pathway, it is assumed that further viable cavity walls will be insulated and all remaining potential for top up loft insulation. Solid wall insulation is stated in the UK budget as generally not being cost effective and is only assumed to be installed in around 15,000 homes. In the Scottish pathway, it is proposed that 9% of households would install 'large' energy efficiency measures, such as cavity wall, loft and floor insulation. No specific targets are proposed for solid wall insulation.

The Scottish carbon budget acknowledges the importance of addressing fuel poverty and cites the need for electricity prices to be addressed by UK Government. The focus is however on achievement of net zero by 2045. No specific measures or considerations are cited in relation to reducing fuel poverty, other than setting minimum energy efficiency standards for privately owned homes. Fuel poverty rates are expected to reduce through insulating homes, and where clean heating will substitute for expensive fuels such as oil.

These pathways set the overall targets related to decarbonisation. But national policy will need to create the structure through which this will be delivered, while also protecting health and mitigating fuel poverty risk.

8.3 Comparing equivalent studies of optimisation scenarios for the UK and Scotland

A study was carried out for the Department for Business, Energy and Industrial Strategy (BEIS) on Cost-Optimal Domestic Electrification (CODE) (Palmer and Terry, 2021). This specifically sought to identify a cost-optimal balance of fabric measures alongside clean heat options for typical UK housing archetypes. The study primarily considered the total cost of ownership of selected measures (i.e. up-front capital costs, running costs, and maintenance requirements). It therefore best represents the position of households responsible for both the cost of retrofitting and the ongoing energy bills, i.e. 'able to pay' owner occupiers.

It found that electric heating can be cost effective in UK homes without extensive insulation upgrades. Data from this study underpins England's Warm Homes Plan, discussed earlier (DESNZ, 2026).

The CODE study was sensitive to the timeframe over which measures were assessed and quoted results over a 15-year period. Short timeframes (e.g. 5 years) favoured heating systems with low up-front costs, but tended to result in higher running costs. Meanwhile, longer timeframes (e.g. over 20 years) favoured storage heaters, despite higher ongoing running costs. This is because heat pumps incurred further maintenance and/or replacement cycles over that period while storage heaters did not. Solid wall or floor insulation were still not deemed cost-optimal over longer timeframes.

These trade-offs could manifest themselves in practice in some property tenures unless backstops were imposed around approaches to deploying clean heat. For example, landlords of rental properties may wish to focus on minimising capital expenditure to meet any imposed decarbonisation requirements. However, this could drive up energy bills for tenants, which could increase risk of fuel poverty.

WWF Scotland commissioned a similar study (ScotCODE) by the same research team for Scottish housing (Palmer and Terry, 2023). The ScotCODE analysis demonstrated that optimisation outcomes for Scottish homes differ materially from wider UK findings. Unlike the UK-wide CODE study, ScotCODE found additional fabric measures to be cost effective in many Scottish archetypes. This reflects the influence of Scotland's colder climate and housing stock characteristics on heat pump performance and running costs. In particular, the Seasonal Coefficient of Performance (SCOP) of heat pumps was noted to be lower in Scotland than England due to the climate. This should be borne in mind when considering findings from other UK-wide studies that do not explicitly consider Scottish circumstances. It suggests that findings from such studies could be overly optimistic and therefore recommendations may be less suited to deployment in Scotland. The ScotCODE study found that:

- Fabric improvement measures (loft, cavity insulation, draught proofing and double glazing) significantly improved heat pump performance and reduced running cost. Solid wall insulation was more cost effective than using heat pumps with larger radiators for older stone homes (over a 15-year assessment timeframe). However, it was noted that such measures were expensive, and suggested they could be recommended as 'optional' where affordable.

- ASHPs were the most cost-effective electric heating solution in almost all types of Scottish homes (alongside the fabric measures noted above). Off-mains gas homes on oil or electric storage heaters saw the largest bill reductions. Air-to-air heat pumps were the most cost-optimal solution in pre-1919 tenements, though were only marginally more cost-effective than an ASHP. Air-to-air heat pumps were also suggested as a solution in 'challenging homes', (i.e. space constrained, or heritage properties).
- Running costs were lower with a heat pump in many homes. However, some homes switching from gas boilers, particularly flats, would see increases in energy bills. Extra measures were modelled and recommended that would also result in reduced bills for these scenarios. These extra measures would result in a higher whole life cost than the 'optimised' scenario that gave higher bills. This may be preferable in scenarios where running costs and fuel poverty risk are a concern.
- It was suggested that communal systems or heat networks may be more cost-effective for flats and tenements over individual heat pumps due to characteristics such as space, size and energy demand. However, this was not specifically investigated in the study.

Subsequent investigations carried out on the Scotland data (Palmer and Terry, 2024) highlight that bill savings were highly sensitive to assumptions on gas versus electricity pricing. The 'medium' predicted pricing scenario modelled would reduce electricity pricing to 2.57 times that of gas. This was based on a projected drop in wholesale electricity costs and removal of policy costs from electricity pricing, with no change to gas pricing. In this scenario, 85% of homes were expected to experience bill savings. However, very few properties (<1%) would recover the up-front cost of the measures.

This may not be a material consideration for a new heating system since replacement is a necessary periodic outlay as systems reach their end of life. The contention when considering a clean heat system is that, currently, systems such as heat pumps are considerably more expensive than systems they will be replacing.

8.3.1 PV and batteries

The BEIS CODE study (Palmer and Terry, 2021) investigated the use of PV and batteries for typical UK archetypes. They did not feature in the 'optimum' scenarios that resulted (i.e. they did not form the most cost-optimal solution for the derived archetypes). However, their benefit for offering demand flexibility was noted. They were also recognised for reducing overall electricity use and offering emissions benefits that were not captured in the purely financial optimisation. It follows that there are wider incentives to government for the deployment of PV and batteries. These relate to overall demand on the electricity network, and in support of more rapid decarbonisation compared to relying on clean heat and fabric efficiency measures alone.

The ScotCODE study (Palmer and Terry, 2023) stated that PV panels and batteries were not part of the analysis, since they affect neither heating nor fabric energy efficiency. However, the study refers to 'early modelling work and optimisation' with PV and batteries. It is not clear whether this was modelling in the context of the Scottish archetypes, or was in reference to the earlier UK-wide CODE study. However, it reported that solar PV was economically viable for all house types over 15 years. This is because high electricity prices

allowed savings to offset capital costs and reduce overall running costs. It was noted that PV could be deployed to offer lower running costs in fuel poor homes if support was provided to meet capital costs. Conversely, it was stated that batteries were never economically viable over 15 years, in part due to a reported 10-year replacement cycle and associated costs.

Neither study quoted an assumed price for PV systems. The CODE study stated that a single 8kWh battery system was modelled across all house types (assumed to have 6kWh useful potential) at a cost of £4,350. Since February 2024, there is a temporary 0% VAT applied to domestic battery storage systems, which will be in place to March 2027 (HMRC, 2024). A recent industry source suggests 8-10 kWh batteries have a battery-only price of £2,800-£4,500, with an installed price of £4,500-£7,000, as at March 2026 (Smith, 2026). Payback periods, when used to optimise self-generation from PV, are quoted between 6-10 years. This suggests that batteries could currently be economical within their expected lifespans. However, it is stated that batteries will not necessarily be economical for all households, particularly those with favourable export tariffs or high self-consumption of PV generation.

8.4 Investigations specifically assessing deployment of heat pumps

As noted in the CCC pathways, it is anticipated that heat pumps will play a significant role in achieving decarbonisation. Many studies have therefore focussed on ‘heat pump suitability’ of homes, or the ‘heat pump readiness’ of homes. Suitability considers the fundamental viability of heat pumps for particular types of home. Readiness considers whether other preceding actions are necessary to facilitate the change. This can include fabric performance, but also other factors, like the suitability of the existing pipework/heating distribution system, or availability of space, etc. The need (or not) for a particular level of fabric energy efficiency alongside clean heat is typically discussed in both types of study.

Studies have taken very different and sometimes novel approaches to assessing potential suitability and readiness. These range from assessing historic boiler performance data (Childs *et al.* 2025), through to modelling of particular example house types.

Studies use a range of different metrics to define ‘heat pump readiness’, making direct comparison difficult. These metrics generally attempt to assess either the technical feasibility of heat pump operation or the likelihood of achieving acceptable running costs and comfort levels.

Several studies determine that some form of fabric improvements to reduce heat loss are often required for efficient heat pump operation. The extent typically depends on the nature of the property.

An assessment of modelling studies from across Europe found optimal demand reduction to complement heat decarbonisation was between approximately 20 to 50%. Lower levels were acceptable in warmer climates, while higher levels would be favourable in colder climates (Rosenow & Hamels, 2023). Other studies suggest that radiator upgrades to facilitate lower flow temperatures would be needed to improve operating efficiency, particularly in solid wall homes. This would typically be in combination with constant running and minimal setback (e.g. to 18°C) to deliver comfortable conditions (Carbon Trust, 2020; Clarke and de Selincourt, 2024).

Various benchmarks are derived across studies to represent proposed fabric efficiency levels. However, they do not always quote the same metrics, which can make simple comparison difficult. For example, the following studies quote ‘space heating demand’ and ‘fabric heat loss parameter’ respectively.

One study suggested a space heating demand target of 45 kWh/m²/yr. This was quoted to reduce heat pump energy consumption to 1kW, stated as being an acceptable maximum threshold for a heat pump (Lingard, 2020). The ScotCODE study recommends a space heating demand of 65-85 kWh/m²/y for homes to be heated effectively using low flow temperatures. However, it was noted that some homes had a higher residual heat demand with limited scope for further improvement (Palmer and Terry, 2023). Where such targets cannot be achieved, alternative options (e.g. high temperature heat pumps) may be needed.

Meanwhile a study by the Passivhaus Trust estimated that a fabric heat loss parameter of 2.5 W/m²K would offer a break-even point between the cost of gas and ASHP heating. This is lower than the target of 4 W/m²K proposed as representing a heat pump ready standard in the DESNZ MEES consultation (DESNZ, 2025). The latter is intended to represent a peak heat loss threshold for which a low temperature ASHP would technically be suitable. However, it does not explicitly consider running cost implications, as the lower Passivhaus Trust derived target does. Where thresholds only consider the technical viability of heat pump operation, there could be risks that energy bills would rise.

The National Retrofit Hub (NRH, 2025b) have raised concerns about existing studies and of heat pump readiness. It notes that studies do not consider occupant heating patterns, real-world heat pump efficiency and commissioning standards. These omissions could leave residents with higher bills than anticipated. Stakeholders consulted suggested that a range of potential actions are required to ensure heat pump readiness for all. This could include:

- Physical measurement to more accurately understand property efficiency, with fabric measures proposed as necessary.
- Installation of PV and batteries to help reduce costs where systems would otherwise be more expensive to run.
- Post-installation monitoring to optimise system efficiency and comfort.

8.5 The potential role of hybrid heat pumps

One study compared hybrid heat pumps with air source heat pumps in properties across all EPC bands. Hybrid heating systems were found to be more cost effective in houses with EPC ratings of D to F, typical of older, poorly insulated houses. The study acknowledged that insulation upgrades have a useful role to play in allowing heat pumps to operate at higher efficiencies. However, high costs of some upgrades to facilitate heat pump usage were seen as a barrier. The study highlighted the potential value of hybrid heat pumps to support short-term heat decarbonisation in poorly insulated mains-gas properties. In particular, it noted that hybrids were the most favourable technology for over 40% of homes in 80% of Local Authorities in Scotland (Hybrid Heating Great Britain consortium, 2025).

Palmer and Terry (2021) also found hybrid systems to be cost effective in their CODE analysis. However, it was noted that these did not deliver complete decarbonisation.

Rosenow *et al.* (2020) concluded that hybrid approaches may help to defer immediate network reinforcement costs.

Hybrid systems may therefore support partial decarbonisation in fossil fuel heated properties in the short term. These homes could be a later focus for decarbonisation pathways, when capital costs and electricity prices are expected to reduce. Such market changes could help make heat pumps more favourable compared to mains gas heating.

8.6 Consideration of fuel poverty risks

Fuel poverty emerges across the literature as one of the key constraints on heat decarbonisation pathways. In many cases, the extent of fabric improvement required alongside clean heat is driven less by technical feasibility than by the need to avoid worsening household energy affordability. Many studies therefore note risks related to fuel poverty when discussing the implications of heat decarbonisation. However, assessments rarely go beyond offering scenarios that do not increase running costs compared to existing heating.

A study by Rossi *et al.* (2026) focussed on retrofit optimisation modelling that mitigates fuel poverty. The scenario assessment included the annualised cost of retrofit measures. In many cases, the high cost of some measures was found to never pay for themselves via reduced operational costs. This was generally the case for solid wall insulation, triple glazing and heat pumps (which aligns with the findings of Palmer and Terry (2024)). However, it may be unrealistic to assume that a new heating system would pay for itself through savings. Many in, or at risk of fuel poverty would be eligible for the cost of measures to be paid for through government grants. Ongoing running costs then become the concern of the occupants. During the scaling exercise to assess stock-level carbon savings, retrofit scenarios that would result in fuel poverty were rejected. The overall potential for national decarbonisation was therefore reduced by a varying extent depending on the method considered for assessing fuel poverty. An indicator linked to households spending more than 10% of their income on energy (as used in Scotland) was found to be most restricting. The findings suggest that targeted financial support and electricity price reform may be necessary to avoid decarbonisation pathways increasing fuel poverty risk. It was noted that solid wall insulation reduces heating demand without increasing risk of fuel poverty. However, heat pumps would need to be accompanied with policies to reduce electricity costs to prevent fuel poverty.

8.7 Recommendations within the literature

Rebalancing gas and electricity pricing: Historically, the UK government has opted to finance policy costs of a range of environmental and social schemes through energy bills rather than general taxation. Most of these costs are applied to electricity bills rather than gas bills, making electricity disproportionately more expensive than gas (Energy UK, 2025). Many sources note that it would be beneficial to the deployment of electrified clean heat to re-balance gas and electricity pricing. This would require moving policy costs either onto gas bills or to general taxation (or some balance between both). Closing the cost ratio between fuel sources would make electrified heat more financially viable. It is however noted that this is an area beyond the Scottish Government's direct control. A few example references include Eyre, N. *et al.* (2023) and Nesta (n.d), although there are many more.

Recognise that flexibility is required to meet differing needs: Many advocate that retrofit decisions on fabric and clean heat measures for individual buildings should be considered on a case-by-case basis. Cost effectiveness of measures can vary according to context, e.g. some upgrade costs may be lower if related building works are already planned. Policies and programmes will need to be sufficiently flexible to meet the needs of different buildings and their occupants. Well-qualified advisors will be needed to support households with decision making (Eyre, N. *et al.* 2023; Retrofit Roundtable, 2024; Rosenow and Hamels, 2023). Nesta cite that, for many homes, relatively modest fabric upgrades could make clean heat (heat pumps) affordable to run. Homes that require more extensive measures should have more complex packages made available to them. However, they warn against treating all homes like the most challenging ones, as this would unnecessarily delay the pace of decarbonisation (Nesta, 2025b). Others note that, due to the expected replacement of heating systems over time, high temperature heat pumps could be used in the short term for immediate carbon reduction. This could buy more time for insulation measures to be deployed, facilitating a more efficient heat pump in the future (Bell, A, n.d).

Prioritise off-gas properties: The ScotCODE study recommends prioritising properties currently on oil over those on mains gas. The study also suggests prioritising houses rather than apartments and flats. These would deliver the greatest carbon savings short term. Reduced system costs over time and rebalancing of gas and electricity prices may help to make gas conversions more cost-effective in due course. The study also recommends homes with existing direct electric or storage heaters be switched to an alternative heating system. This would help address fuel poverty risks, since these systems have high running costs.

Promote opportunities arising from trigger points: Trigger points could be used to drive clean heat or fabric performance, e.g. change of ownership, replacement of a heating system. In such cases, the cost and disruption of retrofit measures can be reduced when combined with other activities (Eyre *et al.* 2023; Killip *et al.* 2024). Minimum standards could be imposed at key trigger points. However, Killip *et al.* note that such standards would inevitably need to be less ambitious than the market's technical potential. This would be required to allow flexibility to address the many potential varied properties and scenarios.

Greater support for those in most need: Homes need to be comfortable and affordable to heat. This can support a greater focus on fabric improvements, particularly for households at risk of fuel poverty (Eyre, N. *et al.* 2023). The Green Alliance issued a position paper on decarbonising heat while addressing fuel poverty. They suggest that deep retrofit should only be pursued for fuel poor households and where it will address health and comfort needs, e.g. in social housing. Cheaper measures, such as loft and cavity wall insulation, should be widely promoted alongside heat pumps, as well as utilising ToU tariffs to help reduce running costs (Carr & Bennett, 2024). An economic analysis of housing and health also recommended that policy efforts should focus on retrofit programmes for low income and medically vulnerable populations (Boyd *et al.* 2025).

9 Interview insights on health, wellbeing and socio-economic impacts

A series of interviews were carried out with key industry stakeholders to gain views on how HWS aspects may influence the balance of fabric measures alongside clean heat.

9.1 Impacts that should be considered when retrofitting

All interviewees generally agreed on the importance of considering the potential to positively influence the following factors when retrofitting:

- Cold homes (underheating) as a detriment to health.
- Risks from overheating.
- Health impacts from damp and/or mould.
- Internal air quality.
- Household bills and risk of experiencing fuel poverty.
- Mental health (e.g. from concerns about energy bills or unhealthy conditions).
- Knock-on impacts on public health services.

Some interviewees also additionally noted:

- The link between a healthier home and better job and education prospects, i.e. less work/school days lost due to ill health.
- Wider consideration of indoor environmental quality beyond damp and ventilation, to include impact from chemicals or products used in retrofit.
- Noise considerations in retrofit approaches (e.g. better sound insulation) since noise nuisance can impact on mental health.
- Lighting and glare (i.e. consideration of shading and passive measures, improvements to internal daylight).
- Resilience with respect to energy bills, i.e. protecting from externally influenced price-rise shocks through self-generated energy.
- The impact disruption from retrofit can have on wellbeing and mental health (even if only relatively short term).

Some of these issues can potentially be worsened by retrofit (e.g. if measures compromise ventilation and indoor air quality). However, there is recognition that there are a significant number of wider 'added value' benefits of retrofit. Many believed these should be framed as the primary, outcome-based drivers of retrofit policy rather than only an associated benefit of the decarbonisation agenda.

It was also believed that it is not enough to just keep energy bills as they are with a new clean heating system. Due to high energy prices, household fuel bills are currently too high. Retrofit therefore needs to seek to reduce energy bills in all cases, but particularly to reduce risk of fuel poverty.

9.2 Positions on fabric energy efficiency measures and clean heat

Respondents had different positions on where they believed the balance should lie between fabric measures and clean heat technologies to ensure positive outcomes beyond decarbonisation. Some felt that fabric measures were fundamental for improved comfort and health outcomes, while also reducing energy demand (to reduce bills); clean heat alone would not improve health in a like-for-like home with existing issues. One interviewee believed there was a more immediate recognition amongst consumers of how fabric measures could help to improve comfort and reduce running costs, compared to heat measures. But it was recognised that measures need to be delivered to a high standard with appropriate consideration of ventilation and thermal bridging to avoid the adverse impacts of some past retrofits.

Some cited that relatively basic, low-cost fabric measures could be sufficient to bring many homes to a 'good' standard. This would help to improve comfort, improve efficiency of heating systems, and reduce running costs of clean heat. This included top-up insulation in lofts, and cavity wall insulation where feasible. It was however also recognised that there is limited remaining capacity for such improvements in the existing stock. Draught proofing was believed by some to be particularly important, since reducing air permeability (while ensuring adequate ventilation is maintained) can be beneficial to heating efficiency.

Consistent with the literature review, interviewees highlighted affordability as a key constraint on clean heat deployment. In some cases, fabric improvements will not be feasible or cost effective, and alternative mechanisms would be needed to deliver comfort and clean heat at acceptable running costs. Suggestions included:

- Deploying renewable energy (typically discussed in the form of PV, often alongside batteries) to reduce bills and improve energy independence in households with high cost/demand.
- Instigating 'social fuel tariffs' (i.e. subsidised electricity tariffs) for those with justifiable and unavoidable high demand (though it was also recognised that dependence on tariffs is unreliable in case they are withdrawn in future).

Many called for an 'outcomes based' approach (i.e. to deliver healthy homes and reduce fuel poverty), rather than focussing on specific measures. This is in recognition that all homes are different and occupants have different needs and priorities. Measured rather than theoretically assumed (modelled) outcomes were also advocated. However, it was acknowledged that there are not robust and universally measured metrics relating to health as there are for carbon emissions and running costs. A study by the National Retrofit Hub (2025) explored potential indicators related to the co-benefits of retrofit, identifying around 40. Yet there was still a disconnect between many indicators and the availability of metrics against which to measure them. Some metrics are used as a proxy for wider outcomes, such as indoor air quality or thermal comfort. But the overall outcome is not guaranteed and will be subjective depending on the preferences of the occupants.

One interviewee noted that while defined performance metrics for health impacts would obviously be ideal, positive change could still be driven by high-level policies. They cited the Well-being of Future Generations Act implemented in Wales (National Assembly for Wales, 2015). Under the Act, public bodies need to consider the impact their decisions may have on

people living in Wales under seven headline goals. One of these goals is for 'a healthier Wales', another is for 'a more equal Wales'. Public bodies need to set objectives designed to maximise their contribution to achieving each goal and take steps to meet those objectives. This is cascaded through to grant and procurement conditions, which typically require alignment with the Act's principles. The interviewee felt that this approach promotes the need for health to be considered, while not being prescriptive as to how; simply setting the ambition makes people think creatively about how things can be improved. To assess whether the Act is having the intended impact, a number of indicators are measured at a national level. In 2025, Welsh Government reported that progress against the milestones was mixed, with around half improved, around a quarter deteriorating, and a further quarter showing little or no change (Welsh Government, 2025).

'Heat as a service' solutions were also noted by some interviewees for their change in emphasis on delivering comfort needs rather than meeting energy demand. They went on to stress that having choices and options (rather than a prescriptive approach) was most helpful to adapt to different circumstances. A concept of 'the right measures for the right properties' occurred across interviews.

Some emphasised that there should be different approaches for different sectors of society. i.e. potentially investing more and pursuing deeper fabric retrofit for households with enhanced needs and most at risk of fuel poverty. It was also acknowledged that cost effectiveness of measures will be different depending on property tenure; economies of scale may influence the viability of measures on area-based retrofit schemes, but equivalent measures may not be so viable for individual property owners.

One interviewee indicated that capitalising on automated demand flexibility with clean heat systems alongside ToU energy tariffs could present an alternative to more extensive fabric measures to reduce running costs. This could also present a wider 'macro' benefit of reducing localised energy grid burden at peak times.

Overall, interviewees broadly supported the literature findings that flexibility and affordability are central to successful retrofit policy.

9.3 Recommendations for retrofit policy and decision making to better support outcomes

Most interviewees cited the need to address the fuel cost balance between gas and electricity to facilitate decarbonisation while not increasing fuel poverty (noted earlier). Though it was recognised that this is beyond the Scottish Government's direct control.

Many also believe that policy needs to specifically recognise and target health and wellbeing outcomes in retrofit. It should not just be assumed they would automatically be delivered as a result of decarbonisation.

Respondents unanimously advocated the idea that support (i.e. government funding) should be targeted where the need is greatest, as a 'social investment'. This was generally acknowledged to include those in fuel poverty, with health conditions exacerbated by cold, with elevated energy demands on health grounds, the elderly and the very young. One interviewee noted that although an enhanced heating regime was recognised for some households in fuel poverty modelling, in some cases this still did not go far enough. 24/7

heating demands (sometimes along with additional energy-using medical equipment) potentially widens the 'fuel poverty gap' in practice in some cases. Many also noted rural homes as requiring focus, as properties are typically older, in a poor state of repair, often underoccupied, have expensive running costs (off-gas) and a higher incidence of fuel poverty. The effectiveness of targeting within government schemes was questioned by some interviewees; there was concern that uptake was low in homes most in need, and that delivery was reactive rather than proactive. Empowering communities (including undertaking Community Health Impact Assessments) and supporting local advisors were noted as potential avenues to help address this, though it was not an area of detailed focus for the interviews.

Capitalising on key intervention points was deemed to be important, e.g. replacing a heating system towards its end of expected life, life events prompting household renovation (e.g. retirement, growing family, moving into a new home, etc). Better public awareness of the associated health and comfort benefits of retrofit, as well as on clean heat in general, is needed. This would help drive positive change, linked to such interventions. However, it was also noted that imposing restrictions linked to interventions can be counterproductive, e.g. a requirement to carry out fabric measures to qualify for a clean heat grant. In some cases, the timing may not be ideal (and self-funding may be insufficient) for such linked measures, deterring households from making otherwise positive changes.

This is aligned with a general call for better advice to improve 'energy literacy' amongst households. In particular, it was suggested that this should include support to choose the most appropriate measures (The Scottish Government's HEETSA proposals were welcomed). However, it was suggested this needs to go further to ensure there is support for optimising measures for most efficient use and delivery of comfort after installation. Advice on when and how best to capitalise on ToU tariffs was also noted. It was also suggested that if EPCs were more dynamic and able to capture specific household circumstances and use patterns, they would be more helpful as a retrofit decision tool for consumers. It is noted that work is ongoing for the Scottish Government exploring the potential for interactivity of EPCs.

Several interviewees noted that aftercare following retrofit, and particularly commissioning of new systems, was very different in private versus area-based social schemes. Commissioning quality can be critical to eventual system performance, and hence delivering comfort and intended running costs (noted in ESC, 2024). A focus on this aspect is therefore likely to be required to deliver expected health and financial benefits of retrofit. Improved system efficiencies ensured through quality installations may also negate the need for more extensive measures to deliver acceptable heating running costs.

It was also believed the retrofit narrative should change focus towards health, wellbeing and comfort, rather than decarbonisation. Cost arguments may also have low impact, since many households are cynical of achieving quoted savings. It was noted that recent bad press in relation to poor quality retrofit, as well as instances of mis-selling, have impacted public trust relating to retrofit. A change of focus and improved post-installation support could help win-back trust and drive uptake of retrofit.

Some risks and concerns were highlighted across the interviews that future policy design may need to consider to ensure beneficial HWS outcomes:

- A recognition that clean heat systems need to be ‘affordably’ efficient (i.e. cost of units to deliver warmth and comfort). There was concern that those already with electrical heating systems other than heat pumps would not be prioritised within decarbonisation agendas. However, such households may currently experience compromised comfort (e.g. under-heating) and have high risk of fuel poverty.
- Concern about ‘green gentrification’ occurring as a result of well-intentioned MEES implementation in the private rented sector. The aim of improving minimum energy standards to ensure comfort and reduced energy bills in this sector was welcomed. However, some noted a risk that costs would in some way be passed on to tenants. This may be through reducing other services to recover landlord costs, or simply through increased rent if properties essentially became more desirable.
- Mechanisms are still lacking to address retrofit-related issues in mixed tenure properties. As noted in Section 6, Scotland has a high percentage of flats and tenements where solutions may be practically limited by difficulties in getting all relevant parties to agree on measures. Heat networks are often cited as a likely solution to decarbonise such properties, though such developments will take time. Meanwhile, many households are unable to take action against compromised comfort and/or high bills.

9.4 Reflections across the literature and interviews

The recent literature identified during this study generally does not support the need for extensive fabric measures to facilitate clean heat. The need for fabric measures typically relates to the drive to reduce household heating costs and improve comfort and health. Those that advocate a rapid transition to clean heat invariably acknowledge that low-cost fabric measures are also worthwhile. Such measures help reduce running costs, while also increasing system efficiencies and reducing peak loads on the electricity grid.

Some critics of historic fabric retrofit initiatives have cited the rebound effect of unrealised energy savings in practice as a failing. However, it could be argued that such measures have served a purpose in improving comfort standards for occupants. Such instances cast a light on areas of society where lived experience is not represented by a theoretical energy model. Retrofit also has an important opportunity to improve people’s health and welfare. However, this is typically less tangible to quantify compared to carbon or energy bill savings.

Key areas where feedback from interviews align with the literature include:

- For retrofit approaches to be flexible, and not too prescriptive, so as to respond to particular property and household needs.
- Those in most need should be supported with enhanced measures to reduce running costs and improve comfort. This may mean more extensive fabric efficiency measures for some homes, or the addition of renewable generation to offset bills. It may also extend to the instigation of ‘social tariffs’ for subsidised energy.

10 Design and scope of a potential future modelling exercise

Part of the research brief for this study was to develop recommendations for the design of a future modelling project. It was envisaged that this would be required to explore the optimal balance of energy efficiency and clean heat for Scottish housing archetypes.

10.1 Establishing aims and objectives

A workshop was held with members of relevant teams within the Scottish Government. A headline theme arising was the need to consider fuel poverty and decarbonisation agendas concurrently. Consultation responses on the initial Heat in Buildings Plan for Scotland had raised concerns over impacts on household running costs from electrification. The Scottish Government needed to better understand what options would deliver a suitable balance. Key aims from modelling would therefore be to understand:

- Which retrofit measures to prioritise alongside clean heat (PV and batteries were also considered in scope for future modelling).
- Where certain measures would be best targeted (house types, household demographics and tenures).
- Fuel poverty implications across all tenures.
- Cost implications for government-funded support schemes.

Measures targeted at fuel poor households should ensure that energy bills should not increase with clean heat systems. This therefore placed an emphasis on understanding running costs before and after measures rather than potentially setting a benchmark affordability level.

Health and comfort impacts of retrofit options were also deemed important. It was recognised that this aspect of retrofit is often more tangible and compelling for households. Appropriate comfort safeguards would therefore need to be considered in any modelling.

The anticipated scale and granularity of any future modelling was also discussed. It was determined that macro level considerations, such as energy pricing and impact on energy infrastructure, would not be a focus. This is because, while clearly important to the decarbonisation journey, the Scottish Government cannot directly influence these.

10.2 Investigating potential data sources to support modelling

During the landscape review, numerous data sources were identified that could be relevant to determining a clean heat versus fabric balance. Studies that discussed approaches to archotyping of the Scottish housing stock were also reviewed. A summary of data sources and archetype studies are presented in Appendix B, in Table 2 and Table 3 respectively.

There is apparent variability in defining archetypes, as may be expected. Some studies consider properties grouped by key construction parameters as core archetypes, with some additional metrics as variables on those archetypes. Others consider such variables to form an entirely distinct archetype. It follows that numbers of archetypes quoted in studies can

vary significantly, from tens, to hundreds, to thousands of cases. Fundamentally, any archotyping approach is dependent on the level of detail the archetypes are being used to assess. In the context of assessing retrofit measures, larger groupings may be acceptable where proposed solutions and outcomes for properties are broadly similar.

10.3 Developing recommendations

When considering gaps in the literature and existing studies against the Scottish Government's aims, fuel poverty impact emerges as an area of focus. In particular, the ScotCODE study highlighted in section 8.3 essentially covered many of the priority areas identified during the workshop with the Scottish Government departments. The study highlighted measures required for typical Scottish housing archetypes to implement clean heat without increasing bills. However, it did not specifically consider the impact of proposed measures on rates of fuel poverty occurrence across Scotland.

Drawing on BRE's expertise in modelling, it was determined that the aims could be met by conducting a relatively typical options appraisal modelling exercise. The modelling tool(s) used would need to be able to appropriately model various combinations of potential retrofit options. Data sets necessary to support the creation of modelling archetypes and to scale these against the Scottish stock were identified. These included the Scottish House Condition Survey (SHCS) and Scottish Household Survey (SHS). Data from these respective surveys is utilised, alongside separate modelling, to estimate fuel poverty statistics for Scotland. This is carried out in-house by the Scottish Government fuel poverty team, with support from BRE to provide underlying home energy analysis.

10.3.1 Aligning present modelling with fuel poverty statistics modelling

In order to estimate the impact of any proposed retrofit approaches on fuel poverty occurrence, it would be necessary to align any modelling outcomes with fuel poverty statistics. Practicalities of the fuel poverty modelling process were therefore explored in more detail to understand how new modelling could consider fuel poverty.

The energy usage of approximately 3000 homes from the SHCS is modelled (by BRE) using the BRE Domestic Energy Model, Version 12 (BREDEM12). BREDEM12 is similar to RdSAP, which is used to produce EPCs for existing homes. However, BREDEM12 allows for additional variables to be assessed compared with RdSAP, including varying climate, occupancy and heating regime. The Fuel poverty (Enhanced heating) (Scotland) Regulations 2020 sets four enhanced heating regimes that recognise some households will require higher heating temperatures for longer periods. The heating regimes ensure that specific energy needs of vulnerable households are reflected in official fuel poverty calculations. The modelled energy data from these sample homes is then taken forward into fuel poverty modelling, alongside SHS data on household income and estimates for fuel pricing. Weighting factors are used to scale this sample to represent fuel poverty occurrence across all Scottish households.

Archotyping presents a challenge when considering how modelling data may be assessed against fuel poverty statistics. Archetypes will typically need to generalise for many aspects, including occupancy and climate, to allow manageable scenario modelling. Meanwhile, each home in the SHCS sample is fundamentally linked to its location and occupants for fuel poverty modelling, and is therefore essentially unique. The BREDEM12 fuel poverty model

does not currently carry out optimisation scenarios for properties. The process does not therefore allow impact of retrofit measures on fuel poverty to be effectively tested 'from the ground up' within the existing process.

The key outputs from the extensive BREDEM modelling taken as inputs to the fuel poverty modelling are energy bills for the 3000 sample homes. Theoretically, if bills after retrofit measures could be determined by an alternative means, these could be input directly into the Scottish Government's fuel poverty model. However, it will not be a small undertaking to replicate 3000 properties and simulate multiple retrofit options in an alternative modelling environment.

Two potential options for estimating the fuel poverty impact of retrofit measures are presented in the modelling scope set out in Appendix C. Any approach would require the adoption of simplifications and assumptions. However, absolute accuracy may not be critical to assess the merits of a future Heat in Buildings policy. It may be sufficient to demonstrate that the logic of the approach would benefit those in fuel poverty, and to approximate the extent.

10.4 Recommendations for potential further modelling

Appendix C sets out a high-level scope and approach for a future modelling project to address the Scottish Government's priorities. It focusses on areas that do not appear to be specifically addressed in the identified research and the learnings from this investigation.

The ScotCODE study has been used as a template. As noted above, that work already addresses a number of the Scottish Government's aims and provides recommendations relevant to much of the Scottish housing stock. The proposed modelling would extend this to consider whether the optimal mix of measures would change when enhanced heating regimes are considered. It would also estimate the impact on national fuel poverty statistics. Results could be scaled against tenure to understand the levels of support that may be required in different sectors, e.g. owner occupiers, private rented, social rented. The findings may influence targets and spending cap considerations proposed for MEES.

ScotCODE modelling was carried out on archetypes reportedly covering 93% of Scottish houses, and similar archotyping logic could be assumed. Not all archetypes were taken forward into the detailed ScotCODE study. It is suggested that fuel poverty statistics are checked against any proposed archetypes to determine if others should be included when assessing fuel poverty.

11 Conclusions and recommendations

Decarbonisation of homes will require widespread deployment of clean heat systems. However, the evidence reviewed suggests that affordability, comfort and health outcomes often depend on accompanying fabric efficiency improvements and wider support measures. The optimal balance between fabric retrofit and clean heat therefore varies according to property characteristics, household circumstances and retrofit objectives.

Improved fabric performance reduces a home's heat loss, lowering overall energy demand and supporting the efficient operation of clean heating systems. Carbon budgets recognise that many homes will still rely on fossil fuels for heating to 2035/2040. Improving fabric efficiency is therefore proposed in carbon budgets to help reduce emissions in the short term. However, fabric measures alone cannot entirely decarbonise the heating of homes.

There is conflicting information on the desirable level of fabric performance for a home to be considered suitable for clean heat. A key factor related to the optimal balance of fabric efficiency and clean heat is the potential impact on running costs. Some level of fabric efficiency improvement alongside clean heat is often cited as being required to prevent energy bill increases. But demand shifting and storage can also reduce bills while helping to address grid constraints linked to electrification. Some propose that deploying hybrid heat pumps in the short term will help to limit running costs in poorly insulated homes while still supporting decarbonisation.

Many homes already have basic fabric efficiency measures in place. This offers scope to install clean heating systems without significant additional retrofit in many circumstances. However, potential solutions and running costs will vary depending on the heating system proposed, house type, fabric efficiency, household characteristics, cost and practical considerations such as level of disruption.

Advancements in heat pumps mean that some form of such system is technically feasible in a very wide range of properties. In some cases, high temperature systems would be required. In others, significant heat emitter upgrades would be needed to facilitate efficient low temperature operation. In those with space constraints, air-to-air systems may be favoured. In an expected minority of homes, other forms of clean heat may be deemed more practical. There is therefore some flexibility to overcome potential constraints at a property level when delivering clean heat.

Retrofit offers opportunities to simultaneously address inadequacies in household health and wellbeing, as well as tackling high energy bills and fuel poverty risk. Sources concerned with these impacts typically advocate a focus on high quality fabric measures. Though there are generally calls for an 'outcomes based' approach (i.e. targeting real-world impacts and achievements, favouring actual performance over predictions) rather than explicitly favouring particular measures. In situations where further fabric measures are unfeasible or cost-restrictive, alternative options such as PV or tariff subsidies may offer solutions. Thus, policies and programmes will need to be sufficiently flexible to facilitate this.

11.1 Recommendations from the literature

- Government home decarbonisation policies should avoid being overly prescriptive. There should be flexibility for households to find a solution that works for their

circumstances. However, in the case of rental properties, some level of safeguarding should be applied (via MEES) to ensure cheaper solutions for landlords do not pose comfort and financial penalties for tenants.

- Households in, or at risk of, fuel poverty are likely to require more extensive retrofit support to deliver affordable clean heat and acceptable comfort outcomes. This may mean e.g. deeper fabric efficiency measures for some homes, or the addition of renewable generation to offset bills for others.

11.2 Recommendations for further investigation

- Investigate the extent of measures likely to be required to remove Scottish homes from fuel poverty (or at least close the gap) while decarbonising. Further modelling aligned with Scotland's fuel poverty assessment methodology would provide important new insight that would assist when considering options for simultaneously tackling decarbonisation and fuel poverty agendas.

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13 Appendices

Appendix A : Methodology

13.1 Evidence review

A desk-based evidence review sought information from academic articles and grey literature. A selection of search terms used in a search strategy are given in Table 1. A cascade approach was used to identify further relevant references. Research focus was directed to less well-evidenced aspects or technologies as necessary to provide quality content for a thorough review. Inclusion/exclusion criteria were set, including a focus on domestic properties, material linking both energy efficiency and clean heat, prioritising experience of relevance to the Scotland stock. References to wellbeing and socio-economic co-benefits were identified alongside energy/net zero impacts to provide additional evidence.

Full texts of selected documents were reviewed to analyse key themes. Findings were identified across the literature on the interaction between clean heat technologies and energy efficiency and/or provide added value alongside clean heat solutions. Potential risks/concerns were highlighted. Areas where evidence was lacking or inconclusive were identified to inform future research.

Table 1: Initial search terms and phrases used for evidence review (not exhaustive)

Retrofit	Zero emission heat	Fabric first	Scottish archetypes
Renovation	Zero direct emission heat	Fabric fifth	Decarbonisation
Refurbishment	Zero carbon heat	EWI, SWI, IWI, CWI	Wellbeing
Energy retrofit	LZE	Insulation	Socio-economic
Net zero	Heat pump	ETICS	Overheating
Clean heat	Electric heat	IAQ, IEQ	Fuel poverty
Cost optimal	Direct electric	Minimum energy efficiency	Damp

13.2 Stakeholder interviews

The CXC project brief required targeted stakeholder engagement. This was suggested in the form of five-to-seven academic or industry interviews, or a small workshop with experts. We committed to undertaking seven interviews for the research, in line with the requirements of the brief. Relevant stakeholders were identified to gather insights into wider wellbeing and socio-economic impacts of installing fabric and clean heat improvements from the perspective of different groups. Some had a UK-wide view and interests, while most specifically operated in the interests of Scotland and/or represented Scottish arms of national organisations. These included:

- Third sector organisations focussed on fuel poverty prevention and/or promoting healthy homes

- Representatives of academic departments and independent organisations delivering research associated with achieving net-zero
- Public sector health bodies

BRE engaged contacts within relevant organisations and additional stakeholders known to the project steering group were also approached.

An interview topic guide was developed to identify relevant wellbeing/socio-economic factors of retrofit, the technologies/measures they link to, determinants of positive or negative outcomes, potentially useful data sources, and recommendations to support positive outcomes. Semi-structured interviews were then conducted with the selected stakeholders, allowing for an in-depth exploration of the areas linked with the topic guide.

Following the interviews, common themes were identified from the responses. The extent to which these corroborated or contradicted the findings of the literature review were assessed.

13.3 Developing recommendations for the design and scope of a future modelling project

A list of potentially relevant data sources was collated and reviewed, to support further analysis into the interaction of energy efficiency measures with different clean heat measures, in the Scottish context.

Existing work on derived archetypes in relation to retrofit assessment in Scottish housing were identified using web searches. The various approaches were assessed to determine the most appropriate approach to underpin the proposed modelling exercise. The assessment considered the nature of the questions intended to be addressed through modelling and what granularity was required within archotyping to facilitate this.

Data gaps or recommendations emerging from the evidence review were collated. A workshop was also held with members of relevant teams from the Scottish Government to understand their aims and objectives from a potential future modelling exercise. Based on the gaps, objectives, and identified data sources, the research team proposed modelling approaches to address these. These were reviewed by relevant Scottish Government teams and refined to create an overall scope and brief for future work.

Appendix B : List of data sources and archetype studies

Table 2: Collated data sources considered for relevance to future modelling of clean heat and fabric efficiency balance

Name	Owner	Scope of coverage and data granularity (e.g. property level, postcode level, etc.)	Notes
Scottish House Condition Survey (SHCS)	Scottish Government	Data on physical conditions of Scottish homes, energy efficiency, heating systems, and fuel poverty	Data request to House Condition Analysis team for record level data

Name	Owner	Scope of coverage and data granularity (e.g. property level, postcode level, etc.)	Notes
Scottish Household Survey (SHS)	Scottish Government	Data on characteristics, finances, and behaviour of private households and individuals	Data request to House Condition Analysis team for record level data
Scottish Fuel Poverty Statistics	Scottish Government	Rates of overall and extreme fuel poverty, fuel poverty gap, rates by tenure, heating type and geography.	Utilises data from SHCS and SHS. Reported in SHCS briefings. Calculated in-house by SG
Scotland EPC database	Scottish Government	Data on building characteristics (age, size, insulation, heating systems) Energy efficiency ratings (SAP/Bands A-G)	Download via statistics.gov.scot
Scotland Heat Map	Scottish Government	Spatial data on heat demand at property level, existing/planned heat networks and energy supply sources	Two access levels: Free version via Scotland Heat Map Interactive website, detailed version via data sharing agreements
Home Analytics Scotland	Energy Saving Trust (EST)	Address-level data on physical characteristics, energy efficiency potential and renewable energy suitability for domestic properties	Licensed access via EST
Electrification of Heat (EoH) Demonstration Project	DESNZ/ Energy Systems Catapult	30-min performance data on heat pumps, info on heat pump systems installed and housing archetypes. Some of the properties in the trial were in Scotland.	Application to UK Data Archive (UKDA) for access

Table 3: Studies incorporating approaches to archotyping

Name of study	Author	Summary
Low carbon heating in domestic buildings – technical feasibility	Scottish Government	Derived 54,000 archetypes. Model to capture the distribution of hard to decarbonise features across Scotland with archetypes derived from Home Analytics data.

Name of study	Author	Summary
Faster Deployment of Heat Pumps in Scotland	Cambridge Architectural Research (for WWF)	Developed an archetype approach with 16 house types. Modelled 12 of these, noted to cover 93% of Scottish dwellings. Additionally modelled constraint variants including space limited, heritage and coastal.
Review of social housing archetypes to support EESSH2	CXC	24 archetypes for Scottish Social housing only, based on basic parameters (house/flat, wall type, floor type), 12 of which represented over 90% of the stock. Includes additional constraints of room-in-roof, no wet heating system, mixed tenure, conservation area/listed status, off gas grid.
Residential Archetypes Dataset	Climate Change Committee (by Kamma Climate)	Detailed archetype dataset representing the UK housing stock. Final dataset includes over 11,000 archetypes. Smaller set for energy archetypes (5,260) and basic archetypes (1,184). 3 Scottish regions noted in 'full' and 'energy' sets.
Cost-Optimal Domestic Electrification (CODE)	Cambridge Architectural Research (for BEIS)	Developed an archetype approach for modelling with 12x house types noted to cover 90% of British housing. Equivalent to Scottish-specific Cambridge Architectural Research study noted above.
Electrification of heat demonstration project summary report	Energy Systems Catapult (for DESNZ)	Trials on various housing archetypes, some specifically in Scotland.
Regional Energy Masterplan – Component D: Archetype retrofit delivery and methodology	University of Edinburgh	Derived 21 archetypes across six Scottish Local Authorities. Identifies constraints that could apply to some archetypes. Considers brick vs render finishes, and sandstone vs granite, which increases the number of types.
Residential retrofit in the UK: The optimum retrofit measures necessary for effective heat pump use	Building Services Engineering Research & Technology	Dynamic simulation modelling study for optimisation options for a semi-detached dwelling archetype.

Appendix C : Future modelling project

13.4 Background

The ScotCODE study (for WWF Scotland) explored cost optimal scenarios (explained in more detail below) of fabric energy efficiency measures alongside clean heat. It also embedded heating control system backstops (i.e. which required the heating system to maintain homes at certain temperatures, e.g. when unoccupied, or through the night) to ensure the retrofit scenarios could deliver on specific 'occupied' heating profiles. The housing archetypes adopted reportedly covered 93% of the Scottish housing stock. Properties were grouped according to certain physical considerations (wall-to-floor ratio and roof-to-floor ratio) and their ability to receive equivalent measures. 12 core house types were dynamically modelled, each with three base heating variants. Numerous combinations of clean heat and fabric efficiency improvement measures were then simulated for each (presenting 7,200 scenarios to support an optioneering assessment).

The study primarily focussed on total cost of ownership, i.e. capital costs, running costs, maintenance and replacement costs, which generally fits with an 'able to pay' end user perspective. The study also reported running costs separately for the optimised scenarios. In some cases, the optimal total cost scenario resulted in higher running costs. This balance may be acceptable for some households who are driven by a whole life value perspective (e.g. those that are likely to remain in the same home for the long-term), but it is likely to be a significant barrier to others e.g. those in fuel poverty, or risk thereof, and/or those who may not necessarily apply long-term thinking. The study recommended further measures to reduce running costs in these cases, though these would incur additional capital costs.

Notably, the ScotCODE study did not include any assessment of fuel poverty impacts beyond the assessment of further measures to ensure bills would not increase, where required. Fuel poverty is an important consideration for the Heat in Buildings Strategy alongside decarbonisation.

Key gaps in the ScotCODE study include:

- Some excluded house types. While a low portion of the total stock, the relative occurrence of fuel poverty in those types could be reviewed. They could potentially be re-introduced into fuel poverty-focussed modelling if deemed significant.
- Does not consider the 4 x statutory heating regimes considered within fuel poverty modelling.
- Only considers a single climate scenario, whereas fuel poverty modelling considers more granular climate data.
- Hybrid heat pumps. (UK CODE study found them to often be cost optimal, though they still have significant use of gas. They were not included in the ScotCODE analysis.)
- PV was reportedly cost effective, though not discussed in detail.
- Occupancy varies according to house type in the study but is fixed per archetype. (This may not be significant enough to fundamentally influence recommended

measures). Meanwhile, fuel poverty modelling includes occupancy and occupation patterns.

These gaps could be explored in a future modelling exercise to assess if/how they influence the selection of measures. Key objectives of modelling, to support the Scottish Government's evolving policy considerations, could include:

Objective 1: To assess measures optimisation aligned with fuel poverty heating regimes

Objective 2: Scale for national fuel poverty impact

Objective 3: Assess measures required to reduce fuel poverty

Note: It is assumed a further study would not repeat variants of listed, space constrained or coastal homes. The alternative approaches for these situations were explored in the ScotCODE study. Implications for the alternative heating regimes could most likely be addressed in a qualitative way with reference to the previous analysis.

13.5 Modelling objectives

Objective 1: To assess measures optimisation aligned with fuel poverty heating regimes

Aim: Identify combinations of retrofit measures alongside clean heat technologies that would not increase running costs for the 4 statutory heating regimes recognised in fuel poverty modelling.

Modelling approach:

Options appraisal to identify the lowest overall cost scenarios for clean heat that do not raise running costs for each archetype, base fuel and heating regime. Costs will be considered over a set timeframe, to be agreed (e.g. 15 years, linked to typical anticipated heating system lifespans).

As with the ScotCODE study, it is proposed that the modelling would use a representative set of Scottish housing archetypes as test cases. Review whether archetypes excluded from ScotCODE become material when viewed through a fuel poverty lens (using the Scottish Government fuel poverty data); if so, introduce additional archetypes (e.g. total could rise to around 14-16).

- Each archetype would continue to be assessed against three baseline heating types (mains gas, oil, older style electric storage heaters) at average Scottish climate conditions. It is recognised that Scottish fuel poverty modelling considers more granular climate data. However, it is assumed that optimising for alternative climate conditions would incur a disproportionate amount of effort alongside the core range of options proposed for consideration below. A sensitivity analysis on climate is proposed as an option in the 'scaling' exercise in Objective 2, below.
- Clean heat systems to be assessed to include:
 - Low temperature air source heat pump
 - High temperature air source heat pump
 - Air to air heat pump

- Modern, high heat retention storage heaters
- Fabric improvement measures (applied iteratively by capital cost) to include (as appropriate to properties):
 - Draught-proofing (assumed to achieve a specified air permeability)
 - Top-up loft insulation
 - Solid wall insulation
 - Floor insulation
 - Triple glazing

(Note that, since the majority of homes with cavity walls are insulated, lofts partially insulated and have double glazing (rather than single), these measures would be considered within the baseline archetypes. It is assumed from previous studies that these measures will always be cost-effective (where feasible). Hence any homes found to be viable to receive these would be recommended to do so. Capital costs for such properties would increase commensurately.)

- Additional renewable generation:
 - PV alone
 - PV + battery

(Options: These could be considered only in scenarios where measures are technically considered optimal but may be deemed too costly, e.g. solid wall homes and/or where (/if) other measures are insufficient to deliver at least running cost parity with a particular heating regime. Could choose to focus on monthly heating season bill reductions from PV (and batteries), rather than annual net savings, to ensure in-month comparability.)

- Test against 4 statutory heating regimes.
- Run separate optimisation scenarios for standard fuel tariff assumptions and a TOU tariff structure (prices to be agreed in both cases).

Key outputs:

- Modelled annual running costs before and after optimised measures, per archetype (derived using set fuel prices – to be agreed). (Assume 14 types x 3 base fuels x 4 heat regimes= 168 baseline scenarios, each allocated an optimisation for standard and TOU tariff structures, with an associated running cost change.)
- Energy demand (kWh) before and after optimised measures, per archetype.
- CO₂ emissions (using set emissions rates – to be agreed) before and after optimised measures, per archetype.
- Overall cost of improvement measures required to achieve savings (noting any closely competing cases where, e.g. PV may be deemed more cost effective).
- Narrative accompanying the analysis to highlight measures that do not feature in optimisation scenarios because they do not meet comfort criteria and/or requirement not to increase bills. This is so the Scottish Government may be clear on

measures that should not be recommended for archetypes (or at least not in isolation from additional facilitating measures).

Objective 2: Scale for national fuel poverty impact

Aim: To scale up the findings from Objective 1 (i.e. with no increase in running costs) to assess the likely impact on national fuel poverty statistics.

Approach:

It is assumed that the effort of replicating data for the ~3000 properties used as the basis for fuel poverty modelling in a separate energy modelling tool capable of running a more detailed energy analysis used for the described optioneering would be impractical. Two alternative options are therefore proposed and summarised in Table 4, along with advantages and limitations of each.

Option 1: Adapt existing Scottish Government fuel poverty energy modelling

- The energy usage of approximately 3000 homes from the SHCS are modelled using the BRE Domestic Energy Model (version: BREDEM12). (This is currently carried out by BRE on behalf of the Scottish Government. However, the methodology used in BREDEM12 is publicly available.) BREDEM12 allows for additional variables to be assessed compared with RdSAP, though the fundamental operation of the model is similar to RdSAP. The 4 statutory heating regimes are modelled in BREDEM. Estimated energy bills for each of the 3000 base cases are then taken forward into fuel poverty modelling.
- The BREDEM model would need to be adapted to include a number of the clean heat measures and energy systems expected to be a focus of the future modelling. Many assumptions would need to be made on how these systems should be applied in the BREDEM model. These assumptions would inevitably require simplifications compared to more detailed modelling tools used for the previous optioneering exercise. It is noted that this would introduce errors/uncertainties and there is a risk that the subsequent BREDEM modelling would not replicate the findings of the earlier detailed modelling.
- Having established the expected optimal measures for the various archetypes and each associated heating regime via separate modelling, these measures would need to be allocated to each of the 3000 base homes. To facilitate this, the SHCS base cases would need to be filtered according to their characteristics and allocated to their most closely related archetype and heating regime. Relevant optimised measures for the archetypes would then be applied to these base cases in the adapted BREDEM model.
- An estimate of the impact of the measures on Scotland's overall fuel poverty statistics could then be run by the Scottish Government according to the usual process (including breakdown by tenure).
- Sensitivity analysis could be carried out on test case properties from BREDEM that are equivalent to those used for the detailed analysis in Objective 1. For these cases, appropriate local climate conditions could also be applied to the earlier archetype models, as per the BREDEM test cases.

Option 2: Fuel poverty gap approach

- From the Scottish Government fuel poverty data, dwellings would need to be filtered according to property and household characteristics and allocated to their most closely related archetype and heating regime. Statistics on the frequency of fuel poor homes aligned to each archetype and heating regime would then need to be extracted.
- Identify how many households from the fuel poverty data have a fuel poverty gap less than the respective estimated bill saving derived for each archetype from Objective 1. This would provide an estimate of the number of households that would be expected to move out of fuel poverty as a result of the Objective 1 optimisation savings.
- Sensitivity analysis could be carried out on a selection of example archetypes to assess climate variables. The proportionate impact of each climate across the archetypes may be expected to be similar, since each climate would effectively become a constant in all archetype simulations using that climate. A sample of the archetypes and their respective optimisation scenarios could therefore be run with climate data from, for example, south, mid and northern Scotland. This would provide an indication of how bill savings may change regionally. If the fuel poverty data could be similarly segregated by the climate regions, the fuel poverty gap could then be assessed and compared against the regional modelled bill savings.

Table 4: Advantages and limitations of options to integrate with fuel poverty modelling

	Option 1: Adapt existing BREDEM approach	Option 2: Fuel poverty gap approach
Accuracy/modelling granularity	Many assumptions would need to be made to adapt the BREDEM model to simulate new systems. May not replicate findings from detailed Objective 1 simulation modelling.	Would allow for more accurate performance modelling.
Climate	Postcode district level weather data applied in BREDEM model.	Running many climate assumptions would be impractical with archetypes. Could potentially run sensitivity on examples with ~3 sets of weather data, if fuel poverty data could be segregated into broadly equivalent regional groupings.
Property specifics (e.g. size)	As per SHCD property data.	Based on an average of the archetype.
Fuel poverty modelling alignment	Direct alignment with each base case, so fuel poverty could be assessed by Scottish Government in the usual way.	Would be based on the fuel poverty gap vs estimated bill savings, assessed outside the Scottish Government fuel poverty modelling method.

Objective 3: Assess measures required to reduce fuel poverty

Aim: Establish what additional measures would be required to close the fuel poverty gap

If the core aim of Objective 1 is only to ensure modelled energy bills are no worse for each archetype, the proposed measures may have a limited impact on fuel poverty statistics (though they may offer decarbonisation while making fuel poverty no worse). A subsequent useful exercise would therefore be to assess the measures required to provide significant decarbonisation and closure of the 'fuel poverty gap' for each archetype. This aspect will address a current gap in knowledge and provide analysis to inform the Scottish Government on potential measures recommendations relevant for fuel-poor households.

In this modelling, the fuel poverty gap would become a new target against which to assess energy bill reduction optimisation scenarios.

Modelling approach:

- Extract data from fuel poverty modelling statistics to provide the average/typical/maximum fuel poverty gap (per house archetype) and how many properties those averages apply to.
- Options modelling alongside clean heat as per Objective 1 scenario, but with the target to reduce the stated fuel poverty gap (e.g. by a certain amount or percentage reduction, in agreement with the Scottish Government), rather than not making bills higher.
- Could use the previous modelling phase as a starting point, so only adding more costly measures rather than an entirely new optimisation process. Rather than re-modelling against different tariff structures, it is suggested that the most cost optimal fuel tariff structure determined for each archetype from the Objective 1 modelling would be taken forward for each case.
- Findings may be scaled, relatively simply, to national level by re-applying the numbers of 'extra measures' required, to the stock/archetype frequency from which the fuel poverty gap was derived. Alternatively, they could be scaled according to fuel poverty scaling option noted in Objective 2.

Key outputs:

- Modelled annual running costs before and after measures, per archetype (derived using set fuel prices – to be agreed).
- Energy demand (kWh) before and after measures, per archetype
- CO₂ emissions (using set emissions rates – to be agreed) before and after measures, per archetype.
- Overall cost of improvement measures required to close fuel poverty gap (noting any closely competing cases where, e.g. PV may be deemed more cost effective)

Optional further modelling variables could include:

- Scenarios considering hybrid heat pumps (to replace only mains gas) to assess impact on short term decarbonisation. CODE study indicates hybrids to generally be favourable, but recognises not full decarbonisation.
- Bio-energy systems (potential for selected house types – this would need further investigation).

13.6 General modelling requirements

To deliver an analysis to address Objectives 1 and 2, the modelling tool (or combination of tools)/approach would need to be capable of:

- Representing detailed dwelling archetypes and retrofit measures, including changes to fabric performance, heating systems, emitters, and on-site technologies (e.g. PV and battery storage).
- Assume at least hourly timestep, to consider:
 - PV and battery charging/discharging
 - Optimisation for TOU tariffs
 - Ability to represent heat emitter size vs flow temperatures to assess benefit/need of increased radiator sizes

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