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The suitability of clean heating options for challenging dwelling types

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1 Executive summary

Only around 11% of occupied homes in Scotland have renewable or low-emission heating systems, with the majority still relying on high-emission sources like gas and oil. To meet Scotland's net zero greenhouse gas emissions target by 2045, over 2 million homes will need to transition to clean heating systems.

Heat pumps and electric resistive heating are the main clean heating options available today and they are likely to work well in most homes. This project investigates the feasibility of clean heating, especially heat pumps, in challenging home types in Scotland, in terms of practicality and cost effectiveness.

We reviewed academic research, industry literature and case studies, and conducted a combination of surveys and semi-structured interviews with industry experts. We identified the advantages, disadvantages, contradictory evidence and research gaps surrounding the application of clean heating technology in Scotland.

We reviewed previous studies and identified the following challenging dwelling types: older properties from before 1919, rural properties, small properties, and flats and tenements.

1.1 Findings

Overall, while there are challenges to implementing heat pumps across different property types, innovative solutions and careful planning can facilitate their adoption and contribute to decarbonising heating systems in Scotland. We found:

- **Older properties:** Buildings constructed before 1919, often characterised by solid walls and potentially holding protected status, may pose challenges for both insulation upgrades and heat pump installations due to planning constraints and preservation concerns. Whilst it is common to prioritise improving energy efficiency prior to the installation of heat pumps, recent studies have concluded that heat pumps can operate effectively when installed into dwellings that have not undergone energy efficiency upgrades. It is also important to note that while increasing energy efficiency stands as a crucial objective, the structural integrity and overall condition of the building need consideration. It is important to ensure a building is in good condition before installing new heating systems, in particular, repairing structural issues, water ingress and damage. Consequently, any new heating technologies will be more effective and contribute to the building's overall energy performance.

- **Rural properties:** Rural areas can present unique challenges due to grid capacity limitations and vulnerability to power cuts. However, heat pump adoption rates are already highest in off-grid regions due to cost savings compared to existing off gas network fuel sources. Evidence shows that heat pumps can operate well in cold climates, with studies evidencing effective performance compared to gas boilers, even at extremely low temperatures. No significant barriers to heat pump adoption have been identified. Heat pumps with additional corrosion protection are available for coastal areas. However, a lack of local contractors, increased servicing costs and higher costs for energy efficiency improvements pose challenges in remote areas, particularly the Scottish islands.
- **Small properties:** Space constraints, such as limited room for hot water storage and radiator upgrades, present challenges for heat pump installations. No evidence of a quantitative threshold to define ‘small’ was identified. Innovative solutions like compact heat batteries or external hot water storage may offer alternatives.
- **Flats and tenements:** In addition to the challenges presented above, flats and tenements face difficulties due to constraints on external locations for air source fans, as well as coordinating changes with neighbours and building owners, due to differing tenancy arrangements. Case studies highlight the importance of careful planning and resident input in determining suitable locations. These are similar to the challenges to basic repairs and maintenance of blocks of flats and tenements and to fabric improvements, such as insulation. Fifth generation heat networks, with individual indoor heat pumps supplied by communal ground sources may provide a potential solution.

1.2 Recommendations

- Establish evidence for the suitability of air-to-air heating and, if found to be appropriate, provide policy support for certification and installation in homes where it is more cost effective than water-based space heating.
- Policymakers should monitor developments in thermoelectric heat pumps, which may provide radical space savings.
- Explore whether there is a role for hybrid heat pumps in certain circumstances, for hot water only.

Contents

2 Glossary

Air-to-air (A2A)	Air to air. A type of heat pump that sources heat from external air and distributes it internally by recirculating air through heat exchangers
Air-to-water (A2W)	Air to water. A type of heat pump that sources heat from external air and distributes it internally using water in pipes and radiators or underfloor heating
ASHP	Air source heat pump
Clean heating	Defined by the Scottish Government as a system capable of providing heat without producing any greenhouse gas emissions at point of use (Scottish Government, 2023a)
EPC	Energy Performance Certificate
Flats and tenements	Any building that contains multiple dwellings. This includes, four-in-a-blocks, low rise blocks, high rise blocks and tenements.
GSHP	Ground source heat pump
PV	Solar photovoltaic panels
Working fluid	The fluid that is compressed and expanded in heat pumps to transfer heat. Also called the refrigerant.
ZDEH	Zero direct emissions heating (Also called ‘clean heating’ for short, throughout this document)

3 Introduction

Of the 2.5 million occupied homes in Scotland, only around 11% currently have renewable or very low emission heating systems with the majority still reliant on high-emission energy sources like gas and oil (Scottish Government, 2021b). To meet net zero greenhouse gas emissions targets, over 2 million homes will have to transition to clean heating by 2045 (Scottish Government, 2021a). Clean heating systems have been defined within the consultation on a Heat in Buildings Bill by the Scottish government as:

“Systems – such as heat pumps and heat networks – that don’t produce any greenhouse gas emissions at the point of use” (Scottish Government, 2023b). Bioenergy is not included in this definition due to emissions at the point of use so were not included in this work.

As described, several technologies already exist, each at different stages of adoption. Electric heating was commonplace in homes throughout the 1960s and beyond, resulting in significant improvements over time to make them more efficient and streamline their design. Alternative technologies, such as heat pumps, which also first became commercially available in the 1960’s, are less mainstream in Scotland, but are expected to play a significant role in the decarbonisation of heat in Scotland. The Climate Change Committee has described them as a 'low regrets' option (CCC, 2020) and they feature prominently in Scotland’s Heat in Buildings Strategy (Scottish Government, 2021a).

While electricity provided from the grid is currently a mix of renewable and non-renewable energy, it is expected that as renewable power generation such as wind and solar power increases, the emissions associated with electricity will continue to reduce, rendering it an extremely low carbon energy option. To capitalise on this, it will be required that heat in homes provided by gas, oil, and other high emitting energy sources be phased out and replaced by electricity.

The Scottish Government's Hydrogen Action Plan States "We do not consider that hydrogen will play a central role in the overall decarbonisation of domestic heat and therefore cannot afford to delay action to decarbonise homes this decade through other available technologies. The potential for hydrogen to play a role in heating buildings depends upon strategic decisions by the UK Government that will be made over the coming years and the Scottish Government will continue to urge the UK Government to accelerate decision-making on the role of hydrogen in the gas grid".

Consequently, this report predominantly focusses on heating systems which utilise electricity as an energy source, specifically heat pumps and their applications. However, it should be recognised that heat networks and each of the clean heating technologies described may play a crucial role in addressing challenging dwelling types.

In this report, we investigate the feasibility, in terms of practical application and cost-effectiveness, of applying clean heating technologies in challenging dwelling types.

Additionally, we explore alternative clean heating options, considering their potential application to the archetypes and examine scenarios where hybrid fossil fuel heating systems may offer a transitional solution, particularly in contexts where the full adoption of renewable technologies poses challenges.

This research focussed on the following building types that we have considered upon review of previous studies as reflecting broadly those that are considered as difficult to decarbonise with clean heating:

- Older properties, especially those built before 1919
- Rural properties
- Small properties
- Flats and tenements of different forms

This project does not consider clean heating challenges that are relevant to all building types, such as skills shortages and capital costs. However, we acknowledge additional challenges such as temporary disruption to households who may need to decant. Particularly when households are without hot water while install work is on-going. This is more acute in winter when losing heating and hot water for a period of time is most impactful to households. This may be perceived as a barrier to adoption, however no evidence was found to corroborate this within this research. Presented below are the results of the evidence review. The research identifies gaps in the available evidence which may inform future research priorities. We also identify where there are best case examples relevant to Scotland.

The evidence reviewed was a combination of grey literature, published research, academic papers, case studies and industry expert feedback through interviews and a survey. For in-situ evidence of how heat pumps are likely to perform in Scotland, we reviewed both large-scale heat pump field trials and small-scale monitoring studies. Whilst, the scope of the research was for both domestic and non-domestic buildings, the majority of identified evidence relates to domestic settings.

4 Method

A Rapid Evidence Assessment (REA) is a systematic and streamlined approach to reviewing existing literature and evidence on a specific topic within a limited timeframe. This method is often employed when there is a need for quick insights and when a traditional comprehensive systematic review may take too long. The full method for the REA can be found in Appendix 10.1.

Using the keyword searches in relevant databases, 147 sources were identified. The results were screened according to the protocol. Each of the screened sources which were analysed further can be found in the references section of this work. The purpose of the deeper dive was to investigate what evidence was available that heat pumps are a practical, technically feasible and cost-effective clean heating option for hard-to-treat archetypes in Scotland. To enhance the literature review, surveys and interviews were carried out with industry professionals. These interactions aimed to determine whether the research gaps identified in existing literature were mirrored in industry and to explore any opportunities or strategies that the industry has developed to address the identified challenges. The survey and interview questions can be found in Appendices 10.2 and 10.3, respectively.

We received 16 survey responses from:

- Six retrofit advisory/consultancies
- Four registered social landlords
- Five architects/Designers
- One utility company

We conducted 10 structured interviews with:

- Three installers
- Four registered social landlords
- Two architects/designers
- One research institute

5 Clean heating technologies

This section outlines the main technologies for heating free of emissions at the point of use. Various clean heating technologies are available, adaptable to specific building and occupant needs. Each technology presents unique opportunities and applications, catering to diverse requirements.

5.1 Direct electric

Direct electric, or electric resistive heating generates heat by passing electricity through a resistive element, in the same way a kettle works. Examples of direct electric heating are storage heaters, panel heaters, electric boilers, infrared heating, and electric underfloor heating. Direct electric heating is 100% efficient, delivering one unit of energy as heat for every unit of electricity consumed.

Direct electric heating has a low capital cost.

A significant barrier in the uptake of electric heating is the unit cost, which remains expensive when compared with gas (Nesta, 2023a, 2023b). To overcome this, there is the opportunity for UK Government to review the distribution of taxes by reducing the tax on electricity and increasing the tax on high emitting energy sources (Ahmad, 2023; Rosenow, 2022; Sevindik, 2023). This may encourage the uptake of heat pumps and also aid in the renewable energy transition.

5.2 Heat pumps

Heat pumps operate by transferring heat from one medium to another. Heat pumps are used in fridges, freezers and air conditioning, as well as in heating systems. Air-source heat pumps use the outside air, while ground-source heat pumps will use water preheated by the ground as the source medium. As the source medium passes through a heat exchanger inside the unit, it causes a refrigerant enclosed in a loop to evaporate into a gas. This gas is compressed, raising its temperature. It then passes through a second heat exchanger, transferring its heat to the inside air, or to water that circulates to radiators, underfloor heating, and to heat up water tanks and so on. The refrigerant, now in a liquid state, then passes through an expansion valve, reducing its pressure and temperature, completing the cycle.

Domestic heat pumps may source heat renewably from the air, ground or water sources such as rivers, lochs, and the sea. They may also use waste heat from industrial sources such as data centres and factories.

The most common form of domestic heat pump in Scotland sources heat from the outdoor air and delivers it through water-filled radiators. Heat is delivered to living spaces through conventional wall-mounted radiators or underfloor heating. This is commonly referred to as an air-source heat pump (ASHP), or air-to-water heat pump (A2W).

'Air to air' (A2A) heat pumps are common in commercial applications such as shops and are also installed in domestic settings. Heat is delivered to living spaces by blowing recirculated air over a heat exchanger. During warmer seasons, A2A heat pumps can also be used for cooling, extracting heat from indoor air and releasing it outside. This operates independently of piping and radiators, and one unit will generally service a single room/space.

Ground source heat pumps collect heat from boreholes up to 200 metres deep or from shallow coil collectors buried over large areas. They can achieve higher operating efficiencies because ground temperatures, which sit consistently between 5°C and 10°C, are warmer than air temperatures in the depths of winter. However, these operating efficiencies can be negated by the higher capital costs, especially in buildings with lower heat demands. The primary influence on heat pump efficiency is the difference in temperature between the source (the outside air temperature for ASHP's), and that of the flow to the indoor emitters. The narrower the gap, the higher the efficiency. In other words, with radiators operating at lower temperatures, e.g., 45°C instead of 65°C, energy use and operating costs will be noticeably lower. Average in situ efficiencies of around 270-300% are reported (HeatpumpMonitor.org, n.d.)

To maintain comfortable room temperatures with this cost-efficient operation, new higher-output radiators and larger pipework may be required. Replacing pipework, if required, is likely to be particularly disruptive. Upgrades to radiators may also be required for condensing boilers to operate in energy efficiency condensing mode. Condensing boilers were mandated in 2005 as a carbon abatement strategy, but Building Standards were never adapted to enforce the changes to the radiators and controls required to achieve the energy efficiency savings. Consequently, boilers often operate significantly below manufacturers efficiency claims. Instead, the upgrades to radiators required for improved efficiency are now being enforced with the transition to heat pumps through the MCS Certification standard for publicly funded installations.

5.3 Heat networks

Heat networks distribute heat, and sometimes cooling, from a central origin to multiple properties. Several clean heat network technology options are currently available, for example, communal networks, which serve a single building, and district heating which covers a wider area. Fourth generation heat networks distribute heat in insulated pipes using water at around 65°C (Lund et al., 2021). Fifth generation district heating and cooling (5GDHC) distributes very low temperature heat, between 10°C and 20°C, from sources including boreholes, mine water and industrial waste heat. Individual heat pumps in each property transfer the heat to the home at high temperature or, in summer, transfer heat from the home to the network for cooling.

This variety of options means that individual building owners, as well as local authorities, may drive heat network adoption. This report will include consideration of communal, fifth generation networks as a clean heat option for some property types.

Heat networks are central to the Scottish Government's Heat in Buildings Strategy with a capacity target of 2.6TWh of output by 2027 and 6TWh by 2030 (Scottish Government, 2021b). Currently heat networks supply 1.18TWh of heat in Scotland to 30,000 homes and 3,000 non-domestic properties (Scottish Government, 2022a). To operate effectively, be economically sustainable, and offer cost-effective solutions, heat networks must be strategically situated. This involves locating them in areas with ample heat demand and density to ensure optimal functionality.

6 Challenges for clean heating

The following section outlines the findings of this work in determining the suitability of clean heating technologies for challenging dwelling types. The primary findings are generated via the literature review, which are corroborated by the relevant findings in the semi-structured interviews, as highlighted. As discussed in Section 5, there are several low or zero carbon heating technologies available. The purpose of this work is to identify strategies that are both cost effective and practical to apply in the identified challenging dwelling types. Where heat pumps are not determined suitable, alternative technologies have been outlined.

6.1 Older properties

In the context of this report, older properties denote traditionally constructed buildings erected prior to 1919 (HES, n.d.). These structures are typically characterised by solid wall construction and may also be designated as protected buildings. This section applies to both houses and tenements.

6.1.1 Heritage and planning

Almost all properties built in Scotland before 1919 have solid walls and often have attractive facades in natural materials, principally sandstone and granite. Pre-1919 properties make up 19% of the Scottish housing stock (Scottish Government, 2023c). Regarding insulation improvements, older properties are often described as 'hard to treat' (HES, 2016), because readily available and cost-effective treatments such as cavity wall insulation are not suitable. Furthermore, heritage and planning constraints may prevent some measures such as external wall insulation or increase the cost of others, such as heritage-compliant double glazing.

Obstacles to implementing heat pump technology in older buildings have been identified in building regulations and planning consents, as in the example of a retrofit of a Glasgow tenement block, which was neither listed nor in a conservation area (K. Gibb et al., 2023). This four-story sandstone block, comprising eight small flats and built in 1895, is representative of a large proportion of tenements across Scotland. However, there are important qualifications about the transferability of findings from this project. This was an empty property wholly under the control of a social landlord aiming to fill a retrofitted empty property with social tenants. Planning officers raised concerns with designers on several fronts, such as the installation of external wall insulation, PV panels on the roof, and attaching air source heat pumps to the rear wall. Consequently, new gas boilers were installed in the top floor flats.

The challenges with planning consent outlined above were echoed in the industry survey and interviews. Interviews with installers and housing professionals identified challenges around gaining approval from local authorities and planning officers to proposed changes to increase energy efficiency and green technologies in existing homes, as well as a lack of consistency between different regions which make it difficult to develop repeatable solutions.

6.1.2 Fabric efficiency

Some sources asserted that building fabric efficiency is important for heat pumps to work effectively. However, the rationale for this assertion was often not explained, such as in Carroll et al. (2020). The innovation charity Nesta also made this assertion 2021 (Nesta, 2021), but reversed it 2024 stating:

> "It is often claimed that homes need to be well insulated to have a heat pump, but this is largely untrue" (Nesta, 2024).

A WWF report focussed on decarbonisation pathways for Scotland's housing stock stated that "it is technically possible to install heat pumps in solid wall properties without insulating the solid walls". However, without insulation upgrades, the heating system upgrade can be more expensive due to the need for larger radiators, pipework and heat pump (Leveque, 2023).

Different household needs in the context of fuel poverty refer to the unique challenges fuel-poor households face in heating their homes due to financial constraints and inefficient systems. These challenges necessitate tailored solutions, like specialised heat pump installations, to ensure energy is used effectively and affordably. Addressing these needs is crucial for reducing overall heat demand, aligning with energy efficiency and sustainability efforts (London Economics, 2023; NEA, 2023a). Where literature describes inefficiencies in heat pump installations without solid wall insulation, this is sometimes referring to the total cost of ownership rather than the pure energy efficiency of the heat pump. For example, the WWF technical report on Scottish housing stock pathways considered capital costs of insulation and heating upgrades (excluding public subsidies), as well as the operating cost over 15 years. It found that the total cost of ownership of a heat pump in a solid walled detached house would be 8% lower over 15 years if solid wall insulation was included in the investment (Palmer and Terry, 2023a).

Total heat required to be delivered from the heating system can increase with heat pumps operating with radiators at lower temperatures, as compared with gas boilers. This is due to the reduced responsiveness of low temperature heating, resulting in the need to maintain temperatures within a narrower range. Essentially a right sized heating system heats up a building more slowly than an oversized boiler. For these reasons, households almost always need to change their heating schedule in order to achieve the same comfort as before (Terry and Galvin, 2023). Modelling found that this is especially important in homes with high thermal mass, such as brick internal walls or solid external walls without insulation on the interior face. Such homes may require up to 20% more heat be delivered from a heat pump, compared with turning off a gas boiler during periods of non-occupancy, such as in households that commute to work. The authors propose that an estimate of increased heating demand would be a useful measure of heat pump readiness, and that the parameters required to assess this should be provided on energy performance certificates.

The long-established ‘fabric first’ approach to energy upgrades prioritises reducing heating demand with insulation and draught proofing before installing clean heating. While the enhancement of energy efficiency stands as a crucial objective, the structural integrity and overall condition of the building necessitate simultaneous consideration. The advantage of this sequence, as opposed to the reverse order, has been to avoid some pipework and radiator upgrades and to reduce the size and cost of the required clean heat sources. However, there is an increasing recognition that, given fabric insulation levels do not influence operational energy efficiency, and depending on individual household needs, decarbonisation may be prioritised ahead of demand reduction to meet emissions targets (Nesta, 2024).

In much of the housing stock potentially no invasive demand reduction is required to meet emissions targets. Instead, the focus should be on electricity pricing and workforce education to enable good installation standards (Eyre et al., 2023). The UK Government’s Review of Electricity Market Arrangements (BEIS, 2022) is considering changes that would significantly reduce the cost of operating heat pumps, such as decoupling electricity pricing from volatile wholesale gas prices.

6.2 Rural properties

Within this work, rural refers to properties located off the gas grid which rely on alternative heat sources such as oil boilers to heat their homes.

Many off gas grid properties use electric resistive heating, which is a clean heating technology, but which partially accounts for higher rates of fuel poverty in rural areas (Scottish Government, 2023c) due to the higher unit cost of electricity compared to gas which leads to higher running costs. Therefore, more energy efficient heat pumps are a potential solution for fuel poverty in off gas grid areas.

Rural dwellings face a unique set of challenges compared to those found in urban settings.

6.2.1 Electricity network

The electricity network is vulnerable to extreme weather. In 2021, 40,000 households were left without power for three days in northern England and north east Scotland following Storm Arwen (OFGEM, 2023). This review did not find evidence establishing whether electric heating is more vulnerable in off gas grid area than on-gas areas. It should be noted that all types of heating – other than solid fuel burners require an electrical supply including gas, oil and biomass boilers.

Grid capacity is expected to be a potential constraint to the electrification of heat in all areas. The grid constraint is alleviated, and infrastructure investments can be postponed, if demand is reduced with insulation and if heat pump efficiency is improved, for example through the use of ground source heat (DELTA, 2018). Off gas grid housing often has the advantage of being built at low density, providing greater opportunity for the use of ground source heat pumps. However, ground source heat pump has a higher capital investment, and consideration should be given to share ground source networks also known as fifth generation heat networks.

Another strategy for reducing or postponing the need for network infrastructure investments is demand levelling. Time of use tariffs, the Demand Flexibility Service and the falling cost of domestic batteries provide incentives for consumer behaviour changes and automated smart demand response systems which can shift some electrical loads out of peak demand periods. Off gas grid areas have the same opportunity to benefit from these incentives as on gas areas.

6.2.2 Cold climates

Concerns have been raised about heat pump efficiency in cold climates (Simons, 2023). Field studies, however, demonstrate that with proper design, heat pumps maintain efficiency even at temperatures as low as -10°C, and can still be effective in conditions down to -30°C. (D. Gibb et al., 2023). It is crucial to understand that the effectiveness of heat pumps is not determined by the type of building or its insulation level. Efficiency is consistent across different environments and for buildings requiring more heat, due to size or less insulation, a larger heat pump can be employed to meet the demand effectively. This adaptability ensures heat pumps can provide efficient heating solutions in a wide range of settings and climates. This finding is applicable to all areas of Scotland but can be particularly relevant to rural areas which can face more severe winters and lower temperatures.

6.2.3 Evidence of adoption

Although challenges are present for rural homes, nevertheless the highest rates of heat pump installation are found in off gas grid areas (Nesta, 2023c). Analysis of the MCS installation database showed the UK's highest adoption rates are in the Highlands & Islands, rural Wales and Cornwall. This is likely because significant operating cost savings are achieved with heat pumps, compared with oil and direct electric heating due to the high efficiencies of heat pumps (see Section 5.2).

6.2.4 Islands and Coastal areas

Research into clean heating for new housing in island communities found no consumer barriers or region-specific capital barriers to heat pump adoption (ClimateXChange, 2022). Additional anti-corrosion treatments are included in coastal locations. However, a lack of local specialist contractors was considered a constraint on installation rates and increased servicing costs were incurred due to mainland contractor travel costs.

6.3 Small properties

This section considers barriers to heat pump adoption related to indoor space, including both houses and flats. There is no formal definition of 'small properties' and categorisation differs in the literature so we have used a broad definition to include properties that are identified as having space limitations since this is what limits the uptake of heating technologies that require more space than existing systems.

6.3.1 Hot water storage

In Scotland, 80% of dwellings currently have boilers and most of these are combi type, producing hot water on demand. Homes with combi boilers do not have space committed to hot water storage. Unlike a combination ('combi') gas or oil boiler, heat pumps and direct electric systems generally do not supply instant hot water. Therefore, it is necessary to have a system in place for storing energy to meet the occupant's hot water demand. The system usually takes the form of a hot water cylinder, the volume of which is driven by the size of the property and number of occupants. This calls for an evaluation of alternative hot water storage systems and a general evaluation of consumer barriers in terms hot water storage.

There is also the opportunity to think more broadly in terms of energy storage and review the viability of communal hot water storage externally.

Finding space for a hot water cylinder is one of the most significant consumer barriers in all homes and is particularly acute in small properties (Nesta, 2021; Palmer and Terry, 2023a; Scottish Government, 2022b).

In an analysis of the Scottish Building stock, homes with less than 18m^2 of floor area per habitable room were assumed to be unsuitable for individual heat pump adoption due to the requirement for a hot water cylinder (Element Energy, 2020). This threshold, which equates to 90 m^2 for a dwelling with 3 bedrooms and two reception rooms, was not explained. Since the average floor area of Scottish homes is 97m^2 (Scottish Government, 2023c) this threshold, if significant, takes in a large proportion of the housing stock.

One technical solution for small properties is compact phase change material heat batteries, such as those produced by Sunamp. These contain a material which is melted when heated by a heat pump, solar thermal panels or internal resistive element. It heats water instantly when a tap is opened, eventually solidifying as it cools. Heat batteries can be up to four times smaller than equivalent hot water cylinders.

Another solution is to locate hot water storage outside. This strategy was trialled in seven small houses by National Energy Action (NEA, 2023b). In this system a compact heat battery is located outside in an insulated enclosure adjacent to the heat pump.

Electrical batteries in conjunction with instant hot water taps and electrical showers may be a feasible solution where hot water demand is relatively low. Lithium-ion batteries can have roughly double the energy density of water storage, so could be effective in space-constrained cases (Energy Saving Trust, 2017). The cost of lithium-ion batteries has reduced dramatically in recent years (BloombergNEF, 2023) new battery technologies such as flow batteries are now emerging in domestic applications (PV magazine, 2023).

An interim solution, highlighted in interviews with housing officers, is to enable decarbonisation of space heating would be to allow the retention of combis for hot water production only. Thus, a heat pump would cover 100% of the space heating requirement. Over time, households may find space for hot water storage, potentially incentivised by the high unit cost of hot water or further technical solutions may emerge.

6.3.2 Radiators

In most UK homes, radiators are currently undersized to meet industry convention comfort standards with efficient gas boiler operation (BEIS, 2021). Consequently, either boilers must heat radiators to higher temperatures or rooms are cold.

In order to meet comfort standards and achieve high operating efficiencies with heat pumps, heating water temperature is typically needs to be lower with a heat pump than with gas or oil boilers. This means larger radiators and changes to pipework are often part of a heat pump installation (BEIS, 2021; Nesta, 2021; Zhuang et al., 2023).

In some cases, dependent upon ease of access, replacing undersized radiators could be fairly trivial, (Leveque, 2023), however in some, space constraints such as the wish to preserve space for bookshelves, may present a consumer barrier (Nesta, 2021; Wade, 2020).

Designing the heating system to operate at a higher temperature can mitigate the need for radiator upgrades. The capital savings may balance out operational cost increases over the life of the system (Palmer and Terry, 2023). Nonetheless, with the availability of modern heat pumps, designers can specify operating temperatures similar to the outgoing heating system which could mitigate the need for radiator upgrades.

6.3.3 Cost effectiveness

In small properties with low heat demands the capital costs of an air-to-water heat pump may not be economic. Alternative technologies can be considered.

Air-to-air heat (A2A) pumps have significantly lower capital costs than air-to-water and may be an attractive solution where there is no existing water-based system (Lowes, 2023). They therefore provide an option for addressing fuel poverty in homes with existing direct electric systems.

A further benefit of A2A heat pumps is that they can also provide cooling from the same capital investment in homes that are at risk of overheating in summer (Khosravi et al., 2023). Air to air systems account for a large part of Europe's lead over the UK in heat pump installation rates, although much of this is for heating in Southern Europe (Nesta, 2023d).

Infrared is proposed by manufacturers as a clean heat solution with low capital cost. Its use in industrial settings such as warehouses with high ceilings is well established (Anwar Jahid et al., 2022; Cao et al., 2023; Kylili et al., 2014). However, there is lack of evidence on energy efficiency benefits over simple resistive heating (Brown et al., 2016) with studies focussing on high ceilings (Roth et al., 2007). Other studies have identified discomfort concerns due to asymmetric temperatures (Corsten, 2021). By reducing the overall heat demand of a building and targeting only certain areas, while you may use less energy, overall, the building will be colder than if you maintained a constant air temperature. As a result, damp and mould could become more prevalent. In general, only things which are hit by the IR radiation will get hot although some heat will be emitted by the things which get hot and heat up the surroundings (Lowes Richard, 2022).

Where heat pumps remain impractical for small properties storage heaters are the most cost-effective option available today. In modelling of total cost of ownership, storage heaters are the optimal clean heating solution in some situations (Palmer and Terry, 2023a).

6.4 Flats and tenements

Flats and tenements are defined here as any building that contains multiple dwellings. This includes, four-in-a-blocks, low rise blocks, high rise blocks and tenements.

In the 2011 Census, it was found that 36% of the Scottish population lived in flats, making up the highest percentage among dwelling types (NRS, 2011). Around a third of tenement flats were built prior to 1919, another third between 1919-1982, and the final third after 1982. Many tenement flats are in a state of critical disrepair, particularly those built before 1919 (Built Environment Forum Scotland, 2019). The Scottish Parliamentary Working Group on Tenement Maintenance has been meeting since March 2018 with the purpose of establishing solutions to aid, assist and compel owners of tenement properties to maintain their buildings. Recommendations include establishing periodic inspections and maintenance sinking funds. This is important for energy efficiency and clean heating to be implemented in flats. (Scotland, n.d.)

6.4.1 Location of heat pump

Typically, air-source heat pumps are installed externally, such as in garden areas, driveways, or other outdoor spaces around the building. Unlike houses, flats and tenements often lack private gardens. Literature cited the lack of external space as a challenge when looking to install heat pumps (Nesta, 2021; Scottish Government, 2022b; Southside Housing Association, 2020).

The Scottish Government undertook a case study on the Dunbeg Phase 3 project in Oban which installed air source heat pumps into 74 flats (Scottish Government, 2022b). A primary finding highlighted the importance of considering a suitable external location for heat pumps specifically, relating to shared gardens. This challenge has not been expanded upon in the Dunbeg case study as it is likely a planning constraint similar to that experienced during the retrofit of a tenement block in Glasgow (K. Gibb et al., 2023). In this case, the aspiration was to utilise heat pumps that were attached to the external wall. However, planning officers determined that heat pumps could only be installed if they were located in the back communal garden on the ground and were fenced off. Consequently, gas boilers were installed in the top two floors.

Southside Housing Association trialled the installation of air source heat pumps to a selection of flats (Southside Housing Association, 2020). The installation work was informed by surveys and feedback from the residents. At the outset, the drying area within each floor of the flats was selected as the location for the heat pump. However, further consultation with residents determined that the preference was for the heat pumps to be installed on the individual flat balconies. This strategy presented some challenges in the beginning, such as difficulty pumping condensate water back to the main drain and heat loss through the external pipework. As a pilot project, the lessons learned should be applied to future projects, having successfully demonstrated alternative locations for flats with limited external space.

Air source heat pumps offer a versatile heating solution for multi-storey buildings. Ground-mounted units are ideal for efficiently heating ground-level and first-floor flats, using tailored circulation systems to distribute heat effectively. For higher floors, split system configurations are beneficial, allowing refrigerant lines to run vertically with greater ease and efficiency than insulated water lines, though this setup requires additional indoor equipment. Additionally, in buildings where rooftop access is available, heat pumps can be strategically installed on roofs or in loft spaces, providing effective heating coverage from the base to the top of the building.

Another option for flats is the adoption of either shared external heat pump units, such as at Hillpark in Glasgow (Star Renewable Energy, n.d.). Such systems have been demonstrated as being more cost effective than individual units whilst also consuming less space (Palmer and Terry, 2023). Agreement between different owners and tenants can be difficult to attain, especially where there are multiple owners and tenure types.

Options exist that enable an air source heat pump to be located fully within the building. Exhaust air heat pumps form part of the ventilation system and draw heat from exhausted stale air. Further heat is drawn directly from outside. They are most readily suited to energy efficient buildings (Energy Saving Trust, n.d.).

Individual room air to air heat pumps could provide further low capital, easy installation options. These systems are gaining popularity in some settings with existing ducted air systems, for example in flats in the United States (Gradient) and in UK hotel rooms (Powrmatic).

Clean hot water heating could be provided independently on the hot water system by using hot water heat pumps which either using excess internal heat or ventilation exhaust air or outdoor heat to generate hot water.

Shared ground source heat networks, also known as fifth generation heat networks, provide a clean heating solution that does not need equipment to be located above ground outdoors. Ground temperature heat drawn from boreholes is shared across homes through a network. Individual water to water heat pumps inside each property supply heat to space and to hot water storage.

In common with the challenges of addressing communal maintenance, the main remaining barrier to heat pump adoption in flats is the challenge of gaining agreement to, and coordinating works, between all owners of the building. These are similar to the challenges to basic repairs and maintenance blocks of flats and to fabric improvements such as insulation. An expert Short Life Working Group presented recommendations for addressing these barriers in 2023 (Scottish Government, 2023a). These centred on whole building approaches and further amendments to the Tenements Act.

7 Future Developments

This review has found that with careful consideration, clean heating technologies are available to suit challenging dwelling types, though there are factors to consider including running cost, space constraints and need for communal agreement. There remains the opportunity to address barriers and support delivery through further technical and policy development as well as sharing best practice by gathering more evidence from pilots on key aspects such as managing costs, disruption levels and post occupancy evaluations.

7.1 Application of existing technologies

This review has reported on a variety of technologies in different forms of application. It shows that there is no panacea, or one-size-fits-all solution for clean heating. Further consideration is required to support the finding that appropriate technologies are available for challenging dwelling types. These recommendations are provided as a cumulation of findings from the literature review, industry interviews and the report authors experience.

As described in section 6, air-to-air heat pumps may provide a cost-effective means of providing low-cost clean heat in small dwellings. However, there is only weak evidence for the energy efficiency of such systems. For related reasons, there is no certification standard to support publicly funded air-to-air installations. Policy makers should consider commissioning field or laboratory studies to clarify the effectiveness of air-to-air heat pumps.

The role of cascade heat pump systems such as exhaust air heat pump and hot water heat pumps should be considered further. These systems use both outdoor air and internal air to provide heating and hot water at different temperature levels. Further research is required to determine appropriate applications and the required skills and policy support.

There is also the opportunity to think more broadly in terms of energy storage and review the viability of communal hot water storage externally, this would be particularly well suited to flats and tenements or small homes in rural areas which may have limited internal area.

7.2 Fifth generation heat networks

Besides wide-area fourth generation heat networks, which operate at around 65°C, this report has covered other heat network configurations including communal air source heat pumps for flats. However, the potential for shared ambient loop networks, also known as fifth generation heating and cooling networks, to serve Scottish challenging dwelling types is not well reported in the independent literature. Further research in this area is merited.

7.3 Improving installed heat pump performance

As described in the context of older buildings in section 6, with some households and buildings it may be appropriate to decarbonise without any new insulation measures. However, while it's possible to install any heating system at any time, it's advised to first enhance the building's fabric. Rather, it is more important to focus on design and installation standards to maximise in situ efficiency (Eyre et al, 2023).

Workforce education should be directed towards better system design. This concerns the right-sizing of heat pumps, radiators and pipework. This enables heat pumps to operate in their high efficiency ‘sweet spot’ for more of the heating season. This can often reduce capital costs and avoid unnecessary radiator and pipework upgrades.

Furthermore, a better understanding is needed about whether demand reduction and energy-saving measures can enable or speed up the deployment of technologies such as heat pumps, for example, by reducing the size and cost of equipment required, smoothing out peaks in electrical demand, and reducing operating costs.

7.4 Emerging technology

Domestic heat pumps use the vapour compression cycle. An alternative heat pump technology, the Peltier Effect is used in thermoelectric heat pumps. In these devices voltage applied to a semiconductor device creates a temperature difference between the two sides of the device, supporting thermal energy collection from renewable sources (Tritt, 2002). Thermoelectric heat pumps, known for their application in industries and portable devices like camping fridges, offer unique benefits for challenging building environments, especially smaller spaces such as flats or compact homes. Their key advantages include a lack of working fluid, eliminating concerns over global warming potential, absence of moving parts which ensures durability and minimal maintenance, and a compact size that allows for flexible installation options. Unlike traditional systems, thermoelectric units do not necessarily require external components, making them an ideal choice for locations where external installations are impractical. This makes thermoelectric heat pumps a versatile and eco-friendly option for urban living spaces where space constraints and building regulations might limit the use of conventional heating systems.

Developments in industry indicate that thermoelectric heat pumps may be suited to heating dwellings. TE Conversion, based in Glasgow, discussed with the author how they expect to test prototypes operationally in domestic settings in 2024.

Emerging technology once recognised as a 'mature' technology, service and maintenance costs are not anticipated to be any higher than for fossil fuel (or biomass) equipment as the intervention period should be longer. Annual service costs whether for gas boilers or heat pumps are likely to be comparable.

8 Conclusions

We conducted a review of existing literature and evidence to assess the feasibility of heat pumps as a clean heating option for building types considered difficult to decarbonise. We found that with careful consideration and effective design, clean heating technology can be applied to all types of challenging dwellings.

However, a key caveat of this report is the need to evaluate the cost-effectiveness of implementing clean heating technology in varied circumstances. Without a comprehensive cost analysis of comparable solutions, it is difficult to determine their economic viability. Therefore, future research should prioritise conducting whole-life cycle cost analyses of different heat pump applications and scenarios, ideally based on industry data wherever available.

The appendices include four key literature pieces that may complement the findings of this report, offering a comprehensive understanding of the challenges and opportunities associated with challenging dwelling types and clean heating technologies.

8.1 Recommendations

Based on the findings of the report, the authors recommend the Scottish Government explore the following:

1. Conduct in-depth case studies, evaluations and surveys on the application of clean heating technology in challenging dwelling types to extract valuable socio-technical lessons learned and develop repeatable solutions.
2. Future studies that facilitate consistent appraisal and comparison in heat pump evaluations.

3. Investigate zero carbon back-up options for areas with vulnerable above ground distribution networks.
4. Consider the recommendations of the Working Group on Tenements - mandatory owners associations, periodic inspections and maintenance sinking funds. This is important for energy efficiency and clean heating to be implemented in flats.
5. Investigate alternatives to hot water storage in flats and small properties and a general evaluation of consumer barriers in terms of hot water storage systems. For example, Community Energy Storage systems.
6. Establishing evidence for the energy efficiency of air-to-air heating and, if found to be appropriate, providing policy support for certification and installation in homes where it is more cost effective than water-based space heating.

In addition, the research team identified several financial and regulatory barriers for Scottish Government to consider:

- Monitoring developments in thermoelectric heat pumps, which may provide radical space savings.
- MCS certification for air-to-air heat pumps or support for communal ambient loops with individual water-to-water heat pumps for flats.
- Hybrid heat pumps where fossil fuels are used only for hot water.
- Resolving inconsistency in planning guidance for heritage buildings and conservation areas.

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10 Appendix

10.1 Methodology

A Rapid Evidence Assessment (REA) is a methodology which enables a researcher(s) to undertake a systematic review of existing literature related to a specific research question and provides a method to search and critically appraise relevant literature. To further complement this, a deeper analysis of the gaps identified in the literature review was undertaken through a combination of surveys and semi-structured interviews with industry experts.

A rapid evidence assessment is split up into 7 key stages:

1. Protocol development
2. Evidence search
3. Search screening
4. Evidence extraction
5. Critical assessment of evidence
6. Synthesis of results
7. Communication of findings

Each of these stages and their methods have been discussed in more detail below.

1. Protocol development

The purpose of the protocol development is to develop a search strategy and formally detail the methodology. Developing a protocol distinguishes Rapid Evidence Assessments (REA's) reviews with less structure. This ensures that the evidence review (ER) process is rigorous and transparent. It also facilitates communication among the User, Steering Group, and Review Team, laying out how the review will be carried out. The Review Team bears the responsibility for developing the review protocol, active input and approval from the User and Steering Group are essential components of the review process.

Background	Approximately 20% of Scotland's total greenhouse gas emissions originate from homes and workplaces. In pursuit of climate objectives, the Scottish Government has established targets, aiming to transition over one million homes to clean heating systems by 2030, with the broader goal of achieving clean heating for all homes by 2045. Over one third of Scotland's housing stock comprises tenement properties, characterised by factors such as accessibility issues, space limitations, ownership complexities, and structural challenges, which can pose difficulties in installing clean heating technology. Although several clean heat technologies exist, heat pumps are expected to play a significant role in the decarbonisation of heat in Scotland. The purpose of this work is to assess whether heat pumps represent a practical, technically viable, and cost-effective clean heating option for various dwelling types, including flats, tenements, and other hard-to-treat archetypes.

Primary question
What evidence is there that heat pumps are a practical, technically feasible and cost-effective clean heating option for Scottish flats, tenements, and other hard-to-treat archetypes?

Population:	Flats, tenements, and other hard-to-treat buildings in climates like Scotland's.
Impact:	Clean heating technologies
Comparator:	Existing fossil fuel heating system
Outcome:	Practical, technically feasible, cost effective
Secondary question	
What evidence is there that dwelling types may be suited to other ZDEH technology such as direct electric heating. Which dwellings are suited to non-ZDEH hybrid heating systems?	

Scope of the work		
Boundaries	**Geography**	Scotland (and other countries with similar economies and policy drivers i.e., wider UK and Europe where applicable)
	Date	Since 2010 We agreed that research carried out within the last 5 years would be the most relevant in terms of technology adoption and the regulatory/ policy framework with what is in place presently. We viewed research carried out in the last 5-10 years to be less relevant but may still be applicable and therefore has been included in this work. Research older than 10 years is anticipated to be the least relevant, using older technologies than available now, and adhering to different standards and policies that are currently in place.
	Outcome	Immediate cost/ benefit to occupants and building owner in terms of technical feasibility, practicality, user acceptance, capital cost and operating cost.

Keyword search	
Population	dwellings; homes; houses; hard to treat; flats; apartments; traditional; solid wall; heritage; small
Intervention	low carbon heat; heat pump; zero carbon heat; renewable heat
Comparator	(we are comparing vs business as usual)
Outcome	economics; costs; comfort; consumer; skills; supply chain
Other	case study; evaluation

Search locations	
Peer-reviewed literature	Engineering, policy, and social science databases
Grey literature	Engineering, policy, and social science databases for conference proceedings and non-peer reviewed academic publications Search engines
Unpublished data	Members of Heat Source; professional contacts of review team; contacts of Steering Team.
Secondary review	Semi structured interviews with industry experts to further complement the findings of the literature review.

2. Evidence search

The search strategy outlined above was utilised to carry out the evidence search. Boolean Operators, including words like AND, OR, NOT, or AND NOT allow the combination or exclusion of keywords, leading to more precise and productive results. This streamlined approach is designed to save time and effort by eliminating irrelevant hits that would otherwise need to be reviewed before being discarded.

Google searches are restricted to searching 32 words at a time; therefore 3 keyword searches were undertaken. As such the core searches performed across the three key databases can be seen in the table below. These were duplicated in each of the chosen search engines, Google, Google Scholar and Edinburgh Napier University academic library.

The keyword searches are outlined below:

Table 1: keyword search

Boolean operator	AND				
Either (OR)	dwellings	hard to treat	low carbon heat	economics	case study
	homes	flats	heat pump	costs	evaluation
	houses	apartments	zero carbon heat	comfort	
		traditional	renewable heat	consumer	
		solid wall	zero emissions heat	skills	
		small		supply chain	
		traditional			
	Search 1		Search 2		Search 3

Search results were then exported to an excel file. Duplicate results between the three searches were removed.

3. Search screening

Search result screening ensures that only the most relevant results are taken forward to the evidence extraction phase. Inclusion and exclusion criteria, in this case RAG analysis, was utilised was then used to carry out this initial screening.

Table 2: boundary conditions

Category	Thresholds	Score
Year	2018 onwards	Green
	2013-2018	Amber
	Pre 2013	Red
Source	Peer Reviewed publication OR Book	Green
	Independent Research (not peer reviewed) OR Government Policy	Amber
	Industry grey literature	Red
Location	Scotland or UK	Green
	Europe	Amber

Restrictions	Rest of World	Red
	Relevant to all 3	Green
	Relevant to 2	Amber
	Relevant to 0 or 1	Red

4. Evidence extraction

Once the initial search screening had been completed, we analysed the searches for further information to determine their alignment with clean heating in Scotland for challenging dwelling types. The following information was extracted or each piece of evidence:

1. Key observation/particular area of interest
2. Evidence overview
3. Key Data

5. Critical assessment

The critical assessment is the part of the REA which is used to determine the robustness and relevancy of the information that has been extracted in the preceding stages.

Assessing relevancy

The initial step in the critical assessment involves assessing the relevancy of evidence in connection to clean heating in hard-to-treat archetypes. The following has been considered:

The appropriateness of the method employed in the evidence to clean heating in Scotland for hard-to-treat property types.
The relevance of the evidence to hard-to-treat archetypes in Scotland.
The relevance of the intervention under scrutiny.
The relevance of the measured outcome.

6. Synthesis of results

This stage involves the systematic analysis and integration of findings from the gathered evidence to draw conclusions or make recommendations. This stage typically follows the data extraction phase and precedes the final reporting or dissemination of findings.

7. Communication of findings

The final step in the REA communicates the findings in a report and provides appropriate recommendations and conclusions.

10.2 Industry survey questions

The survey was conducted through Survey Monkey specifically targeting the HeatSource network, a collaborative low carbon heat knowledge hub, hosted by BE-ST on behalf of Scottish Enterprise. The survey was distributed to 311 people with a return rate of 16. The return of 5% although low provided some insights. The low return in part could be due to the timing, the survey was distributed in December.

Survey questions

1. Provide your view on the suitability of electric heating for challenging property types based on your experience. If unsuitable, please provide the reasons why. As far as possible provide values or data to support your views.

2. For which challenging property types have you considered, assessed, designed or installed clean heating systems? Select all which apply.

    a. Multi-storey flats
    b. Tenements (any age)
    c. Old/heritage properties pre-1919
    d. Four in a block
    e. Off gas grid properties
    f. Small properties of less than $80m^2$
    g. None of the above (please specify other)

3. What experience do you have or have considered in retrofitting any of the following technologies?

    a. Instant electric heating systems, for example, electric boilers, CPSU, infrared, panel heaters
    b. Off peak direct electric, for example storage heaters
    c. Air source heat pumps
    d. Ground source heat pumps
    e. Other (please specify)
    f. None of the above

4. Thinking about the heating projects you have been involved in, what was your desired outcome/ motivation for action? You can define this further in the space provided.

    a. Achieve a reduction in operating costs
    b. Achieve parity operating cost
    c. Reduction in fuel poverty
    d. Achieve reduction in carbon emissions
    e. Improving occupant thermal comfort
    f. Achieve a reduction in cost savings for periodic replacement
    g. Where possible provide supporting figures/data. (for example, reduce carbon emissions associated with a property by x%, increase thermal comfort for tenants) Define your desired outcome, ideally with numbers. Please specify below.

5. Thinking about projects you have been involved in where clean heating systems were considered, did they go ahead?

    a. Yes

    b. No

6. Did you achieve your desired outcomes? Where possible, provide figures or data citing actual versus target for outcomes.

    a. Yes – why?
    b. No – why?

7. If you have abandoned attempts to install a clean heating system, why was this?

    a. Capital cost
    b. Expected operating cost
    c. Installation barriers
    d. Occupant/user barriers – e.g., concerns with heat pump controls
    e. Lack of supply chain
    f. Lack of occupier engagement/support
    g. Lack of funding
    h. Other
    i. Please use the space below to elaborate on the reasons and context for the decision to not proceed with a planned installation.

8. If you are an installer, what is important to successful outcomes in clean heating installations in challenging property types?

9. In your opinion, what additional evidence is needed to increase confidence in deploying clean heating in challenging property types?

10. In your opinion what are the key barriers to increasing deployment of clean heating in challenging property types?

10.3 Semi-structured interviews

Interviewees were identified by the project report authors as key industry experts with experience of clean heating technology. In total ten interviews were conducted with installers, architects, and housing professionals. The interviews were an addition to the literature review process to help draw out key findings in areas such as barriers to adoption and potential solutions to deliver clean heating technology at scale.

Sample questions altered slightly dependent on background and job role.

1. What is your experience of retrofitting zero direct emissions heating systems?

2. What barriers do you perceive with difficult to treat archetypes?

3. What did your previous research reveal to you about ZDEH systems?

4. What is your opinion on alternative solutions (using a table of options)

5. Why do you think retrofitting ZDEH systems in difficult to treat homes is not being done at scale?

6. What are the key things you need to see to enable difficult to treat properties being retrofitted?

10.4 Case examples

Using our sources protocol and deeper dive the four sources below were identified as most insightful in terms of the research question. Although it must be stressed all four still have gaps in findings.

Title of source				
Faster deployment of heat pumps in Scotland: Settling the figures				
Year	**Type of research**	**Country/Climate zone**	**Contains hard to treat and clean heat research evidence**	**Author/ For**
2023	Modelling	Scotland	Yes	Cambridge Architectural Research/ WWF
Note				
The study emphasises integrating heat pumps with energy efficiency measures to reduce emissions in Scottish homes, focusing on the cost, energy efficiency needs, and impact on energy bills and fuel poverty. It leverages the ScotCODE model for dynamic, cost-effective strategies in low-carbon heating deployment.				
Key observations/Implications				
Evidence of technically feasibility (or not) "The study found that it is technically possible to fit larger heat pumps to these homes without external wall insulation, but overall costs are higher" "Flats are less likely than houses to see a benefit from heat pumps because they use proportionately more energy for hot water" "It is technically possible to fit heat pumps in almost all flats and tenements, with ASHP selected in most cases, and air to air units selected where internal and external space for ASHP equipment is limited (also in some flats with electric storage heaters)" **Evidence of cost-effectiveness (or not)** "The modelling and optimisation revealed that homes require a good standard of energy efficiency to ensure efficient and cost-effective heat pump operation" "Around 80% of all homes would require at least one upgrade to reach the cost-optimal level of energy efficiency" "Although in many cases running costs are lower with heat pumps, high capital costs lead to higher whole-life costs. This gap is what Government financial support needs to close in order to make converting to heat pumps more attractive to households" "This modelling indicates that the most effective way to reduce carbon emissions from				

Scottish housing is to prioritise dwellings using oil-fired heating, and older homes with solid walls first, then gas-heated homes and bungalows, and finally newer dwellings built since 1982 and flats, where the potential savings are lower” “the cost and carbon savings from switching to heat pumps are greatest for homes that currently have oil-fired heating” **Evidence of other ZDEH tech** “Shared external units serving multiple flats may work out more cost-effective than separate systems serving individual flats, both for installation and maintenance.

Title of source				
Affordable warmth next steps for clean heat in Scotland				
Year	**Type of research**	**Country/Climate zone**	**Contains hard to treat and clean heat research evidence**	**Author/ For**
2023	Mixed	Scotland	Yes	Fabrice Leveque/ WWF Scotland
Note				
It shows that energy efficiency, electric heat pumps and heat networks can help cut energy bills and lower carbon emissions. With energy prices likely to remain elevated, these solutions are our best strategy to minimise fuel poverty and tackle climate change at the same time.				
Key observations/Implications				
Evidence of technically feasibility (or not) “It is possible to install individual heat pumps in flats, but there are extra challenges to doing so that shared systems like heat networks and communal systems (potentially receiving heat from large heat pumps) could overcome” “a recent field trial for UK Government found internal space to be a limiting factor in only 2% of over a thousand UK homes **Evidence of cost-effectiveness (or not)** “All the typical houses in the study starting with oil and electric storage heating, and just over half of those on gas, make savings” “electric heat pumps, combined with some insulation improvements, are the cheapest way for most Scottish homes to achieve the crucial cuts in climate emissions that we must achieve by 2030” “Air source heat pumps (ASHP) are the least-cost solution for homes starting with gas and oil boilers, with Air to Air heat pumps the best solution for homes with electric storage heaters” “Some houses on gas see modest increases… This is because they have high hot water demand and are relatively more modern and energy efficient and before upgrades already had the lowest energy bills. These factors also prevent the flats from making savings against gas” “heat pump running costs could be further lowered by: … time of use tariff…, solar energy…, more energy efficiency and radiator upgrades…, innovation” **Evidence of other ZDEH tech** “Potential challenges to installing heat pumps in homes were explored… cost-effective alternatives such as air to air heat pumps… and internal wall insulation were found” “there is a risk that space for these may be limited in some smaller homes. The modelling found that in these cases, Air to Air heat pumps and instant hot water heaters provide a cost effective and space-saving alternative. Although not part of this study, heat batteries also provide a smaller alternative to traditional hot water tanks”				

Evidence of non-ZDEH tech "hydrogen heating in Scotland. It found that if available at all, deployment at scale is unlikely to be possible until the mid2030s. It is also likely to be much more expensive to run than natural gas heating"

Title of source				
How to Heat Scotland's Homes An analysis of the suitability of properties types in Scotland for ground and air source heat pumps.				
Year	**Type of research**	**Country/Climate zone**	**Contains hard to treat and clean heat research evidence**	**Author/ For**
2021	Mixed	Scotland	Yes	Energy Systems Catapult/Nesta Scotland
Note				
Narrative summary of barriers. Quantitative assessment of Scottish housing stock. Some view on flats for heat pumps 'difficult'. " It was found that installing a heat pump into a pre-1914 flat without retrofit measures would leave the house below acceptable comfort levels for more than 22% of the time during the coldest periods of the year.				
Key observations/Implications				
Evidence of technically feasibility (or not) "25% of homes surveyed for a heat pump were deemed unsuitable by the surveyor or homeowner because of the lack of a suitable external location, because the routing of services was problematic, or because of significant disruption" "Typically, heat pumps provide a lower temperature than fossil fuel boilers, therefore achieving an equivalent heating experience is affected by the energy efficiency of the property, as well as the detailed design and installation of the system itself." "Space inside the flat for a hot water tank may also be a challenge" "Consideration should also be given to the cumulative noise effect of multiple heat pumps across multiple dwellings." **Evidence of cost-effectiveness (or not)** "Installing a heat pump can be 4x the cost of replacing a gas boiler plus potential additional costs for distribution system upgrades, hot water storage and/or fabric retrofit" "it is known that heat pumps generally result in lower running costs for off-gas households and can be competitive with on-gas where a heat pump system is properly sized" "Heat pumps have a higher capital cost than incumbent heating technologies, without clearly delivering a better experience for the household" "In off-gas grid dwellings, where heating oil, LPG, direct electric or solid fuels are being replaced, heat pumps can offer a competitive alternative when considering running costs, particularly when the heat pump system is well sized and maintains a good coefficient of performance"				

Evidence of other ZDEH tech "Opportunities for pre-1914 flats could include a communal heating system which would reduce the amount of ancillary equipment required within each flat and share the costs associated with installation and maintenance"

Title of source				
Niddrie Road, Glasgow: Tenement Retrofit Evaluation				
Year	**Type of research**	**Country/Climate zone**	**Contains hard to treat and clean heat research evidence**	**Author/ For**
2023	Case Study	Scotland	Yes	UK Collaborative Centre for Housing Evidence/ Scotland Funding Council
Note				
Evaluating the deep 'green' retrofit of a traditional, pre-1919, sandstone tenement in Niddrie Road, Glasgow. A partnership consisting of Southside Housing Association, Glasgow City Council, John Gilbert Architects and CCG Construction to deliver an Enerphit level retrofit. The report contains an evaluation and its wider lessons for retrofitting tenements and older building stock.				
Key observations/Implications				
Evidence of technically feasibility (or not) "ASHPs were constructed into the ground and first floor with gas boilers in the upper two floors. s. This was a direct result of the planning decisions – the hot water piping could only reach the first two floors from the back yard with sufficient heat distribution retained to meet the manufacturing warranty" Planning guidance initially ruled out external wall insulation (EWI) at the rear and partial gable end of the block. It also later argued that residential air source heat pumps could not be used if attached to the rear of the building at windows. It also ruled out photo-voltaic panels on the roof, and it did not approve proposed wider gutters. Tenement planning policy is critical to aligning the fabric first needs of the retrofit (air -tight insulation combining external wall insulation and internal wall insulation as well as mechanical ventilation with heat recovery and other specific components) alongside renewables to deliver low energy. Niddrie road is a standard sandstone tenement. Even so, planning permission for the retrofit was complex and challenging **Evidence of cost-effectiveness (or not)** "The decision to commit to an EnerPHit approach was made possible because the association had control of a complete (and empty) tenement block or close. On the other				

hand, this means that the approach and the standard are not suitable for most situations where ownership patterns are more fragmented."

"Like many other older tenements, 107 Niddrie Road had been poorly maintained and suffered from a wide range of long-term problems such as failing finishes and decayed floor structure which significantly impacted on time and costs"

Evidence of other ZDEH tech

When the space heating demand is reduced by as much as it is at Niddrie Road, then the biggest component of most peoples' fuel bills are hot water costs. Wastewater heat recovery systems can reduce costs (and carbon emissions) of hot water can be reduced by around 40%

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