CLEAN HEATING AND HOT WATER SYSTEMS REVIEW

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A report for Fife Council investigating decarbonised heating and hot water systems suitable for Scottish social housing and existing properties

Written by Changeworks and CeNZ-HighDB

CLIENT

Fife Council

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1. EXECUTIVE SUMMARY

Fife Council is planning to transition its 31,244 social housing properties, 96% of which currently use polluting heating systems, to clean heating and hot water systems by 2045.

To determine the most appropriate systems to install Fife Council appointed Changeworks to assess and analyse options. This report presents the first stage in a wider project to enable Fife Council to install clean heating systems with confidence, whilst being aware of and managing risks.

Delivered by Changeworks in collaboration with CeNZ-HighDB, this report is intended to inform future real-world trials by Fife Council and assist in developing a long-term strategy for heat decarbonisation in its housing stock.

Desktop research, energy modelling and an assessment of Fife's housing stock was carried out to develop an evidence base. A range of qualitative and quantitative aspects of clean heating were analysed to ensure that technology choices are suitable for property types and tenants, while balancing comfort, cost, and carbon reduction. The approach also aligns with Scotland's net zero targets and policies, considering fuel poverty risks and fabric retrofit targets, as set out in the proposed Social Housing Net Zero Standard.

Heating and hot water systems shortlist

Potential clean heating and hot water technologies for use in social housing in Scotland were explored in the project's scoping phase. A long list of commercially available and emerging systems was assessed with Multi Criteria Decision Making tools. Desirable criteria for clean heating technologies from a Fife Council perspective were identified and weighted, and technologies then scored against these. A short list of technologies was established for more detailed exploration in later stages of the project:

Short list of technologies

- Space heating:
  - Air source heat pumps (ASHP) - air to water
  - Electric radiators - oil, water-filled or ceramic core
  - Electric panel heaters - Convector heaters
  - District heat network for heating and hot water
  - High heat retention storage heater (smart)
  - Ground source heat pumps (GSHP) - ground to water
  - Infrared radiant panels
- Hot water:
  - Solar thermal water heating system
  - Electric immersion - Direct hot water cylinder
  - Electric instantaneous at point of use - Water heater

Focus groups and desktop research

Further research was carried out on the shortlisted technologies to address the Council's key questions and concerns regarding clean heating, covering key areas such as cost, efficiency, and suitability. Focus groups were held with Local Authorities and consumer groups to gather real-world experience, and available literature (research studies, manufacturer information and relevant case studies) was reviewed.

Key findings include:

- District heat networks suit high density areas but demands major infrastructure and its development can be outside of an RSLs control.
- Heat pumps, both air and ground source, deliver high efficiency and carbon savings but require significant capital investment, adequate building fabric, and adequate design, installation and operation.
- Smart storage heaters and infrared panels can provide low energy bills, but this is dependent on energy tariffs for storage heaters and building fabric efficiency and suitable room layouts for infrared panels.
- Direct electric options like immersion heaters and panel radiators offer low upfront costs and simplicity of use but suffer from high running costs unless paired with solar PV panels.
- Solar thermal is increasingly less economically competitive versus solar PV panel systems paired with a battery or diverter.

Energy modelling: running costs and carbon

Energy modelling was carried out using the Passivhaus Planning Package (PHPP) to compare energy demand, energy costs and carbon savings for the shortlisted technologies. The technologies were modelled in a range of theoretical properties to explore the impact of form, size and fabric efficiency on running costs. The impact of different heating patterns was also explored, to understand how tenant behaviour could affect energy cost and comfort.

A range of theoretical properties was modelled. The modelling confirms that all clean heating technologies can significantly reduce operational carbon compared to gas boilers. Other key findings include:

- Well-performing air source and ground source heat pumps can have the same or lower running costs as gas boilers.
- Poorly performing air source heat pumps, either badly designed, installed or utilised, are more expensive to run than gas boilers but are still significantly cheaper than direct electric systems.
- Direct electric systems remain more expensive for tenants but could be an alternative for smaller properties with high fabric efficiency where heat pumps are difficult to install.
- Heating patterns influence running costs, but these impacts change with some clean heating technologies. Heat pumps are typically more cost effective when providing constant heat rather than being used intermittently. Using an ASHP for shorter intermittent periods of time could marginally reduce the energy bill but will have a significant negative effect on comfort, with colder internal temperatures.

Balancing fabric efficiency and clean heating

Modelling was also used to evaluate how the heating systems perform in properties with different levels of fabric efficiency, and how estimated energy bills would impact on fuel poverty risks. To install clean heating systems across the stock without significantly increasing the risk of fuel poverty and improving comfort, the following is recommended:

- Improve fabric efficiency through retrofit to a heat retention rating of at least 120 kWh/m^2/year.
- Install efficient heating systems, including GSHP and ASHP, as a priority over inefficient clean heating systems.
- Installing solar PV panels and batteries or diverters to DHW cylinders, where possible.
- For properties that cannot have efficient heating and solar PV panels installed, at a minimum improve fabric efficiency to the following:
    - Small properties around 50m^2 improve the heat retention rating to at least 120 kWh/m^2/year
    - Medium sized properties around 75m^2 improve the heat retention rating to at least 95 kWh/m^2/year.
    - Large properties around 100m^2, improve the heat retention rating to at least 70 kWh/m^2/year

30-year costs to the Council

Estimated costs to the Council (comprising installation, maintenance and replacement) over thirty years were calculated. These can vary widely, from around £5,550 for electric panel heaters to over £29,000 for ground source heat pumps. Typically, systems that are more expensive for the Council to install are cheaper to run for the tenants. This highlights the trade-off between upfront investment and long-term savings for tenants.

Fife Council’s stock and clean heating suitability

Data on Fife Council’s housing stock was analysed to determine the most appropriate clean heating systems. Only 4% of properties currently use electricity-based heating, including limited air and ground source heat pumps, storage heaters, and room heaters. Around 500 homes are connected to communal heating system, all assumed to be communal gas boilers. Solar PV and thermal adoption is minimal, at 5% of the stock.

The stock is diverse in construction, age, and type, with most homes built between 1930 and 1964. Because of this, fabric efficiency varies widely. Over half of the properties do not meet the proposed minimum heat retention rating proposed in the Social Housing Net Zero Standard (120 kWh/m^2/year). This study recommends that properties be upgraded to at least this level prior to or alongside clean heating installation to reduce fuel poverty risks for tenants.

Internal space for equipment was identified a key factor that will help determine what technologies can be installed in properties. A quarter of the stock may have very limited internal space for additional equipment (e.g hot water cylinder, heat pump), and up to 70% is identified as having have some risk of lacking internal space.

Technology assessment conclusions

The analysis suggests that there is no single system which will be suitable for all of Fife Council's properties. A stock wide clean heating strategy will need to consider fabric efficiency and property size and balance fuel poverty risks and long-term costs to the Council.

Considering these factors, the key technologies identified as being the most suitable for Fife Council's housing stock are:

- Air source heat pump
- Ground source heat pump
- District heating networks
- High heat retention smart storage heaters
- Infrared radiant panels and electric radiators
- Electric immersion heaters

Installing clean heating systems across the stock will require a fabric-first approach (e.g. consider fabric efficiency before or alongside heating upgrades), a focus on efficient clean heating systems (e.g. heat pumps) and targeted use of space-saving technologies (e.g. storage heaters, infrared). Location specific conditions, such as local electricity grid capacity and heat networks, should also feed into the Council's clean heating strategy.

Next project stage

For the next stage of the project, it is proposed to pilot clean heating technologies in Fife Council housing. This will allow the desktop analysis and research in this report to be compared with real world outcomes.

Proposed Systems to Monitor

- Communal ground source heat pumps (GSHP) - ground to water
- Air source heat pumps (ASHP) - air to water
- Electric radiators
- High heat retention storage heater (smart)
- Infrared radiant panels
- Electric immersion – Domestic hot water cylinder
- Solar panels with batteries or with diverters to hot water immersion to support heating and hot water systems

Not all of the technologies recommended in this report are currently installed within Fife Council's properties, and it is recommended that these be the focus for next steps. The proposed installations will be monitored alongside the existing clean heating systems within Fife Council's stock to develop clear evidence on all the technologies recommended in this report.

Proposed Installations

- Communal GSHP systems with shared ground loop in flats for properties with communal boilers.
- ASHPs across varied property types, including those with existing gas combi boilers.
- High Heat Retention storage heaters and smart controls for older systems.
- Solar diverters in properties with solar panels but no battery storage.

To evaluate performance and tenant outcomes, insitu monitoring is recommended alongside engagement with tenants. An impact evaluation framework has been developed in this report, setting out the key metrics to gather in the next stage, including measuring comfort, air quality, energy costs, carbon emissions, and installation and maintenance ease. Installations should be accompanied by a tailored tenant support service to provide guidance on system use, tariffs, and energy debt prevention. This will reduce the risks identified in the analysis.

Once real-world outcomes have been analysed and compared to the findings in this report, Fife Council can develop a clean heating strategy for its stock. This strategy, underpinned by research and real-world experience, can give confidence to the Council as it aims to transition to clean heating and hot water systems.

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2. INTRODUCTION

CeNZ-HighDB

CHANGEWORKS.

2.1 PROJECT INTRODUCTION

2.1.1 Project background

Fife Council's existing housing stock currently consists of 31,244 properties, with the majority having polluting heating systems. Meeting Scotland's legislated climate targets (of reaching net zero emissions by 2045) will require the replacement of all polluting heating systems, and the Scottish Government has proposed to make this a part of mandatory standards for socially rented homes.[1] This will require the replacement of existing systems with clean alternatives in the majority of Fife Council's existing housing stock (96%), just under 30,000 properties.

Before starting the transition to clean heating systems, Fife Council seeks to develop an informed approach. The Council want to ensure the most appropriate systems for properties and tenants are installed. A consistent approach to replacing heating systems should lead to satisfied tenants, healthier environments for tenants and buildings, efficiencies in maintenance and procurement, and time and money saved for the Council.

The Council wish to have both theoretical and real-world evidence to support a strategy and provide a degree of certainty before committing to installing systems at scale. This report forms the first stage of a wider investigation into clean heating systems, with a second stage intended to pilot recommended systems in appropriate housing types to test real world outcomes.

The first stage, as presented in this report, is desktop based, involving research, energy modelling and assessment of systems. This analysis lays out the development of a consistent strategy for the Council to choose systems for installation.

The second stage, beyond the scope of this report, is to install, monitor and evaluate heating and hot water systems in Council properties, to test the desktop findings of this report and to demonstrate real-world outcomes within Fife's properties and for Fife's tenants. These installations can work alongside the development of support services to allow a smooth transition to clean heating for both the tenants and the Council.

The wider project composed of the two stages will help form a long-term strategy to decarbonise heating systems and requires alignment with fabric retrofit.

To note, this project analyses heating and hot water systems in relation to Fife Council's housing stock, which is social housing and primarily in high density areas, with the majority classed as located in urban locations.[2] However, the information presented is applicable to other housing across Scotland and the UK.

2.1.2 Project aims and objectives

The wider project's overall aim is to provide a clear body of evidence on options for heating and hot water systems. This will support Fife Council in selecting clean heating strategies and provide confidence to transition its properties to clean heating and hot water systems.

This aim will be achieved through the following objectives in this stage of the project:

- Assess and evaluate a range of clean heating and hot water systems, including assessing that systems are appropriate for a range of heating types and property types.
- Gather, generate and clearly present evidence to enable Fife to develop a consistent strategy to choosing systems for installation.
- Ensure the study is specific to the location and property types in Fife Council's stock.
- Ensure theoretical and practical aspects of heating options are considered.
- Present the benefits and constraints of identified systems.
- Outline unintended consequences or risks for systems and how to mitigate issues for key identified systems.
- Analyse the costs of systems including initial installation, lifespan of components, cost for replacement of components, and maintenance costs.

The evidence and evaluation will consider a variety of aspects including ensuring tenant ease of use, comfort, energy efficiency, energy cost for tenant, ease of install and maintenance in terms of time, complexity and money.

Key concerns and areas of interest for the Council which will be explore in this report include:

- Ease of operation for tenants, including requirements for digital technology and skills
- Level of comfort for tenants (temperature, temperature stability)
- Internal air quality – Humidity and CO2
- Ease of installation
- Ease of maintenance / replacement
- Warranties / Guarantees
- Integration with renewables
- Integration with time of use tariffs
- Wi-fi dependency
- Impact of self-disconnection
- Future flexibility and future proofing
- Life cycle costs
- Carbon reductions
- Energy running costs – tenant bills

2.1.3 Policy background

Scotland has over 2.5m occupied dwellings which account for 13% of the country's total greenhouse gas emissions and around 30% of Scotland's total energy consumption.[3] Most of these emissions are generated by heating and hot water, with around 90% of dwellings heated by fossil fuel powered heating systems.[4]

Scotland has a target of reaching net zero emissions by 2045.[5] As set out in the Heat in Buildings Strategy [6], to meet this target almost all buildings need to use a zero-emissions heating system.

In social housing, this target is supported by the proposed Social Housing Net Zero Standard.[1] The standard and its details are not yet confirmed, but the standard is likely to consist of following main components:

- Replacement of polluting heating systems with clean heating.
- Meeting a fabric efficiency rating (measured in $kWh/m^2/year$).
- Ensuring good air quality, through mechanical ventilation with heat recovery or a ventilation and monitoring strategy.

Additionally, the Scottish Government has set statutory targets to reduce levels of fuel poverty to less than 5% and reduce levels of extreme fuel poverty to less than 1% by 2040.[7]

Fuel poverty is defined as when **'more than 10% (20% for extreme fuel poverty) of net income is required to pay for reasonable fuel needs after housing costs have been deducted.'** [8]

Delivering the Scottish Government's climate and fuel poverty targets is challenging, since clean heating systems can lead to an increase in energy bills and increased risks of fuel poverty. This is due to several factors, including the high cost of electricity relative to gas.

The Scottish Government's Heat in Buildings Strategy proposed a 'fabric first' approach, with energy efficiency prioritised as the first step to decarbonising homes, to deliver immediate energy bill reductions and make homes more suitable for zero emissions heating.[9]

2.1.4 Methodology

The report methodology is desktop and research based, gathering together existing research alongside research from focus groups, energy modelling and analysis of Council property information.

The following outlines the steps alongside the report sections:

Heating & Hot Water Systems Scoping

- A technology long list was developed, compiling all potential clean heating and hot water systems to be considered.
- A weighting process, based on literature research and social housing provider concerns, was developed to assess the long list.
- A technology short list was determined, with these technologies to be investigated in further detail in the next section.

Heating & Hot Water Systems Summary Sheets

- Technologies from the short list were investigated in depth using key criteria provided by Fife Council.
- Changeworks carried out focus groups with 2 key groups:
    - Local Authorities and Housing Associations – to understand the social landlord perspective.
    - Consumer Group – to represent and understand the view of tenants.
- Case studies reviews were carried out to check if technologies claims have been achieved in real world scenarios.
- Research reviews using previous research to check against the key concerns and criteria from the Council.
    - These included constraints mapping to check in which properties technologies are the most applicable.
- Risk mitigation identified the key risks when systems are installed, and the steps needed to reduce this risk.

Heating & Hot Water Systems Modelled Impacts & Cost

- Energy modelling was used to quantify the impact on carbon emissions and tenant energy cost.
    - 11 theoretical property types (representing the Council's stock) and 10 heating and hot water systems were modelled in the Passivhaus Planning Package (PHPP).
- Alongside modelling a 'standard' heating pattern and temperature, variations were modelled to test heating a property under and over this pattern, reflecting a range of use patterns.
- Whole lifecycle costs over 30 years were collated and analysed, which include:
    - Initial installation or capital cost
    - Cost for replacement of components – through analysing lifespans of systems components
    - Maintenance costs
- Cost to the Council (whole lifecycle cost) was analysed against cost to the tenant (energy costs).

Heating & Hot Water Systems Analysis

- Using the findings from the above sections, a matrix summarised the key pros and cons of systems.
- Key property types or characteristics which affect the selection of systems was collated.
- This was then visualised with a decision flow chart.
- Key potential systems are identified as potential systems for Fife Council to install within their stock.

Heating & Hot Water Systems in Fife Council's Stock

- Fife Council's existing stock data was collated.
- Existing heating and hot water systems within the stock were analysed, which identifies the scale of clean technology installation.
- Potential constraints to technology selection as included in the data were analysed, to indicate which technologies may be the most appropriate.
- Existing systems within the Council's properties were compared against the identified systems, to identify where installation of systems will be required for further investigation.

Next Project Stage

- This report leads into the next project stage, where findings from this report will be tested with Council properties and tenants.
- Pilot projects have been scoped and identified to allow real world monitoring and analysis of identified systems.
    - Installation plans for heating options in properties allow for a real-world practical evaluation of systems.
- An Impact Evaluation Framework is mapped

out, considering the potential data that can be gathered and what key criteria it can help analyse.

    - This will be rationalise and refined as part of the next stage and as definitive projects are confirmed by the Council.

- Recommendations for Tenant Support are outlined, which Changeworks can help develop as part of installation of technologies.

2.1.5 Organisations involved

Changeworks was appointed by Fife Council for this project, to provide research and analysis on clean heating and hot water systems.

Changeworks is Scotland's leading environmental charity delivering solutions for low-carbon living. A trusted expert with over 35 years' experience, Changeworks is leading the way in delivering high impact solutions for low-carbon living.

Changeworks' vision is for a world where everyone is able to live, work and enjoy life with a low-carbon impact. We recognise climate change is the most significant threat to the environment and our way of life and work for a positive low-carbon reality for everyone, ensuring a just transition for all. Tackling inequalities is core to this mission, working collaboratively with partners, organisations and householders to drive transformation in energy efficiency and fuel poverty.

Changeworks and the Centre for Net Zero High Density Buildings (CeNZ-HighDB)[10] connected at the launch of the Centre. They have partnered with Changeworks and collaborated on the research sections of the report, Sections 3, 4 and 6.

CeNZ-HighDB is a research centre comprises of Thematic Working Groups (I-VI) that support and develop Net Zero solutions for high density buildings and streetscapes. It will test new prototypes and retrofit buildings with low-carbon materials, heating and cooling systems, and energy storage technologies.

A major proportion of the UK's key workers, low-income households and disadvantaged groups live in high density buildings and the Centre's impacts will enable reduced energy costs, substantial carbon emission reductions and accelerate 'inclusive' retrofit delivery for social housing sectors and urban buildings.

Thematic Working Group II[11] aims to review, design, pilot and assess new heating and energy storage technologies, both in terms of technical efficiency and socio-technical appropriateness.

1 Scottish Government (2023) Social housing net zero standard: consultation

2 90% of Fife Council properties classed as Urban under Home Analytics classification

3 Scottish Government. p.12. (2021) Heat in Buildings Strategy

4 Scottish Government (2025) Scottish House Condition Survey

5 Scottish Government (2019) Climate Change (Emissions Reduction Targets) (Scotland) Bill

6 Scottish Government (2021) Heat in Buildings Strategy

7 UK Government Legislation (2019) Fuel Poverty (Targets, Definition and Strategy) (Scotland) Act 2019

8 Scottish Government (date unknown) Fuel poverty - Home energy and fuel poverty

9 Scottish Government, p.15, p.21, p.33. (2021) Heat in Buildings Strategy

10 CeNZ-HighDB (date unknown) The Centre for Net Zero High Density Buildings (CeNZ-HighDB)

11 CeNZ-HighDB (date unknown) Thematic Working Group II - Heating-Cooling and Energy Storage within Buildings

3. HEATING & HOT WATER SYSTEMS SCOPING

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3.1 SECTION SUMMARY

Initial scoping of heating and hot water systems was undertaken to identify available and emerging technologies capable of contributing to the decarbonisation of social housing owned by Fife Council. The identified technologies are applicable to social housing and high-density buildings across Scotland.

From the long list of all technologies, a focussed short list of the most applicable technologies was determined. Each short listed technology is then explored in detail in the next sections through summary sheets.

This section is accompanied by the technology repository. This is a spreadsheet which include and expands upon the technology scoping process, including the technology long list, short list and methodology.

The process of the scoping phase was threefold:

- To identify and categorise a comprehensive set of heating and hot water technologies suitable for retrofit applications in high-density environments. A combined targeted literature search and defined inclusion/exclusion criteria was followed, ensuring relevant and feasible technologies were captured and categorised.
- Technical, economic, and environmental data was gathered from authoritative sources to inform subsequent evaluation stages.
- The most promising clean heating technologies were then identified using Multi-Criteria Decision-Making (MCDM) and Analytic Hierarchy Process (AHP).

3.2 TECHNOLOGIES LONG LIST

A long list was developed to capture both established and emerging systems capable of contributing to low-carbon heat delivery in Scotland's social housing and high-density domestic buildings.

The scope was limited to commercially available heating and hot water technologies for domestic properties in Europe. The long list covers a spectrum of electrical, thermal, and hybrid technologies representing different levels of technological maturity and market readiness.

Technologies were identified through a structured review of recent national and regional studies and datasets, these are listed in the appendix.

Sources were scanned and screened for suitability to low-carbon alternative heating and hot water options for retrofit within 5-10 years depending on technology. Data was extracted using a consistent template and key characteristics were captured and organised into groupings or families for further evaluation. Additional peer-reviewed and industry literature was consulted to ensure coverage of all major technology families currently being piloted or proposed.

3.2.1 Technologies Considered

The long list of clean heating and hot water systems included the following technologies. These are included in the accompanying technology repository:

- Direct acting electric boiler - Electric flow boiler
- Direct acting electric boiler - Electric combi boiler
- Storage electric boiler - Electric system boiler
- Electric boiler - Electric combined primary storage unit (CPSU)
- Electric boiler - Dry core storage boiler
- Electric boiler - Microwave boiler
- Electric immersion - Direct hot water cylinder
- Thermal heat battery
- Electric instantaneous at point of use - Water heater
- High heat retention storage heater (smart)
- Slimline storage heaters
- Conventional / traditional storage heater
- Combination storage heater
- Fan assisted storage heater
- Infrared radiant panels
- Infrared radiant film / wallpaper
- Electric panel heaters - Convector heaters
- Electric radiators - oil, water-filled or ceramic core
- Resistive fan heaters
- Electric underfloor heating
- Electric warm air system
- Air source heat pumps (ASHP) - air to water
- Air source heat pumps (ASHP) - air to air
- Ground source heat pumps (GSHP) - ground to water
- Water source heat pumps (WSHP) - water to water
- Exhaust air source heat pump - air to water
- ∗District heat network for heating
- ∗District heat network for hot water
- ∗District heat network for heating and hot water
- ∗Ambient loop heat network
- Solar thermal water heating system
- Hydrogen boiler (individual)
- Biomass boiler
- Biofuel boiler

* Considered as part of a re-run under a place based approach where heat networks and other community-scale technologies are assessed in their proper context. This provides fairer scoring when technologies are applied at scale (e.g. neighbourhoods, estates, or urban regeneration projects).

To note, under the proposed SHNZS, systems such as biomass are not considered as clean zero direct emissions systems.

3.3 TECHNOLOGIES SHORT LIST PROCESS

The long-list was reduced to a short-list of the most suitable technologies by applying structured decision-making methods: the MCDM and AHP framework. These allow structured evaluation using expert inputs, in this case, those from the project team. These tools used to identify the technologies that have the highest potential for delivering low-carbon, scalable, and cost-effective solutions suitable for integration into social housing and urban contexts. The short-listed technologies, as shown below, were then taken forward to the next stage for more in-depth research.

Table 1: Clean heating and hot water technology short-list

Alternative	Merit Figure
Electric immersion - Direct hot water cylinder	0.79
Electric radiators - oil, water-filled or ceramic core	0.76
Electric panel heaters - Convector heaters	0.75
Air source heat pumps (ASHP) - air to water	0.74
Electric instantaneous at point of use - Water heater	0.73
*District heat network for heating and hot water	0.73
High heat retention storage heater (smart)	0.72
Infrared radiant panels	0.72
Ground source heat pumps (GSHP) - ground to water	0.72
Solar thermal water heating system	0.72

* District heat was considered as part of a re-run under a place-based approach where heat networks and other community-scale technologies are assessed in their proper context. This provides fairer scoring when technologies are applied at scale (e.g., neighbourhoods, estates, or urban regeneration projects).

3.3.1 Overview of the MCDM AHP Method

The AHP framework decomposes a complex decision problem into a hierarchical structure consisting of a primary goal, multiple evaluation criteria, and a set of alternatives. The process is carried out in steps:

Step 1: Define the Decision Problem

In this study, the goal was to identify technologies with the greatest overall suitability for achieving Net Zero heating and hot water provision in buildings.

Step 2: Build the AHP Hierarchy – criterion & alternatives

Seven key criteria were established through expert consultation, literature review, and policy alignment with Scottish and UK decarbonisation targets

Table 2: AHP hierarchy criterion

Criterion	Definition	Weight (W)
User Experience (UE)	How well the technology delivers comfort, convenience, and control for households compared to conventional heating systems	0.21
Energy Efficiency & Running Cost (EERC)	The proportion of input energy converted into useful heat output. High efficiency reduces total energy demand and operational emissions.	0.20
Tech. Maturity (TM)	The level of technological readiness, reliability, and proven performance in real-world or pilot applications (Technology Readiness Level, TRL).	0.17
Scalability (s)	The potential to deploy the technology at scale within all contexts without major technical or logistical constraints.	0.17
Infrastructure Suitability (IS)	The extent of new or upgraded infrastructure (e.g., electrical networks, thermal grids, or water loops) required for successful deployment. The level of technological readiness, reliability, and proven performance in real-world or pilot applications (Technology Readiness Level, TRL).	0.11
Cost Effectiveness (CEf)	The balance between capital, operational, and maintenance costs relative to delivered energy savings and carbon benefits. The extent of new or upgraded infrastructure (e.g., electrical networks, thermal grids, or water loops) required for successful deployment.	0.09
Carbon Emissions (CE)	The direct and indirect greenhouse gas emissions associated with the technology's operation, including fuel source and lifecycle impacts. How well the technology delivers comfort, convenience, and control for households compared to conventional heating systems	0.05

Each criterion was scored against the seven criteria on a 1–9 scale, where 1 = very low performance and 9 = very high performance. This assigned a relative weight (**W**) based on its perceived importance to achieving Net Zero outcomes in dense urban environments.

Criteria were weighted to reflect priorities identified through discussions with Fife Council and insights from previous retrofits.

UE (0.21) and EERC (0.20) received a high weighting because tenant comfort, system affordability and ease of operation are critical for successful adoption in social housing.

TM (0.17) and S (0.17) were strongly weighted due to the Council's need to begin deployment in the near term and for solutions that can be delivered at scale with manageable, mitigatable risk.

IS (0.11) and CEf (0.09) were given moderate weightings to reflect importance of installation and across a diverse housing portfolio.

CE (0.05) were lower weighted, not because these factors are unimportant but due to all the shortlisted technologies being inherently low carbon alternatives already and played a minor role in differentiating technologies.

The alternatives consisted of the long list of technologies, detailed in section 1.2.1.

Step 3: Comparison of Alternatives for Each Criterion

Each technology alternative was scored compared to each criterion. These scores were based on empirical data from published sources, prototype trials, project team judgement. These were then normalised and calculated weights (priority vector) derived.

For consistency and validation, pairwise comparison matrices were developed to verify the internal consistency of criterion weightings[1]. This step checks that the weights given to each criterion make sense and aren't contradictory. By comparing criteria in pairs, the process ensures that judgments are consistent.

Step 4: Compute Global Priorities

The weighted sum method was then applied to calculate an overall score (Merit Figure, MF) for each technology. Refer to the appendix for scoring of the full long list. The resulting Merit Figures provide an objective ranking of all technologies against the chosen criteria. This process ensures that technology selection is reproducible, data-driven, and aligned with both scientific and policy priorities for low-carbon transition in urban environments. A cut off point equal to or above 0.72 was selected and technologies scoring at or above this were taken forward to form the short list.

Those with the highest scores formed the shortlist for further technical, economic, and feasibility analysis.

3.3.2 Analysis of technology short list

The shortlisted technologies were grouped to simplify the carrying out and reporting of more in-depth research.

1 The Consistency Ratio (CR) was calculated to ensure logical coherence in judgements. A (CR < 0.10) indicates acceptable consistency and a score of CR = 0.08 was achieved.

- ➢ **High heat-retention storage heaters (smart) (Ref 4.1)**
  - High heat retention storage heater (smart) and load-shifting capability for space heating
- ➢ **Electric immersion and electric instantaneous point-of-use (Ref 4.2)**
  - Electric immersion hot-water cylinders
  - Electric instantaneous water heaters installed at point of use
- ➢ **Air Source Heat Pumps (ASHP) – air-to-water (Ref 4.3)**
  - Monobloc and split-system air-to-water heat pumps providing both heating and hot water
- ➢ **Ground Source Heat Pumps (GSHP) – ground-to-water (Ref 4.4)**
  - Vertical borehole and horizontal loop GSHP systems supplying space heating and hot water
- ➢ **Infrared radiant panels (Ref 4.5)**
  - Wall- or ceiling-mounted Infrared radiant panels designed for radiant space heating
- ➢ ***District heating networks (Ref 4.6)**
  - *Heat supplied via a centralised low- or medium-temperature district energy network providing both heating and hot water
- ➢ **Solar thermal hot-water systems (Ref 4.7)**
  - Roof-mounted solar collectors with hot-water cylinders for domestic hot-water production
- ➢ **Electric radiators and electric panel heaters (Ref 4.8)**
  - Oil-filled, water-filled, or ceramic-core electric radiators for space heating
  - Electric panel heaters, including convector-type heaters for space heating

4. HEATING & HOT WATER SYSTEMS SUMMARY SHEETS

CeNZ-HighDB

CHANGEWORKS.

4.1 HIGH HEAT RETENTION (HHR) STORAGE HEATERS

4.1.1 Technology Summary

Storage heaters are designed to benefit from cheaper off-peak electricity prices by storing energy during the off-peak hours and releasing heat gradually during the day. In high heat retention heaters, heat is stored in a high-density thermal storage material made of ceramic or clay bricks which can retain heat for longer than a conventional model. Stored heat is then released based on temperature and time settings with adaptive learning. If stored heat runs out, the boost function can provide instant heat at the current electricity rate.

Warranty : 2 years standard (10 extended)

Main Manufacturers : Dimplex, Creda, Elnur, Fischer, VentAxia[1]

Control Options : Compatible with 'Dimplex Control' smart control app (required Dimplex hub and wifi)

4.1.2 Findings Summary

Pros

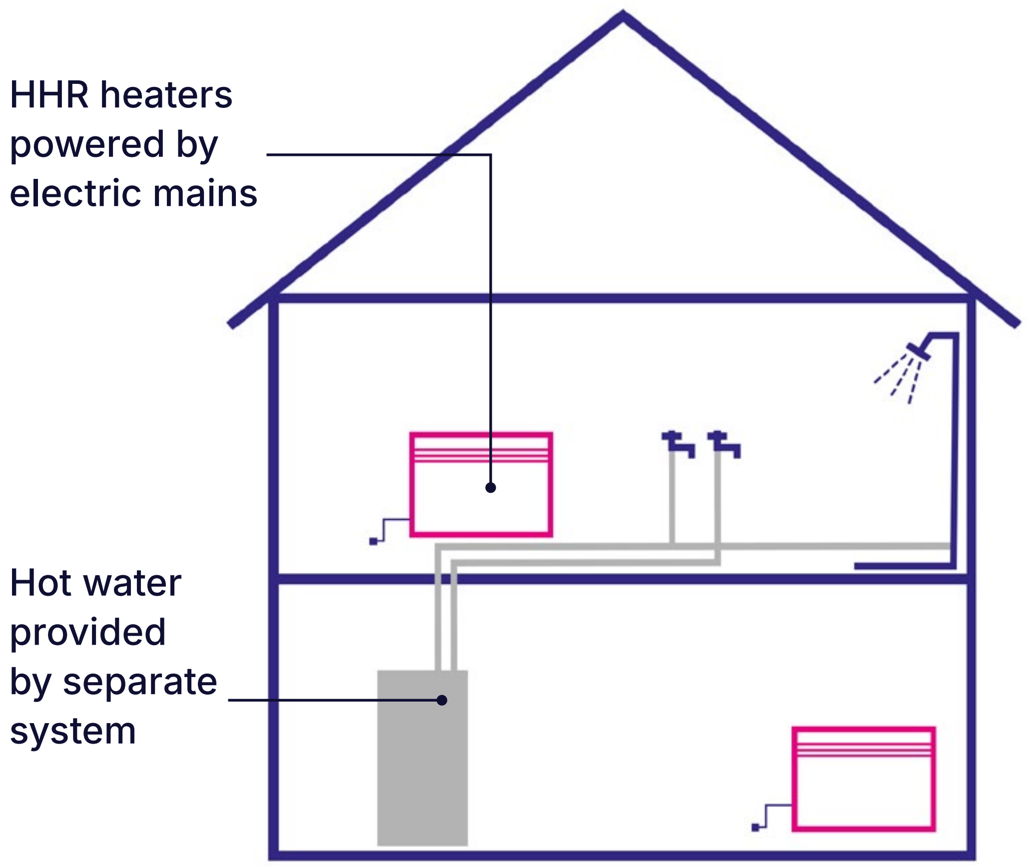
- Widely used and documented
- Long established technology
- Opportunity to benefit from lower off-peak rates
- Off-peak usage can help balance the grid
- Adaptive technology can learn usage patterns and adjust heat delivery accordingly
- Comparatively low capital cost
- Minimal installation disruption
- Low maintenance

Cons

- High unit cost of electricity can increase bills when compared to gas (current night unit rate of electricity 14p and gas 6p)
- Tariff issues (delays in switching tariffs and use of standard tariffs will increase cost)
- Timer settings must be used to store energy during off-peak hours. If the manual setting is used, no nighttime charge will occur
- May not suit residents with irregular routines
- Reliance on digital controls

4.1.3 Focus Group Findings

- Damp and mould due to underheating
- Storage heaters seen as contributory risk to fuel poverty
- Tenants struggle with timing, tariffs and settings
- Incorrect tariff set up leading to high bills



4.1.4 Main Findings

Suitability

Complimentary Technology: Heating systems can be used with a voltage power optimiser, however a NEA trial found that this technology did not provide the anticipated 10% reduction in energy use.[2] Systems can also be combined with PV panels and battery storage to increase efficiency.

Insulation and airtightness: Poorly insulated, draughty homes will experience higher increases in bills when switching to electricity from gas.[3] Improvements in fabric are crucial to reducing heat demand and offsetting energy cost increases.[4]

Heat demand: Properties with a space heating demand of >150kWh/m^2/y are deemed unsuitable, as high heat demand on cold days may trigger the fuse limit. Load increases of over 100A may also require a three-phase connection with significant associated cost.[3]

Grid Suitability: Increase in electric heating may place burden on electricity distribution network.

Tenant Experience

Running Costs: Dimplex claim to be able to reduce running costs by 27% compared to a standard storage heater system.[5] However, case study findings vary, with some seeing increases in running costs.[2]

Tariff Issues: Difficulties in changing tariff and smart meter installation (switching from a standard to off-peak tariff requires new smart meter). Issues have also been seen with tariffs being incorrectly read by suppliers, resulting in incorrect billing.[1]

Ease of Use: Conflicting information exists regarding ease of use. Dimplex claim simplicity of use, however a trial by NEA found that more advice was needed to help residents control their new heating system.[2]

Landlord Experience

Installation: Simple installation.[3] Can be combined with rewiring programmes.

Maintenance: Low maintenance, with fewer servicing requirements than heat pumps.

Training Available: Toolbox talk available from Dimplex.

4.1.5 Gaps and Limitations

Limited peer-reviewed evidence. Most case study information is from main manufacturer, Dimplex.

4.1.6 Future Development

Whilst HHR storage heaters are currently designed to work with off-peak tariffs, the technology can also be used with flexible tariffs to align with renewable energy availability.[6] HHR also offers potential in buffering the grid and being able to store excess energy generation at times of high supply.[1]

1 Element Energy (2019) Electric heating options in off gas grid homes
2 National Energy Action (2017) CP 744 Technical Evaluation Report: Dimplex storage heaters with water heaters and voltage optimisation
3 Scottish Government (2020) Technical Feasibility of Low Carbon Heating in Domestic Buildings
4 Energy Saving Trust (date unknown) Electric Heating
5 Dimplex (date unknown) Guiness Homes Warm to Dimplex Quantum
6 Centrica (2022) Centrica and Glen Dimplex to run UK's largest trial of domestic smart storage heaters

4.1.7 Risk Matrix

Stage	Risk	Risk Mitigation
Design	Incompatible tariff (no Economy 7/10)	Tariff review; smart metering
	Undersized units or poor layout coverage	Room-by-room heat loss calcs
Installation / Commissioning	Poor connection to time-controlled circuit	Commissioning checklist; test charging cycle
	Faulty thermostat or sensor	Quality checks; certified equipment
Use	Tenant fails to program correctly → high cost	On-site demonstration; simple controls
	Confusion about pre-charge periods	Printed/visual guide, remote assist

Case Study 1 Vale of Aylesbury Housing Trust Sets Decent Homes Standard with Dimplex Quantum; Dimplex, 2017	**Case Study 2** CP 744 Technical Evaluation Report: Dimplex storage heaters with water heaters and voltage optimisation; Nottingham Community Housing Association and National Energy Action, 2017	**Case Study 3** South Kesteven Council, 1 Eastcliffe Square; Dimplex, 2025
• Quantum HHR storage heaters • 10-year warranty on storage heaters • 47% cheaper to run than electric convector or radiator system • Positive feedback from tenants	• 51 households assisted, 11 monitored: Quantum HHR storage heaters with water heaters and voltage optimisers • Fewer residents used supplementary hearing and had to wear extra warm clothes • Improvements in residents' satisfaction with running costs, but no improvement in level of satisfaction with ease of use of the system • Slight increase (4%) in residents' energy bills	• One property; Quantum HHR storage heaters with Edel hot water heat pumps • Dual wiring for off-peak tariffs • Energy savings up to £48 per month

4.2 ELECTRIC WATER HEATERS

4.2.1 Technology Summary

Electric water heaters heat water directly using electric elements to provide domestic hot water or in some cases space heating. They can either be centralised systems (storage tanks with immersion heaters/separate boilers or instantaneous systems such as electric combi boilers), or decentralised point-of-use.

Systems include:

- **Point-of-use –** Individual units positioned at hot water outlets which provide instant hot water.
- **Centralised Instantaneous System –** Water is heated instantaneously within a centralised unit (e.g. electric flow boilers). Storage may also be provided (via a hot water cylinder).
- **Centralised Storage System –** Immersion element heats water which is stored within an insulated tank.

Warranty : Point-of-use – 2-5 years   Electric Boiler – 2 years (5 years extended)   Cylinder with immersion heater - 25 years

4.2.2 Findings Summary

Pros

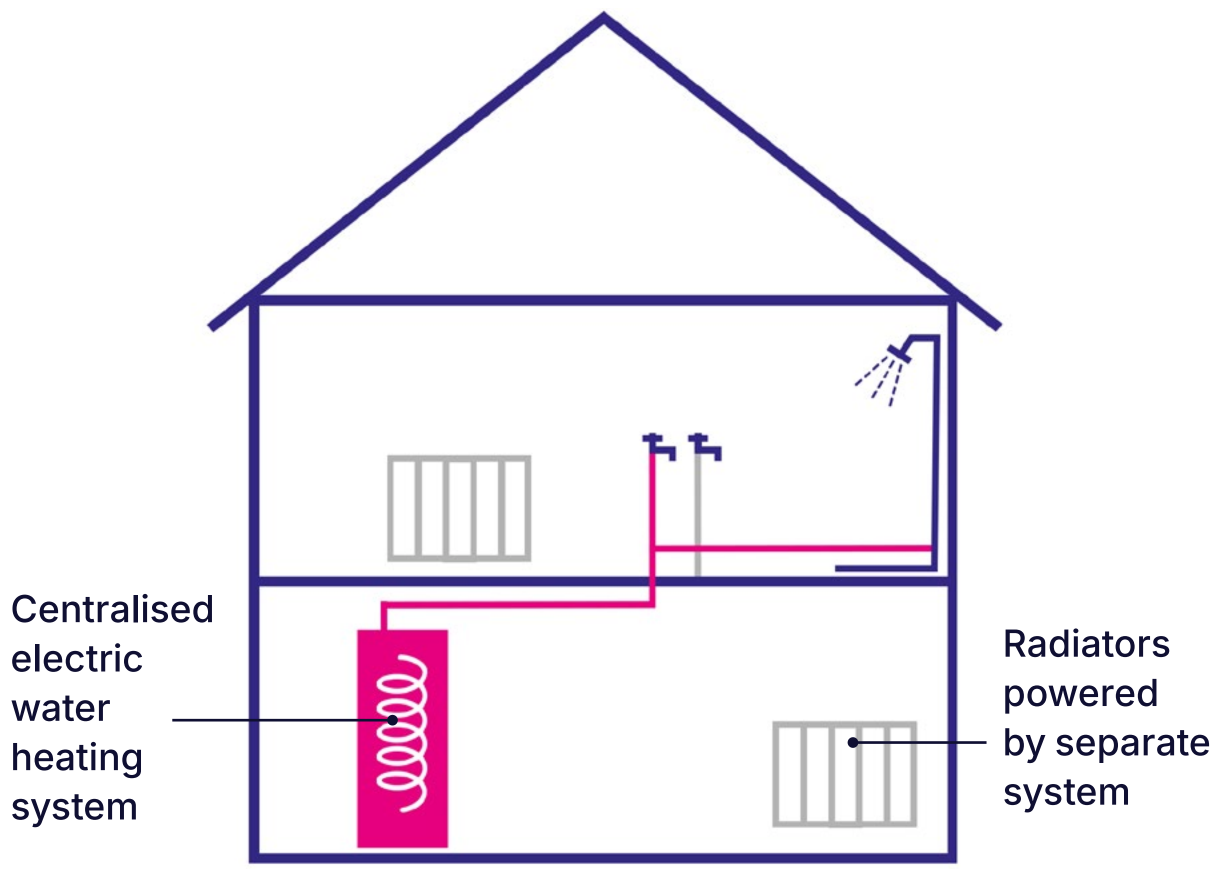
- Simple, longstanding technology
- Easy installation and maintenance
- Similar controls to a conventional gas boiler
- Instantaneous delivery of heat with point-of-use and centralised instantaneous systems
- Ability to benefit from off-peak rates if storage is provided

Cons

- Low efficiency of these systems (1:1 conversion of electricity to heat) and high unit cost of electricity often makes systems more expensive than gas or ASHP options, especially when providing heating
- Centralised storage systems require storage space within property

4.2.3 Focus Group Findings

- Direct electric boilers deemed too costly to run under current electricity unit rate
- Issues with accessing dual tariffs and therefore benefiting from cheaper off-peak rates
- Incorrect usage / set up leading to lack of benefit from cheaper off-peak rates



4.2.4 Main Findings

Suitability

Dual Immersion Heater: Two immersion heaters required to benefit from off-peak rates.

Space Requirements: Storage systems require space for hot water storage tank. Storage space can be reduced by using a smaller thermal store (for example a thermal battery).

Tenant Experience

Behaviour change: Effective use of system during off-peak times requires behaviour change.[1] Issues where occupants turn off system which may impact utilisation and recovery.[2] Some systems require behavioural adaptation (e.g., staggering showers, managing simultaneous usage) to maintain comfort.[3]

Programming: Complexity of programming may discourage some users, reducing efficiency if systems are not understood.[1]

Comfort: Reports of stable hot water supply with correctly sized systems however instantaneous heaters may limit flow rate and comfort due to temperature regulation mechanisms.[3]

Tariff Issues: High bills when systems used during peak times.[1]

Monitors: Real-time monitoring allows optimisation for off-peak energy use.[1]

Running Costs: Costs significantly more than a heat pump producing hot water, due to the UK's historically high electricity-to-gas price ratio. However, smart control and off-peak operation can reduce running costs.[4]

Self-disconnection: Self-disconnection (when the heater automatically shuts off either due to a built in safety mechanism or system fault) leads to the immediate loss of hot water.[2]

Maintenance: Requires monthly pressure checks and management.

Landlord Experience

Ease of installation – widely used technology with simple installation and readily available skills.

Maintenance – low maintenance (annual maintenance required including visual inspection and tank flush).

Low unit cost (point of use heaters).

Self-disconnection: Self-disconnection may require professional reset or repair.[2]

4.2.4 Gaps and Limitations

Although immersion and direct electric systems are well-established technologies, there is a lack of lifecycle and embodied carbon data.

Case studies of electric domestic hot water (DHW) retrofits are sparse.

Gap in understanding resident behaviours with electric water heating systems, particularly in households with dual-tariff or pre-payment meters.

Very limited research has been done to date on hot water tanks and there have been limited technological improvements beyond insulation.[2]

4.2.5 Future Development

Opportunity for integration with smart controls designed to integrate with ToU tariffs.[5]

New boiler designs, for example Mixenergy boiler, enable more efficient water heating and improved information displays.[5]

Hot water can also be stored with a Sunamp thermal battery.

1 BEIS (2019) Evidence gathering for electric heating options in off gas grid homes
2 SSEN (2020) An Electric Heat Pathway : Looking Beyond Heat Pumps
3 Big Blue Plumbing (date unknown) How do Instantaneous Water Heaters Work?
4 House of Commons Library (2025) Gas and electricity prices during the 'energy crisis' and beyond
5 EPC Works (date unknown) Water Heating

4.2.6 Risks Matrix

Electric Immersion / Direct Hot Water Cylinder

Stage	Risk	Risk Mitigation
Design	Poor fabric leads to high energy use: oversized cylinders increase standing loss	Fabric upgrade; right-size cylinder; pipe insulation
	Fuse limit reached when combined with electric space heating	Pre-install electrical load assessment
Installation / Commissioning	Incorrect wiring or lack of RCD protection	Certified electricians; compliance checks
	Poor thermostat positioning or control setup	Test operation; calibrated thermostats
Use	Tenants leaving immersion on continuously	Timer & thermostat; user training
	Legionella risk from low storage temperatures	Maintain ≥60°C storage temp; annual check

Electric Instantaneous (Point-of-Use) Water Heater

Stage	Risk	Risk Mitigation
Design	Insufficient flow for multi-point use	Correct system selection
	High electrical demand near fuse limit	Load check; diversify supply
Installation / Commissioning	Incorrect pipework, earth bonding issues	Use competent installers; pre-checks
	No flow restrictor leading to overload	Fit flow restrictors
Use	Scalding from high output temperatures	Thermostatic mixing valves
	Users unaware of short duration limits	Tenant education materials

Case Study 1 National Energy Action, Evaluating solar PV with electric heating; Mixergy cylinders, 2025	Case Study 2 Tackling fuel poverty in Mid-Wales with Mixergy and solar PV; Mixergy, 2022	Case Study 3 CP 744 Technical Evaluation Report: Dimplex storage heaters with water heaters and voltage optimisation; Nottingham Community Housing Association and National Energy Action, 2017
• North Devon Homes (RSL) installed 11 electric hot water cylinders with solar PV diverters • Costs ranged from £2,700 for direct cylinder and solar diverter, to £3,300 for those also incorporating a heat pump interface with an ASHP • Cylinders provided improvements to EPC energy scores of 2 to 7 points • Positive responses regarding costs and energy savings from households, although there were issues with ease of use and understanding of controls	• Smart hot water cylinders and solar PV installed in 15 new-build flats and 23 existing homes • Tenants reportedly seeing savings on water heating bills of over 30% • Remote diagnostics function means that the housing association can identify faults remotely	• 51 households assisted, 11 monitored: Quantum HHR storage heaters with water heaters and voltage optimisers • Fewer residents used supplementary heating • Improvements in residents' satisfaction with running costs, but no improvement in level of satisfaction with ease of use of the system • Slight increase in residents' energy bills

4.3 ASHP (AIR TO WATER)

4.3.1 Technology Summary

Air Source Heat Pumps (ASHPs) are electrically powered systems which extract heat from the external air through compression. In air-to-water systems, heat is transferred to water, which can be distributed around the home through a wet central heating system with hot water for domestic uses stored in a cylinder. Heat pumps work differently to conventional boilers, as their efficiency increases as the output temperature decreases (e.g. they are most efficient providing flow temperatures of 35C to 55C). This means that radiators may need upgrading and constant rather than intermittent operation, since heating a home from a low temperature (e.g. if allowed to cool overnight) requires higher, less efficient, output temperatures.

Warranty : Mitsubishi - 3 years standard (7 years extended) | Daikin – 1 year standard (5 years extended) | Valliant – 2 years standard (7 years extended) | Efficiency : SCOP – 3.01-5.03

4.3.2 Findings Summary

Pros

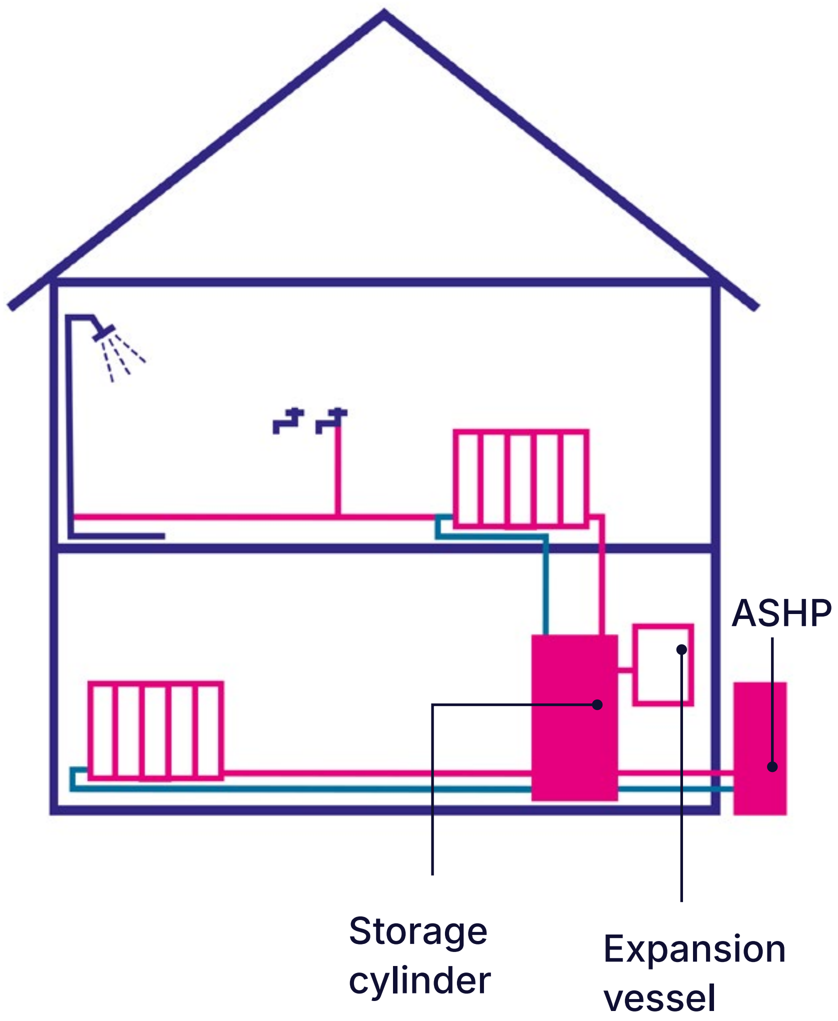
- Widely used and documented with skills becoming increasingly widespread with growing uptake
- Most ASHP components can be situated outside, reducing requirement for indoor space, although a cylinder is still required for hot water storage.
- Efficiency - if designed, installed and operated properly, heat pumps are the most efficient clean heating system available thus reducing running costs and carbon emissions

Cons

- Install process can be disruptive if new radiators and pipework are required
- Higher CAPEX cost than other forms of electric heating and conventional gas boilers
- Complexity of operating can result in sub-optimal performance and higher costs
- Performance has been found, in some cases, to be lower than manufacturer efficiency claims
- Performance has been found to drop in cold weather[1]

4.3.3 Focus Group Findings

- Performance issues attributed to poor property insulation
- Incorrect metering and tariffs increasing bills
- Complex controls confusing tenants and staff and leading to misuse and inefficiency
- Instances of tenants turning systems off due to perceived high cost or distrust
- Need for early education, engagement, and aftercare to build confidence
- High risk of fuel poverty without correct setup and property upgrades
- Tenant perspective of system being imposed rather than beneficial
- Installer quality and staff training inconsistent across councils



4.3.4 Main Findings

Suitability

External Factors: R290 refrigerant heat pumps should be sited away from drains or enclosed areas due to risks of leaks. Heat pump should be accessible for maintenance and sited with manufacturer clearance zone requirements. Must be 1m from boundary if installed under permitted development rights. Coastal protection models are required if installed near to the coast.

Internal Space Requirements: Requires space for storage cylinder which can be larger than previous cylinder if using a low-temp system.

Heating System: New pipework and larger radiators may be required. Insulation of pipes and storage cylinders will increase effectiveness of ASHPs.

Fabric Efficiency: The fabric efficiency requirements for an ASHP are debated.[2] Some sources cite fabric efficiency is critical to effective (and affordable) heat pump use.[3] For example, the Scottish Government claims that heat pumps installed in dwellings with a peak heat demand of above 150W/m^2 are at risk of not being able to meet thermal comfort and will reduce energy performance.[4] However, others claim that insulation is not essential since primary factors affecting a heat pump's efficiency are system design and adequately sized radiators.[5] Regardless, increasing fabric efficiency will reduce operational cost as less energy is required to heat the space.

Noise: ASHP noise may be disruptive[6] if models are not performing as per manufacturer claims, or if noise from multiple heat pumps is considered cumulatively.

Network Suitability: Electricity network costs were not found to be a significant influence in decision making, however large increases in electrical load (e.g. connection of many units in a location) may require distribution network upgrades.[6] Network operators must be notified of installations, and in some cases applications and any required upgrade works can cause delays.[7,8]

Tenant Experience

Lack of confidence: Evidence that performance could be increased by increasing confidence amongst consumers and supply chain.[9]

Occupant Satisfaction: Multiple reviews finding high degree of consumer satisfaction.[9, 7]

Running Costs: Whilst CXC find that monitored running costs of ASHPs were cheaper than previous electric, oil or LPG heating systems[9], other reviews evidence tenant complaints over running cost increases.[10] Findings of one review found that running costs may increase due to properties being heated more.[11] Incorrect sizing and system design may also increase running costs.[12]

Efficiency: Whilst manufacturers state that SCOPs[13] (test performance) of between 3-5, one study of actual performance across the UK found the average SPF (measured performance) to be 2.71.[14] Performance has also been found to decrease with external temperature.This highlights the importance of correct design, installation and operation to achieve highly efficient systems.

Behavioural Change: User behaviour is commonly cited as a major factor in the successful deployment of heat pumps[15], with incorrect usage often contributing to lower efficiencies and higher energy bills. When comparing user groups, lower efficiencies were seen with social housing residents with intermittent heat pump use (turning heat pumps off and on) cited as the main issue.[1]

Disruption: installation can be disruptive especially if new radiators and pipework is required.

User Information: Clear information critical to successful installation and use[16], alongside well delivered and consistent guidance. However, difficulties may arise due to inconsistencies found in system operation information.[17]

Landlord Experience

Lack of confidence: Evidence that performance could be increased by increasing confidence amongst supply chain.[9]

Cost: Low CAPEX however wide range in costs observed.[10] Opportunity to benefit from economies of scale with multiple installs.

Maintenance: Increased maintenance costs due to incorrect usage and lack of resident information.[15]

Financing: Whilst multiple finance options are available (including finance only, financing lease, subscription and heat as service), there are a lack of heat pump finance offerings currently available in Scotland.

Skills: May be issues finding suitable and skilled local installers.

4.3.5 Additional Points

Demand Side Flexibility: Heat pumps have a role in demand side flexibility, as they can adjust operation in relation to electricity availability.

4.3.6 Gaps and Limitations

Behavioural Factors: Future investigation into the variables relating to the user from a behavioural perspective to better understand how behavioural factors influence transition to heat pumps.

Measured Performance: Need for further research into real-life measured performance of heat pumps retrofitted to social housing with the specific aim of understanding how to ensure that optimal design, installation and operation can achieve higher efficiencies.

4.3.7 Future Development

Heat pumps offer growing potential for compatibility with smart grids with flexible tariffs. This enables users to benefit from cheaper electricity rates and shift demand based on grid capacity.

Future development (and access to) financial options such as financing lease, subscription and heat as service will increase viability of heat pumps and lower financial barriers to uptake.[11]

1 Energy Systems Catapult (2023) Heat pumps shown to be three times more efficient than gas boilers
2 CXC (2024) The suitability of clean heating options for challenging dwelling types
3 Scottish Government (2023) Social housing net zero standard consultation
4 Scottish Government (2020) Low carbon heating in domestic buildings - technical feasibility: report
5 Nesta (2024) Insulation impact : how much do UK houses really need?
6 Scottish Government (2021) Renewable and zero emissions heating systems in affordable housing projects: evaluation
7 Energy Systems Catapult (2024) Electrification of Heat Demonstration Project
8 LCP Delta (2022) BEIS Electrification of Heat Demonstrator Project - Home Surveys and Install Reports
9 CXC (2021) Heat pump use in Scotland – an evidence review
10 Scottish Government (2021) Renewable and zero emissions heating systems in affordable housing projects
11 Jager, LA. (2025) Household heat pump adoption and user behaviours: a systematic review of drivers and barriers
12 Ahmad, S. (2023) Motivations and barriers associated with adopting domestic heat pumps in the UK
13 Average efficiency over an entire heating season, accounting for varying outdoor temperatures and real-world conditions
14 Meek, C. (2022) Heat Pumps: lessons learnt from an Ofgem dataset
15 UK Government (2019) What are the barriers to retrofit in social housing
16 Moore, N. (2015) Improving the installation of renewable heating technology in UK social housing properties through user centered design
17 CXC (2023) The experiences of early adopters of zero direct emissions heating systems in Scotland

4.3.8 Risks Matrix

Stage	Risk	Risk Mitigation
Design	Undersized unit leads to poor SCOP	Proper sizing via (Heat Load Calculator) MCS calc
	High fabric heat loss	Insulate before install
Installation / Commissioning	Incorrect refrigerant charge or flow rate	Certified installer; full commissioning
	Noise nuisance to neighbours	Acoustic screen: siting checks
Use	Tenants misusing settings or switching to resistive mode	Tenant support & smart control
	High bills from tariff mismatch	Set smart tariff; monitor usage

Case Study 1 North Lanarkshire Council, Lorne Gardens; Climatexchange, 2024	**Case Study 2** Hebridean Housing Partnership, Climatexchange, 2024	**Case Study 3** Rural Stirling Housing Association, Climatexchange, 2024
• Installation of ASHPs in 20 1970s bungalows, mainly in response to costs of running electric wet systems • Positive feedback from tenants, including some reporting reduced energy use and lower bills • One challenge identified was that some tenants did not understand how to operate the new systems	• ASHPs installed in 102 social housing properties; a mixture of bungalows, houses and flats, built between 1971 and 2008 • Most properties saw a slightly increased EPC rating • Very high tenant satisfaction reported, with anecdotal evidence that indicates energy consumption and fuel costs have decreased	• 41 time-framed cottage flats and terraced properties • Older storage heaters replaced with ASHPs, as well as solar PV and electric battery storage • The average energy efficiency rating moved from band D to band B after installation • Indoor temperatures increased after installation, however humidity levels also did

4.4 GSHP

4.4.1 Technology Summary

Ground Source Heat Pumps (GSHPs) work by extracting heat from the ground. Systems collect heat through underground pipes either via a vertical borehole or horizontal trench system. An electric heat pump upgrades this heat before transferring it to a wet central heating system where it can be circulated around the home or stored in a hot water cylinder.

Warranty : Kensa – Controller and water pumps 2 years
Core heat pump 5 years

Efficiency : SCOP (35°C) – 3.45 - 5.3
SCOP (55°C) – 2.97 – 3

4.4.2 Findings Summary

Pros

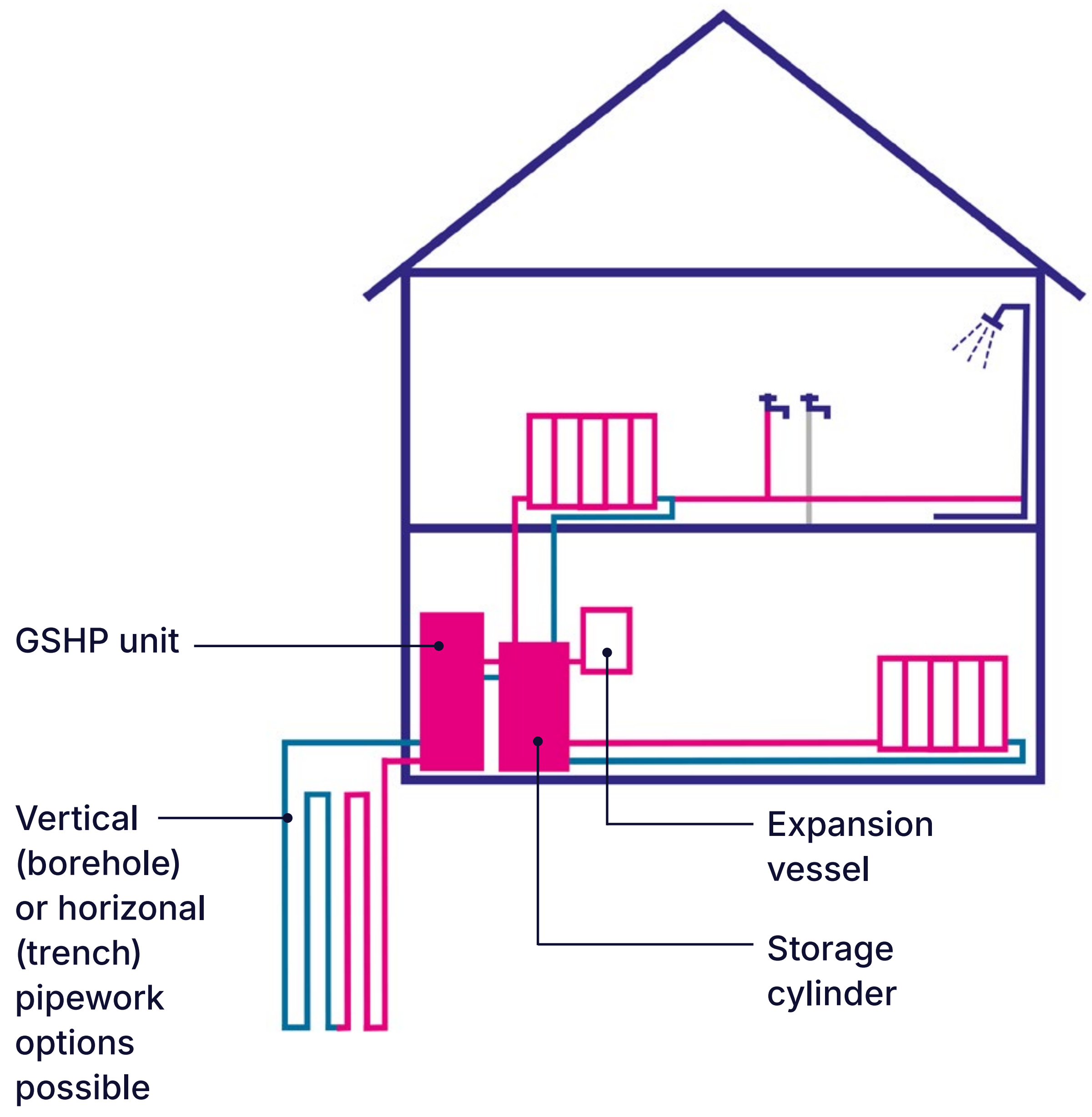
- Low operational costs
- Ease of maintenance
- Long lifespan

Cons

- External space requirements for trenches/boreholes can be onerous and not suited to every site
- Internal space impacts of equipment
- High upfront capital cost, largely due to groundworks. These could be reduced by sharing infrastructure (e.g. small-scale heat networks)

4.4.3 Focus Group Findings

- High capital cost
- Complex land ownership challenges
- High potential for shared ground loops (both for high rise retrofit and village scale developments) but challenges experienced in implementation
- Exploring potential for mine-water heat



4.4.4 Main Findings

Suitability

External Space Requirements: Requires external space for horizontal trenches or vertical boreholes alongside clearance and access for groundwork machinery. Large properties may require multiple boreholes. Roots and sloping ground may present challenges.[1]

Permits and Permission: Whilst most boreholes fall under permitted development, some locations may need planning permission which can add time and cost.[2] An environment agency permit or abstraction license may also be required.

Site Survey: Site survey required to confirm suitability.[3] Existing services may prevent development or require relocation.

Site Requirements: Soil composition may prevent installation.[4]

Internal Space Requirements: Requires space for internal heat pump, roughly the size of a gas boiler (no external unit) and hot water tank. GSHPs can however be combined with heat batteries, to reduce internal space requirements.[2] Alternatively, an external unit (with weatherproof enclosure) may be used.[5]

Electricity Connection: Larger properties may require three-phase electricity supply which can be a complicated and expensive process.[6]

Fabric Efficiency: Increased fabric efficiency optimises performance[2], but is not a requirement for installation.[7] Design heat losses of the home should not exceed the heating capacity of the heat pump.

Tenant Experience

High satisfaction: Tenants 'overwhelmingly' satisfied with increased comfort reported.[2]

Lowest Running Costs: Lowest operational cost of all major clean heating technologies [1] (observed running costs 66% lower than storage heaters[2] and 15% lower than ASHPs[1]).

Efficiency: Provide around 3–4 times the amount of heat than the electricity they use.[8] Real world performance (average SPF) found to be 3.07, with average manufacturer performance (SCOP) at 3.6.[9]

Noise: Low noise / less noise than ASHP.[2]

Behaviour Change: As per ASHPs, instances of reluctance to adjust heating schedule to accommodate lower flow temperatures.

Guidance and Controls: Confusion over controls observed[2], with poor guidance often a source of dissatisfaction.[10] Conversely, examples of clear guidance not influencing behaviour change.[2]

Disruption: Approximately 2-5 days disruption.[8] Drilling may be disruptive, especially if in garden space.[6] Reports of 'acceptable level' of disruption for occupied homes through careful management and good communication.[5] Internal disruption if new pipework and radiators are required.

Service Charge: For shared systems, residents may be required to pay an annual service charge (example of £25 a month service charge for Kensa systems).[11]

Internal Changes: Tenants need to be informed about internal changes, including size and placement of heat pump and loss of storage space.[12]

Seasonal Variation: Whilst research states that GSHPs are more efficient than ASHPs in winter[2], reduced performance in winter was observed.[13]

Landlord Experience

Low Maintenance: Low operational and maintenance costs (inspection every 5 years).[1]

Cost: High CAPEX can deter landlords (examples of costs over double that of ASHPs[1]), however shared systems can significantly reduce costs. Boreholes more expensive than surface loop. Cost variability depending on site specific factors.

Installation Time: Groundworks add to installation time. Example of 84 days total installation for 16 flats.[6]

Maintenance: Low maintenance burden.[1]

Installer Skills: Need for skilled drilling contractors can add procurement complexity. Skills gap exists in design and installation.[2]

Lifespan: Long lifespan of over 50 years.[8]

Tenant Information: Review recommends that tenant information consists of; hard copies, face-to-face demonstrations on commission, and clear routes for accessing further assistance.[2]

Procurement: Issues found with procurement of drilling works, including high contingencies and co-ordination of works packages.[5]

4.4.5 Gaps and Limitations

- Shared-loop GSHPs are under researched with a clear need for policy, financial and technical analysis.[2]
- Limited field demonstrations with diverse building types due to a focus on new build. Need for more investigations into occupancy and lifecycle costs.[4]
- As per ASHPs, limited behavioural research on tenant adaption and operation.

4.4.6 Future Development

Ongoing investigation into effect on groundwater temperature with the Environmental Agency. Future restrictions may be placed on areas deemed at risk from groundwater temperature changes.[14]

1 Scottish Government (2021) Renewable and zero emissions heating systems in affordable housing projects: evaluation

2 Brown, Hampton and Fawcett (2024) Accelerating renewable heat: Overcoming barriers to shared-loop ground source heat pump systems in the United Kingdom

3 Energy Saving Trust (date unknown) GSHP's

4 CXC (2024) Social housing decarbonisation case studies : summary report

5 Penwith Housing Association (2007) Installation of ground source heat pumps in social housing homes Chy An Gweal, Penzance, Cornwall

6 LCP Delta (2022) BEIS Electrification of Heat Demonstrator Project - Home Surveys and Install Reports

7 Nesta (2024) Insulation impact: how much do UK houses really need?

8 Nesta (2025) Domestic heating technology options – GSHP (individual)

9 Meek, C. (2021) Heat pumps: lessons from an Ofgem dataset

10 Tewari, S. (2025) Integration of Heat Pumps in Social Housing—Role of User Behaviour and User Satisfaction

11 Nesta (2023) Kensa's Heat in the Streets

12 Moore, N. (2015) Improving the installation of renewable heating technology in UK social housing properties through user centred design

13 Stafford, A. (2012) Predicting in situ heat pump performance: An investigation into a single ground-source heat pump system in the context of 10 similar systems

14 Environment Agency (2024) Environmental impacts of temperature changes from ground source heating and cooling systems

4.4.7 Risk Matrix

Stage	Risk	Risk Mitigation
Design	Ground not suitable for boreholes	Ground survey: feasibility
	High capital cost	Shared loops; grant funding
Installation / Commissioning	Borehole drilling disruption	Communication; phase install
	Loop contamination or leaks	Pressure testing; commissioning
Use	Tenants unaware of low flow temp behaviour	Training and monitoring

Case Study 1 Hanover Housing Association, Kensa, 2016	**Case Study 2** Chadwell Sr Mary's, Thurrock Council, Kensa, 2023	**Case Study 3** Installation of ground source heat pumps in social housing homes Chy An Gweal, Penzance, Cornwall, European Commission, 2007
• 23 GSHP systems (shoebox 6kW heat pumps) fitted, with unvented hot water cylinders, using 12 communal boreholes • 40-year life span of GSHPs • There are no components for the HA to manage as they are all individually controlled by residents • Average annual energy bill saving of £350 per household	• Shared GSHPs for 273 flats, including three high-rise blocks, using 109 boreholes • 70% reduction in carbon emissions • Heating was three times more energy-efficient than residents' old night storage heaters, reducing heating and hot water bills by up to 66%	• First project involving GSHPs in social housing the UK, involving 14 bungalows • Heat distribution inside the homes with high water content radiators • Heat pumps were to be installed in small purpose-built enclosures outside homes to avoid loss of internal space

4.5 INFRARED HEATING

4.5.1 Technology Summary

Rather than heating the air as with traditional heating, infrared heating uses radiant heat waves to warm objects and people. Heat is absorbed within objects to provide thermal mass, which can gradually release heat back into the space. In theory, air temperatures (and therefore energy use) can be lower than for convective heating (e.g radiators) since the perceived heat and comfort can be high, even if the air temperature is low. However, this will depend on individuals' preferences.

Main manufactures : Herschel, Ecostrad, Kiasa, Ambion, Wondrwall

Life Expectancy: >100,000 hours (Wondrwall)

Warranty – 5-10 years (Herschel), 2 years (Ambion)

4.5.2 Findings Summary

Pros

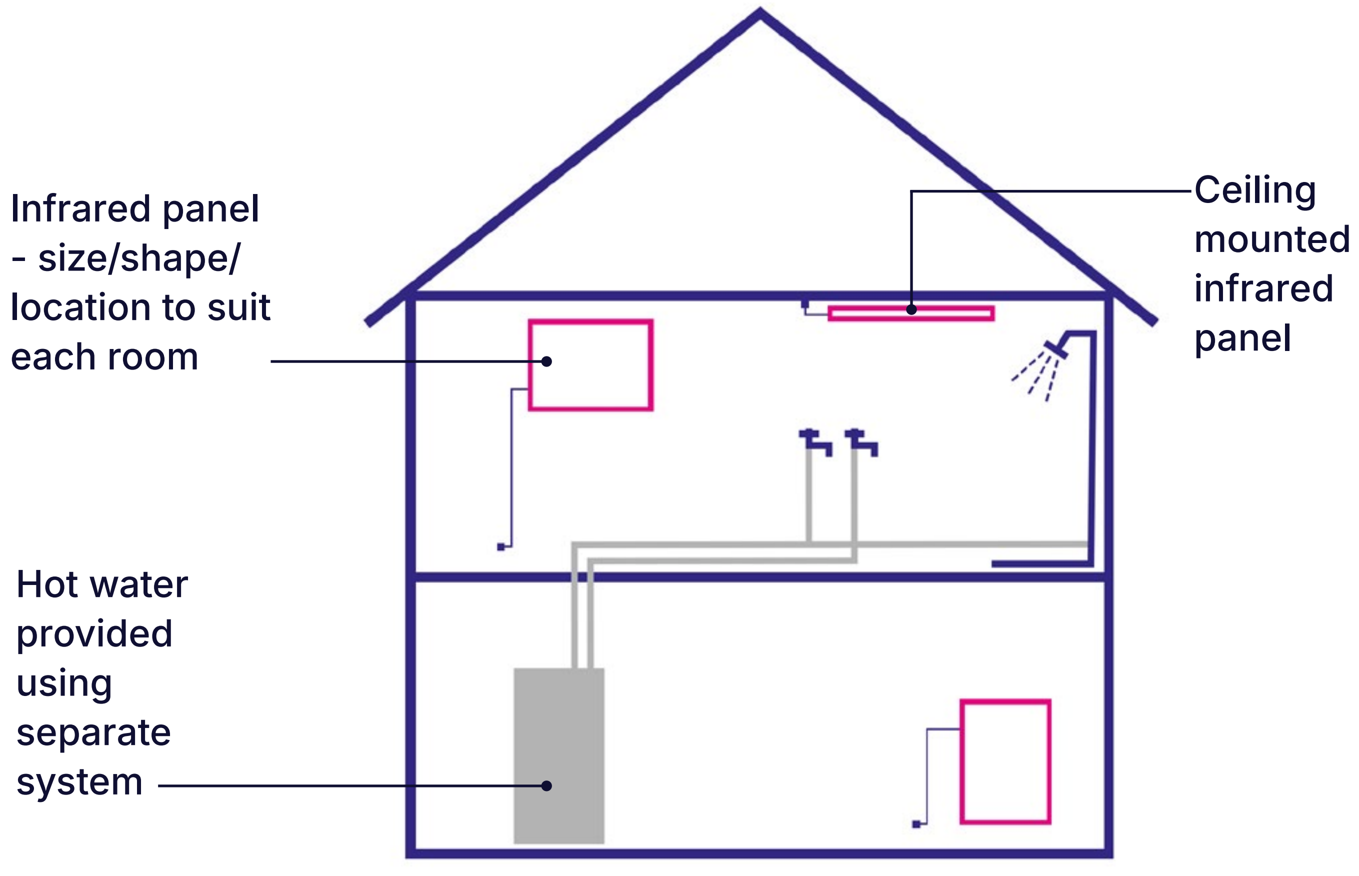
- Low installation cost
- Low maintenance cost

Cons

- Variable levels of comfort experienced by tenants
- Conflicting reports of effectiveness and cost
- Higher energy consumption than alternatives

4.5.3 Focus Group Findings

- Used mainly in high-rise blocks or where space is limited
- Testing use of smart controls
- Surface temperature concerns raised
- Tablet controls often broken; simpler manual interfaces preferred
- Seen as supplementary rather than a suitable core heating strategy



4.5.4 Main Findings

Suitability

Thermal Absorptivity: Properties with materials with higher absorptivity (e.g. stone) may absorb and release heat, adding to effectiveness of the system.

Fabric Efficiency: High fabric efficiency frequently cited as a pre-requisite for viability of infrared heating.[1 2] Higher efficiency homes may also not require users to be as close to, or within line of sight of a heat emitter.[1]

Property Type: Mid-terrace houses more suitable than detached, due to reduced heat loss through external walls.[1]

Panel Location: Ceiling mounting produces higher efficiency than wall mounting. User proximity and avoidance of obstacles between heater crucial to comfort.[1]

Panel Insulation: Insulation behind the panel can increase its effectiveness.

Tenant Experience

Comfort: Findings illustrate mixed results. Evidence of rooms not being able to be heated to required temperatures quick enough and systems ‘unable to provide comfort’.[3] Discomfort experienced when residents are not close to, or within a line of sight of a heater.[1] Other studies however found ‘good overall levels of comfort’.[1]

Positioning: Panels found to be more suitable for rooms where residents stay for short amount of time.[1]

Running Costs: Opposing results were found regarding running costs. Two social housing case studies required removal of the system after resident complaints and expensive bills.[4, 1] Evidence of increased costs due to heating being increased as energy is perceived to be cheaper.[1] Running cost savings require lower temperature set point (as indoor air temperature can be 0.6°C cooler to achieve the same comfort outcomes), however reports found that this saving was not realised as lower set points were not selected.[1] Conversely, other reports state 50% savings when replacing electric underfloor heating or storage heaters.[1]

Tenant Suitability: NEA recommend that infrared heating should not be installed in homes of those at risk of fuel poverty, particularly if homes need to be continually heated.[3]

Efficiency: Higher energy consumption than ASHPs: ‘to maintain a constant internal room temperature, it was found that radiant panel heaters consumed 2.9 times more electricity than an HP system'.[1] Radiant efficiency of models ranges from 40-70%. Efficiency of different models depends on insulation at the back of models and positioning.

Controls: Mixed results, with some tenants finding control systems confusing and others ‘appreciating innovative features’.[3] Instances of tenants being wary of using controls without assistance.[3] Other reviews saw tenants finding infrared systems easy to operate.[1]

Tariffs: Ensure tenants are on monthly billing plan and correct tariff prior to, or just after, moving in.[3]

Landlord Experience

EPC Calculation: Technology not currently included in SAP (classed as electric panel heater).

Resident Information: Recommendations to adapt onboarding process to tenant needs, make sure tenants are on monthly billing cycle, provide clear information about energy consumption through home displays and make contingency plan if predicted savings are not achieved[3].

Surface Condensation Risk: Whilst manufacturers claim that heating the building fabric will reduce the risk of mold and surface condensation[5], others propose that lower background air temperatures may increase surface condensation risk.[1]

Cost: Low installation and maintenance costs.[1]

4.5.5 Gaps and Limitations

Whilst limited existing research into the effectiveness of infrared heating in domestic settings exists, modelling and limited field trials indicate benefits can be gained under certain conditions. Many findings however present contradictory results limiting interpretation.

Within existing information there are issues around the variability in perceived comfort between individuals and the complexity around measuring thermal comfort existing methodologies may overlook certain discomforts related to the proximity and sheltering of heaters.[1] Issues are cited around manufacturer performance claims and lack of verification / available data to evidence claims.

4.5.6 Future Development

Need for further investigation into this technology, with focus on social housing setting. Need for clear guidance on the conditions for successful installation.

4.5.7 Risks Matrix

Stage	Risk	Risk Mitigation
Design	Poor layout leads to uneven heating	Heat mapping before install
	Over specification raises cost	Match wattage to room load
Installation / Commissioning	Incorrect mounting height / proximity to combustibles	Install to manufacturer's spec
	Inadequate electrical isolation	Electrical inspection
Use	Tenants block or cover panels	Education; signage
	Misuse (treating as convector heater)	Simple control guide

Case Study 1	Case Study 2	Case Study 3
Various heating solutions for social housing in North Lincolnshire Ongo Homes, National Energy Action, 2018	Alternative Heating systems, WDH, technical evaluation report, National Energy Action, 2018	Adopting intelligent infrared heating technologies in social housing, Nesta 2023
• Infrared heaters installed in 14 properties, with monitoring data from 6 of these • Tenants reported greater ease of control of heating system, although the system was more expensive to run than previous systems for 4 of 6 households, where they replaced storage heaters • Internal temperatures and RH levels remained unchanged after the installation of infrared heaters	• Infrared heating installed in 5 semi-detached houses and one flat, alongside hot water system. Heating system removed in one home as it was not suitable for household's needs • Post-installation, 4 of the 5 homes monitored fell from EPC band D to E • Feedback from tenants showed improvements in ease of control and how warm homes felt • Increase in annual energy costs post-installation	• Pilot involving Newcastle City Council, installing infrared heating systems in two terraced properties • Difficulties in engaging tenants, which impacted the level of support that could be offered • Mixed experiences among tenants, with some finding the system confusing and others appreciating 'innovative' features • Energy consumption and bills higher than expected

1 UK Government (2025) Infrared Heating – Investigations from literature and user experience tests
2 Rangel, A et al (2015) Evaluating infrared heating in Passivhaus
3 Nesta (2023) Adopting intelligent infrared heating technologies in social housing
4 NEA (2018) CP 758 Technical Evaluation Report: Comparing advanced heating systems in Wakefield
5 Ambion (date unknown) Low Carbon Heat Panels

4.6 DISTRICT HEATING

4.6.1 Technology Summary

District Heating is a large-scale system of heat generation and distribution in a local area. Heat is generated from a central source, which could be fossil fuel or renewable based, before being circulated through insulated pipework to the connected buildings on the network. Different heat networks are powered by different energy sources and, therefore, have different levels of environmental impact.

Heat networks can vary in configuration, but generally can be grouped into two distinct types:

High temperature heat network: heat is generated and circulated at high temperatures (e.g. above 65°C) and transferred to domestic heat distribution systems (e.g. radiators) through a Heat Interface Unit (HIU). Hot water can often also be provided. Typically connected to large heat generation sources (e.g. Energy from Waste plant).

Low temperature (or ambient) heat network: heat is generated and distributed at much lower temperatures (e.g. below 65°C) and upgraded for space heating and hot water within each property via a small heat pump. Hot water storage is required. Typically connected to ground source heat array (e.g. boreholes or collectors), the low temperature distribution minimises heat losses and makes these systems more suitable for lower heat density areas.

Heat networks are also categorised by their size and extent. **'Communal heat networks'** denote a single shared heating system serving multiple dwellings in a block or a small number of buildings. A **'district heat network'** denotes a system serving many individual buildings.

4.6.2 Findings Summary

Pros

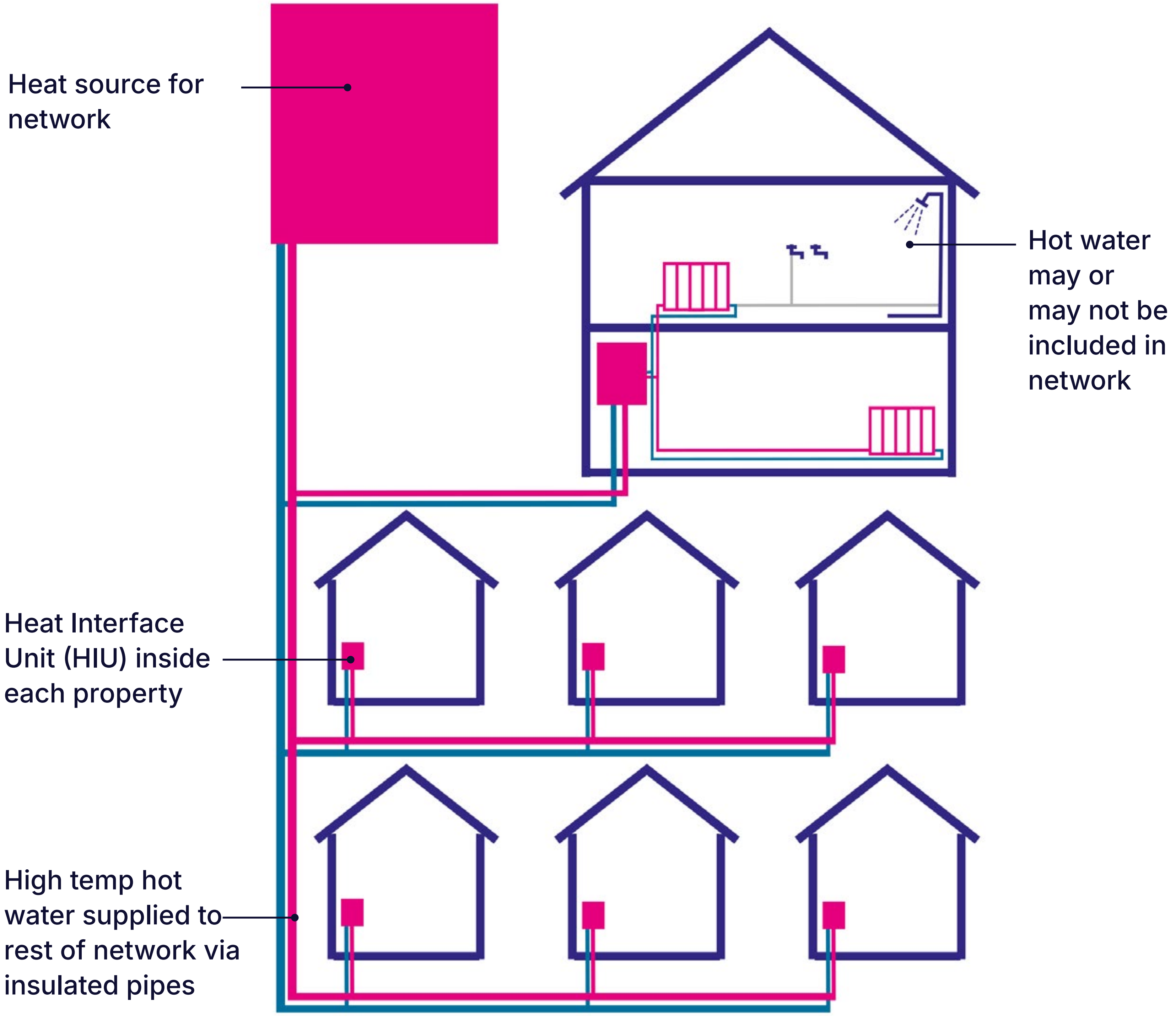
- Ease of installation and limited maintenance
- Potential for use of waste heat
- Simple usage for tenants
- Benefits from economies of scale

Cons

- Issues with complicated billing and contract systems
- Reports of issues relating to rising energy costs and unsatisfactory customer service of externally controlled networks
- Limited consumer protection, however, recent improvements in regulatory protection and Ofgem has been appointed as an independent regulator
- Monopoly markets limit competition and prevent users switching suppliers
- Concern over rising operational costs

4.6.3 Focus Group Findings

- Reports of resident dissatisfaction due to poor communication, billing confusion and limited responsiveness with network provider
- Success with biomass and anaerobic systems
- Currently a lack of consumer protection as many providers operate outside of price-caps with residents seeing increasing costs
- Opportunities discussed for housing associations to take on provision with an ethical, as opposed to profit, motive


Heat source for network
Hot water may or may not be included in network
Heat Interface Unit (HIU) inside each property
High temp hot water supplied to rest of network via insulated pipes

4.6.4 Main Findings

Suitability

Integration with renewables: DH is key for large-scale low-carbon integration, using sources like Waste Heat and large Heat Pumps. Thermal Energy Storage (TES) is vital for balancing supply.[1]

Space requirements (cylinder): Space usually required for a hot water cylinder however thermal energy storage may or may not be required within the property depending on the size and type of heat network.

Space requirements (heat interface unit): Space required for heat interface unit, often the size of a domestic gas boiler[2]. HIUs must be in accessible place for regular maintenance / potential replacement. Location of HIU should keep riser and lateral pipework short and be places so flow/return pressures are optimal[2].

Tenant Experience

Comfort: Overall satisfaction if often higher than non-network systems.[3]

Outages: Common outages experienced.[3]

Ease of use: Operational complexity if low.[4]

Information: Issues with lack of initial information provided.[4]

Billing: Reported tenant experience of complex billing/contracts. Future regulation focuses on implementing a Fair Pricing mechanism to ensure DH remains cost-competitive and provides transparency.[4]

Tariffs: By combining large electric heat pumps with TES, DH can run the pumps during off-peak Time-of-Use (ToU) tariffs to store heat.[5]

Landlord Experience

Ease of installation: HA/LAs must manage high upfront capital costs and construction disruption. Centralised maintenance is a benefit, but robust long-term contracts are essential for service quality and risk.[3]

Warranties/guarantees: New regulation introduces obligations for Security of Supply.[6]

4.6.5 Gaps and Limitations

Verifiable running cost models for tenants and specific contractual warranties/guarantees on equipment lifespan are generally restricted.[7]

4.6.6 Future Development

DH is technology-neutral and essential for futureproofing, allowing LAs to transition the central heat source.[8]

1 UK Government (2018) Heat Network Case Studies
2 Mayor of London (2021) London Heat Network Manual II
3 UK Government (2022) Heat Network Consumer and Operator Survey
4 Housing Ombudsman Service (2021) Spotlight on complaints about heating, hot water and energy in social housing
5 UK Government (2021) Transitioning to a net zero energy system
6 Ofgem (2025) Heat networks regulation: implementing consumer protections
7 UK Government (2023) Heat Networks Regulation: Government Response
8 UK Government (2018) Heat Networks Investment Project

4.6.7 Risks Matrix

Stage	Risk	Risk Mitigation
Design	Insufficient diversity or redundancy	Oversized plant; storage buffer
	Poor HIU or network sizing	Transparent metering & contracts
Installation / Commissioning	Poor insulation of heat mains	QA inspection; insulation spec
	Tenant disruption (digging up roads for pipework etc)	Comms & scheduling
Use	Heat outages; slow fault response	Backup boilers
	Tenant billing confusion	Regular billing support

Case Study 1 HNIP Case Studies: Swaffam Prior Heat Network, Triple Point Heat Networks Investment Management, 2023	**Case Study 2** HNIP Case Studies: Bristol Old Market, Triple Point Heat Networks Investment Management, 2023	**Case Study 3** HNIP Case Studies: Leeds Pipes Scheme, Triple Point Heat Networks Investment Management, 2023
• Heat network connects to 297 previously off-gas homes and the village hall • Uses 500kW ASHP, two 750kW GSHPs and connection to a 12MW solar park • Average annual carbon savings over first 15 years estimated at 1,052 tCO2e	• 3MW water-source heat pumps with peak & reserve gas boilers in Bristol city centre • 25 buildings connected, including 4 residential block, 10 office block, 2 hotel and 2 schools • Average annual carbon savings over first 15 years estimated at 3,073 tCO2e	• Heat network in central Leeds, generating 26 GWh in 2023 and with plans to increase export • 16km of pipework connecting the energy from a waste Recycling and Energy Recovery Facility to commercial properties, council homes and non-domestic buildings • Anticipated connections to almost 2,000 residences

4.7 SOLAR THERMAL

4.7.1 Technology Summary

Solar thermal panels (also known as solar collectors) use sunlight to heat water. This differs to solar voltaic panels, which use sunlight to create electricity. Sunlight heats a fluid within the panels which is transferred to the hot water cylinder through a heat exchanger. Panels may also combine electrical generation with heat (PV-thermal, PV-T) which can produce more renewable energy per m^2.

System level (annual) efficiency – 30-40%[1] (taking into account distribution system losses)

Warranty – 10 years[2]

System lifespan – 10-30 years[2,1]

4.7.2 Findings Summary

Pros

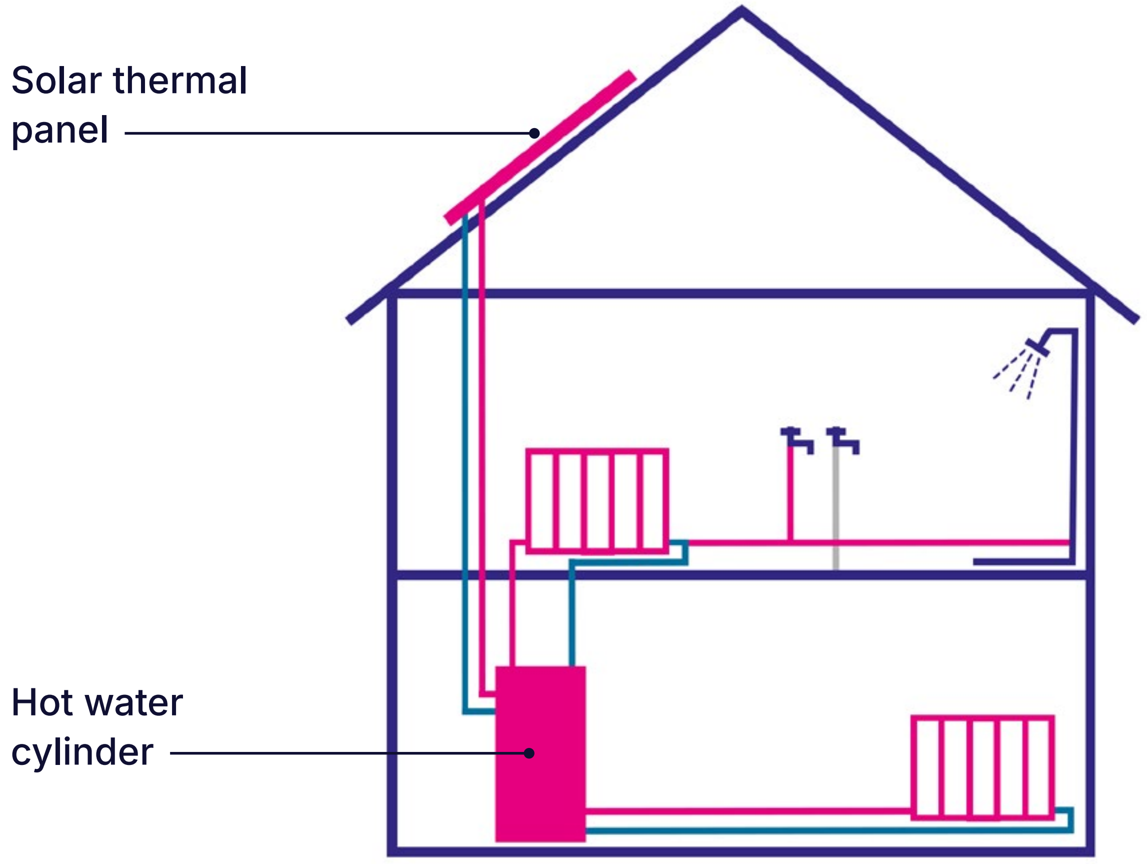
- Can be used alongside PV panels
- Minimal maintenance cost across lifespan

Cons

- Limited contribution to domestic hot water provision and overall energy use, since there is very low output in winter
- Variable installation costs
- Limited use and resulting operational data available
- Appropriateness of use dependent on specific building/site

4.7.3 Focus Group Findings

- Use of solar thermal diverters with PV to divert excess PV energy to hot water cylinder
- No reported use of solar thermal collectors



Solar panels to generate electricity could also be used in combination with this system, as a complimentary technology

4.7.4 Main Findings

Suitability

Roof Structure: Structural surveys should ascertain suitability of roof for additional load alongside care when adding load to joists when working within roof space. For unusual roof structures, a qualified structural engineer should be consulted.[3]

Clearance: Arrays should be mounted 400mm from roof edge.

Planning Permission: Most installations fall under permitted development and do not require planning permission. Systems may, however, require planning permission in conservation areas or on listed buildings.

Site Factors: Site orientation, shading and roof angle (optimum angle 30^{O}) will influence performance.

Roof Size: Collector area of 4m^2 recommended for average sized family home[1], however evidence of a 15m^2 PV-T system contributing to 50% annual electricity and 30% annual hot water demand.[4]

Distribution heat losses: Existing layouts may limit system layout and increase distribution heat losses.

Combination technology: Reports of successful use alongside PV panels.[5]

Tenant Experience

Winter performance: System performance drops in winter requiring combination with back-up system.[6]

Future Flexibility: Locks in hot water storage requirements, therefore, less future proof than PV.

Tariff Limitation: No integration with time-of-use tariffs compared to PV.

Landlord Experience

Roof Warranty: If relevant, checks should be made to ascertain that PV-T system will not invalidate roof warranty.

Maintenance: 1[7] to 2-year maintenance schedule (domestic rented properties).[3] Minimal lifetime maintenance costs.[4] Important to check for scaling on heat exchanger in hard water locations. The heat transfer fluid (glycol) needs replacing every 3-7 years.

Installation Skills: Solar thermal requires specialist knowledge of high temperature pipe joining and insulation.[4]

Cost: Costs for PV-T systems can fluctuate dramatically.[4]

Resident Information: System requires special briefing for occupant.

4.7.5 Gaps and Limitations

Small UK market for PV-T systems. Limited performance data from the UK.[4]

With reference to PV-T systems 'Unless large thermal stores and/ or low temperature distribution becomes common in UK domestic properties, PV-T is likely to remain a niche choice, with application limited to exceptionally low carbon new build homes'.[4]

4.7.6 Future Development

With the rising cost of electricity and the falling cost of PV panels, solar thermal collectors are increasingly less cost effective than PV panels, limiting exploration for future development of technology.

1 Greening, B. Azapagic (2014) Domestic solar thermal water heating: A sustainable option for the UK?
2 The Renewable Energy Hub (2024) Solar Thermal System Lifespan, Maintenance and Warranties, UK
3 MSC (2025) The Solar Heating Standard
4 UK Government (2016) Evidence Gathering – Low Carbon Heating Technologies Hybrid Solar Photovoltaic Thermal Panels
5 NEA (2023) Increasing self-consumption of solar PV
6 Energy Saving Trust (date unknown) Solar Water Heating
7 Grant (date unknown) Looking after solar thermal hot water systems

4.7.7 Risks Matrix

Stage	Risk	Risk Mitigation
Design	Poor solar gain or roof orientation	Solar mapping; correct pitch, SolShare tech
	Roof structure cannot support array	Structural survey
Installation / Commissioning	System leaks or poor glycol mix	Commissioning checklist
	Controller sensor misplacement	Check calibration
Use	Freeze risk or stagnation	Antifreeze fluid; annual service, PVT
	User unaware of seasonal limits	Information materials and reporting

Case Study 1 Improving Energy Efficiency of Social Housing Areas: A Case Study of a Retrofit Achieving an "A" Energy Performance Rating in the UK; Sunikka-Blank, M. et al.; 2012	Case Study 2 Alternative Heating systems, WDH, technical evaluation report; National Energy Action; 2018
• Case study of home retrofit that improved the building to an "A" energy performance rating • 3m^2 solar collectors to provide solar thermal in steel frame, socially rented home in Cambridge • Included as part of package of retrofit measures to act as prototype for other social housing in the area	• Solar thermal system installed alongside new gas boiler in 5 semi-detached houses • Increased satisfaction amongst tenants in cost, ease and warmth of new system • Increased energy performance scores across all homes, with all achieving EPC band C post-install, from bands E-C pre-install

4.8 ELECTRIC RADIATORS & ELECTRIC PANEL HEATERS

4.8.1 Technology Summary

Electric radiators can be filled with oil, water or are dry with a ceramic core. They provide heat through convection (heating the air) and radiation (heating people and surrounding objects). Electric radiators are suitable as a primary heating source.

Both radiators and panel heaters can be free standing or wall mounted and may either be plugged in to a socket or be hard wired into the mains supply. They require minimal maintenance and are relatively easy to install but may require an electrician[1].

Warranty: 2 years standard (up to 10 years)

Main Manufacturers: Dimplex, Enviroheat, Stelrad, Creda, Elnur, Fischer, Rointe

Control Options: Options available with wireless thermostat control, Wi-Fi connection and smart control apps (i.e. 'Dimplex Control').

4.8.2 Findings Summary

Pros

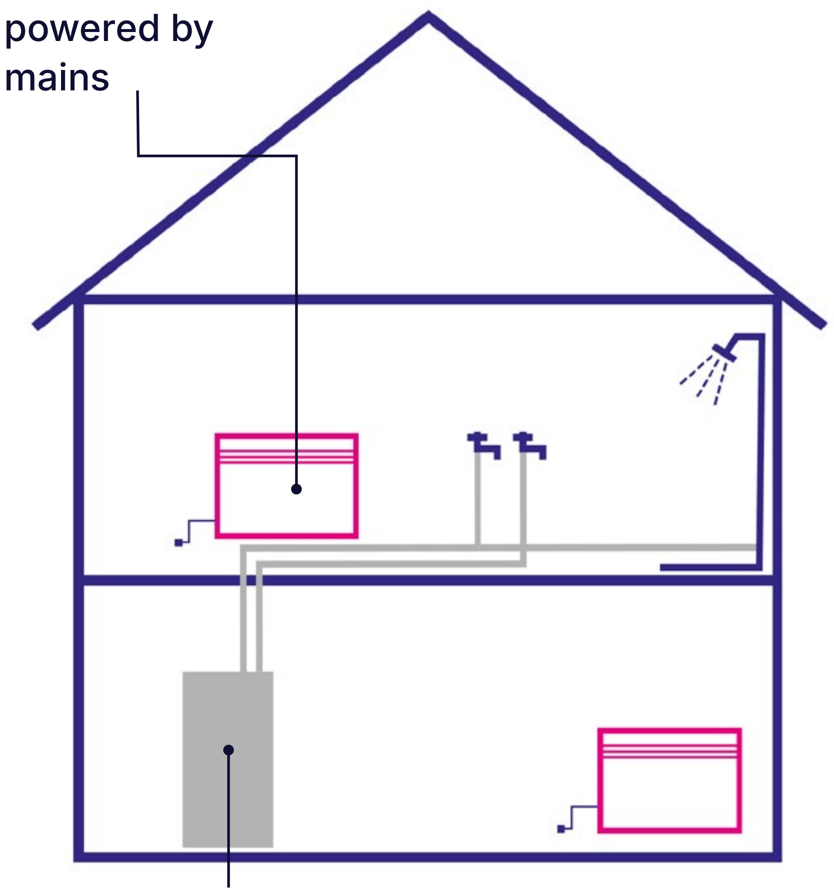
- Low upfront cost
- Less maintenance required than central heating system
- No requirement for a 'wet' central heating system
- Zone heating capability
- Basic operation with smart features available

Cons

- High unit cost of electricity and low efficiency increases bills when compared to gas
- Poor heat retention/comfort from electric panel heaters
- Potential disruption and additional costs if building requires supply fuse upgrades
- Significant fabric upgrades may be required to reduce energy use and provide savings on bills due to unit cost difference with gas

4.8.3 Focus Group Findings

- Some tenants only heating one room (a pro and con of zone heating control), leading to under heating and mould and damp risk
- Tenants can struggle with digital controls for different systems



4.8.4 Main Findings

Suitability

Complimentary Technology: Electric radiators have been used in conjunction with smart thermostat controls and data tools[2], such as a Switchee device. Systems can also be combined with PV panels and battery storage to reduce energy bills.[3]

Insulation and airtightness: Poorly insulated, draughty homes will experience higher increases in bills when switching to electricity from gas. Improvements in fabric are crucial to reducing heat demand and offsetting energy cost increases.[4]

Heat demand: Properties with a space heating demand of >150kWh/m2/y are deemed unsuitable, as high heat demand on cold days may trigger the fuse limit. Load increases of over 100A may also require a three-phase connection with significant associated cost.[5] Upgrades to building supply fuse and fabric upgrades may be required to make a direct electric heating system a viable option.[6]

Grid Suitability: Increase in electric heating may place burden on electricity distribution network especially during peak times.[7]

Tenant Experience: Electric radiators and panel heaters mostly have basic controls such as knobs and thermostats which require lower digital skills to operate. Smart features are available offering timing and temperature control, zone heating, open window detection, frost protection, and app control.[5] There is evidence of residents still requiring supplementary heating systems to heat their homes as they felt the electric radiators weren't sufficient.[1 8]

Tenant Experience

Running Costs: Higher running costs as the standard rate of electricity is more expensive than gas or oil.[3] In a study, where occupants heating was changed from older storage heating systems to on-peak electric heaters it was found that residents' annual electricity costs increased by 29%. [7] A separate study where storage and panel heaters were replaced with electric radiators found that residents didn't experience savings in their bills and were potentially limiting their usage to maintain affordability.[1] Energy bill savings are possible with heating through electric radiators if there are significant building fabric improvements and MVHR installed.[9]

Tariff Issues: Residents may need to switch to a single-rate tariff as the electric radiator and panel heating systems do not have the ability to store energy and so they provide the best savings in bills on a flat rate tariff[1]. Issues have also been seen with tariffs being incorrectly read by suppliers, resulting in incorrect billing[5].

Ease of Use: Conflicting information exists regarding ease of use. Manufacturers of the radiators and panel heaters claim simplicity of use, however a trial by NEA found that more advice was needed to help residents control their new heating system.[7]

Landlord Experience

Installation: Relatively simple installation of the individual panels or radiators which can be combined with rewiring programmes.[10] However, complications can arise installation if upgrades to building electrical supply fuse and further insulation measures are required.[5]

Maintenance: Low maintenance, with fewer servicing requirements than heat pumps.

Training Available: Product training available from Dimplex.

4.8.5 Gaps and Limitations

Limited peer-reviewed evidence and limited case study evidence of modern electric radiator and panel heater systems.

4.8.6 Future Development

There is potential for electric radiators to be installed as a primary heating source in conjunction with solar PV and batteries.[2] This would lead to reduced bills from limiting reliance on the grid.

1 Electric Radiators Direct (date unknown) Electric Radiators vs Panel Heaters
2 National Energy Action (2019) CP1138 Comparison of Two Electric Heating Solutions for a Tower Block WHG
3 Intelligent Heat (2023) Case Study Can you run electric radiators from solar panels?
4 Energy Savings Trust (date unknown) Electric heating
5 Scottish Government (2020) Low carbon heating in domestic buildings-technical feasibility: report
6 BEIS (2019) Evidence gathering for electric heating options in off gas grid homes: Final Report
7 Regen (2024) Electrification: the local grid challenge
8 National Energy Action (2019) CP1022 Comparison of Modern Electric Heaters Nottingham Community Housing Association
9 Dimplex (2017) Fighting fuel poverty in social housing
10 Ecostrad (date unknown) iQ Ceramic Smart Electric Radiators

4.8.7 Risk Matrix

Stage	Risk	Risk Mitigation
Design	High running cost from poor insulation	Fabric improvements before install
	Oversizing or under-sizing rooms	Room heat loss calculations
Installation / Commissioning	Overloaded circuits or wrong fuse rating	Electrical design verification
	Poor mounting or airflow obstruction	Site supervision, standardisation of placement
Use	Tenants bypass thermostats or run heaters constantly	Smart control lock; user training
	Inconsistent heat distribution	Add thermostatic zoning

Case Study 1 Fighting Fuel Poverty in Social Housing: Installation of Q-Rad radiators in Wilmcote House in Portsmouth; Dimplex, 2017 [8]	Case Study 2 CP1022 Comparison of Modern Electric Heaters Nottingham Community Housing Association; Nottingham Community Housing Association and National Energy Action, 2019 [7]	Case Study 3 CP1138 Comparison of Two Electric Heating Solutions for a Tower Block, National Energy Action, 2019 [1]
• Q-Rads installed within Block A of Wilmcote House alongside energy efficiency measures of external wall insulation cladding and MVHR • Retrofit to Enerphit Standard • 2-year warranty on Q-Rad electric radiators • Decrease in energy bills but other energy efficiency measures (improved fabric and new MVHR) may have led to this	• 2 properties had Rointe Electric Heaters installed and one had Osily Electric Heaters installed. • One tenant continued to use an LPG heater as they didn't feel they were getting sufficient heating from new system. • Tenants who received support in set up of heating system reported better control of system and they could maintain indoor temperature of 20-21°C. • Residents with Rointe electricity saw their electricity costs increase by 29% (previously heated by electric storage heaters) and Osily system had high annual costs (£1,561).	• Storage heaters and panel heaters replaced with EconoRad electric radiators • Radiators controlled by individual room thermostats, with overall control provided by Switchee. • Enviroheat's EconoRad radiators claim to use up to 70% less energy than standard electric heaters. • Residents with the technology installed found an improvement in thermal comfort, increased heating usage, required less supplementary heating, found their home heated quicker. • Residents were able to use their heating more but did not experience savings in overall energy use or savings in their bills.

5. HEATING & HOT WATER SYSTEMS MODELLED IMPACTS & COSTS

CeNZ-HighDB

CHANGEWORKS.

5.1 SECTION SUMMARY

The previous summary sheets set out key research from focus groups, analysis of case studies and an overview of previous research. This generally covered key qualitative concerns for the Council.

The following section analyses key quantitative concerns. These include:

- Energy modelling of a range of properties and range of heating and hot water options to measure the impact on the following:
    - Carbon emission reductions
    - Energy running costs – tenant bills
- Review and collation of costs of systems including:
    - Capital costs – item costs and costs of installation
    - Maintenance costs
    - Lifespan of system and components
    - Replacement cost of units and components

The balance between the cost of installation and maintenance by the Council against the cost of energy for tenants is analysed. Analysis shows the trend that systems that are cheaper to run for tenants, cost more for the Council. However, fuel poverty risk should be considered in selecting systems.

5.2 MODELLED IMPACT

5.2.1 Energy modelling purpose and methodology

The heating and hot water options in the short list were modelled across several property types to understand key quantitative aspects.

These quantitative items are:

- Carbon reductions
- Energy running costs – e.g. tenant bills

11 property types were selected to be representative of Fife Council's Stock. For each property 10 heating and hot water systems were modelled. Then for selected technologies, different heating patterns were modelled. Together this demonstrates the effect of a range of heating and hot water systems with different properties, and the effect of user behaviour.

The Passivhaus Planning Package (PHPP) was used for energy modelling. This method was chosen as it offers detailed and flexible input into heating and hot water options, compared to SAP. It is also accepted as having accurate outputs and assumptions, as shown by the developing Home Energy Model being validated to PHPP to confirm accurate simulation of home energy use.[1]

5.2.2Modelled key assumptions

Energy cost per year

- Energy costs for the whole property are shown including heating, hot water, other energy (including appliances and lighting) and standing charges (including where gas standing charges have been removed).
- Energy costs do not include potential further savings from PV solar panels and battery storage.
- Costs are based on current energy unit and standing charge prices.[2]
- The baseline heating scenario is a gas combi boiler and all other systems electricity based.
- Fuel poverty follows the Scottish Government definition, where a household spends more than 10% of its net income spent on fuel needs after housing costs are deducted. Most socially rented households had a net income of less than £25,000 and an average of £10,000-£15,000 in 2019.[3] This has been adjusted for inflation.[4]
- National household income data shows that 15% of all households have an income at or below £15,000 per year, and that 96% of these households are in fuel poverty. This compares to 34% of all households estimated to be in fuel poverty.[5] Risk thresholds vary based on geographical area and rent levels and so two risk thresholds have been determined for Fife Council. Fuel poverty risk lines shown are based on an annual take home income of £18,000 and £30,000 household income, and adjusted for average 3-bedroom property social rent from Fife Council.[6]

Heating pattern cost sensitivity

- The modelling explores the impact of three different heating patterns on the total energy cost per year: 2 heating periods with a total of 8 hours at 21 degrees, 2 heating period with a total of 6 hours at 20 degrees and 1 heating period with a total of 14 hours at 20 degrees.
- Three key systems were modelled: ASHP, electric radiators and Infrared panel heaters, with the three heating pattern

variations.

Total carbon saved

- The total usage and subsequent reduction in carbon for operational energy over a year is shown, as compared to a gas combi boiler.
- Electricity carbon intensity is based on Scotland specific data for grid emissions.[7]

5.2.3 Modelled property types

Several property types were selected to test the impact of different heating and hot water systems. The selection was carried out by analysing the space heating demand and area of Council properties and future changes as outlined below.

Space heating demand and area are two key factors which determine the overall delivered energy properties require for heating.

The space heating demand of a property is mainly influenced by form factor of a property, level of insulation, airtightness and ventilation system. A lower figure shows that a property is better at retaining heat, as less energy is needed for heating. As space heating demand is measured in kWh/m²/year, the area of a property is required alongside this to determine the delivered energy needed for the whole property.

Floor area and space heating demand from existing properties within the stock data were analysed. Existing space heating demands were adjusted with expectation that most homes in the stock will reach at least the minimum level of the proposed fabric efficiency standard for the SHNZS (e.g. 120 kWh/m²/year).

It is assumed that the Council will carry out retrofit works to improve properties to at least this level. However, for some hard-to-treat properties, reaching the minimum fabric efficiency may be impractical and could be exempted from the SHNZS minimum standard. Therefore, an option with a higher space heating demand has been included in the modelling.[8]

To note, space heating demand has been based on the SAP10 heating regime. Other modelling inputs, such as window size and orientation, were based on social housing properties previously modelled by Changeworks.

Table 3: Modelled property type key characteristics

Property type no.	Space heating demand kWh/m²/year	Equivalent HRR Band	Fabric efficiency description	Floor area (m²)	Property size description
PT 1	30	A	Very Good	75	medium
PT 2	70	B	Good – Very Good	50	small
PT 3	70	B	Good – Very Good	75	medium
PT 4	70	B	Good – Very Good	100	large
PT 5	95	C	Good	50	small
PT 6	95	C	Good	75	medium
PT 7	95	C	Good	100	large
PT 8	120	C	Average	50	small
PT 9	120	C	Average	75	medium
PT 10	120	C	Average	100	large
PT 11	220	E	Poor	75	medium

CHANGEWORKS.

5.2.4 Modelled heating and hot water options

Combinations of heating and hot water systems from the shortlist have been selected for energy modelling.

Options 6, 7 and 8 have the same heating system to allow comparison between the hot water systems. Options 6, 9 and 10 have the same hot water system to allow comparison between the heating systems.

Three options for ASHPs have been modelled to reflect a range of possible outcomes. Heat pump systems will achieve the highest efficiencies where radiator and pipe sizes are adapted to enable lower flow temperature operation (35°C to 55°C) and the system is appropriately operated. This may not be possible for every property; however, research has shown that around a third of properties could operate with Low Temperature Heat Pumps without radiator upgrades.[9] A SCOP (Seasonal Coefficient of Performance) of at least 3.0 is considered a good target to aim for. HS 2 achieves an average SCOP, due to existing radiators and pipes being used requiring relatively high flow temperatures of 50C. HS 3 achieves an excellent SCOP, thanks to installation of larger radiators enabling a flow temperature of 40°C. HS 4 achieves a very poor SCOP, which can be possible despite adequate system design due to poor installation and/ or operation. This option can and should be avoided for properties, using the risk mitigation suggestions in Section 4.

Table 4: Modelled heating systems key characteristic

Heating System No.	Type	Heating	Hot water	Heating emitters	Solar PV note
HS 1	Gas	Gas Boiler (Baseline Technology)	From heating system - combi gas boiler	Existing wet system - appropriately sized	PV and battery system does NOT reduce heating & hot water cost
HS 2	Heat pump based	ASHP - air to water Flow temperature: **50°C** Modelled SPF: **2.3 to 3.1** CoP: **good** Quality: **well-designed** / installed and commissioned	From heating system - DHW cylinder	Existing wet system - smaller sized radiators and pipework	PV and battery system can reduce heating & hot water cost
HS 3	Heat pump based	ASHP - air to water Flow temperature: **40°C** Modelled SPF: **3.4 to 4** CoP: **good** Quality: **well-designed** / installed and commissioned	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system can reduce heating & hot water cost
HS 4	Heat pump based	ASHP - air to water Flow temperature: **60°C** Modelled SPF: **1.9 to 2.6** CoP: **bad** Quality: **poorly designed** / installed and commissioned	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system can reduce heating & hot water cost
HS 5	Heat pump based	Communal GSHP - ground to water	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system might reduce heating & hot water cost (impact on hot water and heating dependent on system set-up)
HS 6	Emitter based	Electric radiators and electric panel heaters	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 7	Emitter based	Electric radiators and electric panel heaters	Electric instantaneous point of use & Electric shower	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 8	Emitter based	Electric radiators and electric panel heaters	Solar thermal water heating system	Individual heaters	PV panels not/less possible to install
HS 9	Emitter based	Infrared radiant panels (modelled through lower temperature)	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 10	Emitter based	High heat retention storage heater (smart)	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost

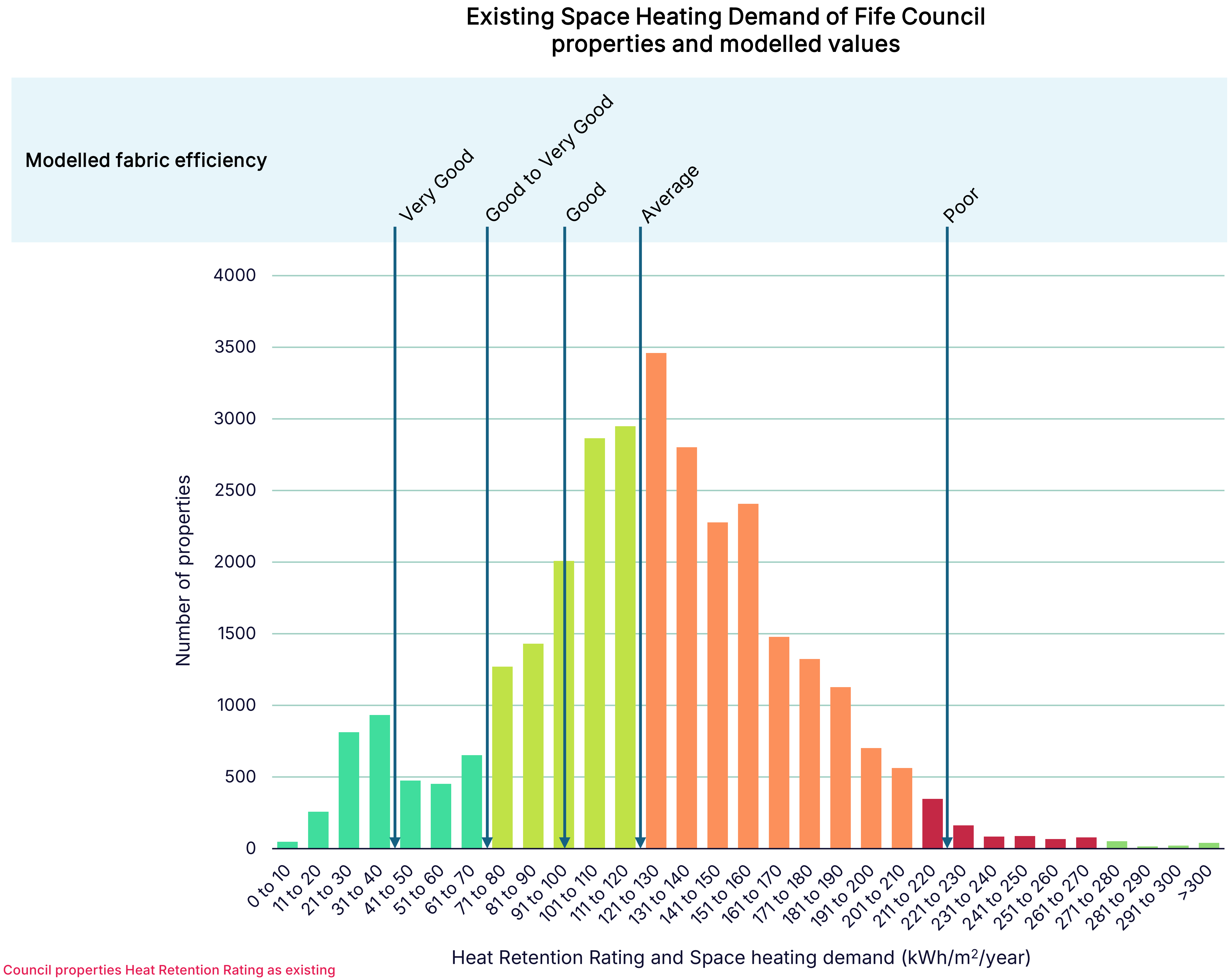


Figure 1: Fife Council properties Heat Retention Rating as existing

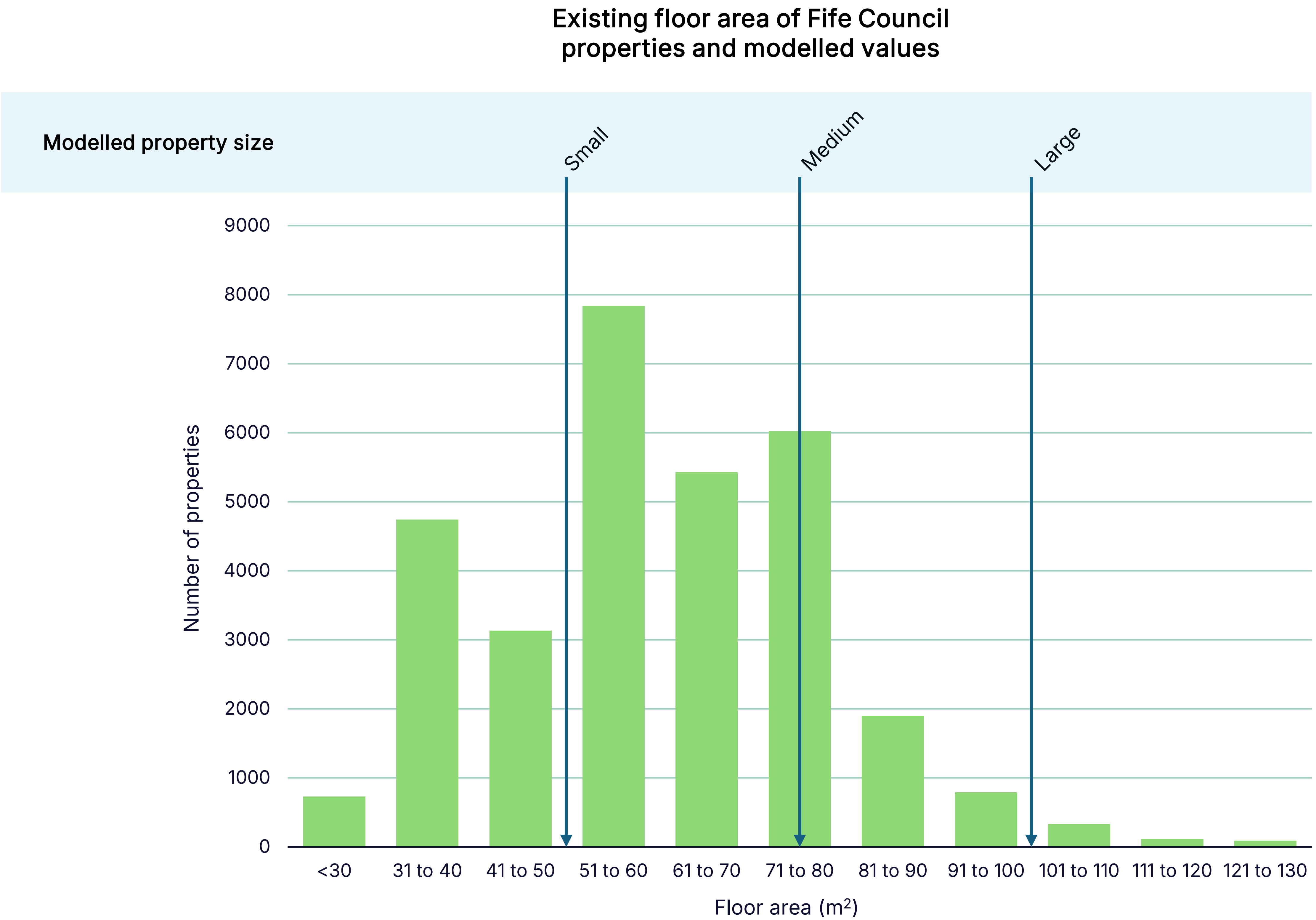


Figure 2: Fife Council properties floor areas

5.2.5 Modelled heating patterns

A property's heating pattern encompasses the number of hours the heating is turned on and the temperature a property selected. The heating pattern is controlled by tenants and owner occupiers directly. Therefore, a heating regime can vary widely within both the general population and social tenants.

Different people heat their properties over different hours based on a range of factors. However, those in fuel poverty, which includes social tenants, may underheat to an uncomfortable and unhealthy level. For this analysis, heating patterns have been selected which represent realistic user behaviour. However, an option demonstrating severe underuse of the heating, which could seriously increase the risk of unhealthy outcomes for both the occupier and property, has not been modelled.

The main heating regime was based around the SAP10 heating pattern[10] which is used as the standard assumption in the production of EPCs.

The developing HEM and Future Home Standard heating pattern utilise the 2017 Energy Follow Up Survey (EFUS),[11 12] which surveyed several thousand householders about how they used their heating system. This study was used to examine alternative heating patterns.

Variation 1 is a reduction in heating hours and heating temperature. This covers a variety of circumstances in the survey including the following trends:

- People out the house for most of the day
- Someone in employment
- Fuel poor
- Households in the lowest income quintile heated for fewer hours
- Single person households aged under 60 heated the least
- Those without a pensioner present
- Households in the RSL sector

Variation 2 is an increase in hours and a decrease in temperature. This covers a variety of circumstances in the survey as following:

- Switching on heating once a day (23% people surveyed in weekdays)
- Heat pump use with research suggesting that continuous heating is more common

Many other variables affect heating and hot water, including occupancy and water usage. Standard occupancy within the energy model has been used for all options.

To note, the internal temperature was lowered by 1 degree for infrared panel heaters to reflect manufacturer information on how energy cost savings are designed to work with these systems. This reflects information on the air temperature being lower in properties within manufacturer guidance and information. However, research has shown that this may not be reflected in real life scenarios. In terms of the reflected savings refer to Section 4 summary sheet on infrared heating.

Modelling does not demonstrate the risk of tenants turning off or self-disconnecting systems. These risks include reducing temperatures to an unhealthy and uncomfortable level for tenants and for the property. Variation 1, and the subsequent reduction of average internal temperature, starts to demonstrate the effect of energy and risk of low temperature.

Table 5: Modelled heating regimes

Heating Regime	Total hours per day	Heating periods across the day	Temperature of living areas
Standard	8 hours	2	21 °C
Variation 1	6 hours	2	20 °C
Variation 2	14 hours	1	20 °C

5.2.6 Overall key findings from energy modelling

To note, the energy cost results are highly sensitive to the unit cost of gas relative to the unit cost of electricity. Currently, the cap on the unit cost of electricity is approximately four times that of gas. A heat pump would need to be at least 320% efficient (SCOP 3.2) to reach cost parity with a gas boiler of 80% efficiency on a ratio of 4:1.[13] If price cap of these unit costs changes then this could affect the results. A relative cost reduction in electricity would greatly incentivise heat pumps over gas boilers.

Heating and hot water systems

- All clean heating and hot water options greatly reduce the carbon use when compared to gas.
- GSHP and ASHPs, except the badly performing ASHP, are cheaper compared to gas.
- The badly performing ASHP is more expensive to run than gas, but still substantially cheaper to run than other electrical heating options.

Heating systems

- Storage heaters are the cheapest of the direct electric technologies for the majority of the options, but these are still around 160% more expensive than ASHPs

Hot water systems

- The three options with the electric radiators show differences in hot water options, with solar thermal being the cheapest option, point of use water heaters next and cylinders being the most expensive. Practicalities, however, might prevent their use.
- Solar thermal could reduce bills, however, if a property has roof space then solar PV panels and battery storage or a solar diverter to the cylinder could be installed, which could have a significant effect on the overall energy bill.

Property types and fabric efficiency

- For the largest and least fabric efficient property modelled, only the well performing ASHPs and GSHP are below the higher fuel poverty risk line.
- For the smallest and most fabric efficient property, solar thermal is the cheapest of the direct electric options. This is due to the proportion of energy used on heating being less and therefore the proportion of energy for hot water of the total energy is higher.

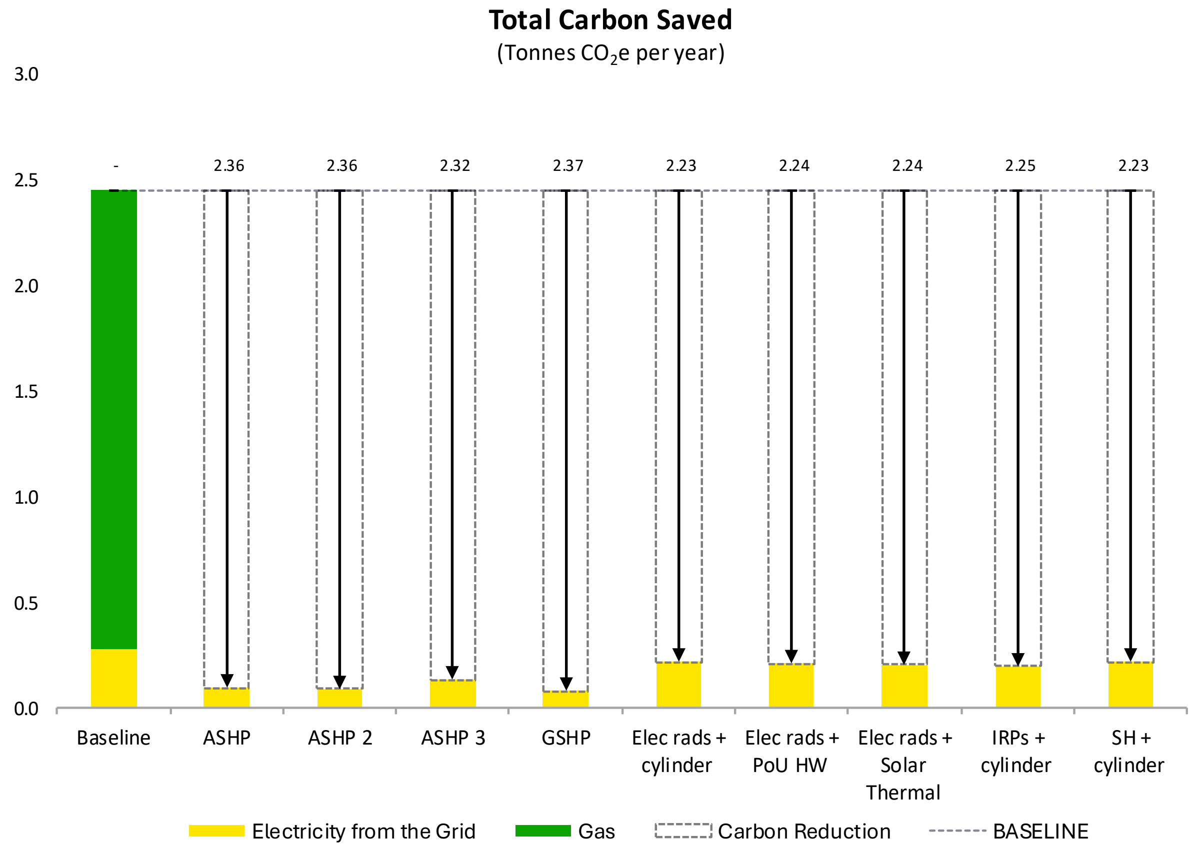


Figure 3: Total Carbon Saved graph, Property Type 6

Property 6 shown as median modelled property type - medium sized with good fabric energy efficiency.

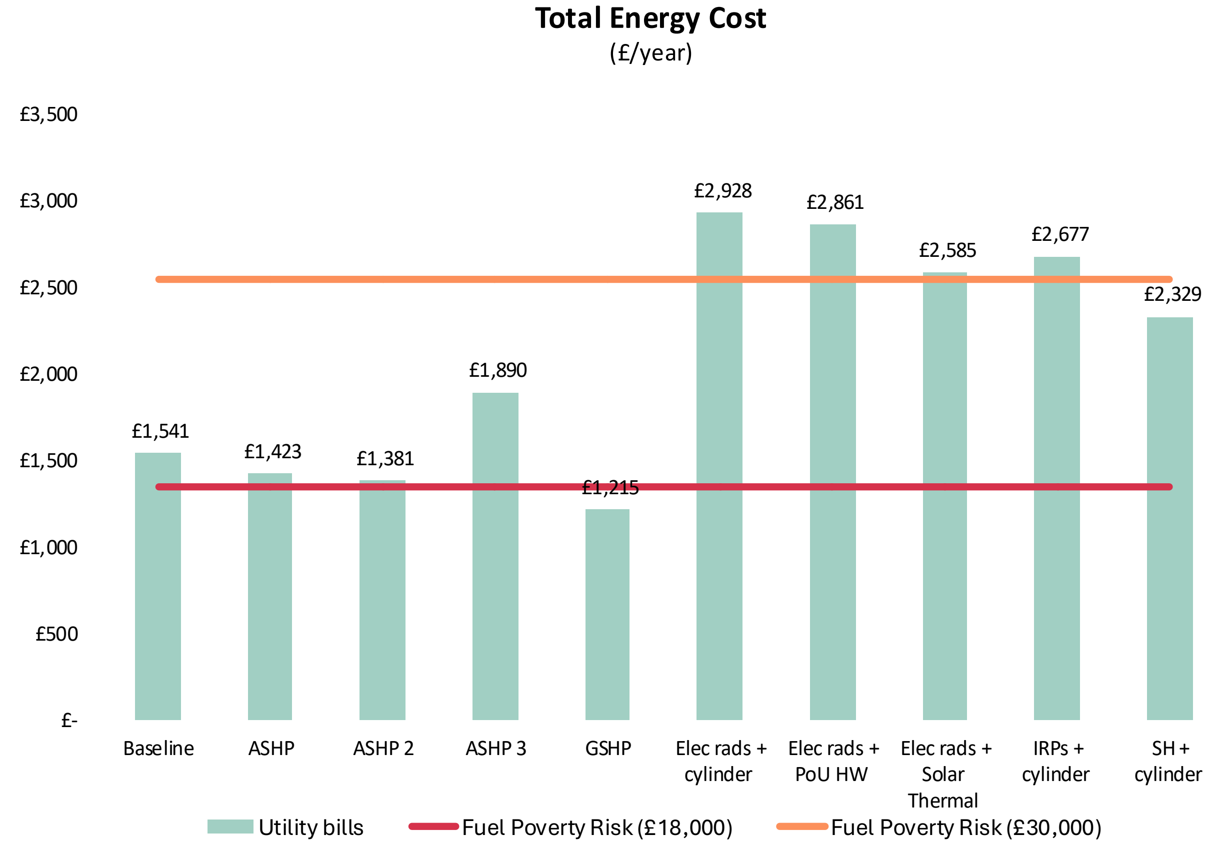


Figure 4: Total Energy Cost graph, Property Type 6

75m² floor area, 95 kWh/m²/year space heating demand

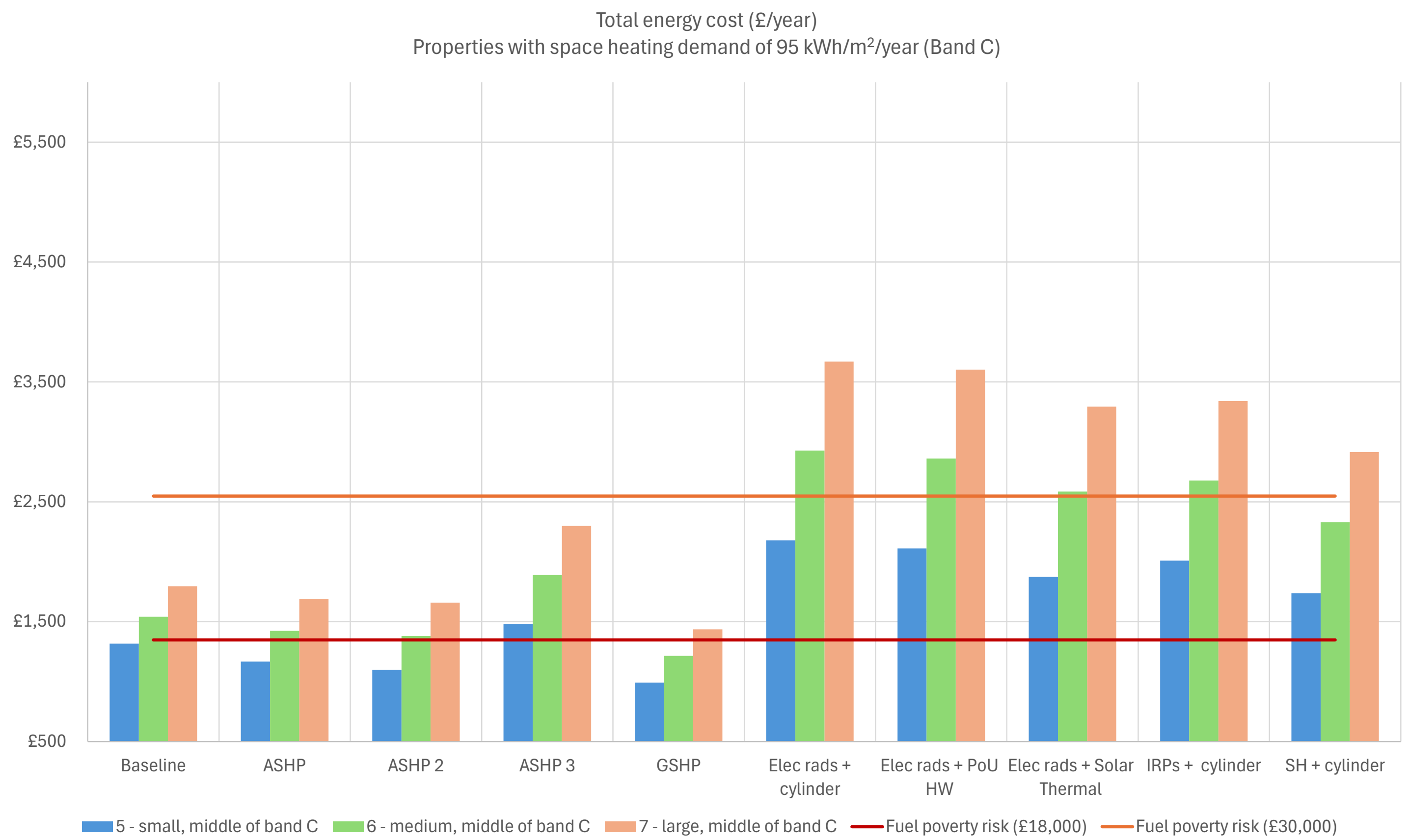


Figure 5: Total energy cost per year for three different sized properties with space heating demand of 95 kWh/m²/year

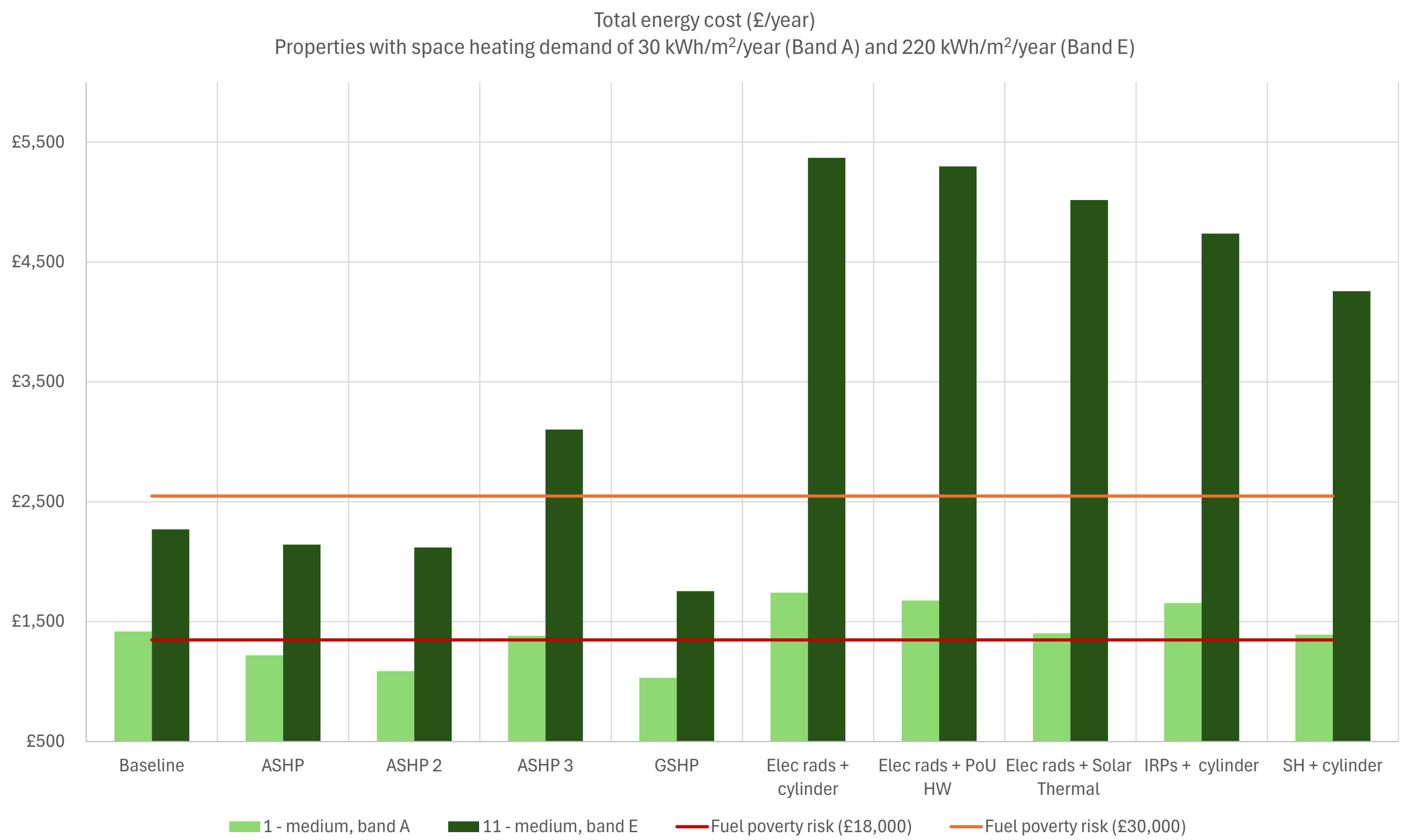


Figure 6: Total energy cost per year for properties with space heating demand of 30 and 220 kWh/m²/year and same size

5.2.7 Key findings from heating pattern variations

The results of the different modelled heating patterns show potential differences between the standard SAP and EPC assumptions and real-life impacts such as fuel poor households underheating their homes.

Key findings are as following:

- There is little significant difference in cost compared to the standard heating regime where homes are heated for longer at slightly lower temperatures (variation 2):
  - This indicates that when tenants heat their homes longer at a slightly reduced temperature, this should not lead to a significant increase in their energy bills.
- For the reduced heating patterns (less hours and a lower temperature) cost savings for are much lower (7%) for ASHPs than for other heating types (15%)[14]:
  - This is likely due to the impact on heat pump efficiency of intermittent, rather than constant, heating. For social tenants, there is a risk that using an ASHP for shorter periods of time, will not result in the same cost savings as could be achieved with gas boilers or electric radiators.
- With the reduced heating pattern, electric panel heaters can have a similar cost to storage heaters used at the standard heating pattern:
  - In the right circumstances electric panel heaters could lead to reduced energy bills, for example if the tenant is home for fewer hours and their schedule is variable. However, if hours of heating are reduced when tenants are home, this could lead to under heating.

In terms of ASHP use, the modelling aligns with modelling carried out by the Passivhaus Trust which shows ASHPs are more expensive to run when used intermittently.[15] If operated in start/stop fashion this could result in unexpectedly high energy bills whereas the additional cost of longer heating hours would be much smaller than expected. but without the payout of warmth and comfort

Tenants may feel they have less direct control of their fuel bills with ASHPs, if they expect ASHPs to work in a similar way to electric radiators and central gas heating systems. This emphasises the importance of supporting and sharing knowledge with tenants, so that they can use their ASHPs effectively and have the right balance of heat, comfort and energy cost.

For electrical panel heaters or radiators, the reduced heating regime brings costs in line with storage heaters used for a longer heating period. Storage heaters are pre-programmed to store energy overnight, and therefore do not have the same controls as electric heaters. With electric panel heaters, tenants can turn the heating on and off for a more immediate effect on energy use and cost. This then can have implications on the health of the tenant and property if significantly underutilised but could suit tenants with variable schedules and hours at home.

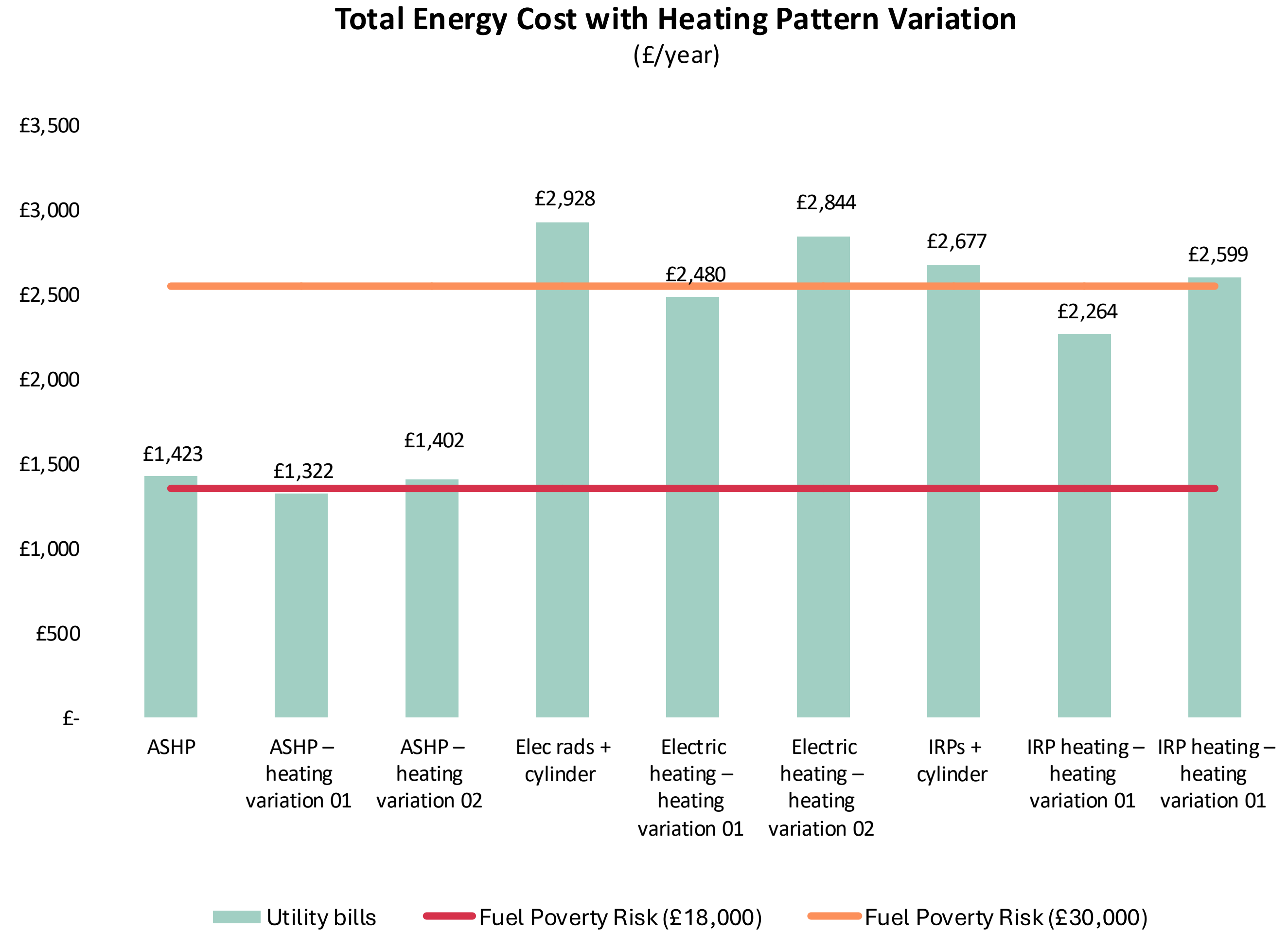


Figure 7: Total Energy Cost with Heating Pattern Variation graph, Property Type 6

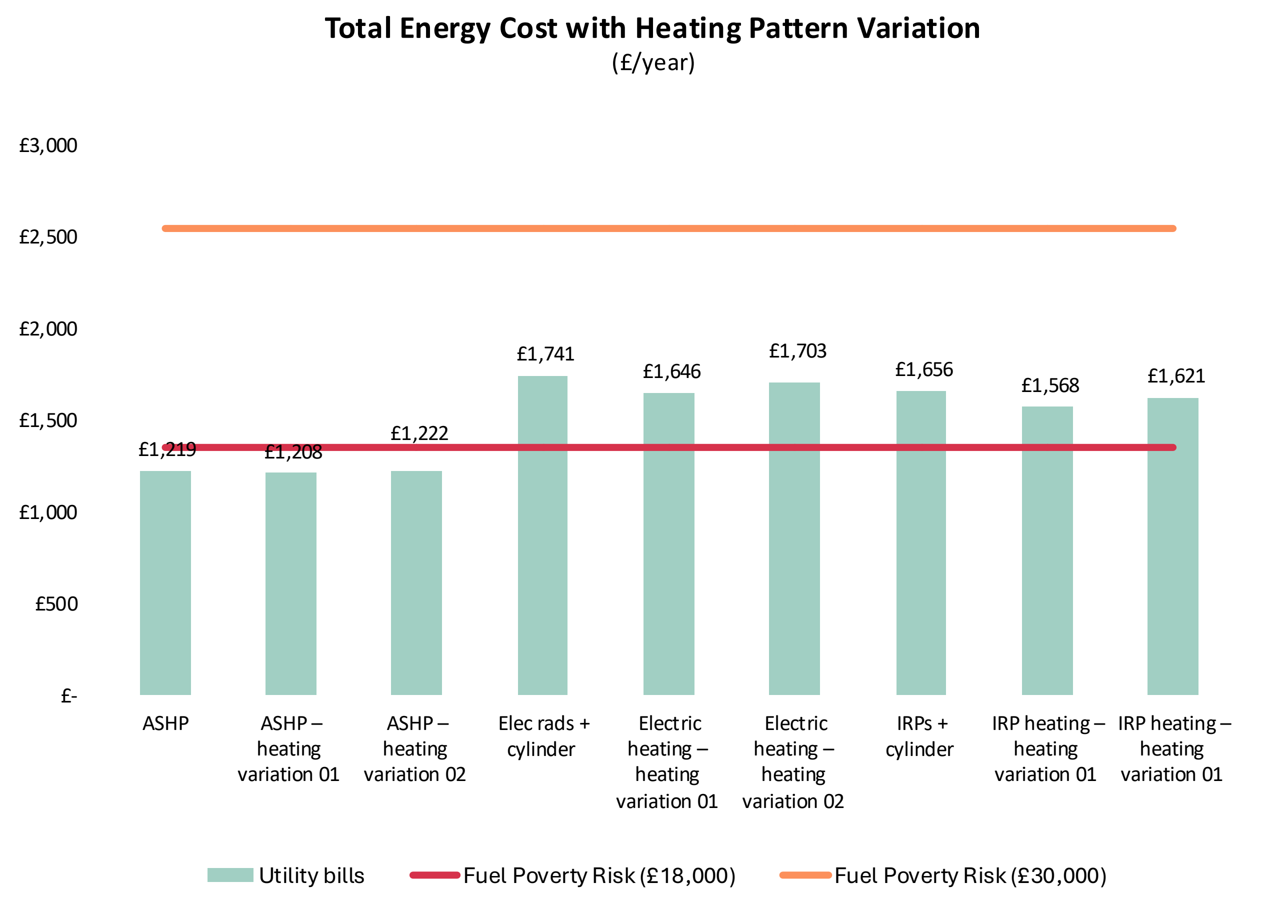


Figure 8: Total Energy Cost graph, property type 1

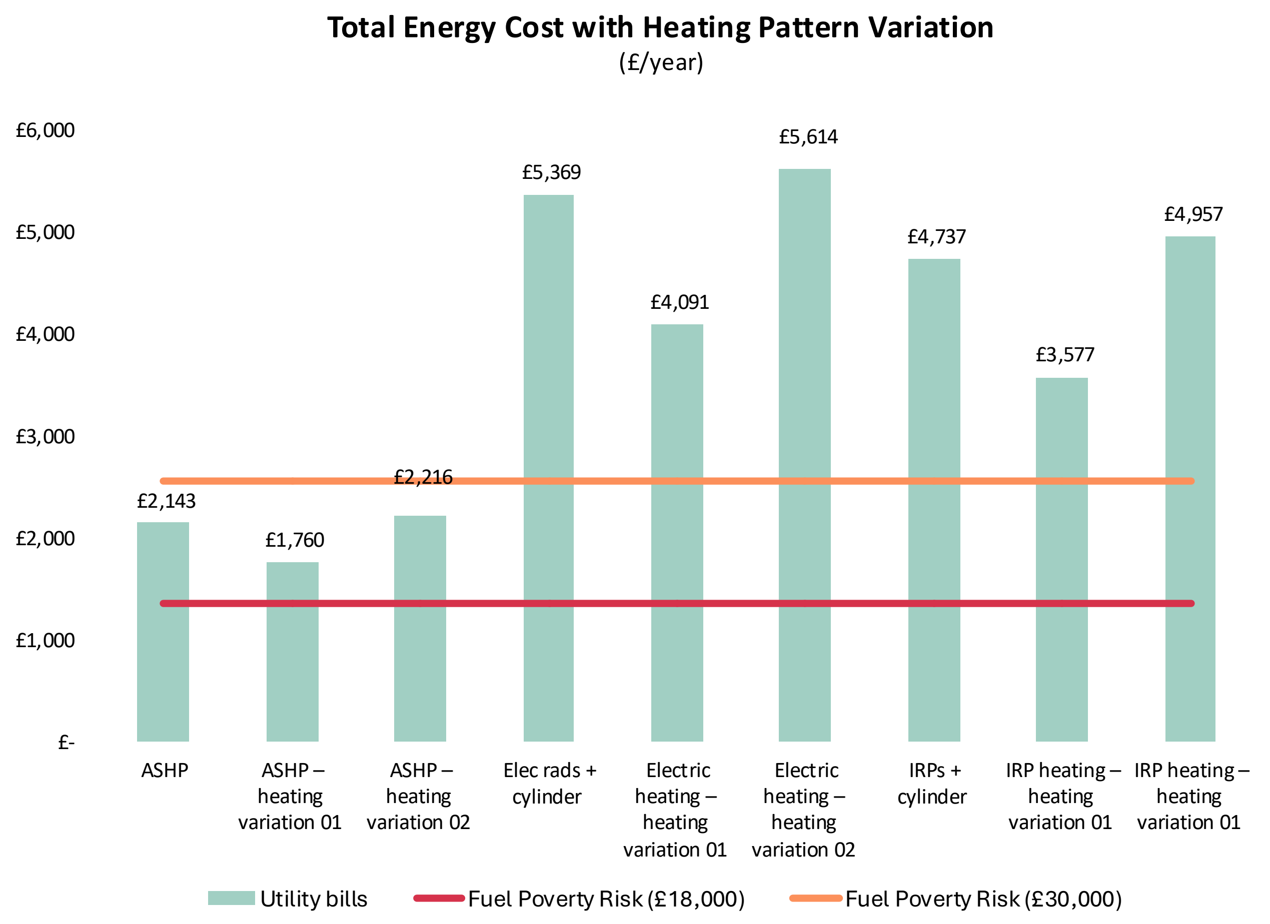


Figure 9: Total Energy Cost graph, property type 11

For graphs for all property types, refer to appendix.

Table 5: Modelled heating regimes

Heating Regime	Total hours per day	Heating periods across the day	Temperature of living areas
Standard	8 hours	2	21 °C
Variation 1	6 hours	2	20 °C
Variation 2	14 hours	1	20 °C

5.2.8Key findings on comfort and health

Across the property types, average internal temperature varies, as properties with a lower fabric efficiency lose heat quicker. Varying the heating pattern also directly effects the average internal temperature. This can impact tenant comfort, alongside factors such as cold draughts negatively impacting the perception of comfort.[16]

In addition to low temperature causing discomfort, it affects the health of both occupants and the property. For the health and longevity of a property this is caused primarily by the increased risk of condensation, moisture and mould. Occupants' health can be impacted by both the increases risk of mould and the cold itself. Health impacts can include respiratory illness, cardiovascular disease and mental health conditions.[17]

The modelled heating patterns for properties result in the varied average internal temperature in the heating months. This shows that the lower heating pattern with the least efficient property may result in discomfort or health issues. This also demonstrates the co-benefits of improving the fabric efficiency in additional to the reduction in energy cost.

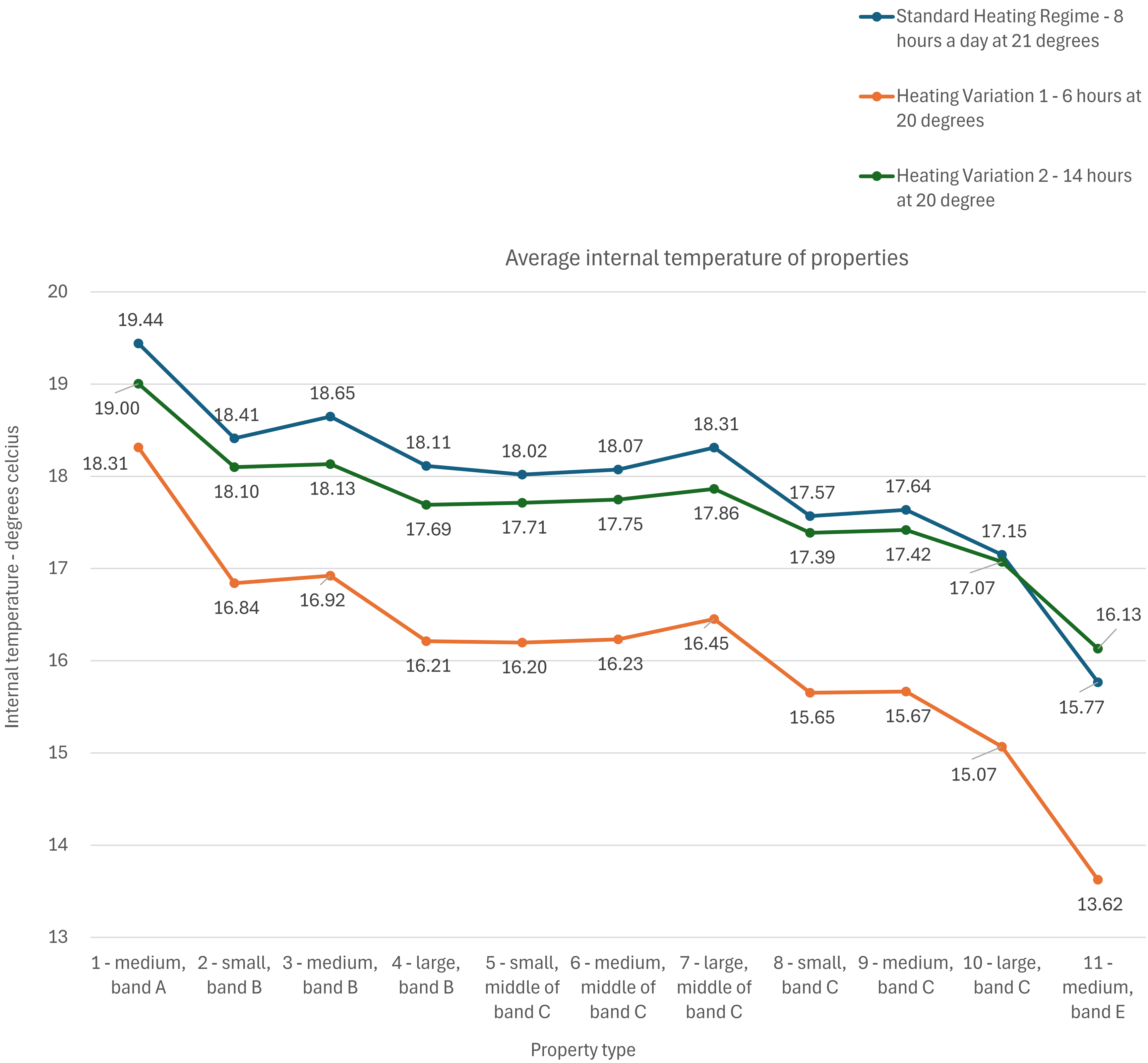


Figure 10: Average internal temperature of properties

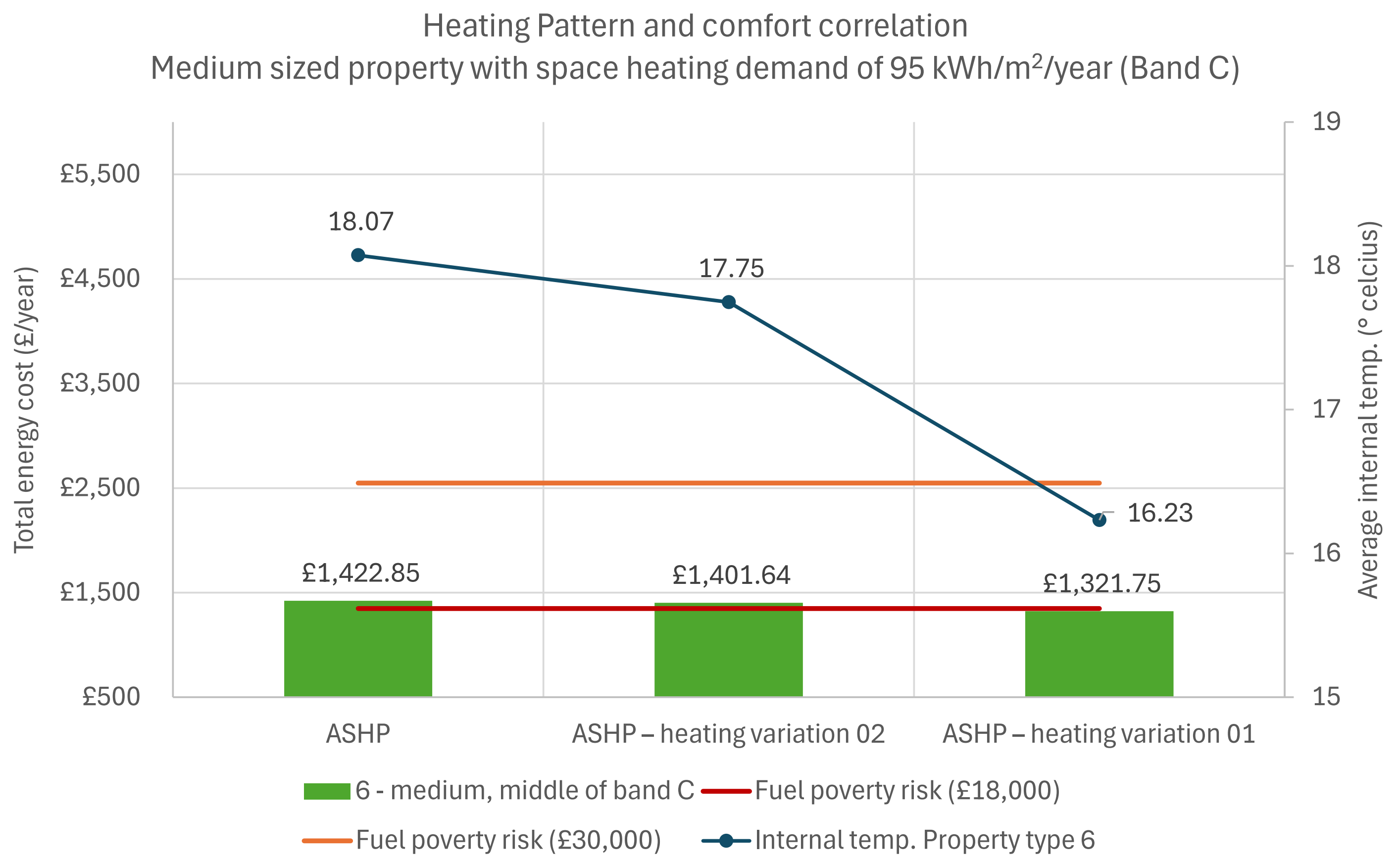


Figure 11: ASHP: Heating pattern, comfort and cost correlation

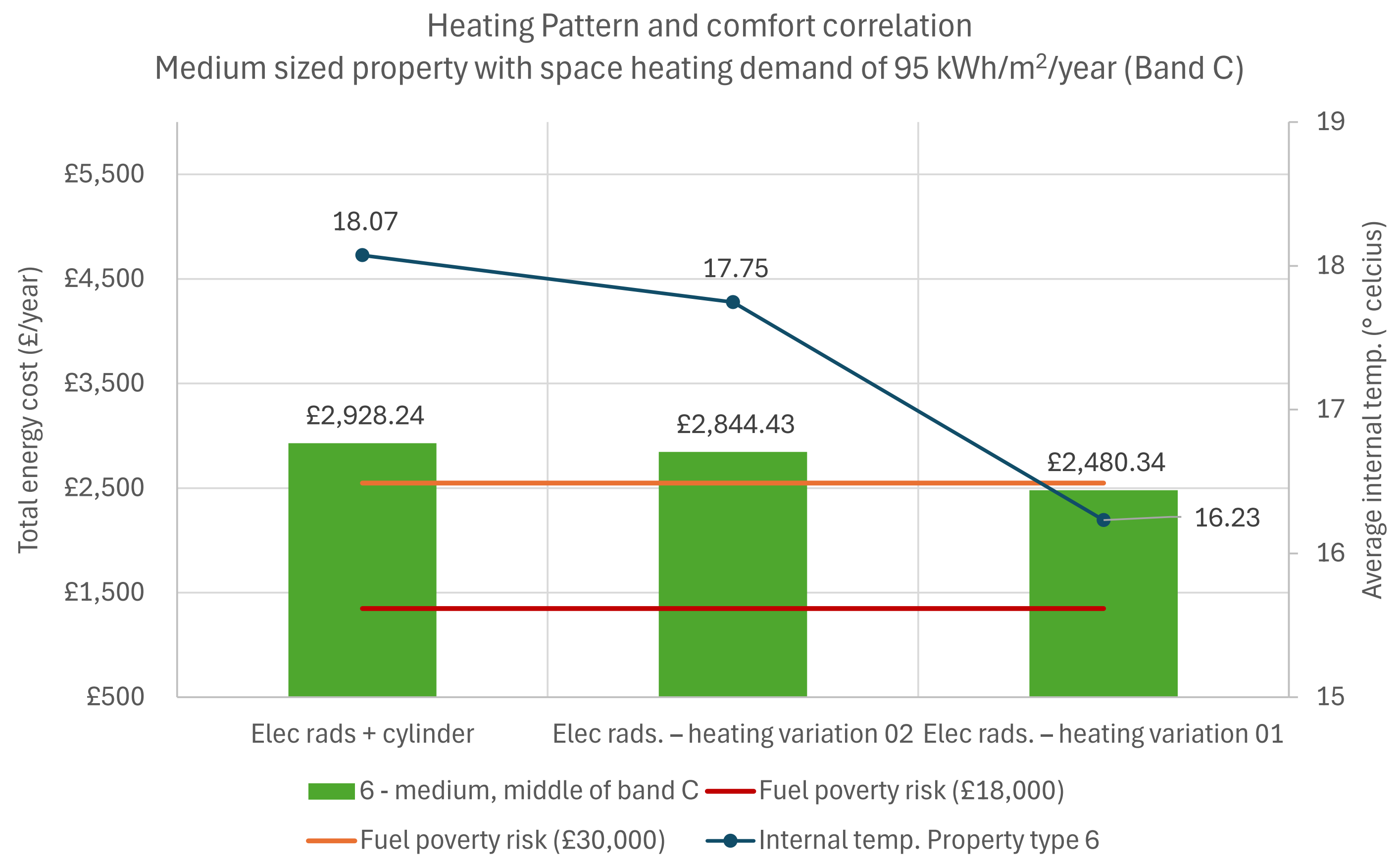


Figure 12: Electric radiator: Heating pattern, comfort and cost correlation

Table 5: Modelled heating regimes

Heating Regime	Total hours per day	Heating periods across the day	Temperature of living areas
Standard	8 hours	2	21 °C
Variation 1	6 hours	2	20 °C
Variation 2	14 hours	1	20 °C

5.2.9Balancing fabric efficiency and heating system

The modelled results from section 5 have been analysed to show how the heating systems perform in properties with different levels of fabric efficiency, and how estimated energy bills would impact on fuel poverty risk.

Alongside fabric efficiency, property size or floor area has a large impact on the energy cost. As the property size gets bigger, bills increase.

The tables below set out general guidelines in terms of deciding if a property is suitable for less efficient heating systems, for example electric radiators, or efficient heating systems, such as ASHPs and GSHPs. For clarity in this section, heating systems have been simplified under these criteria.

This can help determine if a property requires retrofitting to improve the fabric efficiency and improve the heat retention rating.

National household income data shows that 15% of all households have an income at or below £15,000 per year, and that 96% of these households are in fuel poverty. This compares to 34% of all households estimated to be in fuel poverty.[18] Risk thresholds vary based on geographical area and rent levels and so two risk thresholds have been determined for Fife Council.[19] Under the higher fuel poverty risk threshold using a £30,000 annual household income, more tenants will be at risk of fuel poverty. Under the lower fuel poverty threshold risk using a £18,000 annual household income, less tenants will be at risk of fuel poverty.

Table 6 below shows the results of the modelling and whether energy bills with selected heating technologies are below the fuel poverty risk thresholds.

Solar PV panels with or without a battery can reduce energy bills further and the following tables explore the effect of solar panels and battery on fuel poverty risk. A flat rate reduction of £500 to all properties has been applied for simplicity in table 7. This represents a best case scenario with no battery where usage of the panels is maximised or a conservative scenario with a battery.[20 21] In reality, this will differ significantly, based on solar generation, size of panels and battery, user behaviour and existing energy usage.

For all properties, solar panel installation will reduce the risk of fuel poverty. Cases where the addition of solar energy changes the combined fabric and system suitability from ‘No’ to ‘Yes’ have been highlighted in yellow below.

Key findings from the analysis are that to install clean heating across Fife Council’s housing stock without significantly increasing the risk of fuel poverty and whilst improving comfort, it is recommended to:

- Improve fabric efficiency through retrofit to a heat retention rating of at least 120 kWh/m^2/year.
- Install efficient heating systems, including GSHP and ASHP, as a priority over inefficient clean heating systems.
- Installing solar PV panels and batteries or diverters to DHW cylinders, where possible.
- For properties that cannot have efficient heating and solar PV panels installed, at a minimum improve fabric efficiency to the following:
    - Small properties around 50m^2 improve the heat retention rating to at least 120 kWh/m^2/year
    - Medium sized properties around 75m^2 improve the heat retention rating to at least 95 kWh/m^2/year.
    - Large properties around 100m^2, improve the heat retention rating to at least 70 kWh/m^2/year

Table 6: Fuel poverty risk assessment for properties with no solar panels

Property Type			Are energy bills below the lower fuel poverty risk threshold (£18k annual household income)?		Are energy bills below the higher fuel poverty risk threshold (£30k annual household income)?	
Property type no.	Property fabric efficiency	Property size	Efficient clean heating system	Less efficient clean heating system	Efficient clean heating system	Less efficient clean heating system
PT 1	Band A – 30 kWh/m²/year	Medium – 75m²	Yes	No	Yes	Yes
PT 2	Band B – 70 kWh/m²/year	Small – 50m²	Yes (except poorly performing ASHP)	No	Yes	Yes
PT 3	Band B – 70 kWh/m²/year	Medium – 75m²	Yes (except poorly performing ASHP)	No	Yes	Yes
PT 4	Band B – 70 kWh/m²/year	Large – 100m²	No	No	Yes	No (except storage heaters)
PT 5	Band C – 95 kWh/m²/year	Small – 50m²	Yes (except poorly performing ASHP)	No	Yes	Yes
PT 6	Band C – 95 kWh/m²/year	Medium – 75m²	No (except GSHP)	No	Yes	No (except storage heaters)
PT 7	Band C – 95 kWh/m²/year	Large – 100m²	No	No	Yes	No
PT 8	Band C – 120 kWh/m²/year	Small – 50m²	Yes (except poorly performing ASHP)	No	Yes	Yes
PT 9	Band C – 120 kWh/m²/year	Medium – 75m²	No (except GSHP)	No	Yes	No
PT 10	Band C – 120 kWh/m²/year	Large – 100m²	No	No	Yes (except poorly performing ASHP)	No
PT 11	Band E – 220 kWh/m²/year	Medium – 75m²	No	No	Yes (except poorly performing ASHP)	No

Table 7: Fuel poverty risk assessment for properties with solar panels and batteries (cost reduction assumed at £500)

Property Type			Are energy bills below the lower fuel poverty risk threshold (£18k annual household income)?		Are energy bills below the higher fuel poverty risk threshold (£30k annual household income)?	
Property type no.	**Property fabric efficiency**	**Property size**	**Efficient clean heating system**	**Less efficient clean heating system**	**Efficient clean heating system**	**Less efficient clean heating system**
PT 1	Band A – 30 kWh/m²/year	Medium – 75m²	Yes	Yes	Yes	Yes
PT 2	Band B – 70 kWh/m²/year	Small – 50m²	Yes	Yes (except electric radiators marginally)	Yes	Yes
PT 3	Band B – 70 kWh/m²/year	Medium – 75m²	Yes	No	Yes	Yes
PT 4	Band B – 70 kWh/m²/year	Large – 100m²	Yes (except poorly performing ASHP)	No	Yes	Yes (except electric radiators marginally)
PT 5	Band C – 95 kWh/m²/year	Small – 50m²	Yes	No (except storage heaters)	Yes	Yes
PT 6	Band C – 95 kWh/m²/year	Medium – 75m²	Yes (except poorly performing ASHP)	No	Yes	Yes
PT 7	Band C – 95 kWh/m²/year	Large – 100m²	Yes (except poorly performing ASHP)	No	Yes	No (except storage heaters)
PT 8	Band C – 120 kWh/m²/year	Small – 50m²	Yes	No	Yes	Yes
PT 9	Band C – 120 kWh/m²/year	Medium – 75m²	Yes	No	Yes	No (except storage heaters)
PT 10	Band C – 120 kWh/m²/year	Large – 100m²	Yes (except poorly performing ASHP)	No	Yes (except poorly performing ASHP)	No
PT 11	Band E – 220 kWh/m²/year	Medium – 75m²	No (except GSHP)	No	Yes (except poorly performing ASHP)	No

5.3 30-YEAR COSTS TO THE COUNCIL

5.3.1 System costs

Indicative 30-year costs to the Council for the short-listed technologies are presented below. These are costs that will be borne by the Council. It is important to note that the lower cost solutions will result in higher energy costs to tenants.The collated costs of systems include:

- Capital costs – item costs and costs of installation
- Maintenance costs
- Lifecycle costs of system and components – over a 30-year period
- Replacement cost of units and components

To note, costs between systems and properties can vary significantly, based on property constraints and the specifications of a system. The costs are presented to provide a guideline for support in selecting a system, and do not include for inflation. These costs will be checked and verified by a Quantity Surveyor at Fife Council.

Table 8: Heating system costs to the Council

Heating and Hot Water system	Provides heating or hot water	Assumptions	Typical indicative installation cost [22]	Yearly maintenance cost	Lifecycle replacement	Components replacement cost in 30-year lifecycle	Total 30 year cost
Communal GSHP - ground to water	Heating / Heating and Hot water	Cost per property for communal multi-property system	£21,500 [23 24]	£250	Heat pump and other indoor components - 25 years Ground system - 50+ years [25 26]	£10,750	£39,750
ASHP - air to water	Heating and Hot water	Replacement distribution system and radiators	£14,500	£200[27]	ASHP unit - 20 years Distribution system - 30+ years	£7,620	£28,120
ASHP - air to water	Heating and Hot water	Existing distribution system and radiators used	£9,500	£200	ASHP unit - 20 years	£7,620	£23,120
District heat network	Heating / Heating and Hot water		N/A*	N/A*	HIU - 15-20 years [28]	N/A*	N/A*
High heat retention storage heater (smart)	Heating	Quantum storage heaters	£9,000	£0	Radiators - 20 years	£7,650	£16,650
Solar thermal water heating system	Hot water		£6,000 [29 30]	£200 [31]	Pump - 10 years System - 25 years	£5,300	£12,200
Infrared radiant panels	Heating		£5,000	£0	Panels - 15-20 years [32]	£3,650	£8,650
Electric instantaneous at point of use - Water heater	Hot water	2 instant heaters plus electric shower assumed per property	£2,500 [33]	£0	Units - 20 years [34]	£3,000	£8,500
Electric radiators - oil, water-filled or ceramic core	Heating	Dimplex Q-rad	£4,500	£0	Radiators - 20 years	£3,150	£7,650
Electric panel heaters - Convector heaters	Heating		£2,750	£0	Panel heaters - 15 years [35]	£2,800	£5,550
Electric immersion - Direct hot water cylinder	Hot water		£1,250	£100 [36]	Cylinder - 25 years	£1,250	£5,500

*Cost to connect to a heat network and ongoing maintenance costs for property owners vary network to network.

CHANGEWORKS.

1 UK Government (2023) Inter-Model Comparison Summary Report

2 Costs taken from Sutherland Tables for Scotland from September 2025 – refer to Appendix

3 Scottish Government (2019) Rent affordability in the affordable housing sector: A Literature Review

4 Scottish Government (2024) Employee Earnings - Annual survey of hours and earnings: 2024

5 Scottish Government (2024) Neighbourhoods and Communities (2024). Findings from the Scottish Household Survey

6 Scottish Housing Regulator (date unknown) Fife Council

7 Scottish Government. (2025) Electricity Generation Emissions - Energy Statistics for Scotland - Q1 2025

8 Scottish Government (2025) Energy Performance Certificate Reform Consultation: Government Response - 220 kWh/m²/year selected to align with top of band D, adjusted for 10 kWh increments in data analysis

9 Laurence Childs, George Bennett, Stephen Watson, Grant Wilson (2025) Predicting the heat pump readiness of existing heating systems in the UK using diagnostic boiler data

10 BRE (2025) Standard Assessment Procedure SAP 10

11 UK Government (2021) Energy Follow Up Survey: Heating patterns and occupancy

12 BRE (2023) Space heating and cooling assumptions within the Home Energy Model: FHS assessment

13 Nesta (2024) Insulation impact: how much do UK houses really need?

14 The percentage saving may be slightly overstated (<1%) as with the ASHP option, heating and hot water is a smaller percentage of overall energy consumption.

15 Passivhaus Trust (2024) The right time for heat pumps

16 Lampret Žiga, Gorazd Krese, Vincenc Butala, Matjaž Prek (2018) Impact of airflow temperature fluctuations on the perception of draught

17 Bukky Balogun, Felicia Rankl, Wendy Wilson, Cassie Barton, Paul Bolton, Rachael Harker (2023) Health inequalities: Cold or damp homes - House of Commons Library

18 Scottish Government (2024) Neighbourhoods and Communities (2024). Findings from the Scottish Household Survey

19 Calculation based on weekly rent of £86.97, based on average weekly rent of Fife Council – Scottish Housing Regulator Fife Council

20 Sunbright Energy (2025) How Much Can You Save with Solar Panels in 2025?

21 Changeworks (2023) East Lothian Council Solar PV and Battery Average energy savings of £604 across 10 properties with solar PV panels and batteries.

22 Costs developed from previous Changeworks projects

23 KENSA (2020) Ground Source Heat Pumps and Shared Ground Loop Arrays presentation – Shared Ground Loop Array System Total capital cost (ex. VAT) based on average property for completed scheme - £17,165. Adjusted for inflation with approx. 25% increase.

24 Scottish Government (2021) Renewable and zero emissions heating systems in affordable housing projects: evaluation – Project 19 Communal GSHP – Heat capex per unit £11,500

25 Greentech Renewables (date unknown) What is the life expectancy of a ground source heat pump?

26 Greentech Renewables (date unknown) How much does it cost to install a ground source heat pump?

27 Checkatrade (2024) Heat pump servicing and repair cost

28 Add Detail (date unknown) HIU Installation & Replacement Services London: Quality and Reliability Guaranteed

29 Changeworks (date unknown) Solar Thermal System

30 The Renewable Energy Hub UK (2026) How much does a Solar Thermal System Cost? UK Guide for 2025

31 Cost provided by Fife Council Quantity Surveyor

32 Scottish Energy Saving (2025) Best Infrared Heating Panels Scotland (2025): Far Infrared, Portable & Wall-Mounted Options Explained

33 Checkatrade (2024) Tankless water heater cost guide

34 US Department of Energy (date unknown) Tankless or Demand-Type Water Heaters

35 Electric Radiators Direct (2023) How much maintenance do electric radiators need?

36 Wirral Gas (2025) Do Hot Water Cylinders Need Servicing? Here's What Every Homeowner Should Know

6. HEATING & HOT WATER SYSTEMS CONCLUSIONS

CeNZ-HighDB

CHANGEWORKS.

6.1 SECTION SUMMARY

This section summarises the key pros and cons of the shortlisted systems, using information gathered in the focus groups (whose findings are reported in the technology reviews and the appendix), technology reviews and modelling sections.

Overall findings for the suitable selection of systems for each property type are presented. However, the installation and selection of systems depend on individual property characteristics and constraints. The suitability of installation by system types is broken down for key property characteristics. This is presented visually in a decision flow chart, mapping the key choices to select a suitable system per property type.

6.2 OPTIONS COMPARISON

6.2.1 Pros and cons of systems

Key pros and cons of the heating and hot water systems from the technology summary sheets are presented in the table below to allow comparison between the systems. This table does not consider the suitability of these systems for different property types as this is discussed in the following section.

Table 9: High level assessment of systems

Technology	Tenant Experience	Efficiency*	Installation	Maintenance	Upfront Costs	Operational Costs	Additional Pros	Additional Cons
ASHP	Tenant education critical High satisfaction when designed correctly	High (if potential SCOP 2.5-3.5 achieved)	Requires careful design & installation - poor installs cause low efficiency and complaints	Annual maintenance required	High - but funding is available	Low - if efficiency optimised	Good funding availability	Performance degrades at low ambient temperatures Noise risk
GSHP	Excellent results in dense housing	Very high (if potential SCOP 3-4.5 achieved)	Long install High installation disruption risk	Annual maintenance required Ground collector / borehole has long-life span & minimal maintenance	Very High	Low - if efficiency optimised	Low visual impact Quiet operation	
District Heat Network (Heating & Hot Water)	Tenant does not have flexibility to change supplier	Efficient at scale	Moderate	Centralised maintenance	Medium	Low to high - risk of billings issues	Ability to have diverse sources of low carbon heat	Risk of outages
Electric Immersion / Direct Hot Water Cylinder	Simple, reliable, familiar to tenants	Less efficient from tank heat loss or Moderate when paired with PV and diverter to immersion	Simple installation Compatible with PV	Low maintenance	Low	High - if not PV-assisted Least cost-effective option if grid-only		
Electric Instantaneous (Point-of-Use) Water Heater	User dissatisfaction in properties with multiple people High load spikes can exceed fuse capacity in older stock	Less efficient	Simple installation	Low maintenance	Low	High	Compact No stored water (reduced legionella) Ideal for single hot water outlets	High instantaneous electrical load (6-12 kW per unit) Limited flow rate No benefit from PV generation since no storage
High Heat Retention (Smart) Storage Heater	Performance hinges on tariff access and user understanding (guidance needed) Smart controls improve comfort	Less efficient	Simple installation	Low maintenance	Medium	Medium - if utilising off peak electricity (high if programming fails or tariff not compatible)		Requires dual-rate tariff
Infrared Radiant Panels	Mixed experience from comfort benefits to higher running costs	Less efficient	Simple installation	Low maintenance	Low	High to Medium - if installed in suitable properties	Instant heat Suited to spot-heating	No stored warmth in system Risk of cold spots and lack of comfort if installed incorrectly
Electric Panel / Convector / Radiator Heaters	Easy tenant control but prone to higher running costs	Less efficient	Simple installation	Low maintenance	Low	High		
Electric Radiators (oil, water-filled, ceramic core)	User-friendly controls, even temperature	Less efficient	Simple installation	Low maintenance	Low	High (5-10% savings over convectors)	Better heat retention than convectors	Heavier than convectors
Solar Thermal Water Heating	Low winter yield	Moderate	Moderate	Higher maintenance than PV	Medium - Declining viability vs PV+ immersion due to falling PV costs	Medium	Works well with storage cylinder	Most suitable where wet hot water cylinder already present Requires back up immersion supplied by grid

*The efficiency of a system is highly linked to the operational carbon footprint of the system. The more efficient the system the less carbon emissions are associated with the system use.

6.2.2 Technology and property suitability overview

Table 10: Property suitability by technology

Technology	Suitable Properties	Less Suitable Properties
ASHP	Houses Low-rise blocks with outdoor space	High-rise flats or leaky solid-wall stock without retrofit insulation Properties without external areas Properties with internal space constraints, i.e. without cupboard or storage space for cylinders. Listed properties or in a conservation area may have additional planning requirements
GSHP	Mid and high-rise flats with outdoor space for communal system Rural or semi-detached homes or homes with land	Flats, terraced housing with limited land access Properties with unsuitable ground conditions and space Properties with internal space constraints, i.e. cupboard or storage space for cylinders and individual system components. Listed properties or in a conservation area may have additional planning requirements
District Heat Network (Heating & Hot Water)	Dense estates of all property types Tower blocks Mid-rise flats	Dispersed rural stock Mixed-tenure stock
Electric Immersion / Direct Hot Water Cylinder	Flats with storage space for cylinder Small well-insulated dwellings with storage space for cylinder Sheltered housing with storage space for cylinder	Large family homes with HRR < C unless PV and battery or diverter installed. Properties with internal space constraints, i.e. without cupboard or storage space for cylinders.
Electric Instantaneous (Point-of-Use) Water Heater	Bedsits Small flats Supported housing	Large family homes Multi hot water outlet dwellings Where main fuse <100A
High Heat Retention (Smart) Storage Heater	Mid/high-rise flats Smaller insulated homes Sufficient local electricity grid capacity available	Large homes (due to fuse limit) or leaky older stock with HRR of >150 kWh/m²/year Properties without Economy 7/Smart tariff available
Infrared Radiant Panels	Modern flats with smaller rooms Communal spaces	Larger homes when used for full-home heating Uninsulated or poorly insulated properties Open-plan layouts
Electric Panel / Convector / Radiator Heaters	Newer properties with EPC band A or B Small insulated flats	Large, poorly insulated homes New retrofit installations Rural off-gas properties
Electric Radiators (oil, water-filled, ceramic core)	Newer properties with EPC band A or B Small insulated flats	Large, poorly insulated homes New retrofit installations Rural off-gas properties
Solar Thermal Water Heating	Houses with south-facing roofs	High-rise blocks Low-demand homes Shaded, north-facing roofs Used in combination with solar PV panels, which may reduce energy cost to tenant more than solar thermal water system Properties with internal space constraints, i.e. cupboard or storage space for cylinders Listed properties or in a conservation area may have additional planning requirements

Table 11: Technology suitability by property

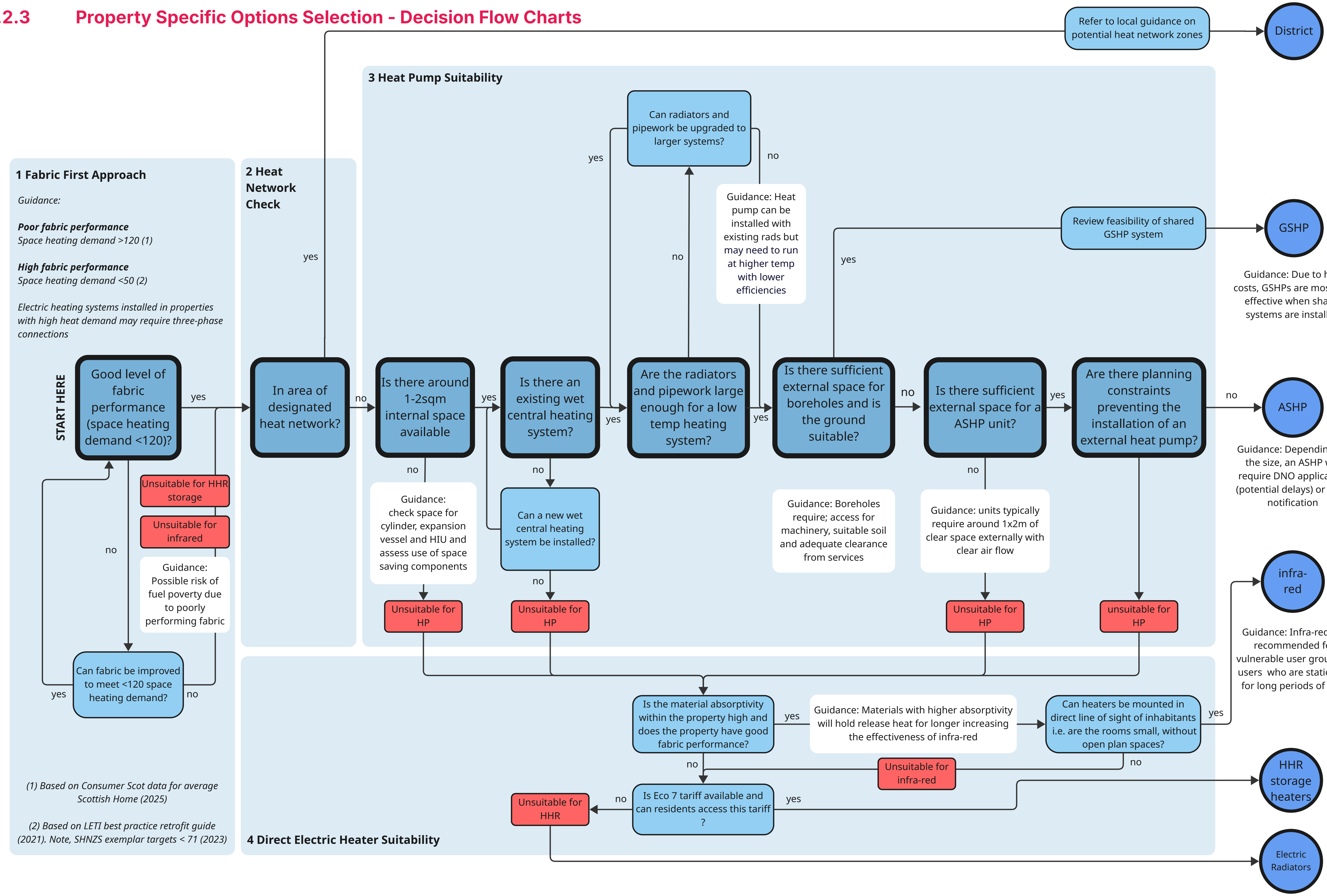
Properties	Suitable systems – in general order of suitability	Key exclusions and suitability
Houses – including detached, semi-detached, terraced, and bungalows	District Heat Network (Heating & Hot Water)	Dependant on heat networks areas, as determined by density of area and properties
	GSHP (Communal)	Exclude where no ground access and with unsuitable ground conditions and space. Can be additional planning requirements in listed/conservation area properties. Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders and individual system components.
	ASHP	Less suitable for properties without external areas. Can be additional planning requirements in listed/conservation area properties. Less suitable for properties with internal space constraints, i.e. without cupboard or storage space for cylinders.
	Electric Immersion / Direct Hot Water Cylinder	Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders. Ideally paired with solar PV
	High Heat Retention (Smart) Storage Heater	Suitable only for smaller insulated homes, and with no outdoor area. Exclude for areas with insufficient local electricity grid capacity
Four-in-a-block flats	District Heat Network (Heating & Hot Water)	Dependant on heat networks areas, as determined by density of area and properties
	GSHP (Communal)	Exclude where no ground access and with unsuitable ground conditions and space. Can be additional planning requirements in listed/conservation area properties. Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders and individual system components.
	ASHP	Less suitable for properties without external areas. Can be additional planning requirements in listed/conservation area properties. Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders.
	Electric Immersion / Direct Hot Water Cylinder	Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders. Ideally paired with solar PV
	High Heat Retention (Smart) Storage Heater	Exclude for areas with insufficient local electricity grid capacity
	Electric Panel / Convector / Radiator Heaters Electric Radiators (oil, water-filled, ceramic core)	Suitable only for smaller insulated flats
	Infrared Radiant Panels	If not supplementary to other heating system - Only suitable for modern insulated properties with smaller rooms

Mid and high-rise flats	District Heat Network (Heating & Hot Water)	Dependant on heat networks areas, as determined by density of area and properties
	GSHP (Communal)	Exclude where no ground access and with unsuitable ground conditions and space. Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders and individual system components.
	ASHP (Communal)	Suitable where sufficient flat roof space is available. Exclude where no suitable external area available.
	Electric Immersion / Direct Hot Water Cylinder	Less suitable for properties with internal space constraints, i.e. cupboard or storage space for cylinders. Ideally paired with solar PV
	Electric Instantaneous (Point-of-Use) Water Heater	If not supplementary to Direct Hot Water Cylinder – Suitable for small flats with low occupancy – ideally with electric shower and no bath
	High Heat Retention (Smart) Storage Heater	Exclude for areas with insufficient local electricity grid capacity
	Electric Panel / Convector / Radiator Heaters Electric Radiators (oil, water-filled, ceramic core)	Suitable only for smaller insulated flats
	Infrared Radiant Panels	If not supplementary to other heating system - Only suitable for modern insulated properties with smaller rooms

To note, for all properties improvement of fabric efficiency through retrofit will improve the comfort and energy cost of all systems, see the analysis on comfort and health in section 5.2.8.

Most decarbonised systems require internal space for system components and/or hot water storage. Components have been designed to address this issue, for example, reverse hot water cylinders for use with ASHPs[1] and under sink or slimline direct electrical hot water cylinders to fit within kitchen cabinets. Assessing the right components to fit within the property constraints whilst delivering heat and hot water to the number of occupants would be determined on a property by property or property typology basis.

6.2.3 Property Specific Options Selection - Decision Flow Charts



6.2.4 Costs to tenants vs. 30-year costs to the Council

30-year costs to the Council (installation, maintenance and replacement) for options was calculated in section 5.3. These costs are compared here to running costs for tenants.

The less efficient electric technologies are cheaper for the Council, at approximately half of the cost for ASHPs. However, tenants would have higher energy and heating costs.

The table and graph below present the running costs and 30-year costs for the modelled systems. There is a general trend of systems with a greater capital investment cost costing less to run.

6.2.5Key potential systems

The analysis of systems demonstrates there is no single system which will be suitable for all social housing properties in Scotland. RSLs will have to make decisions based on their priorities and properties.

A stock wide clean heating strategy, to be decided by the RSL, should balance fuel poverty risk and life cycle costs for the RSL, and consider stock conditions including fabric efficiency and property size, and future retrofit plans. Location specific conditions, such as local electricity grid capacity and heat network potential, should also feed into any clean heating strategy. Alongside this, system choice will heavily depend on individual property suitability.

The following key heating and hot water systems have been identified as having the most potential for systems in social housing in Scotland:

- District heating networks
- GSHP - ground to water
- ASHP - air to water
- High heat retention storage heater (smart)
- Infrared radiant panels and Electric radiators
- Electric immersion - Direct hot water cylinder

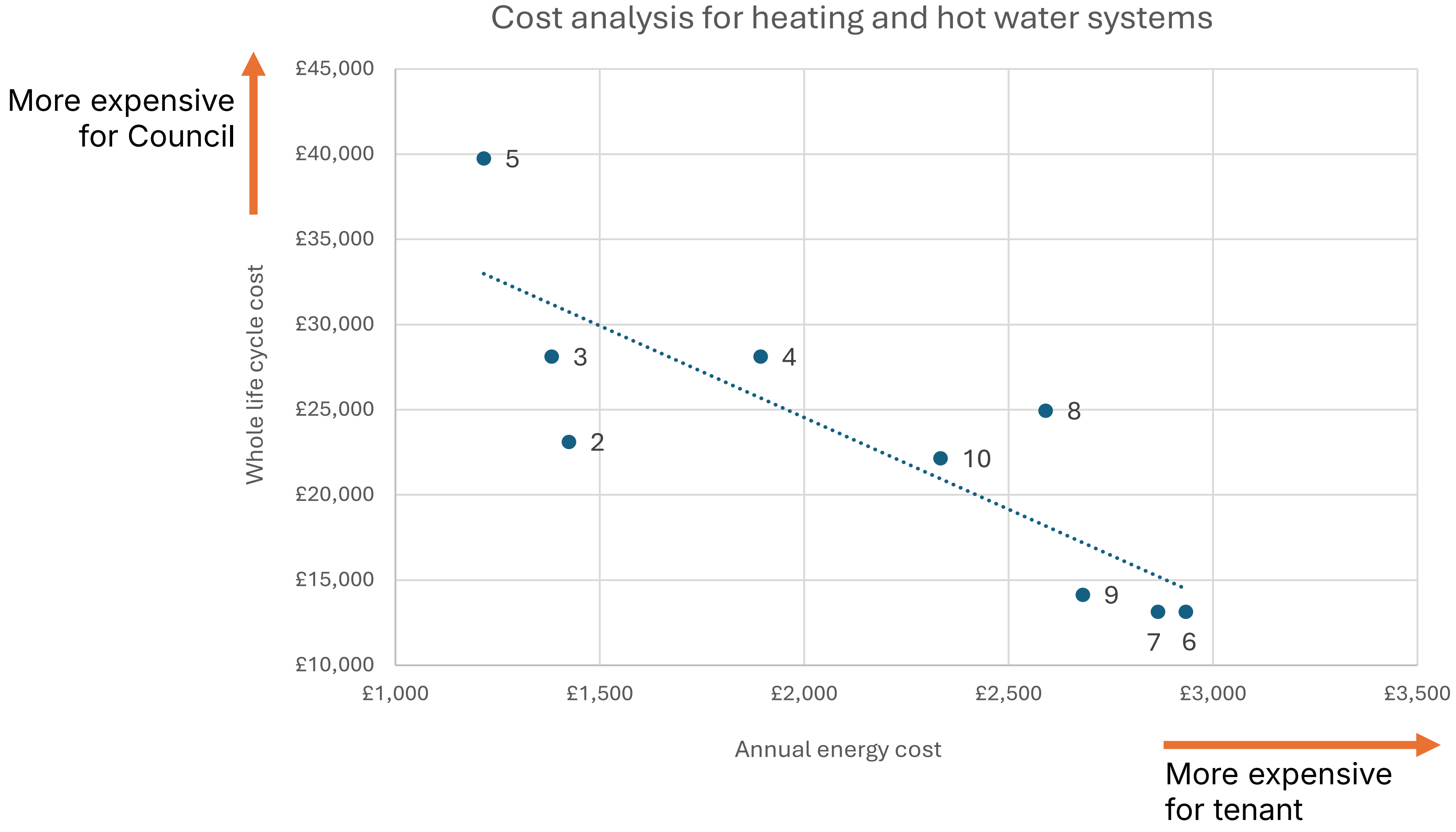


Figure 14: Cost analysis for heating and hot water systems

Table 12: Cost comparison to tenant and to Council

Heating System no.	Heating	Hot water	Heating emitters	Annual energy cost (Property Type 6)	30-year cost to Council (installation, maintenance and replacement)	Total lifecycle costs
HS 2	ASHP - air to water - SCOP average	From heating system - DHW cylinder	Existing wet system - smaller sized radiators and pipework	£1,423	£23,120	£65,810
HS 3	ASHP - air to water – SCOP good	From heating system - DHW cylinder	New system - appropriately sized	£1,381	£28,120	£69,550
HS 4	ASHP - air to water – SCOP bad	From heating system - DHW cylinder	New system - appropriately sized	£1,890	£28,120	£84,820
HS 5	Communal GSHP - ground to water	From heating system - DHW cylinder	New system - appropriately sized	£1,215	£39,750	£76,200
HS 6	Electric radiators and electric panel heaters	Electric immersion - Direct hot water cylinder	Individual heaters	£2,928	£13,150 (£7,650 + £5,500)	£100,990
HS 7	Electric radiators and electric panel heaters	Electric instantaneous point of use & Electric shower	Individual heaters	£2,861	£13,150 (£7,650 + £5,500)	£98,980
HS 8	Electric radiators and electric panel heaters	Solar thermal water heating system	Individual heaters	£2,585	£24,950 (£7,650 + £17,300)	£102,500
HS 9	Infrared radiant panels (modelled through lower temperature)	Electric immersion - Direct hot water cylinder	Individual heaters	£2,677	£14,150 (£8,650 + £5,500)	£94,460
HS 10	High heat retention storage heater (smart)	Electric immersion - Direct hot water cylinder	Individual heaters	£2,329	£22,150 (£16,650 + £5,500)	£92,020

1 Newark Cylinders Heat Geek Mini Store

7. HEATING & HOT WATER SYSTEMS IN FIFE COUNCIL'S STOCK

7.1 SECTION SUMMARY

The following section sets out the existing condition of Fife Council's properties, including heating types and key constraints on installing clean systems. This firstly serves as a baseline to understand the scale of clean heating system installation needed before 2045.

This data helps to indicate which systems are appropriate to install in Fife Council properties. This builds on the property constraints that can affect system suitability identified in previous sections.

Of the systems identified as suitable for installation and for real world analysis, not all are currently installed within existing council properties or are too few to enable gathering of significant data. These 'gaps' are identified. This then leads into the final section of the report, where next steps are identified including which systems are proposed to be installed for monitoring.

7.2 EXISTING HOUSING STOCK

Fife's existing housing stock currently consists of 31,244 properties. The majority, 96%, have polluting heating system. This means by 2045 just under 30,000 properties will require clean heating and hot water systems installed. This information is gathered from the council's own stock data and home analytics.

The following tables show an overview of Fife Council's existing key stock characteristics.

7.3 EXISTING CLEAN HEATING SYSTEMS

A small proportion of the Council's properties already have clean heating and hot water systems. The below tables detail the available heating fuels, installed clean heating systems and details.

Fife Council's housing stock currently has the following clean heating and hot water systems installed:

- Electrical boiler
- Room heaters
- ASHPs
- GSHPs
- Storage heaters

Additionally, around 500 properties are on a communal heating system, assumed to be a communal centralised gas boiler providing heat and hot water to multiple properties. For these properties, the shared heating and hot water source could potentially be decarbonised, with parts of the communal system (e.g. heat distribution) being retained.

For the next step of the project, it is proposed that existing systems be monitored and evaluated to test if they are suitable to installed in further Council properties.

Further details from Fife Council have been provided:

- Electric Heating Company – comprises of electrical panel radiators (dry heating).
- District heating network connection – the Jubilee Grove Housing Complex is on the Glenrothes district heating, and this is currently expanding to the 17 bungalows in Jubilee Grove.
- Storage heaters – no high heat retention (Quantums). The Council indicated they previously had high heat retention storage heaters, but they have been renewed with electric heating (The Electric Heating Company). Data shows properties with storage heaters.
- Infrared heating panels – supplied by Logicor, now Ambion Heating.

Table 13: Council property archetypes

Wall construction group	No. properties	% of stock
Cavity Construction	23,807	76%
Non-traditional or System built	5,459	17%
Timber Frame	1,801	6%
Solid Brick or Stone	177	1%
Total	**31,244**	

Table 14: Council property types

Property type	No. properties	% stock
House	**12,061**	**39%**
Mid-terrace	5,278	
Semi-detached	4,737	
End-terrace	1,929	
Detached	117	
Four-in-a-block flat	**8,042**	**26%**
Ground floor	4,191	
Top floor	3,851	
Flat (stairwell)	**7,363**	**24%**
Ground floor	2,734	
Top floor	2,668	
Mid floor	1,961	
Bungalow	**3,778**	**12%**
Semi-detached	1,421	
Mid-terrace	1,290	
End-terrace	845	
Detached	222	
Total	**31,244**	

Table 15: Council property ages

Age band	No. properties	% stock
Before 1919	116	<1%
1919-1929	36	<1%
1930-1949	7,940	25%
1950-1964	11,538	37%
1965-1975	6,589	21%
1976 -1983	2,083	7%
1984-1991	612	2%
1992-1998	68	<1%
2003-2007	No properties in age band	
1999-2002	126	<1%
2008-2011	103	<1%
2012-2023	1,778	6%
2024 onwards	255	1%
Total	**31,244**	

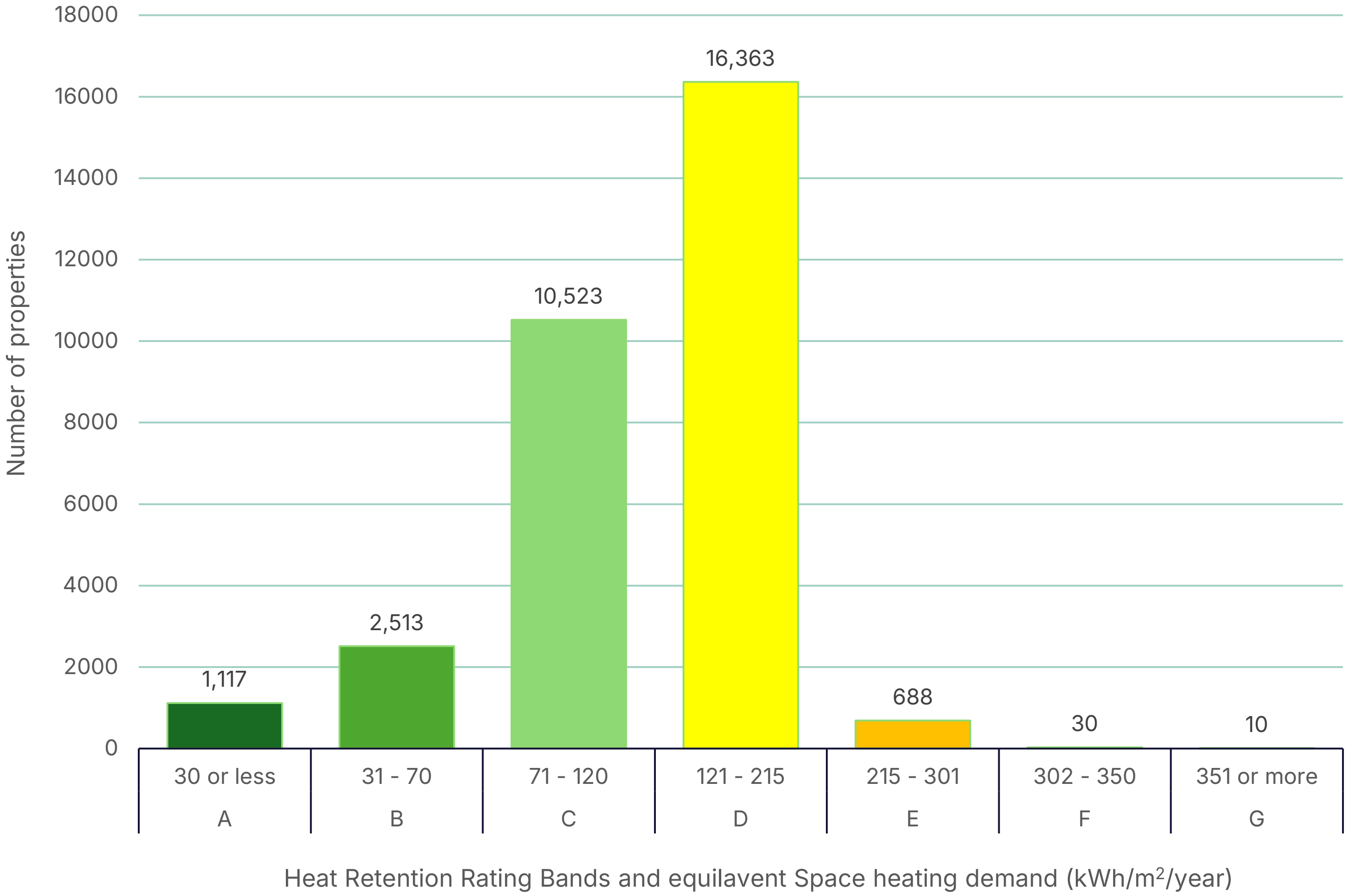


Figure 15: Existing Heat Retention Rating bands of Fife Council properties

Table 16: Fife Council's Housing Stock off gas grid based on postcode[1]

Off gas grid	No. properties
Yes	250
No	30994

Table 17: Fife Council's housing stock existing heating systems

	Heating system							
Heating fuel	Boiler	Community heating	Room heaters	Air source heat pump	Ground source heat pump	Storage heaters	No. properties	Percentage
Mains gas	29,380	515	0	0	0	0	29,895	96%
Electricity	14	0	365	16	9	912	1,316	4%
Solid fuel	32	0	0	0	0	0	32	0%
LPG	1	0	0	0	0	0	1	0%
Total								**31,244**

Table 18: Types of clean heating systems already installed for properties with electricity as a heating fuel

Heating system	No. properties
ASHP	16
Boiler	14
Electric Wet System	9
Electric Combi Boiler	4
Undefined	1
GSHP	9
Room heaters	365
Electrical panel radiators (Electric Heating Company)	188
Infrared System	165
Undefined	8
Electric Fires/Panel Heaters	4
Storage heaters	912

Table 19: Proportion of Solar PV and Solar Thermal in properties by heating fuel type

Solar type	Heating source	No. properties
Solar PV panels	Electricity	34
Solar PV panels	Mains gas	1204
Solar PV panels	Solid fuel	1
Total Solar PV Panels		**1239**
Solar thermal	Electricity	35
Solar thermal	Mains gas	309
Solar thermal	Solid fuel	2
Total Solar thermal		**346**

7.4 FIFE STOCK & SYSTEM SUITABILITY

The appropriate selection of heating and hot water system depends on the characteristics of a property. The technology suitability overview in Section 6 maps the systems and property characteristics which exclude or limit these options. Fife Council's stock data has been analysed to identify property constraints for systems.

Most property constraints affecting heating systems selection are not included in the data, and not included in typical data collected, including internal space constraints and external area. Therefore, property specific surveys will be required to determine the best system for each property.

Property characteristics which are available in the data sets are as follows:

- Within conservation area:
  - 931 properties are within a conservation area.
- Listed property:
  - 189 properties are listed.
- Space heating demand – represented by Heat Retention Rating in the data:
  - 11.4% of properties below 70 kWh/m^2/year – high level of energy efficiency.
  - 33.3% of properties 70-120 kWh/m2/year – good level of energy efficiency.
  - 50.3% of properties 120-200 kWh/m2/year – lower level of energy efficiency.
  - 5.0% of properties more than 200 kWh/m2/year – lower level of energy efficiency.
- Property characteristics which are indirectly available in the data sets are:
- Adequate internal space for equipment such as a cylinder – for example a spare cupboard or storage space. This data is available indirectly through the floor area and habitable rooms.
  - A high percentage of the properties (70.2%) would be classed as space constrained under this calculation method, and 26% of properties would be classed as highly space constrained.
- Occupancy level for DHW demand – heat pumps in homes with a high ratio of hot water to space heating demand will see lower efficiencies. However, analysis of properties' estimated occupancy, produced large ranges which are unable to be used for further analysis at this stage, but are included in the appendix.

Property characteristics which are not available in the data are as below:

- External area availability and size - for siting external ASHP units.
- External ground and condition - to enable drilling or laying of boreholes or ground collectors for use with a GSHP.
- Local electricity grid capacity – areas with a constrained local grid may incur additional charges for upgrading electricity supplies.
- Structural considerations – for weight of equipment such as heat batteries.

Analysis of the above criteria in relation to the Council's properties is detailed in the appendix.

To note, the proposed Social Housing Net Zero Standard sets a minimum level of fabric efficiency (a Heat Retention Rating of a maximum of 120 kWh/m^2/year). It is assumed in this study that fabric measures will be installed to at least the minimum level of compliance, and therefore the energy efficiency of Fife's housing stock will improve over time. This is best if this takes place prior to clean heating systems being sized and installed, which is a 'fabric first' approach.

Space constraints are a key factor that can determine whether clean heating technologies are suitable for a home, since some have different equipment and space requirements compared to existing fossil fuel heating systems. For example, many electric technologies require separate hot water storage, and heat pumps require equipment be placed outside of a home.

A method, for assessing how internally space constrained a property is, was adopted from previous Scottish Government analysis and applied to Fife council's housing stock.[2] This is an indicative method and individual property surveys need to be carried out to determine the location of new services.

A high percentage of the properties (70.2%) would be classed as space constrained under this calculation method, and 26% of properties would be classed as highly space constrained. This suggests that it may be difficult to install technologies requiring additional space (compared to the current system) in these homes, and consideration should be given to space saving technologies.

7.5 STOCK & SYSTEMS GAP ANALYSIS

7.5.1 Gaps within Fife Council's stock

For the next stage of the project, identified clean heating and hot water systems are proposed to be investigated and monitored for real world affects and impacts. These are detailed in the table below and more detail will be provided in the next section of the report.

To carry out a robust analysis, a statistically significant number of properties would need to have systems installed and then monitored. The heating systems shortlisted in this study were compared to current installation in the Council's stock, with several gaps identified. It is proposed that systems not currently installed in the housing stock be prioritised for installation and monitoring in the next phase of the project. This is set out in the next section of the report.

Table 20: Number of the suitable clean systems installed within Fife's housing stock

Selected clean heating and Hot Water system	Provides heating or hot water	Within Council properties
GSHP - ground to water	Heating and Hot water	Yes but minimal – 9 properties
ASHP - air to water	Heating / Heating and Hot water	Yes but minimal – 16 properties
District heat networks	Heating / Heating and Hot water	Yes – minimal properties - Glenrothes district heating supplies Jubilee Grove Housing Complex, and expanding to 17 bungalows
Electric radiators - oil, water-filled or ceramic core	Heating	Yes – assumed Electric Heating Company 188 properties
Electric panel heaters - Convector heaters	Heating	No
High heat retention storage heater (smart)	Heating	Yes – to be checked if smart – 912 properties
Infrared radiant panels	Heating	Yes – 165 properties
Electric immersion - Direct hot water cylinder	Hot water	Assumed yes where room heaters – 1,265 properties
Electric instantaneous at point of use - Water heater	Hot water	Assumed no
Solar thermal	Hot water	Yes – 346 properties

Fife Council indicated that off-gas grid properties would be the most suitable for system installation and monitoring in the next project stage. Existing systems in off-gas grid properties are identified below, to help identify whether new systems should be installed in these for monitoring and analysis.

Table 21: Break-down of Fife Council off-gas grid properties by existing heating type

Heating Type	No. properties
ASHP	10
Boiler - Electric Wet System Boiler	2
Boiler - Solid Fuel	8
GSHP	3
Room heaters	11
Room heaters - Electric Heating Company	9
Room heaters - Infrared System	2
Storage heaters	39

1 Xoserve (2025) Off Gas Postcode Register

2 Scottish Government (2020) Technical Feasibility of Low Carbon Heating in Domestic Buildings - Calculation method taken from a report authored by Element Energy for Scottish Government's Directorate for Energy & Climate Change: Element Energy (2020)

More space constrained – Properties where the floor area per habitable room < $16m^2$

Space constrained – Properties where the floor area per habitable room < $18m^2$

8. NEXT PROJECT STAGE

CeNZ-HighDB

CHANGEWORKS.

8.1 SECTION SUMMARY

This report forms the first stage of a wider project to enable Fife Council to select clean heating and hot water systems and to install these with confidence whilst minimising risk to the Council and tenants.

This report forms a foundation of desktop evidence and analysis. The next stage will build on this research by testing and analysing clean heating and hot water systems in a real-world setting. The aim is to test the conclusions of this report, ensuring expected impacts are achieved.

Installation of technologies will firstly allow monitoring of the expected impacts. In addition, by installing systems the Council can gain familiarity with technologies, including with tenant support and maintenance.

Once real-world testing and analysis has concluded, the Council can develop a clean heating strategy for its stock and identify a clear route to decarbonised heating and hot water systems by 2045.

In this section, pilot projects are identified, following on from the previous section analysing the Council's stock. These pilot projects are based on the technologies identified for further investigations in this report. Alongside this, an impact evaluation framework is set out, which details the possible data and evidence which could be gathered and evaluated for the pilot projects.

Any installations of new systems should be paired with tenant support throughout the process, to ensure optimal use of systems.

8.2 PILOT PROJECT SCOPING

8.2.1 Aims of next stage

The overall project will be approached in stages to understand both the theoretical and practical aspects of heating systems within the council's housing stock. The desktop analysis undertaken in this report will lead to in-situ analysis and monitoring specific to Fife's stock.

These next steps will include:

- Pilot project with installation of identified heating options in properties to allow for a real-world practical evaluation of systems.
- Project management support for specifications, installation and QA of works.
- Impact evaluation and environmental monitoring of pre- and post- installation, to assess the comfort and health of the tenant and property.
- Development of a post-install support service for tenants.
- Assessment of maintenance of systems and development of Fife Council in-house services.

Further steps which can be undertaken on a longer-term scale include:

- Development of a delivery plan to implement project outputs at scale:
    - Programme of clean heating systems installations in council housing stock by 2045, aligned with planned council works including fabric efficiency retrofit.
- Aligned with LHEES and development of heat networks.

8.2.2 Heating and hot water systems to monitor

The key systems to monitor identified by this report are as follows:

- Communal ground source heat pumps (GSHP) - ground to water
- Air source heat pumps (ASHP) - air to water
- Electric radiators
- High heat retention storage heater (smart)
- Infrared radiant panels
- Electric immersion – Domestic hot water cylinder
- Solar panels with batteries or with diverters to hot water immersion to support heating and hot water systems

To note, district heating is also identified as a viable technology. However, installation and connection depends upon the development of individual heat networks and therefore is outside the scope of this project.

The Council indicated that generally if a property can be connected to a heat network, this would be the system selected.

8.2.3 Projects identified for installation

Proposed projects have been scoped based on the gaps within Fife Council's stock identified in the previous section. These projects will be discussed with Fife Council and outlined in more detail, including which properties and addresses. This will be aligned with the fabric efficiency and systems analysis carried out and paired with fabric retrofit where required to mitigate the risk of fuel poverty.

Projects may need to be combined with fabric measures where properties do not meet the proposal minimum SHNZS.

Proposed installation projects are:

1. Communal GSHP systems with shared ground loop system in low-rise flats. There has so far been little experience with this approach in Scotland, which potentially offers a more flexible solution for high-density buildings. This project would provide an opportunity to test a solution that is likely to form the focus of upcoming LHEES updates.
   - Properties with existing communal gas boilers would be appropriate for this communal system.
2. ASHPs – installation in a range of property types of different sizes and fabric efficiency, with a focus on achieving high real-world efficiencies. Existing UK field trials have focussed on owner-occupied housing and there is a need to establish that heat pumps can be operated efficiently (and therefore cost effectively) in social housing. This pilot could test innovative approaches to procurement and installation (ensuring good system design and installation) and tenant support to determine how a larger scale roll-out could be completed successfully in Fife.
   - As energy costs should be comparable or lower than gas, ASHPs could be installed in properties with gas combi boilers.
   - Properties could be compared where the distribution system is replaced and where it is retained to check if capital cost savings offset loss of efficiencies in the system.
   - As analysis of Council properties indicated a majority are internally space constrained. Innovative and space saving solutions such as reverse cylinders[1] and heat batteries could be installed and tested.
3. High Heat Retention storage heaters: new installations and retrofit of smart controls
   - Installation of HHR smart storage heaters in properties unable to have ASHPs fitted.
   - Older storage heaters retrofitted with smart controls.
   - To note, Fife Council previously installed storage heaters in a large number of properties. However, the Council has been replacing these with other systems.
4. Although not explored in depth within the research, solar diverters to hot water cylinders could provide a way to use excess power generated without the capital cost of battery storage.
   - Of the 1239 properties with solar panels and the ones without batteries, solar diverter could be installed and compared with properties with existing solar panels and batteries.

8.3 IMPACT EVALUATION FRAMEWORK

8.3.1 Purpose of impact evaluation

In order to monitor the outcomes of the installed heating and hot water systems and compare against the research and analysis in this report, and compare between the technologies, key data needs to be collected.

The following framework details the range of data which can be collected for the next stage of the project. This includes data on systems already installed in properties and systems to be installed.

Once projects have been fully scoped and decided by Fife Council, the framework will be applied to individual projects. This entails refining what data is to be collected based on technology, practical limitations and budget.

To note, installation of heating and hot water options rely on properties at a minimum meeting the Social Housing Net Zero Standard fabric efficiency and being identified by Fife Council as not planning to have further fabric retrofit measures. This aligns with analysis of heating system switch being based on a fabric first approach.

Table 22: Impact Evaluation framework

Objective	Indicators	Timeframe (post-install)	Data and sample targets	Data source / collection methods
Improved or maintained comfort for tenants				
Allow for comparison of fabric efficiency rating between properties with different systems installed	Modelled fabric efficiency rating or space heating demand following retrofit works Floor area of a property	3-6 months	Post-retrofit RdSAP worksheet or EPC for 100% of retrofitted properties	Post-installation EPCs (Project Records)
Good thermal comfort for tenants (temperature, temperature stability)	Tenants' perceptions of thermal comfort	9-12 months	Self-reported via surveys shared with 100% of tenants	Tenant engagement (surveys or focus group / interview with 10% of tenants)
	Proportion of days where relevant heating regime and recommended average temperatures are achieved (sample)	9-12 months	Post-installation internal and external temperature in a sample of 10% of retrofitted properties	Environmental monitoring
Good internal air quality - humidity	Tenants' perceptions of internal air quality	9-12 months	Self-reported via surveys shared with 100% of tenants	Tenant engagement (surveys or focus group / interview with 10% of tenants)
	Proportion of days where healthy relative humidity achieved (sample)	9-12 months	Post-installation relative humidity in a sample of 10% of retrofitted properties	Environmental monitoring
Good internal air quality – ventilation and CO_2	Tenants' perceptions of internal air quality	9-12 months	Self-reported via surveys shared with 100% of tenants	Tenant engagement (surveys or focus group / interview with 10% of tenants)
	Proportion of days where healthy CO_2 levels achieved (sample)	9-12 months	Post-installation CO_2 in a sample of 10% of retrofitted properties	Environmental monitoring
Effective ventilation systems	Number of ventilation systems (existing or installed) quality assured	3-6 months	Installation and quality assurance figures for 100% of retrofitted properties	Council records
Allow for comparison between properties with different systems installed	Number and type of ventilation systems (existing or installed)	3-6 months	Installation and quality assurance figures for 100% of retrofitted properties	Council records
Ease of operation for tenants, including requirements for digital technology and skills	Tenant perceptions of ease of use	3-6 months	Self-reported via surveys shared with 100% of tenants	Tenant engagement (surveys or focus group / interview with 10% of tenants)

Impact on tenant energy bills and levels of fuel poverty				
Households switching to clean heating do not pay more for energy	Tenants' perceptions of energy costs Actual bill amounts	9-12 months	Self-reported perceptions of bills and affordability via surveys shared with 100% of tenants Billing or smart meter data (minimum 10% sample)	Tenant engagement (surveys or focus group / interview with 10% of tenants) AND/OR Mandates or Tenants supported to provide energy data
Tenants do not become fuel poor as a result of clean heating installations	Tenants' perceptions of energy costs Actual bill amounts	9-12 months	Self-reported perceptions of bills and affordability via surveys shared with 100% of tenants Billing or smart meter data (minimum 10% sample)	Tenant engagement (surveys or focus group / interview with 10% of tenants) AND/OR Mandates or Tenants supported to provide energy data
Overall impact on annual energy consumption	Annual energy consumption (sample)	9-12 months	Billing or smart meter data (minimum 10% sample)	Tenant engagement (mandates or supported to provide energy data)
Tenants supported to manage energy use and utilise new technologies effectively	Tenant trust and have confidence in using energy systems	3-6 months	Self-reported via surveys shared with 100% of tenants	Tenant engagement (surveys or focus group / interview with 10% of tenants)
	Number of resolved tenant complaints about energy systems	12 months	Records of tenant communications	Council service records
Reduction in self-disconnection	Incidences of self-disconnection	12 months	Self-reported via surveys shared with 100% of tenants Records of tenant communications	Tenant engagement (surveys or focus group / interview with 10% of tenants) and other tenant feedback (Council service records)
Integration with time of use tariffs	Reported tariffs Actual energy bills	9-12 months	Self-reported via surveys shared with 100% of tenants Billing data (minimum 10% sample)	Tenant engagement AND/OR Mandates or Tenants supported to provide energy data
Reduction in carbon emissions				
Overall decrease in carbon emissions as a result of tenant energy use	Energy consumption	9-12 months	Billing or smart meter data (minimum 10% sample)	Tenant engagement (mandates or supported to provide energy data)
Impact on installers / maintenance teams				
Ease of installation	Reported ease of installation	3 months	Installation reports Interviews with sample of installers	Council records, including property surveys, project progress meeting notes AND/OR Installer interviews
	Increases in installation costs (indicating installation difficulties)	3 months	QS reports	Council records
Ease of maintenance	Reported ease of maintenance	3 months	Maintenance reports and/or call-out records Interviews with sample of maintenance teams	Council records AND/OR Maintenance team interviews
Cost implications				
Acceptable cost of systems and installation	Actual capital costs Cost of labour	3 months	QS reports Timesheeting / labour reports Interview with sample of council teams	Council records, including QS reports AND/OR Council team interviews
Acceptable life cycle costs	Actual capital costs (including replacements) Actual maintenance and labour costs Lifespan of system and components	Prior to installation	QS reports Timesheeting / labour reports Manufacturer data sheets	Council records

8.4 TENANT SUPPORT

8.4.1 Outcomes

As part of the next steps, supporting tenants will be key. Where new systems are installed as part of the next stage of the project, to ensure that hot water and heating systems work as efficiently as possible, tenants should be supported.

A tenant support service could provide information about new technologies, energy tariffs, supplier changes and cost-effective use of systems. Additionally, there should be tenant engagement events and outreach as part of any project prior to and during the construction phase.

The common challenges for tenants after new heating and hot water systems are installed are:

- **Optimising settings**: Tenants are often unfamiliar with how to best operate or use zero emission heating systems and solar panels and require support to ensure that the systems reduce their energy bills. Tenants should be supported to fully understand and used their systems.
- **Switching to the right tariff**: When tenants receive a new system, they could lack the knowledge of which tariff to be on and how to change this. Early intervention advice can ensure that tenants' tariffs are appropriate and reduces cost.

Early and ongoing support reduces the challenges of new technologies and helps achieve positive long-term outcomes for tenants. As part of the delivery of pilot projects, an approach can be developed that will look to address support for new tenants to properties.

1 Newark Cylinders (date unknown) Heat Geek Mini Store

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9.0.2Summary sheet key references

Technology	Key claim supported	Evidence summary	Link
Electric Immersion / Direct Cylinder	Direct electric heating → high running costs and higher fuel-poverty risk (vs gas)	Analyses households with electric heating; shows many electric-heated homes have lower income / higher fuel poverty exposure and higher bills.	Ofgem (2015) Insights paper on households with electric and other non-gas heating Nesta (2025) Domestic heating technology options
	Immersion + PV (smart immersion) materially improves DHW economics vs grid-only	EST explains PV can be used to run immersion elements (smart controllers) to reduce running costs for hot water.	Energy Saving Trust (date unknown) Solar panels Energy Saving Trust (date unknown) Solar water heating
Electric Immersion / Direct Cylinder	Feasibility / load / network constraints for electric heating solutions in off-gas homes	Technical and cost evidence for electric options (storage, immersion, point-of-use), including network/load constraints and where PV/ storage helps.	BEIS (2019) Evidence gathering of electric heating options in off gas grid homes: Final Report
Electric Instantaneous (Point-of-Use)	Very high instantaneous electrical load (6–12 kW) and limited flow → often unsuitable for multi-outlet homes	Modelling and analysis show point-of-use units have high kW draw; multiple units can overload household circuits in older stock.	BEIS (2019) Evidence gathering of electric heating options in off gas grid homes: Final Report (see sections on hot water)
	No stored water → reduces legionella risk but gives no ability to absorb PV generation	MCS site lists installation standards; EST explains storage vs instantaneous trade-offs (storage may integrate with PV).	MCS (date unknown) Standards & Tools Library Energy Saving Trust (date unknown) Solar water heating
High Heat Retention (Smart) Storage Heater	Reliant on off-peak/ differentiated tariffs (Economy 7 / smart) for cost-effectiveness	Storage heaters designed to charge at cheaper tariffs; the economics depend on access to time-of-use pricing and correct programming.	BEIS (2019) Evidence gathering of electric heating options in off gas grid homes: Final Report Ofgem (2015) Insights paper on households with electric and other non-gas heating
	Need for tenant programming & user support — mis-programming causes poor performance / high bills	PAS 2035 emphasises occupant engagement, commissioning and controls to ensure systems deliver intended savings.	UK Government (2023) PAS 2035:2023 Retrofitting dwellings for improved energy efficiency – Specification Guidance

Infrared Radiant Panels	Infrared best for spot/top-up heating; limited value as a large whole-house heating in poor fabric homes	BEIS evaluation lists IR as a niche/spot option; Nesta pilot reports show comfort gains but limited whole-house scalability.	BEIS (2019) Evidence gathering of electric heating options in off gas grid homes: Final Report Nesta (2023) Adopting intelligent infrared heating technologies in social housing Local Energy Scotland (date unknown) Glasgow's Infrared Heat Demonstration Project University of Strathclyde (2023) Electric wallpaper among projects powering a net zero future in Scotland
	Running cost vs ASHP (whole-house) - IR can be more expensive at scale	Comparative analyses indicate resistive IR cannot match heat-pump efficiency for whole-house heating.	Catapult (2025) Electrification of Heat Decarbonisation Project
Electric Panel / Convector / Radiator Heaters	Low capex but high operating costs; considered short-term/fallback in decarbonisation plans	PAS 2035 / SHDF guidance and Ofgem highlight that new direct resistance installs are not preferred long-term due to running cost and fuel poverty risk.	PAS2035: UK Government (2023) PAS 2035:2023 Retrofitting dwellings for improved energy efficiency – Specification Guidance SHDF: UK Government (2023) Social Housing Decarbonisation Fund Wave 2.2 Ofgem (2015) Insights paper on households with electric and other non-gas heating
Electric Radiators (oil/ water/ceramic)	Slightly better retention/ comfort than convectors but still expensive compared with gas/heat pumps	BEIS compares direct electric options; NEA and consumer orgs report higher operating costs for electric vs gas and urge caution re fuel poverty.	BEIS (2019) Evidence gathering of electric heating options in off gas grid homes: Final Report NEA fuel poverty: NEA (2023) UK Fuel Poverty Monitor 2022-23
ASHP	ASHPs can deliver high seasonal performance (COP/SPF) if correctly sized and paired with low flow emitters; sensitive to design/ commissioning	Real-world rollout monitoring (700+ installs) shows performance heavily dependent on design, emitter sizing, flow temps and fabric.	Catapult (2025) Electrification of Heat Decarbonisation Project
	Noise & siting issues and tenant education required for effective operation	BEIS/SHDF guidance and field reports note complaints from poorly sited units and the need for tenant induction/ training.	UK Government (2023) Review of Air Source Heat Pump Noise Emissions, Permitted Development Guidance and Regulations
Ground Source Heat Pump (GSHP)	GSHPs achieve high COPs in monitored schemes; strong for rural/grouped housing but require ground access and higher capex	RHI monitoring and Net Zero Hub / Midlands case studies report good GSHP performance and highlight ground-access and disruption constraints.	RHI monitoring: GRAHAM Energy Management (2018) Monitoring of Non-Domestic Renewable Heat Incetive Ground-Source & Water -Source Heat Pumps Final Report UK Government (2023) Evaluation of the reformed Renewable Heat Incentive Changeworks (date unknown) Ground source heat pump

District Heat Networks	Efficient at scale but governance, metering and billing issues can undermine consumer outcomes	BEIS qualitative research and GOV.UK guidance document consumer/ operator issues, metering regulation, and the need for SLAs/backup.	Consumer research: UK Government (2018) Qualitative research with consumers and operators of heat networks Guidance: UK Government (2014) Guidance Regulations: heat networks (metering and billing)
	SHDF & BEIS see heat networks as strategic for dense estates if heat is decarbonised	SHDF documentation supports estate-scale approaches; BEIS policy positions heat networks as strategic where decarbonised heat is available.	SHDF: UK Government (2023) Social Housing Decarbonisation Fund Wave 2.2 BEIS heat networks collection: UK Government (2016) Collection Heat networks Energy Transitions Commission (2025) Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible
Solar Thermal Water Heating	Solar thermal provides renewable DHW but low winter yield; requires cylinder & backup immersion	EST explains solar thermal performance profile and need for backup; useful in summer but limited in winter without backup.	Energy Saving Trust (date unknown) Solar water heating
Solar Thermal	PV + immersion economics now often outperform solar thermal; sector reports show declining standalone viability	SolarEnergyUK and others show PV + storage/immersion is often a better option financially and operationally than standalone thermal in many UK cases.	Solar Energy UK (2022) The Value of Solar Heat Energy Transitions Commission (2025) Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible
Fabric-first importance	Insulation and airtightness are critical for any low-carbon heating tech to be effective	PAS 2035 mandates a fabric-first approach in retrofit planning; SHDF guidance prioritises achieving EPC C and fabric upgrades before heating changes.	PAS2035 : UK Government (2023) PAS 2035:2023 Retrofitting dwellings for improved energy efficiency – Specification Guidance SHDF: UK Government (2023) Social Housing Decarbonisation Fund Wave 2.2 UK 100 (2022) End Social housing energy efficiency and the energy crisis
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Our own tech summary sheets and risk register	Other sections		Technology Summary Sheets & Risks

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10 APPENDIX

CeNZ-HighDB

CHANGEWORKS.

10.1 FOCUS GROUP ANALYSIS: HEATING OPTIONS FOR FIFE COUNCIL

This section synthesises the findings from two focus groups: one with local authorities and housing associations (LA/HA) and one with consumer groups. It is organised under the headings set out in the topic guides: system selection and design, usability and common issues, perceptions of new systems, tenant support and behaviour, and cross-cutting themes.

10.1.1 Themes in the Local Authority and Housing Association Group

Heating System Selection, Specification, and Design

- Several housing providers reported that the vast majority of their stock remains on mains gas (around 90–95% for Fife Council), with smaller numbers of properties heated by, heat pumps, electric storage systems, electric boilers, oil and coal. Some properties, particularly off-gas, have had air source heat pumps (ASHPs) installed. While ASHPs were increasingly used in new builds, retrofits were often described as problematic, with higher rates of breakdown and tenant dissatisfaction.
- Earlier experiments with ground source heat pumps (GSHPs) were characterised as unsuccessful, although technology has improved since those pilots. Other trials included infrared heating (in high-rise blocks) and electric boilers, though the latter were judged costly and inefficient. Several local authorities are also piloting solar panels with diverters and battery storage, though results were mixed.
- Selection is influenced by property type and quality/ condition, e.g., ASHP more suitable for new builds. Further, upfront capital and running costs of tech, tenant affordability, integration with insulation of property and carbon targets were also common important variables.
- Comfort levels for tenants were also critical when selecting a system, as participants noted that fuel poverty risk and cheaper bills often outweighed carbon reduction as the immediate concern for tenants. One participant noted that 'carbon emissions are not the problem of social housing.'
- Participants noted that whilst technically electric storage and quantum heaters were effective, they would immediately put tenants at risk of fuel poverty as gas prices are approximately three times cheaper than electricity. They acknowledged that whilst ASHP in theory offer the same efficiency and cost savings as gas, they do not work for high rise buildings.
- Having a robust maintenance system in place before installing any technology was also deemed important for system selection. Participants noted that servicing a boiler is considerably cheaper and that it easier to find qualified servicemen for gas boilers, when compared to emerging/ newer technologies such as ASHPs. Warranties were not a major concern when selecting a system as manufacturers can often be flexible with this, however, oftentimes manufacturers will send parts to repair/ service systems but will not include labor.
- Participants noted that they are guided by EESH2 and EPC reform. This presents a 'catch 22' as the EPC score for gas is better than it is for electricity.
- For design considerations, the quality of building fabric was seen as more critical than size of the property. Participants warned against over-reliance on manufacturer performance/ lifespan data, which may be overstated.
- Ensuring usability for tenants was considered vital for the success of technology; For example, participants noted that tenants commonly only heated one room in their property or switched off one of their storage heaters to try and save money, which drained the capacity from the remaining storage heater and led to high bills and low heating outputs. Furthermore, tenants often misused the controls on ASHP as they didn't understand leaving the technology on continuously. Similarly, participants noted that tenants with battery systems couldn't understand why the batteries needed to be charged to function, so switched off the batteries due to fear that their electricity was being 'stolen'. This then kills the battery, which leads to high costs to get them recommissioned. One participant noted that this usually occurs over winter, which leads to a large number of batteries being recommissioned in the spring. This is particularly problematic in rented properties, where there has been a change of tenancy.

Installation Challenges

- Access and disruption were a consideration, as gaining entry to homes was a common barrier with some tenants refusing installations due to distrust or inconvenience.
- Property constraints were also noted, as internal space for hot water cylinders was limited, especially where gas conversions had previously removed storage. External siting for ASHPs caused disputes in shared blocks or gardens.
- Technical barriers were also mentioned, such as problems with metering complications (e.g. off-peak, RTS switch-off) and grid capacity, which limited PV rollouts.
- Skills and supply chains considerations were also critical as local authorities struggled to find contractors and maintainers for ASHPs, with higher costs than gas servicing. Some councils trained in-house staff to address this.

Tenant Experience

- Tenants were generally wary of change, often distrustful of unfamiliar systems.
- Complex controls caused widespread confusion. Problems included tenants misusing "boost" settings, switching off systems, or expecting ASHPs to perform like boilers.
- New tenants often inherited systems without adequate instruction, leading to further misuse. This was noted as an issue with electric heating, where tenants were given an iPad to control their heating which they didn't understand.
- Older residents found digital controls particularly difficult. Some tenants heated only one room, worsening damp and condensation issues.
- Digital/ online resources are available to support tenants with heating systems, however this absence of face-to-face contact has led to acute issues for elderly residents who are less digitally literature and thus struggle more.
- Younger residents were also noted to be more 'apathetic' and struggle with mental health issues which prevented them from addressing issues with heating systems.
- Installers provided initial guidance, but follow-up was inconsistent. Sometimes tenants would have systems installed/ serviced and would be told to leave the controls, rather than explained what/ why their settings were set up. Some support came from housing officers or Home Energy Scotland, though capacity was limited.
- There were common concerns with solar PV, as several participants noted that tenants who did not

fully understand the system would turn them off to avoid unexpected charges.

- Some participants had in-house resources to support tenants with their heating systems e.g., customer liaison teams or online resources. However, usually in-person support was restricted to first-time installs. Beyond this, housing officers would be the point of contact. Others have contacts through Scottish Power, but this is again usually reserved for the point of install.

Barriers and Opportunities

- High upfront costs and lack of funding were major barriers.
- Retrofitting ageing, leaky housing stock was seen as particularly challenging.
- Participants again cited regularly shifting standards and lack of clarity in national policy as barriers to long-term planning. EPC scoring was highlighted as an issue, as current metrics often favour gas over electricity.
- Opportunities included hydrogen trials, geothermal schemes, and sea/mine water heating. GSHPs and solid-state ASHPs without external units were identified as promising for high rise flats, although they are large and noisy. Solar diverters and batteries showed benefits, however, had usability and cost challenges.
- Geothermal villages were also suggested for areas that had dense granite deposits. However, it was also noted that this can be challenging in areas where social housing providers do not own all of the properties.

10.1.2 Themes in the Consumer Group

Usability and Common Issues

- Tenants are often introduced to properties via tenancy officers and often have challenges that aren't included in a tenancy pack/ handover.
- Tenants often misunderstood heating controls, tariffs, or storage heaters, leading to high bills.
- Metering issues, especially after the RTS switch-off, created widespread problems with understanding systems.
- Long queues from change from meters to smart meters, in combination with RTS is causing issues for tenants. This is being compounded by smart meter targets, which are leading to issues for tenants who don't have suitable support mechanisms in place.
- Refugees, asylum seekers, and non-English speakers struggled most due to lack of effective support. Prefer warmer indoor climates and don't understand how system operates. This requires call-out charges, as well as translation services. Digital tenancy packs not useful to tenants where English is not their first language.
- The installation process is too siloed – need education and support to be right from the start (manufacturer stage) rather than 6-month post installation when problems arise.

Perceptions of New Systems

- Most common belief is that they're not as effective and more expensive. Participants noted that more work needs to be proactively done to show the benefits of these technologies.
- RSLs see transition to low carbon systems as a 'duty rather than a benefit'
- New systems were frequently seen as imposed rather than chosen, creating resentment.
- District heating schemes were reported to have led to sharp cost increases, undermining trust.
- Solar PV was perceived as tokenistic or ineffective, while heat pumps were often misused or misunderstood. Wider misinformation about net zero and smart meters contributed to scepticism.

Support and Behaviour Change

- Early, tailored support was identified as essential. Positive examples such as Changeworks' 'Energy Confident New Tenants' service demonstrated the value of early-stage and regular engagement. Option for further in-depth calls or visits are given as an option.
- Energy support often comes too late, reinforcing negative perceptions.
- Without early, proactive engagement with consumers to explain why new systems are being installed, what they are, how they work etc, the effectiveness of low carbon systems will be significantly undermined. One way to achieve this is to frame as the solution to fuel poverty by taking consumers on the customer journey.
- Participants emphasised the need for myth-busting and clear communication of both how and why new technologies are introduced.
- Vulnerable groups (migrants, disabled/ long-term-illness, elderly) disproportionately impacted by fuel poverty.

10.1.3 Consistent Themes Across Both Groups

Complexity and Understanding

Both groups identified usability as a major challenge. Overly complex controls and lack of clear education led to misuse and dissatisfaction across heating options, for both established and emerging technologies. Responsibility for tenant support was often unclear.

Affordability and Fuel Poverty

Concerns about fuel poverty were central. Housing providers sought to balance affordability with carbon targets, while consumer groups emphasised unaffordable bills as a result of electric heating systems as an inevitable reality. Tariff mismatches and lack of consistency in advice messaging were also highlighted as an issue by both groups.

Perceptions and Trust

Both groups reported tenant distrust of low-carbon technologies, often viewed as imposed rather than beneficial. Negative experiences with ASHP, solar PV and storage heating systems were most common.

Diversity of Stock and Tenants

Participants agreed that no single heating solution suits all properties or tenants. Diverse stock types and tenant needs require tailored approaches for both installation and ongoing support. Such support requires consultation with tenants and consumers at every stage of the customer journey, including early pre-selection engagement, installation support and ongoing advice provision post-installation.

Policy Context

Race to meet targets e.g., smart meter/ EPC reform, means that fabric first approach is now a secondary consideration to the installation of new systems. This has negative consequences for tenants by limiting the efficiency of systems, increasing the risk of fuel poverty, and increasing the likelihood of damp, mould and health issues. This is especially noticeable with ASHP, particularly when meters/ tariffs haven't been changed as part of the installation process.

10.2 LONG LIST MERIT FIGURE WEIGHTING

The following table sets out the Merit Figure for each technology from the long list, as determined by the Multi-Criteria Decision-Making (MCDM) and Analytic Hierarchy Process (AHP).

∗Adjustment via re-run method: To account for this bias, the analysis was re-run under a *place-based approach* where heat networks and other community-scale technologies are assessed in their proper context. This provides fairer scoring when technologies are applied *at scale* (e.g., neighbourhoods, estates, or urban regeneration projects).

Interpretation - Single-house basis (excluding heat networks): Initial scoring and comparison are done for *individual dwellings*, assuming standalone heating systems. District and ambient-loop heat networks are excluded here because they are designed for multi-dwelling or community-scale applications. This creates a disadvantage for large-scale systems when compared directly with single-house solutions. A hydronic system has been assumed as the pre-retrofit heating system. As this is for social housing, we are assuming no funding available.

Used as designed: Each technology is assessed based on its intended application (e.g., panel heaters for room-by-room use, GSHPs for hydronic systems, district heating for high-density housing or areas of large space). This avoids misrepresenting performance by comparing technologies outside their design.

Note: Running costs must be inverted for normalisation, as a low value is desirable in this single case.

Table 23: Long-list weighting

Alternative	Merit Figure
Direct acting electric boiler - Electric flow boiler	0.65
Direct acting electric boiler - Electric combi boiler	0.65
Storage electric boiler - Electric system boiler	0.68
Electric boiler - Electric Combined Primary Storage Unit (CPSU)	0.63
Electric boiler - Dry core storage boiler	0.69
Electric boiler - Microwave boiler	0.32
Electric immersion - Direct hot water cylinder	0.79
Thermal heat battery	0.69
Electric instantaneous at point of use - Water heater	0.73
High heat retention storage heater (smart)	0.72
Slimline storage heaters	0.69
Conventional / traditional storage heater	0.69
Combination storage heater	0.71
Fan assisted storage heater	0.71
Infrared radiant panels	0.70
Infrared radiant film / wallpaper	0.60
Electric panel heaters - Convector heaters	0.75
Electric radiators - oil, water-filled or ceramic core	0.76
Resistive Fan heaters	0.66
Electric underfloor heating	0.60
Electric warm air system	0.48
Air source heat pumps (ASHP) - air to water	0.74
Air source heat pumps (ASHP) - air to air	0.71
Ground source heat pumps (GSHP) - ground to water	0.72
Water source heat pumps (WSHP) - water to water	0.63
Exhaust Air Source Heat Pump - air to water	0.70
∗District heat network for heating	0.69
∗District heat network for hot water	0.69
∗District heat network for heating and hot water	0.73
∗Ambient loop heat network	0.68
Solar thermal water heating system	0.72
Hydrogen boiler (individual)	0.44
Biomass boiler	0.00
Biofuel boiler	0.58

10.3MODELLED KEY ASSUMPTIONS

Table 24: Energy costs used for modelling

Costs	
Electricity price per kWh	£0.26
Electricity daily standing charge	£0.62
Gas price per kWh	£0.06
Gas daily standing charge	£0.30

Day/Night Tariff for storage heaters	
Day	£0.30
Night	£ 0.14

10.4 HEATING & HOT WATER SYSTEMS IN FIFE COUNCIL'S STOCK

The below tables set out key existing conditions and constraints within Fife Council's stock, as discussed in Section 7.

10.4.1 Planning constraints

Table 25: Council properties in a conservation area

Property in a conservation area	No. properties
Yes	931
No	29,843
Unknown	470

Table 26: Listed Council properties

Listing	No. properties
A	4
B	92
C	93
Not listed	30583
Unknown	472

10.4.2 Existing fabric energy efficiency

Table 27: Council property heat retention rating, derived from SAP space heating demand:

Heat Retention Rating - kWh/m²/year	Equivalent fabric efficiency rating scale	No. properties	%
0-70	Very good to good	3572	11.4%
70-120	Good to average	10409	33.3%
120-200	Average	15727	50.3%
200-300	Poor	1536	4.9%
300-500	Very poor	41	0.1%

To note, the proposed Social Housing Net Zero Standard sets a minimum level of fabric efficiency (a Heat Retention Rating of a maximum of 120 kWh/m²/year). It is assumed in this study that fabric measures will be installed to at least the minimum level of compliance, and therefore the energy efficiency of Fife's housing stock will improve over time.

Table 28: Heat Retention Rating EPC Band Scale (as per EPC Reform)

EPC Bands	Heat Retention Rating (kWh/m²/year)	Basis (level of energy efficiency)
A	30 or less	High level
B	31 - 70	High level
C	71 - 120	Good level
D	121 - 215	Lower level
E	215 - 301	Lower level
F	302 - 350	Lower level
G	351 or more	Lower level

10.4.3 Space constraints

Table 29: Analysis of adequate internal space for installation of heating and hot water systems

Space constraint level	Percentage of stock
More space constrained	26.0%
Space constrained	44.2%
Less space constrained	29.8%

10.4.4 Estimated occupancy

Table 30: Number of habitable rooms and maximum occupancy as calculated from Fife Council's Occupancy Entitlement [1]

No. habitable rooms per property	Typical occupancy range	No. properties
1	1	4
2	1-2	433
3	1-4	7238
4	2-6	14554
5	3-6+	7131
6	4-6+	1671
7	5-6+	197
8	6+	7
9	7+	9

To note, habitable rooms include bedrooms, sitting rooms and kitchen-diners. However this does not include smaller kitchens without space for seating. Therefore a property with 3 habitable rooms could be a 2 bedroom property with a sitting room and separate smaller kitchen or a 1 bedroom property with a sitting room and a kitchen-diner.

This definition of habitable rooms, plus Fife Council's Occupancy Entitlement calculation means there is a range of the numbers of occupant expected in properties if relying on the available data.

1 Fife Council (2022) Housing allocations policy

10.5 MODELLED PROPERTY TYPES AND HEATING SYSTEMS

10.5.1 Modelling Outputs

The following graphs show the results of energy modelling of the following property types, and heating and hot water systems.

Table 31: Modelled property type key characteristics

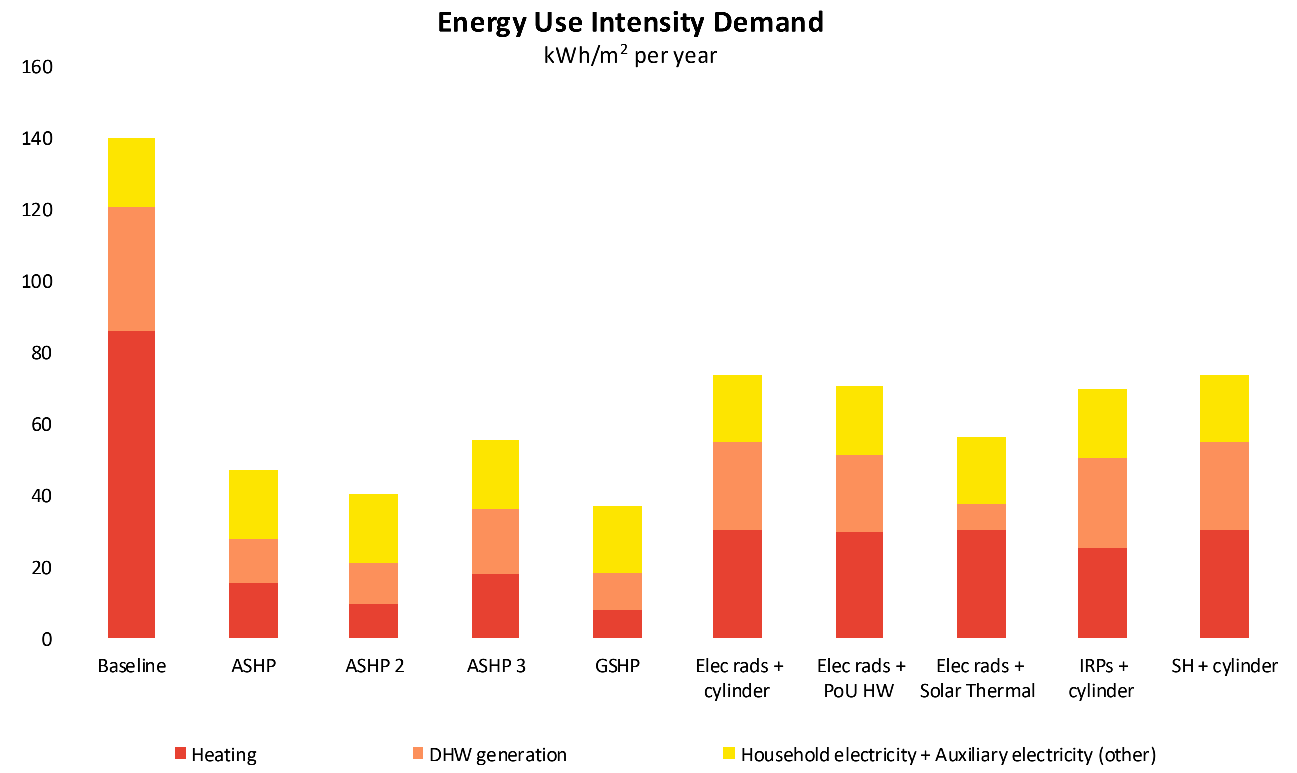
Property type no.	Space heating demand kWh/m²/year	Equivalent HRR Band	Fabric efficiency description	Floor area (m²)	Property size description
PT 1	30	A	Very Good	75	medium
PT 2	70	B	Good – Very Good	50	small
PT 3	70	B	Good – Very Good	75	medium
PT 4	70	B	Good – Very Good	100	large
PT 5	95	C	Good	50	small
PT 6	95	C	Good	75	medium
PT 7	95	C	Good	100	large
PT 8	120	C	Average	50	small
PT 9	120	C	Average	75	medium
PT 10	120	C	Average	100	large
PT 11	220	E	Poor	75	medium

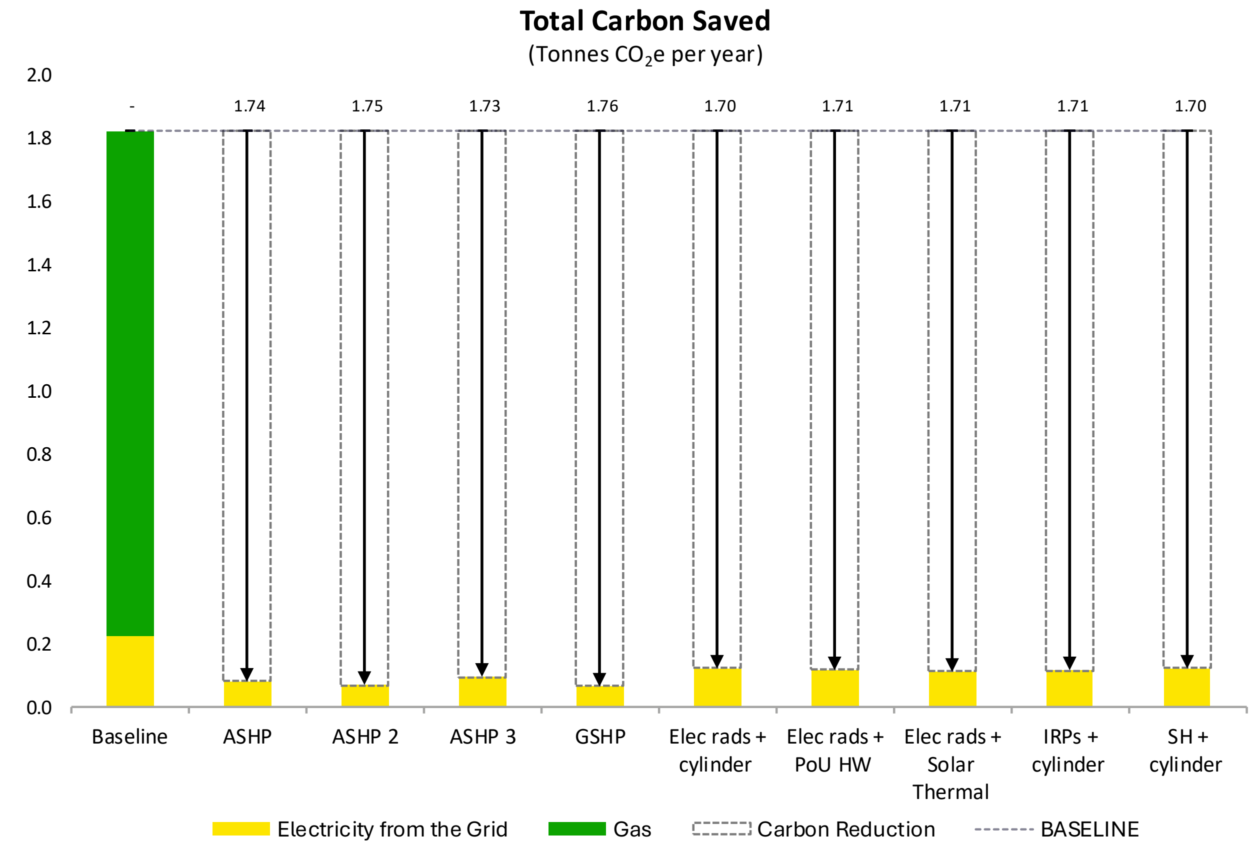
Table 32: Modelled heating systems key characteristic

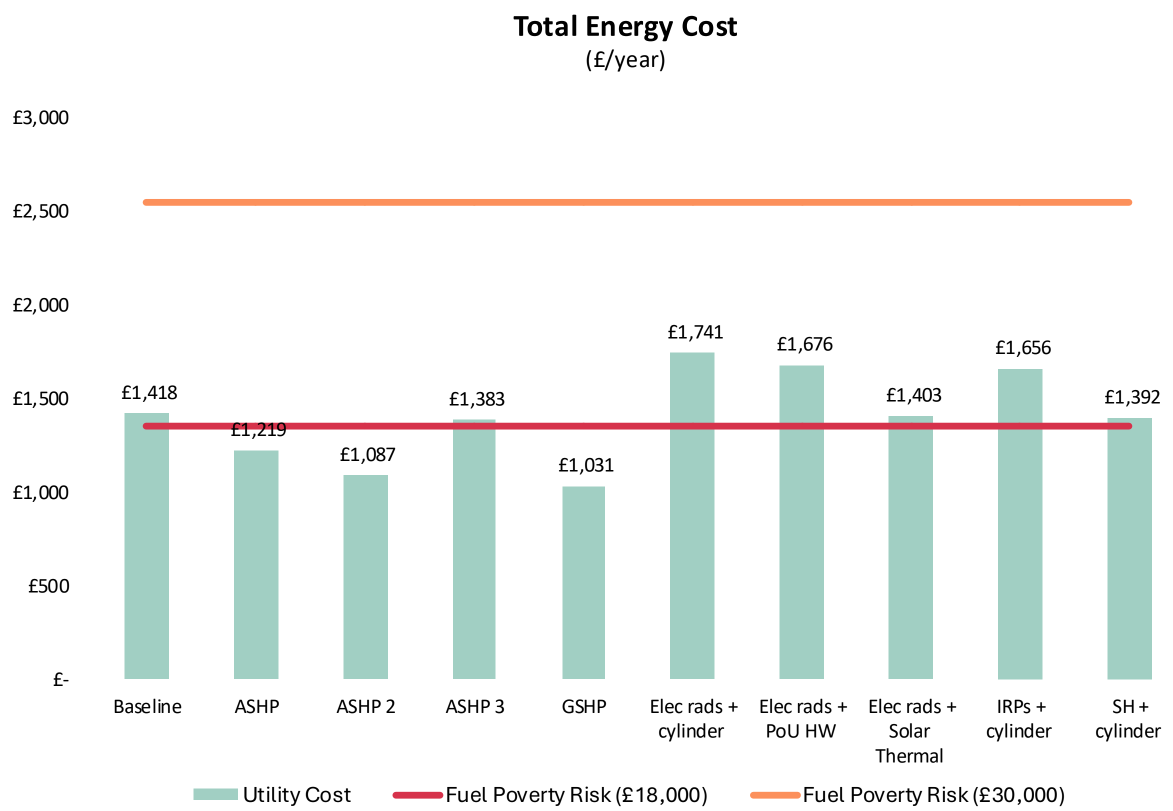
Heating System No.	System Type	Heating	Hot water	Heating emitters	Solar PV note
HS 1	Gas	Gas Boiler (Baseline Technology)	From heating system - combi gas boiler	Existing wet system - appropriately sized	PV and battery system does NOT reduce heating & hot water cost
HS 2	Heat pump based	ASHP - air to water Flow temperature: **50°C** Modelled SPF: **2.3 to 3.1** CoP: **good** Quality: **well-designed** / installed and commissioned	From heating system - DHW cylinder	Existing wet system - smaller sized radiators and pipework	PV and battery system can reduce heating & hot water cost
HS 3	Heat pump based	ASHP - air to water Flow temperature: **40°C** Modelled SPF: **3.4 to 4** CoP: **good** Quality: **well-designed** / installed and commissioned	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system can reduce heating & hot water cost
HS 4	Heat pump based	ASHP - air to water Flow temperature: 60**°C** Modelled SPF: **1.9 to 2.6** CoP: **bad** Quality: **poorly designed** / installed and commissioned	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system can reduce heating & hot water cost
HS 5	Heat pump based	Communal GSHP - ground to water	From heating system - DHW cylinder	New system - appropriately sized	PV and battery system might reduce heating & hot water cost (impact on hot water and heating dependant on system set-up)
HS 6	Emitter based	Electric radiators and electric panel heaters	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 7	Emitter based	Electric radiators and electric panel heaters	Electric instantaneous point of use & Electric shower	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 8	Emitter based	Electric radiators and electric panel heaters	Solar thermal water heating system	Individual heaters	PV panels not/less possible to install
HS 9	Emitter based	Infrared radiant panels (modelled through lower temperature)	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost
HS 10	Emitter based	High heat retention storage heater (smart)	Electric immersion - Direct hot water cylinder	Individual heaters	PV and battery system can reduce heating & hot water cost

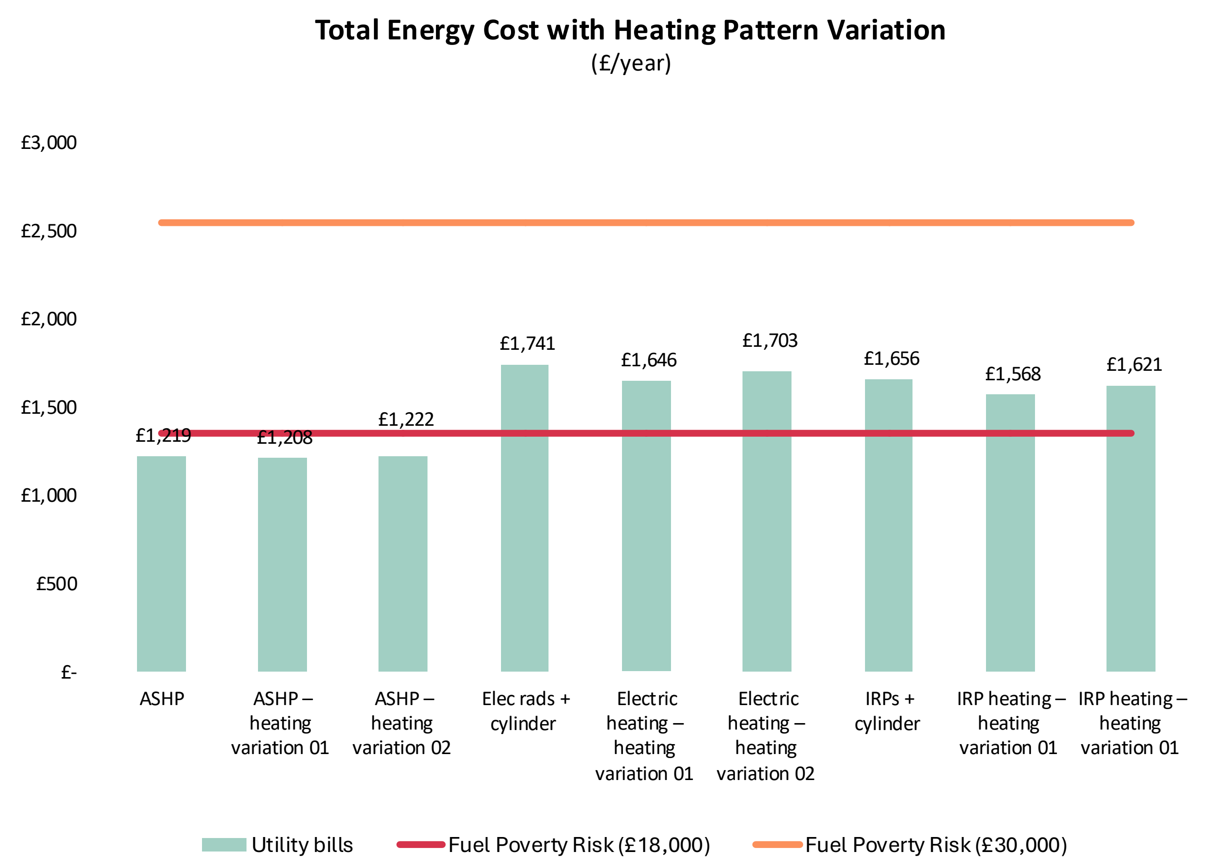
Property Type 1 - Medium sized, very good fabric efficiency

75m² Floor area, 30kWh/m²/year Space Heating Demand



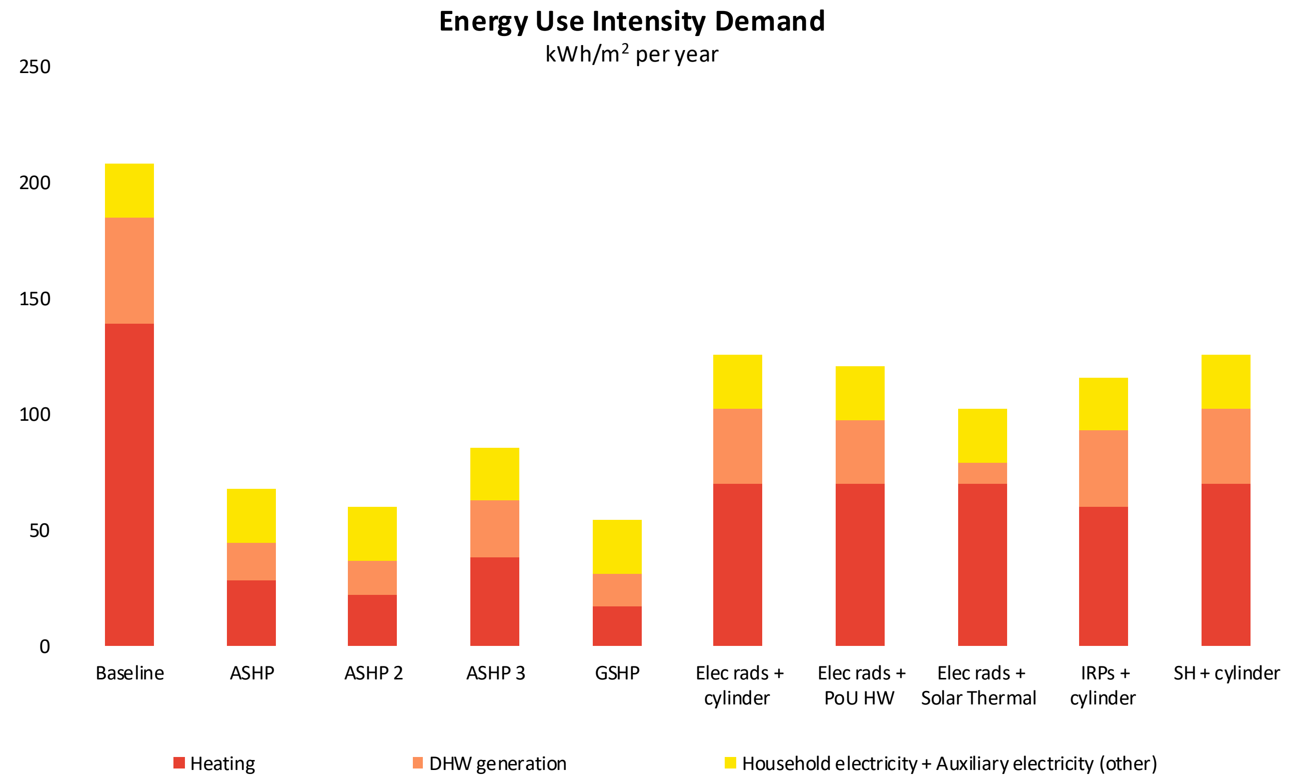


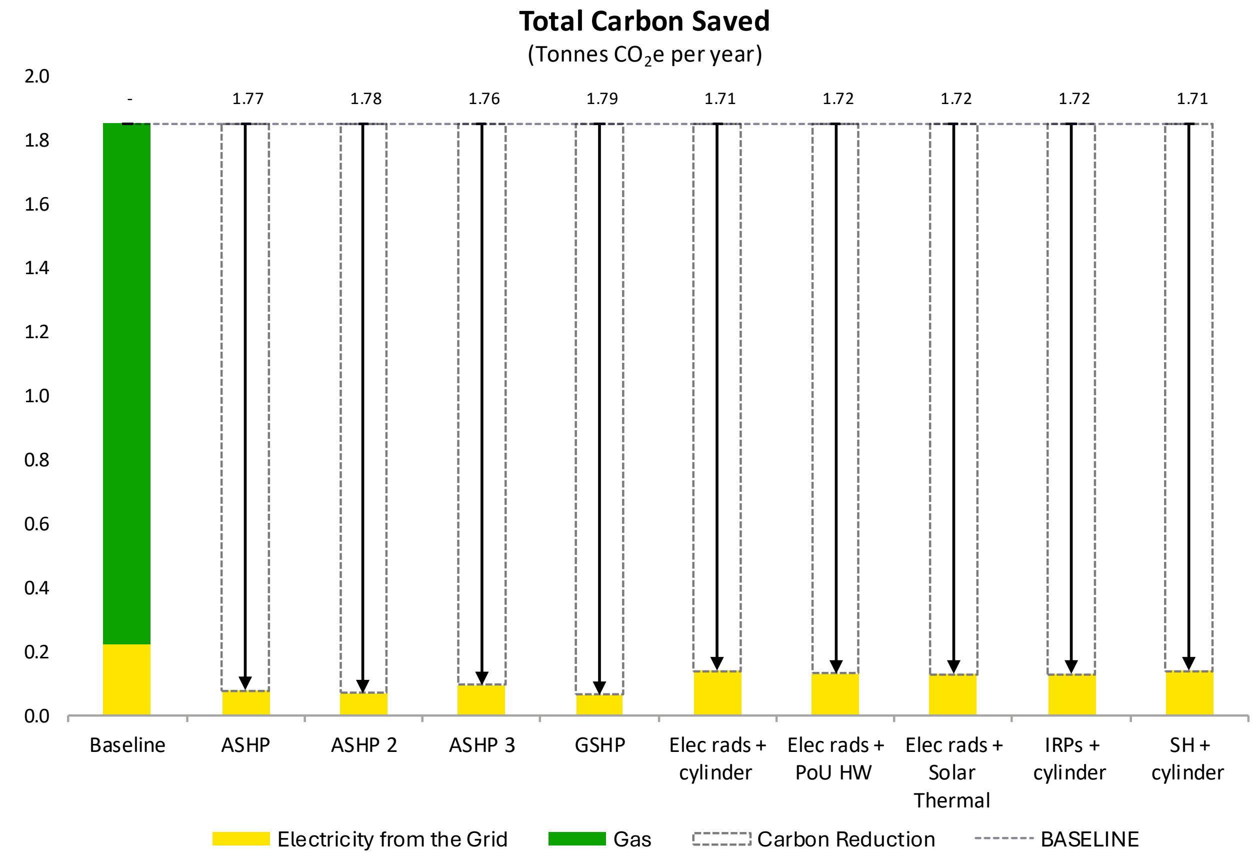


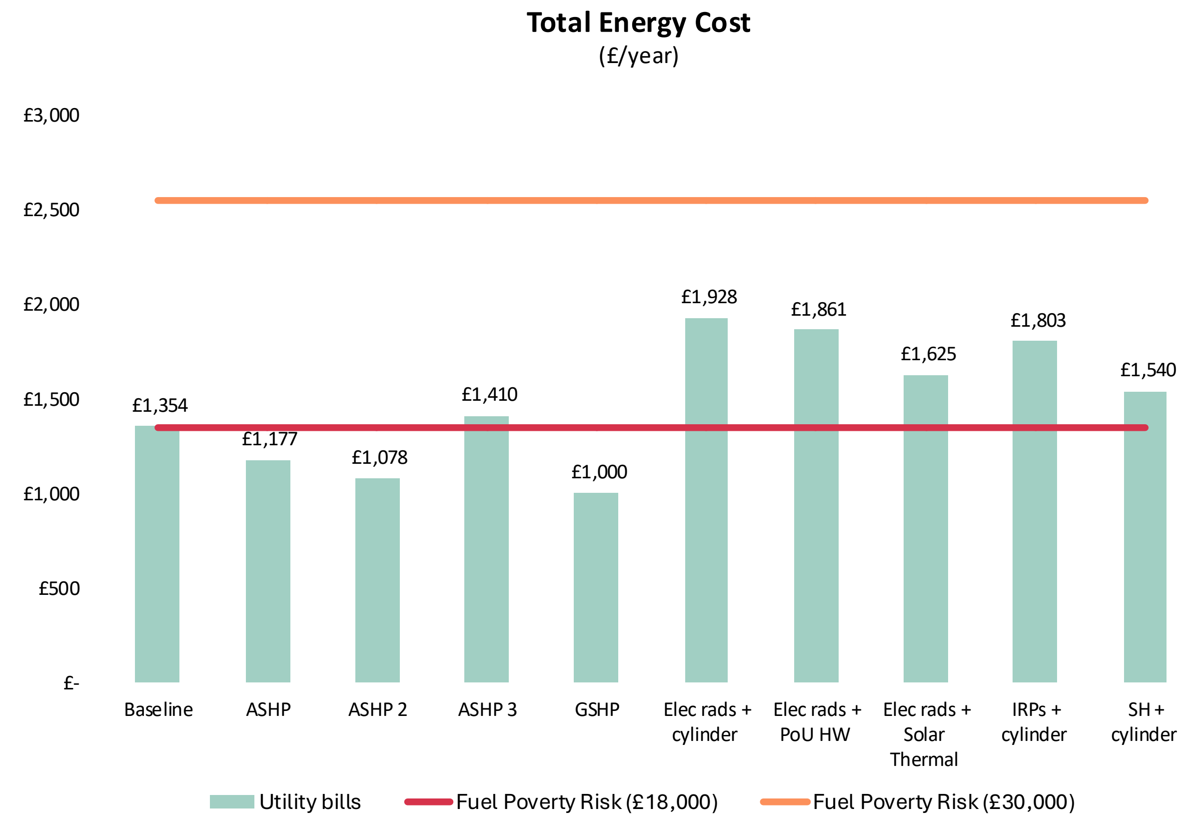


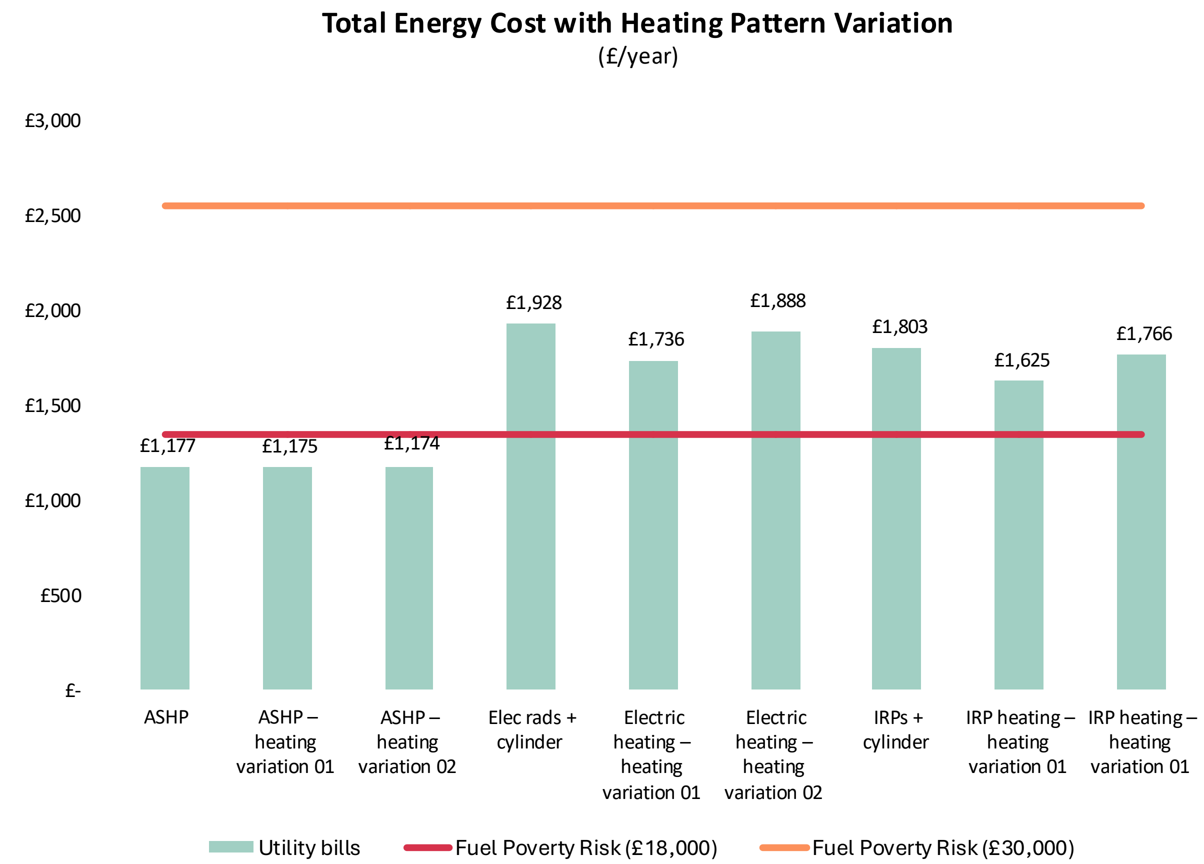
Property Type 2 - Small sized, good to very good fabric efficiency

50m² Floor area, 70kWh/m²/year Space Heating Demand









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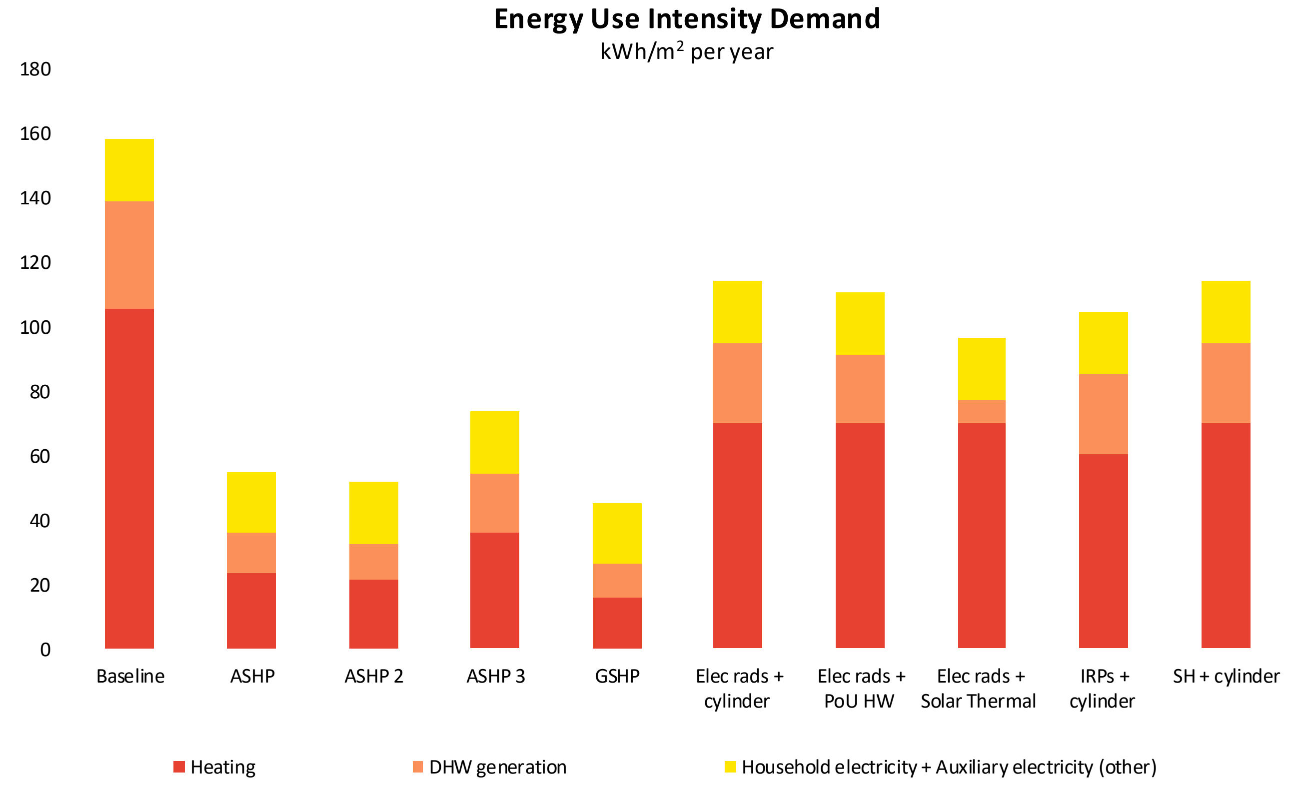
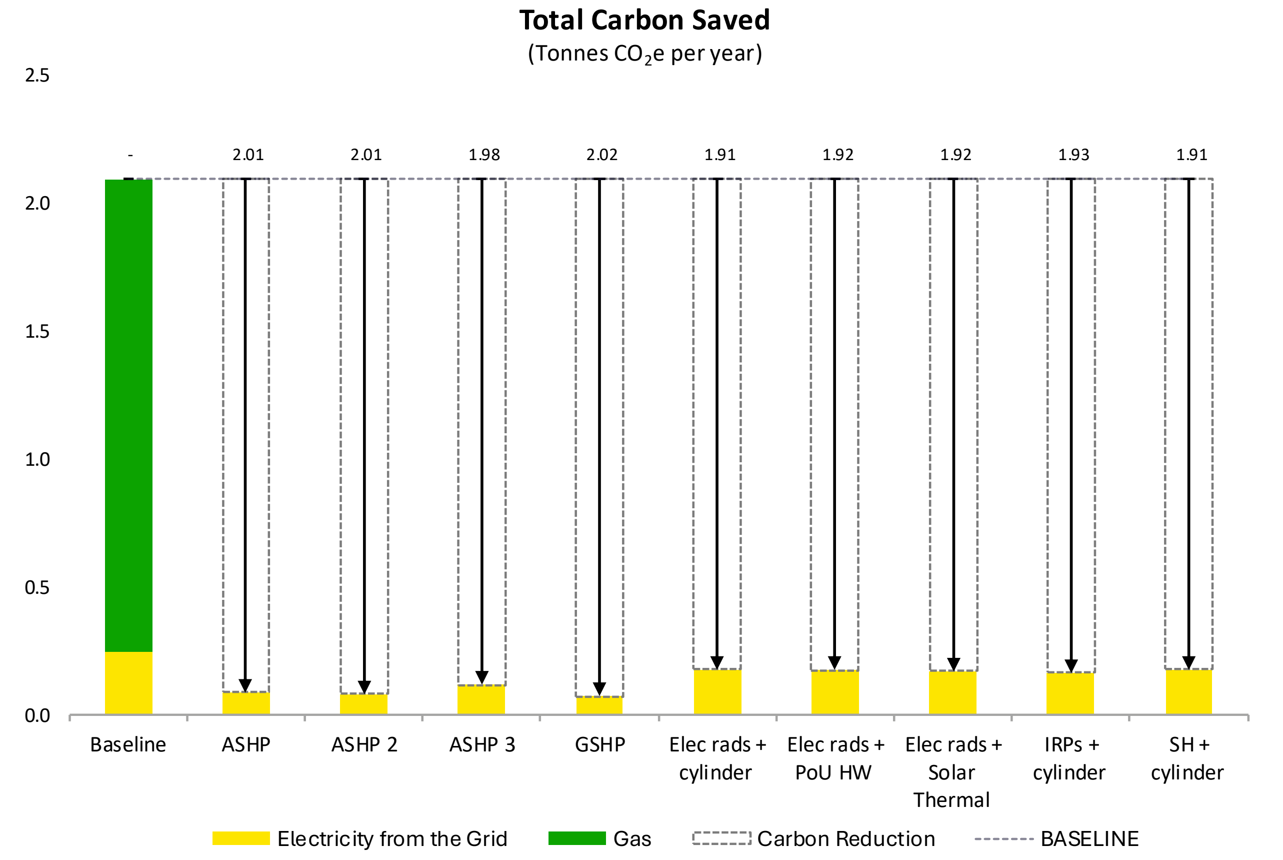
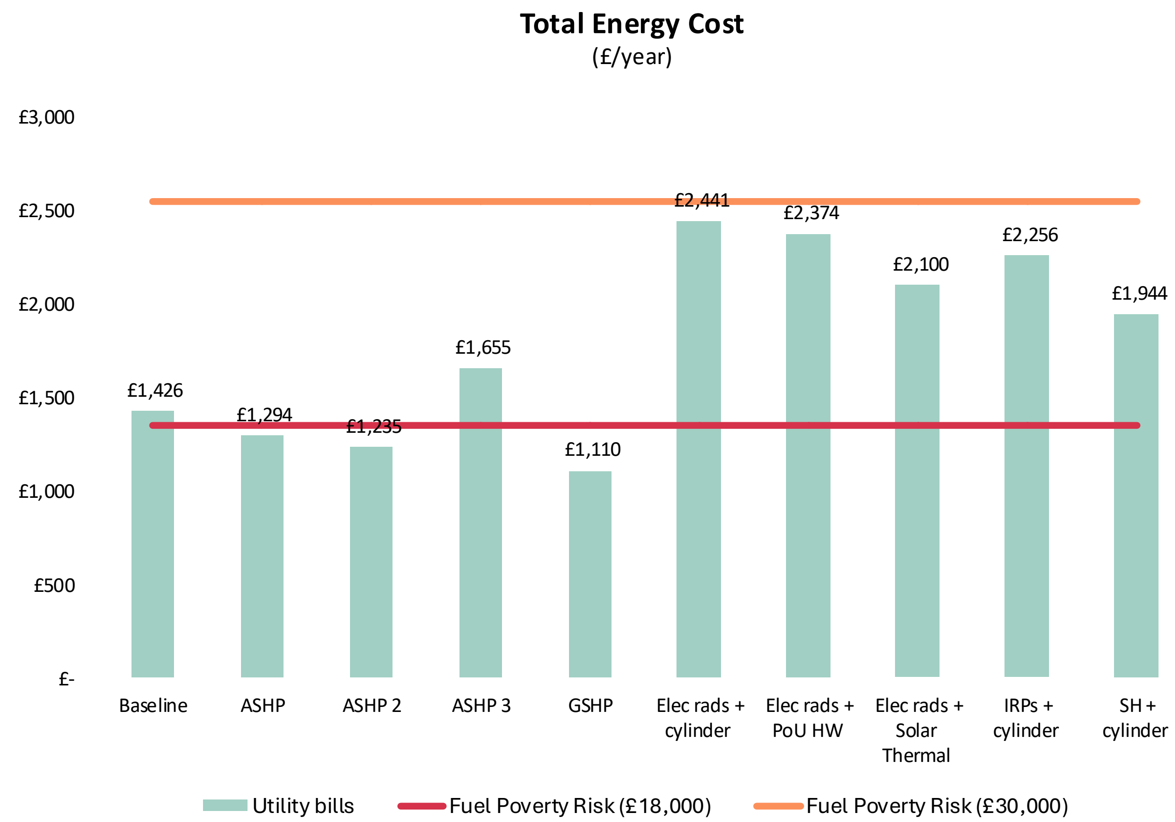
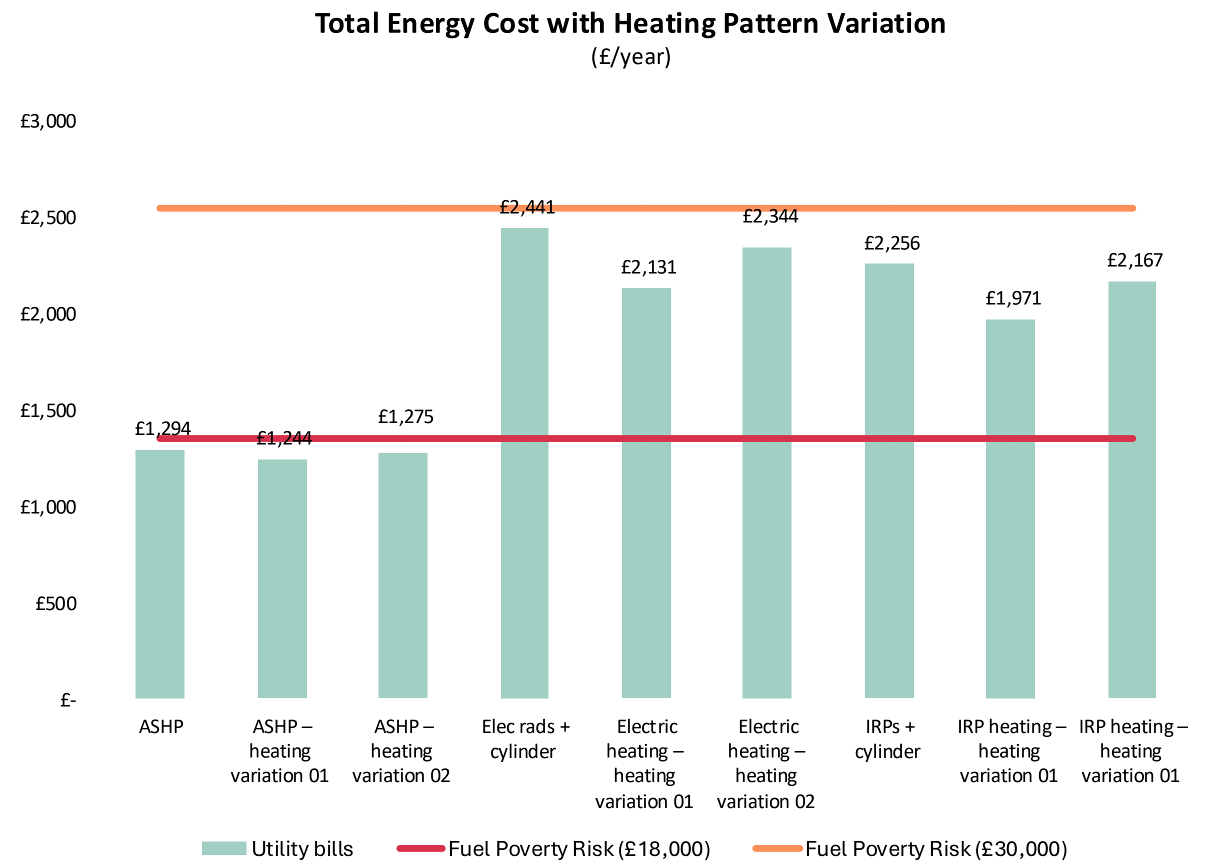
Property Type 3 - Medium sized, good to very good fabric efficiency

75m² Floor area, 70kWh/m²/year Space Heating Demand









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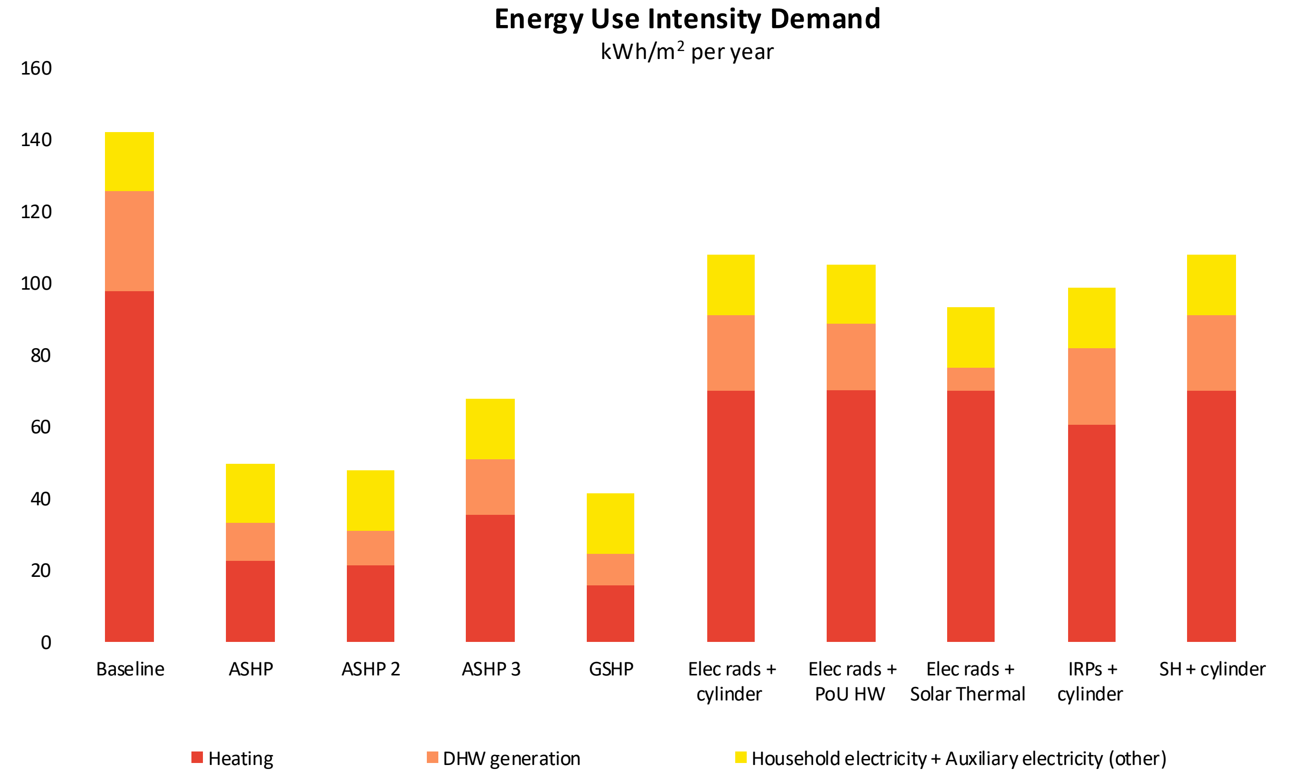
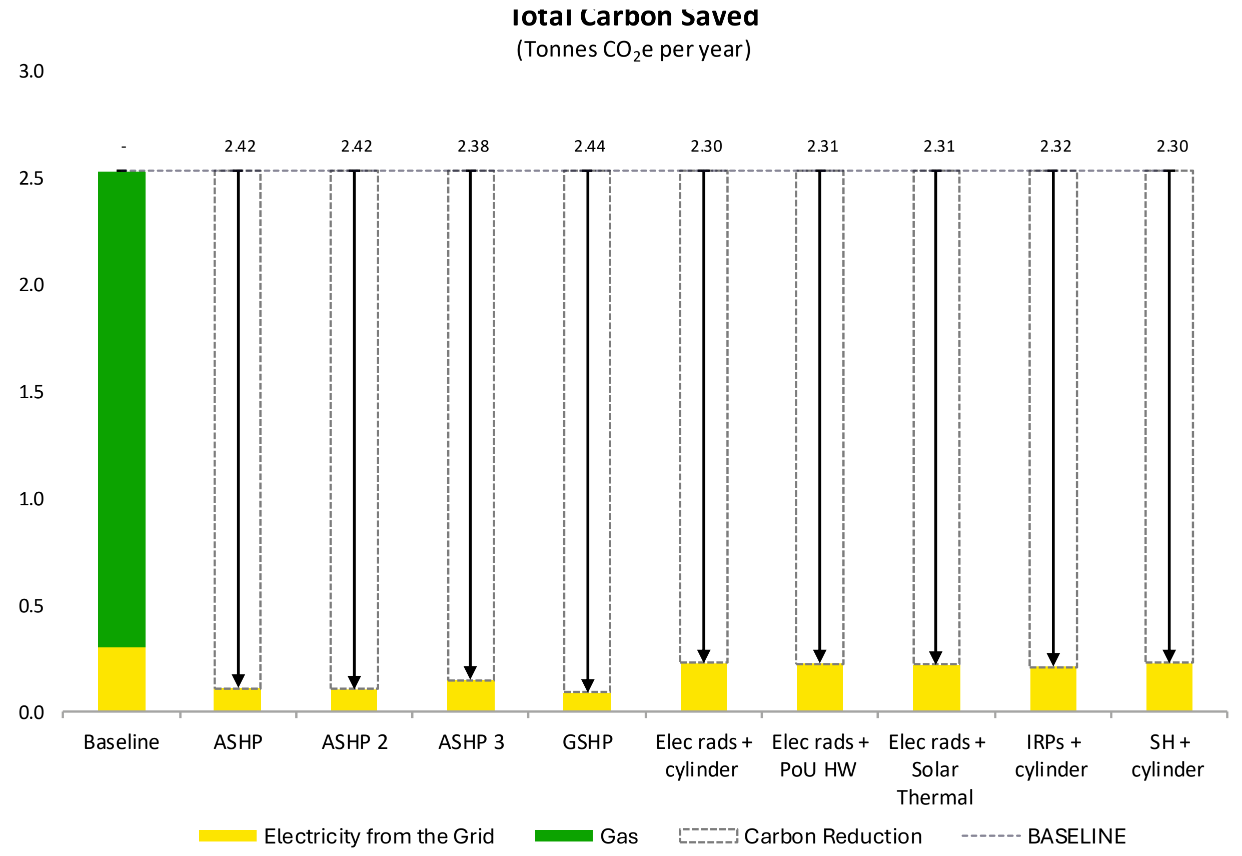
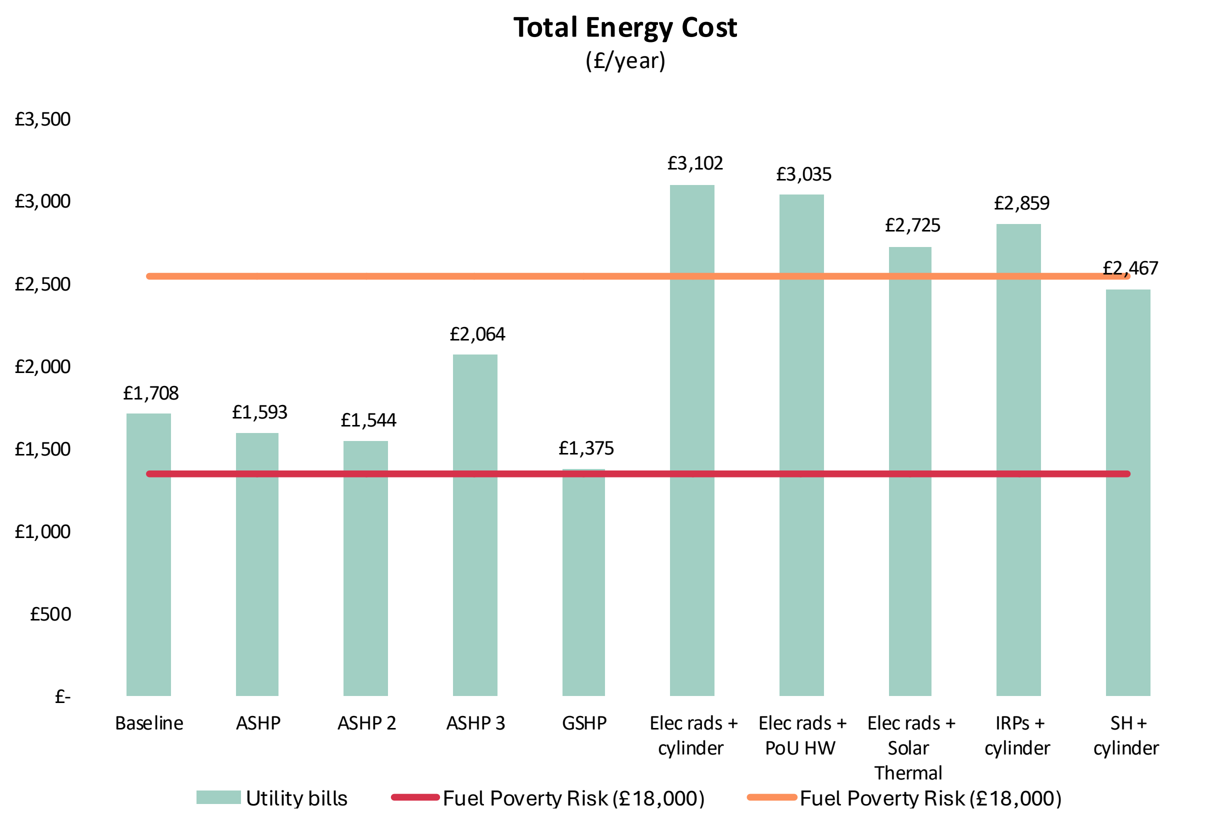
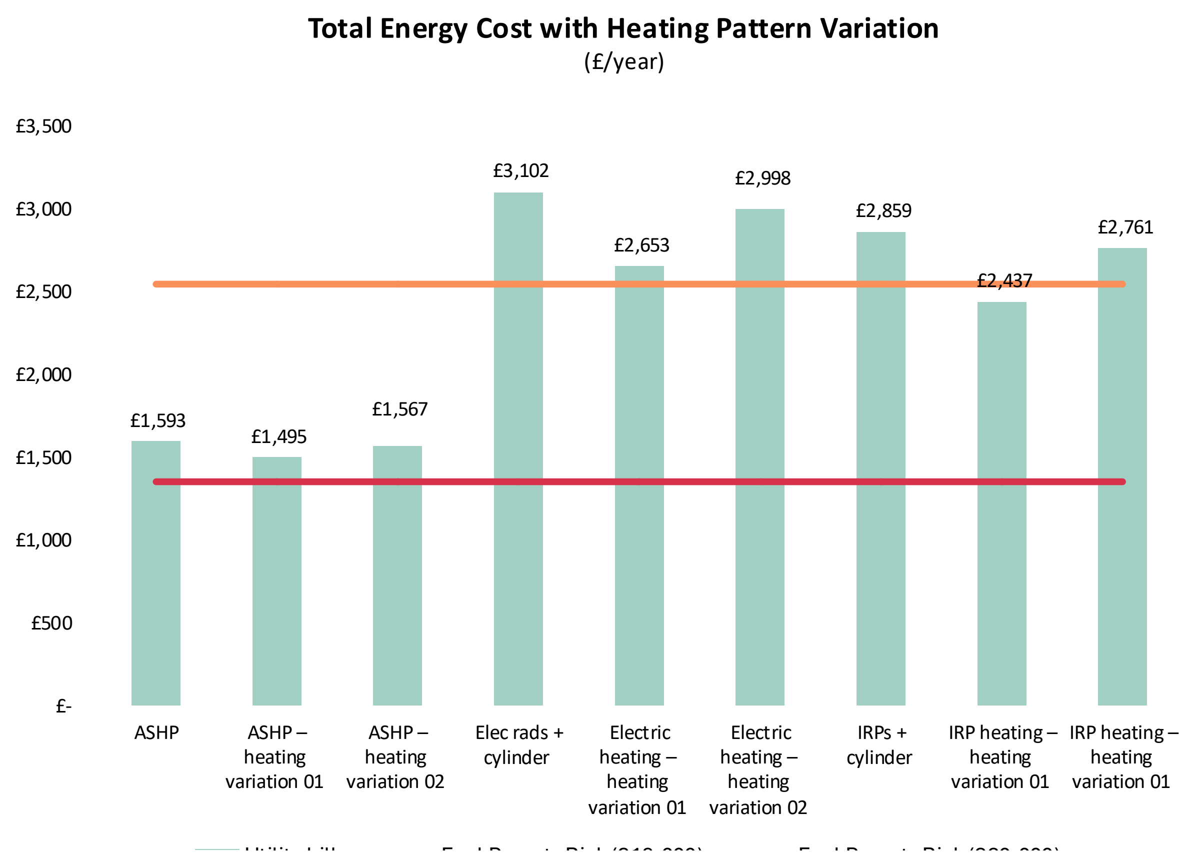
Property Type 4 - Large sized, good to very good fabric efficiency

100m² Floor area, 70kWh/m²/year Space Heating Demand









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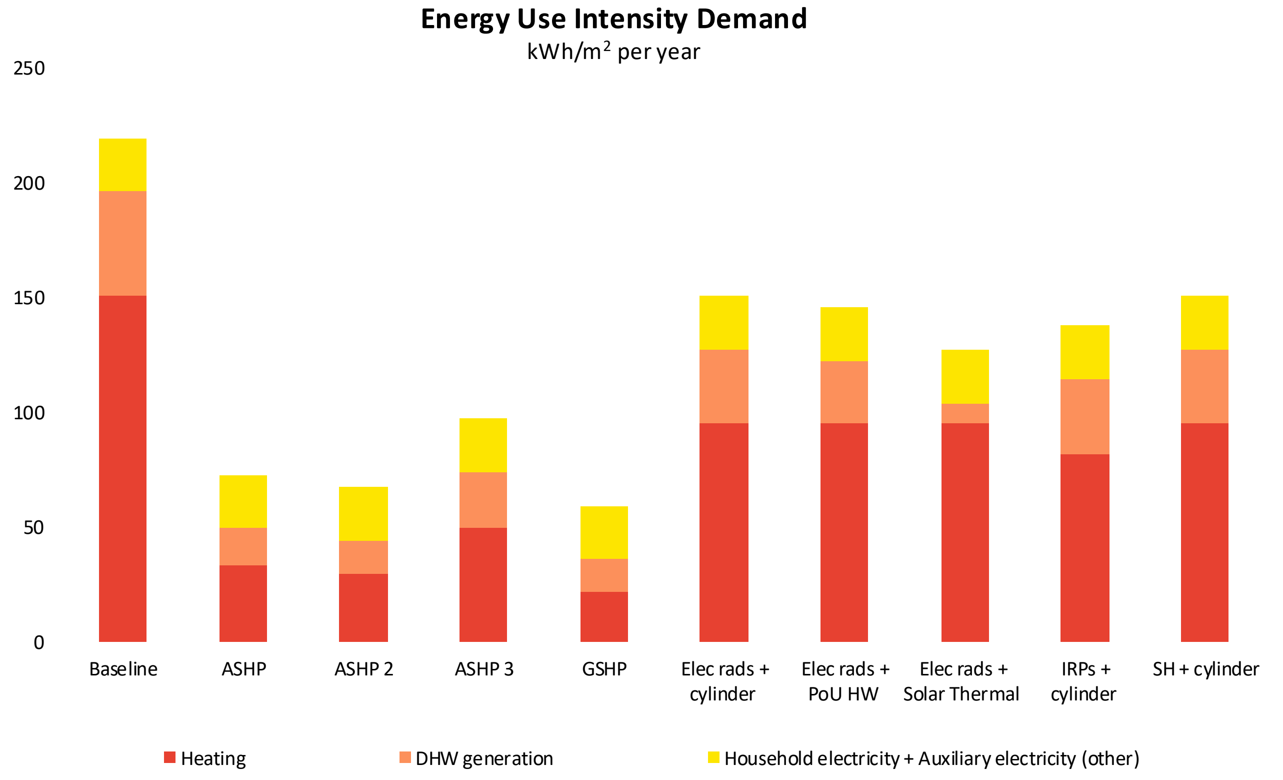
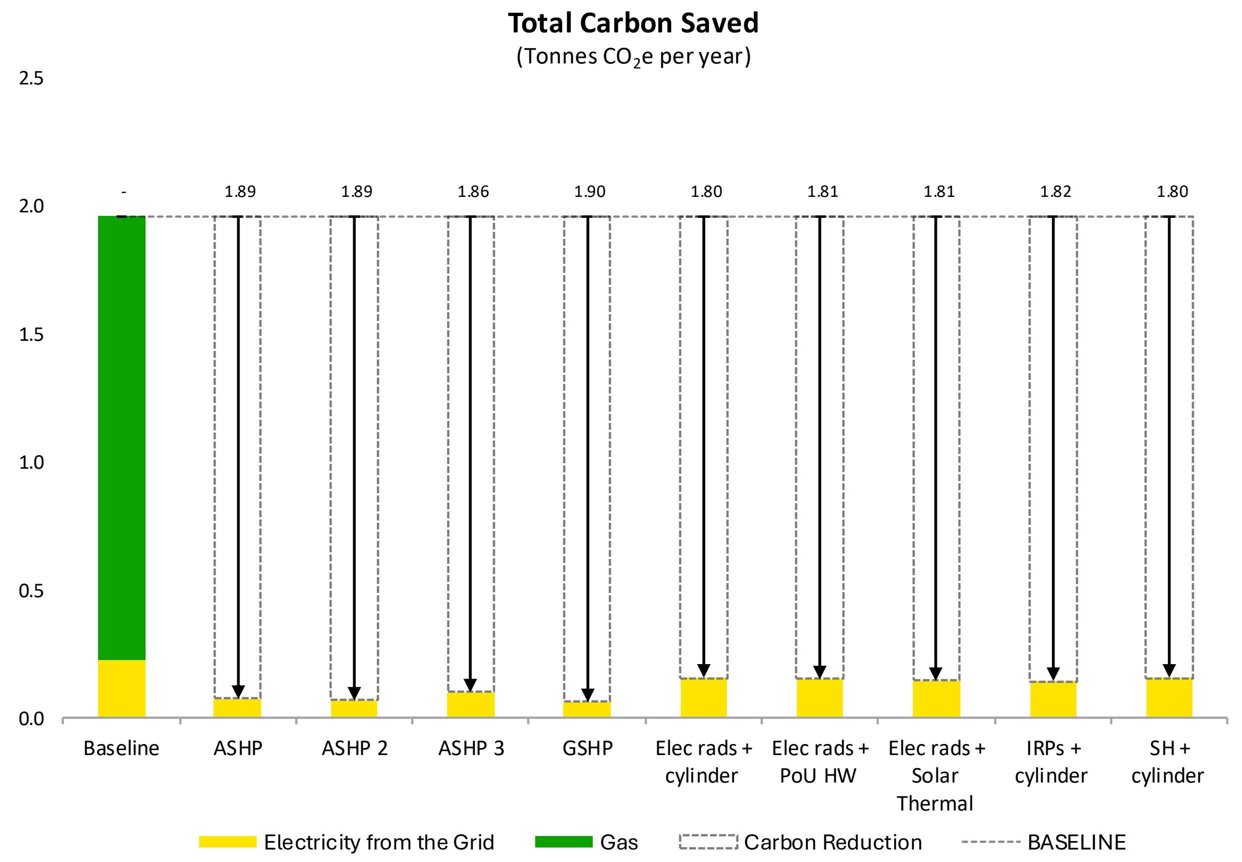
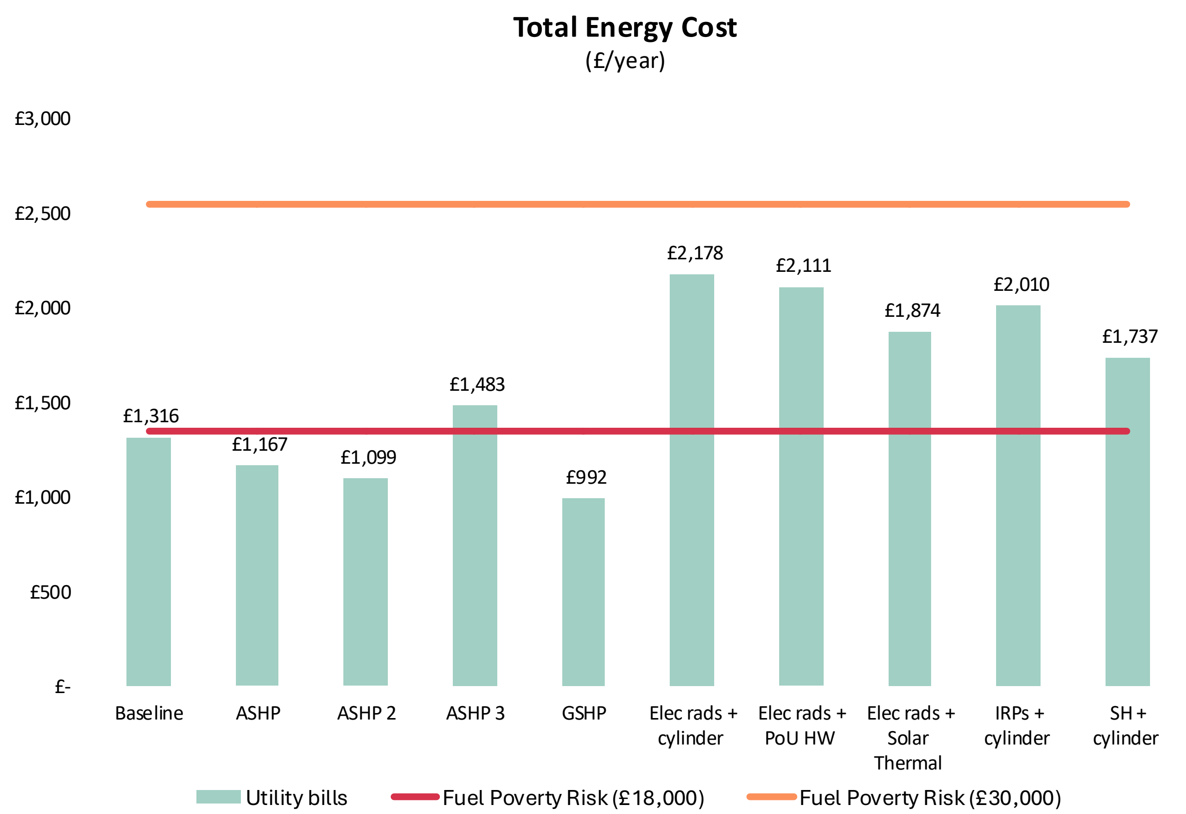
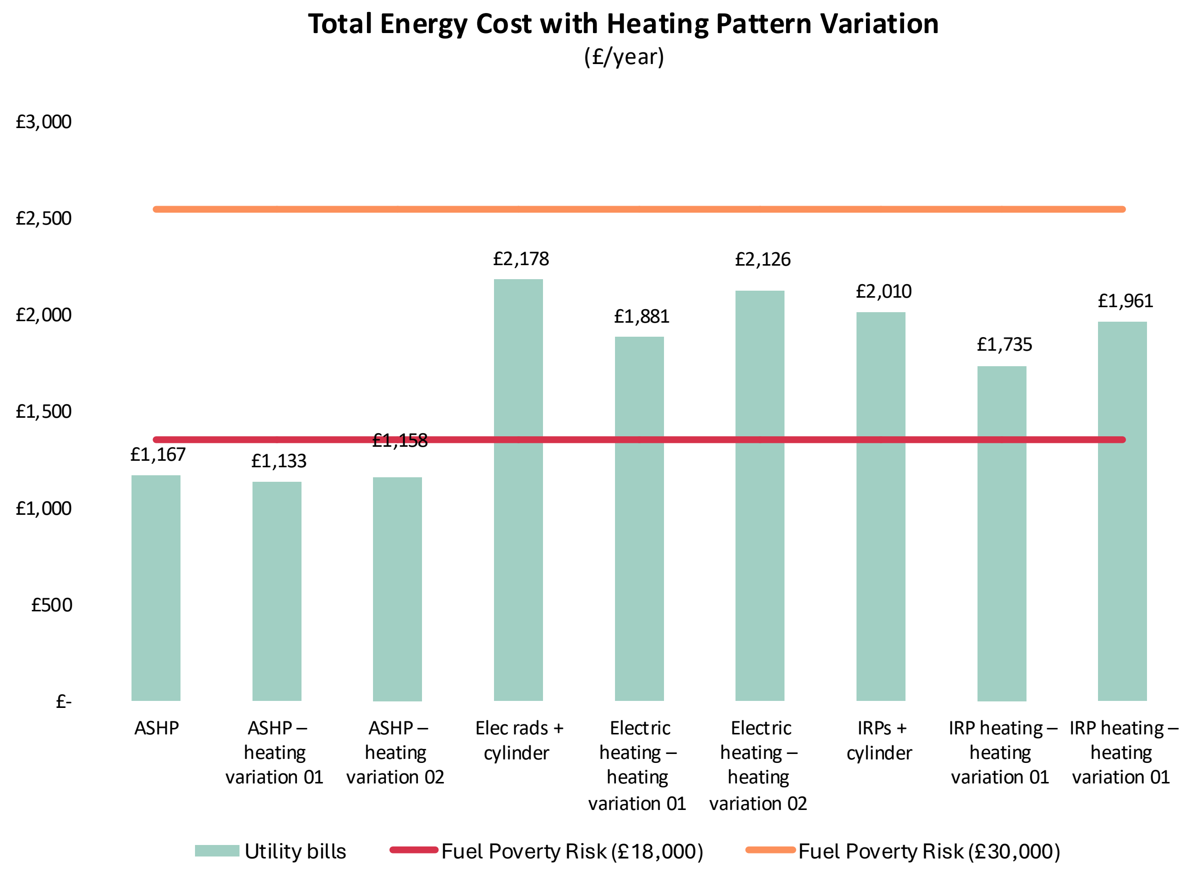
Property Type 5 - Small sized, good fabric efficiency

50m² Floor area, 95kWh/m²/year Space Heating Demand



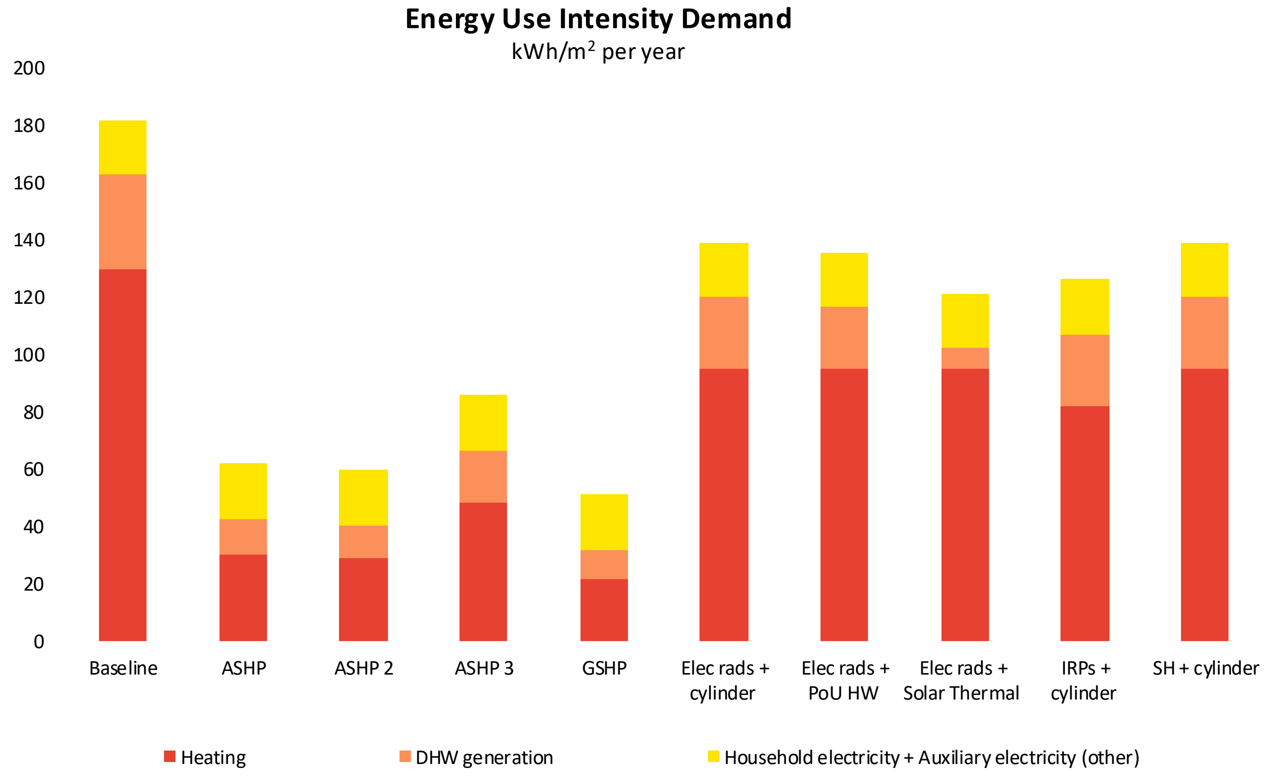


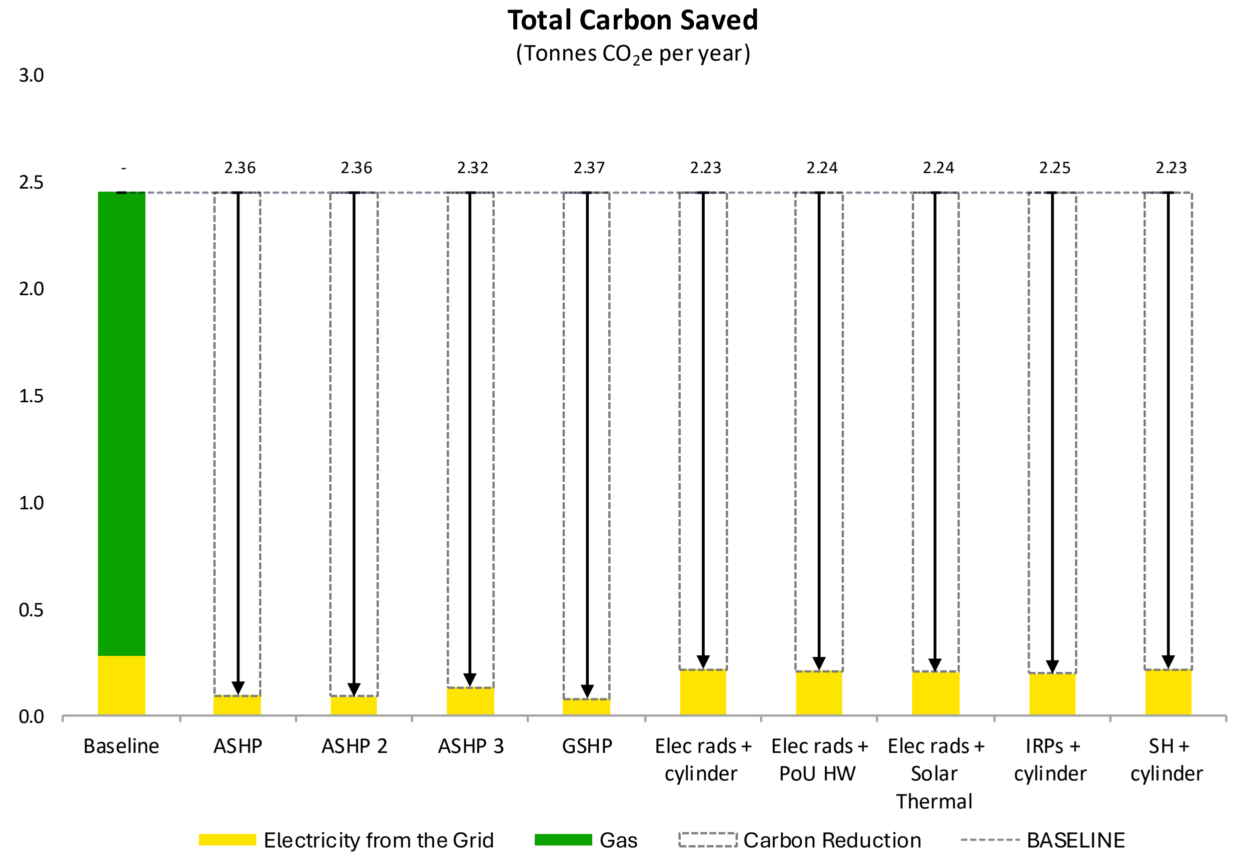


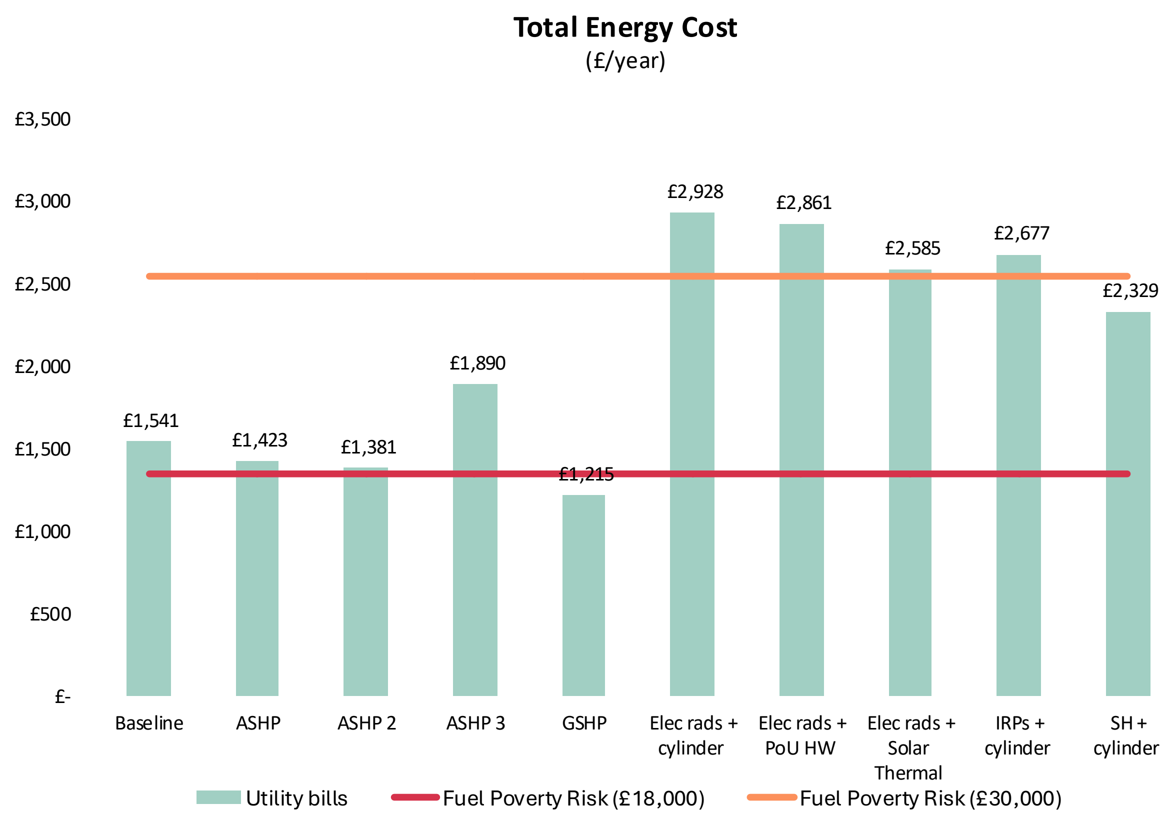


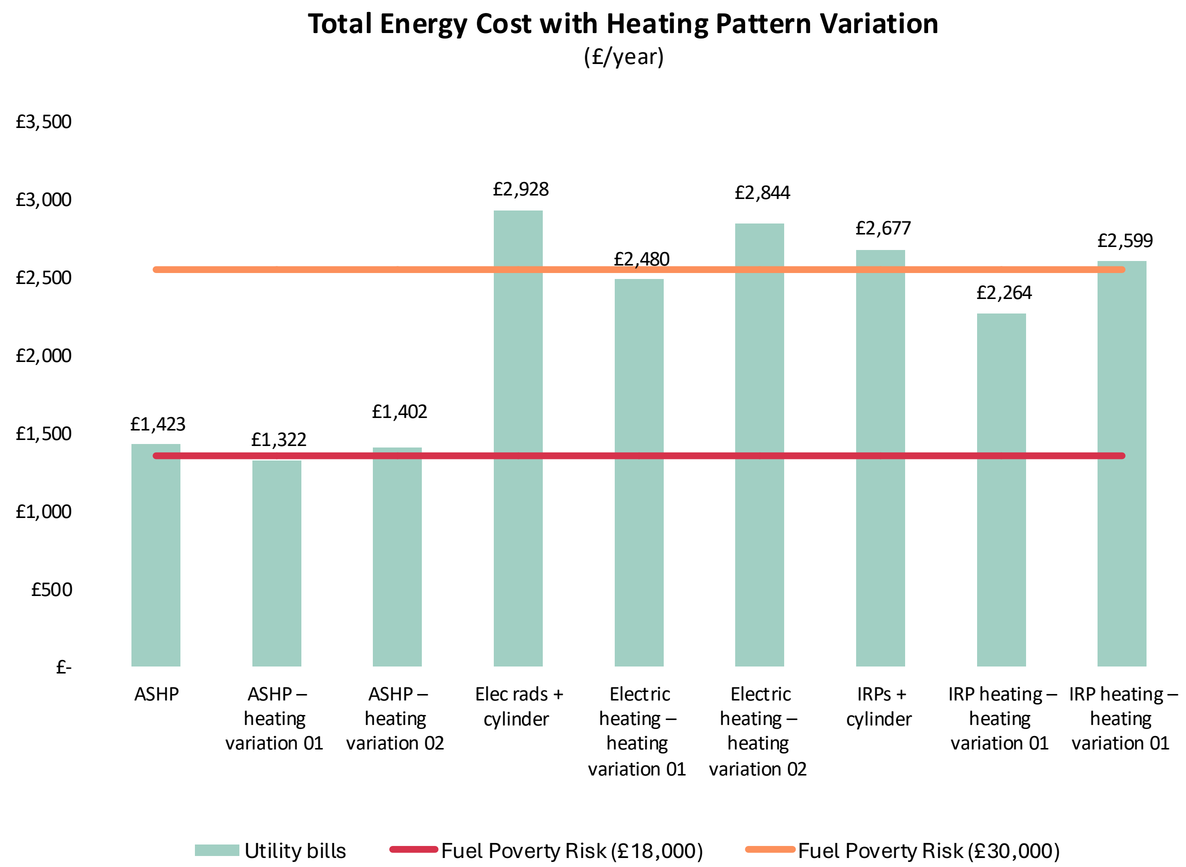
Property Type 6 - Medium sized, good fabric efficiency

75m² Floor area, 95kWh/m²/year Space Heating Demand



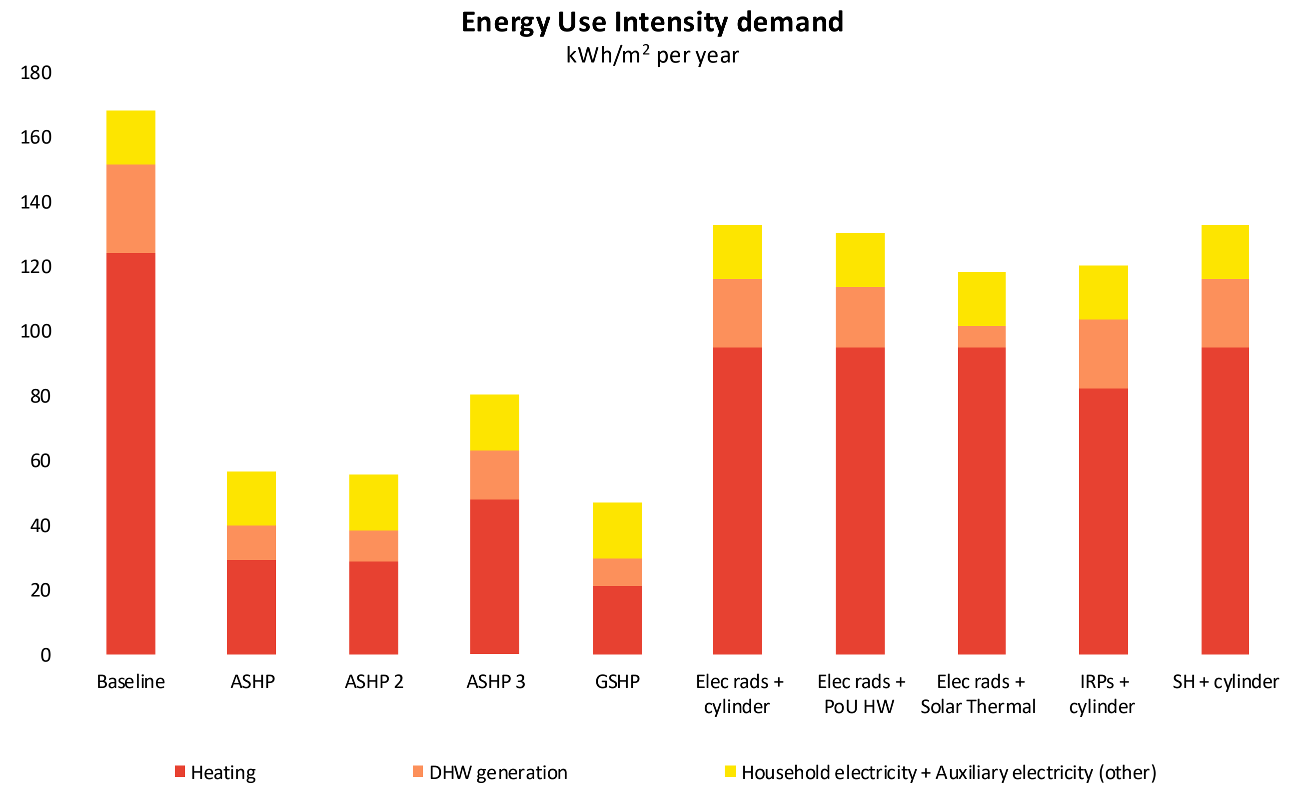


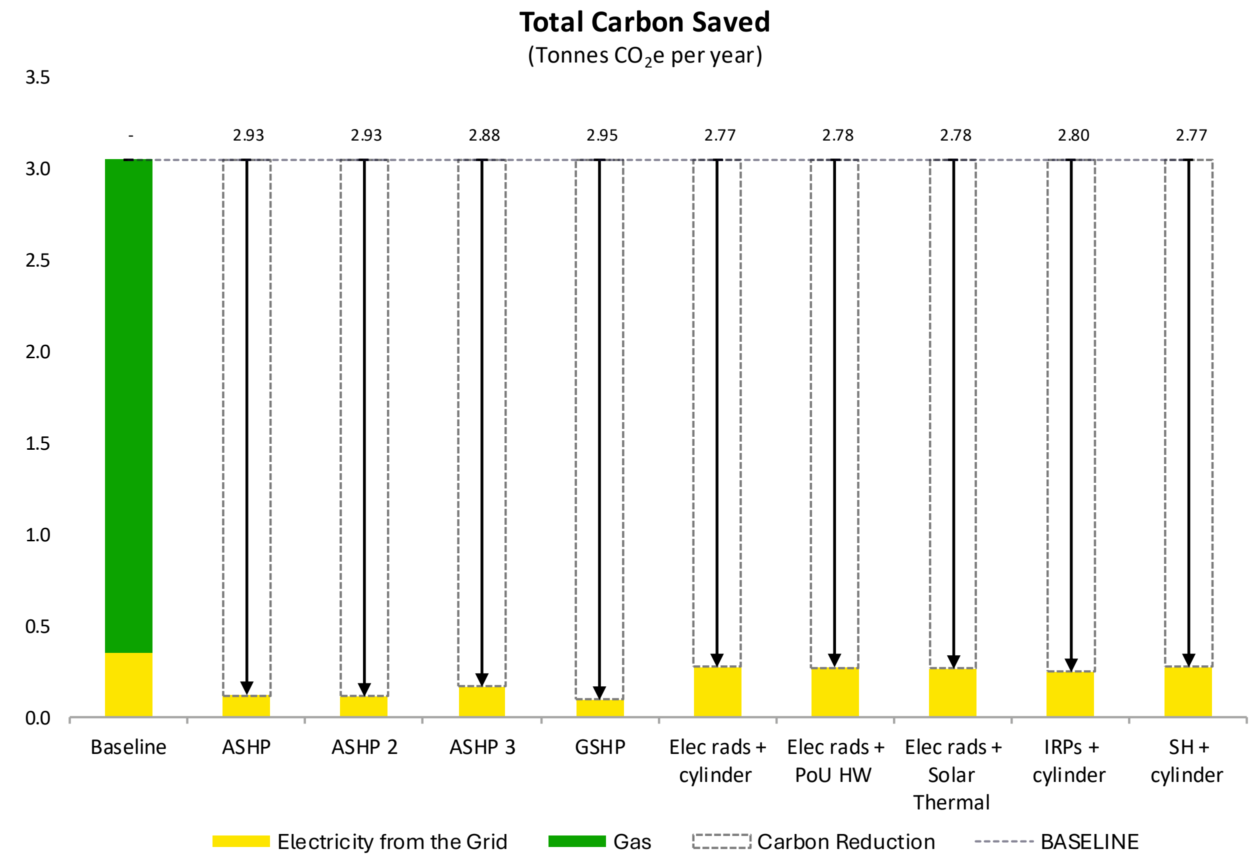


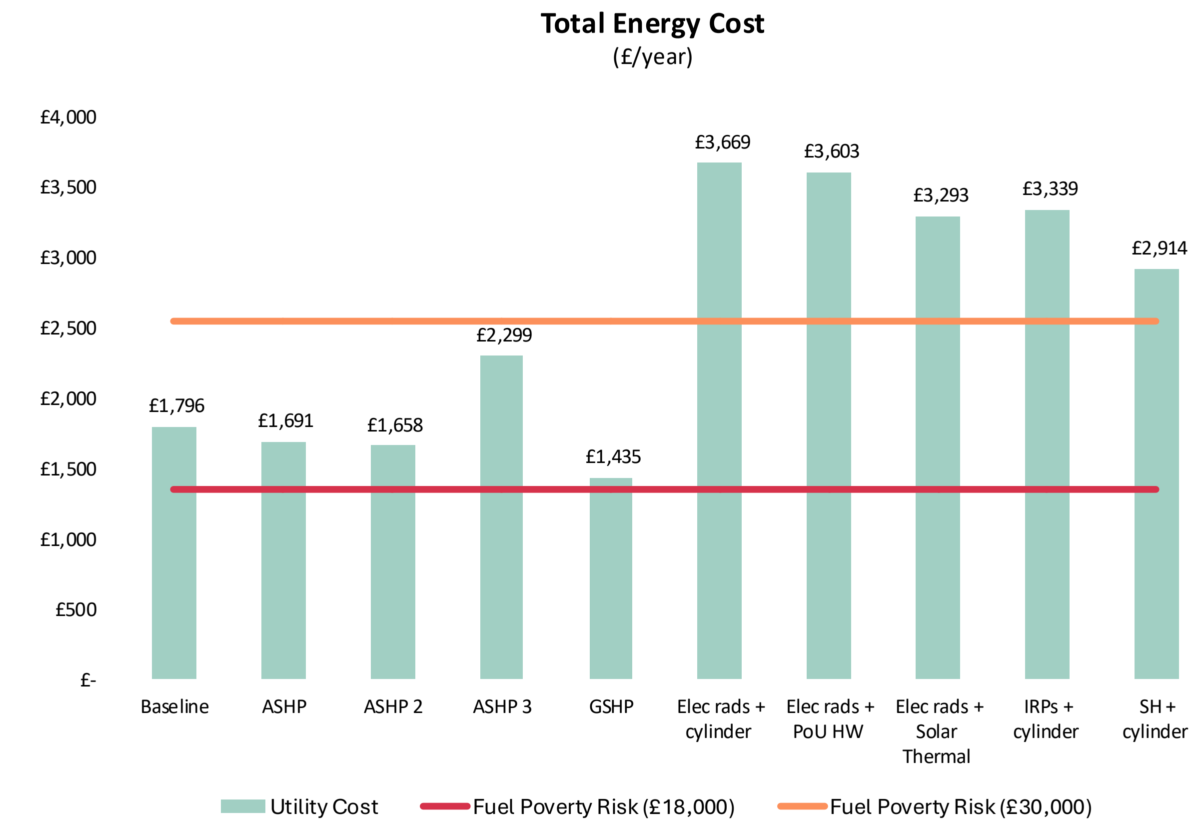


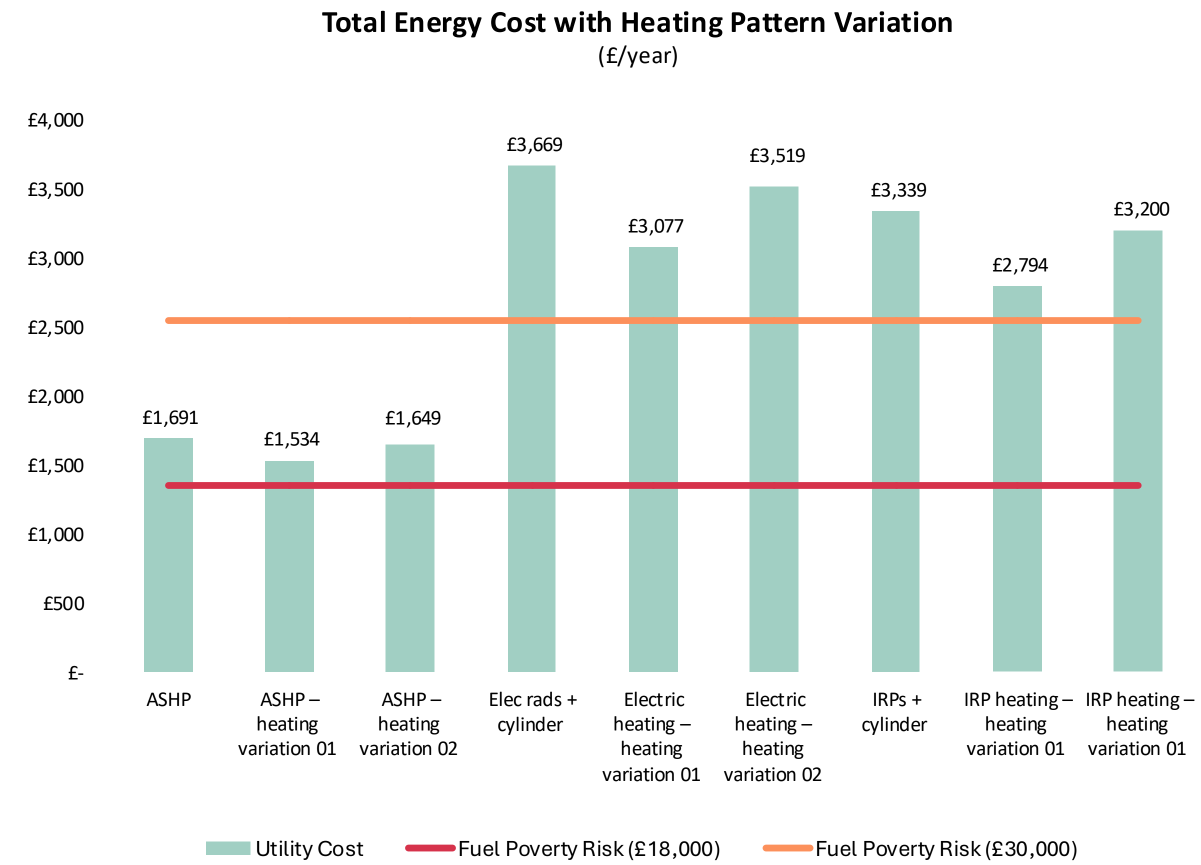
Property Type 7 - Large sized, good fabric efficiency

100m² Floor area, 95kWh/m²/year Space Heating Demand



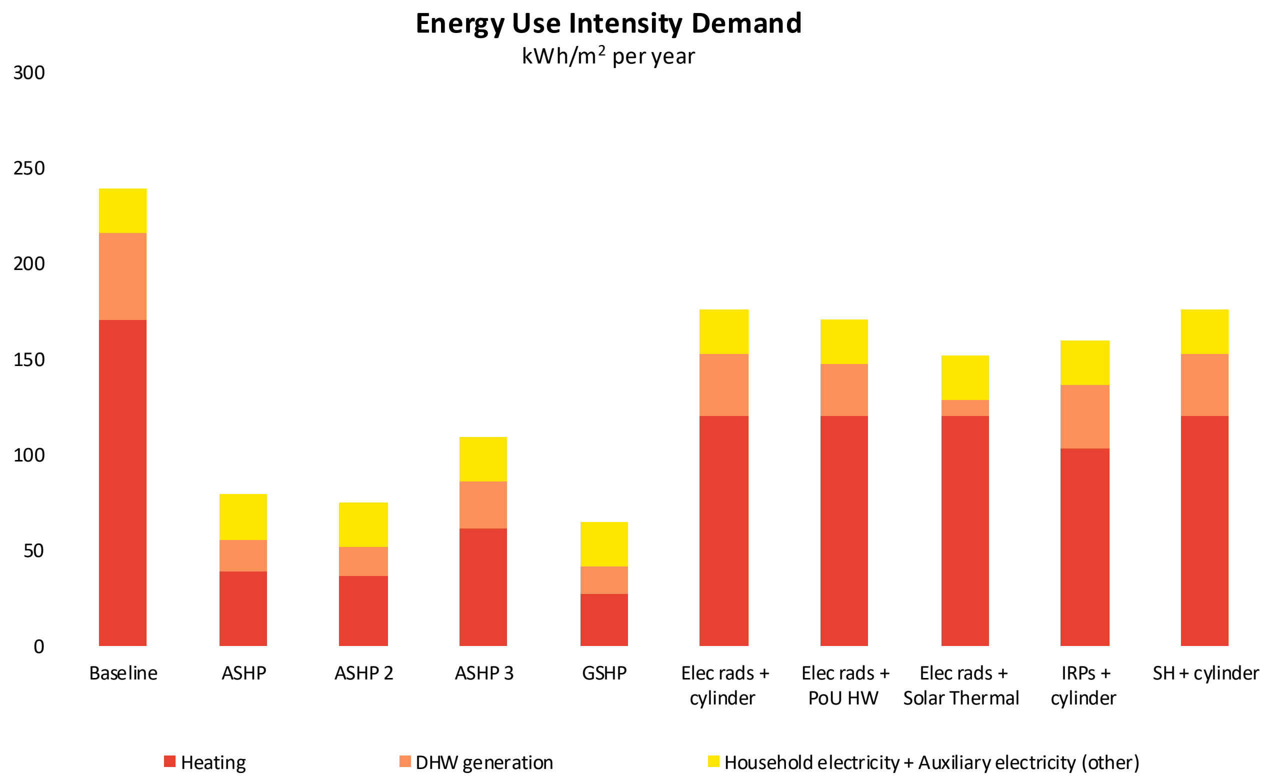


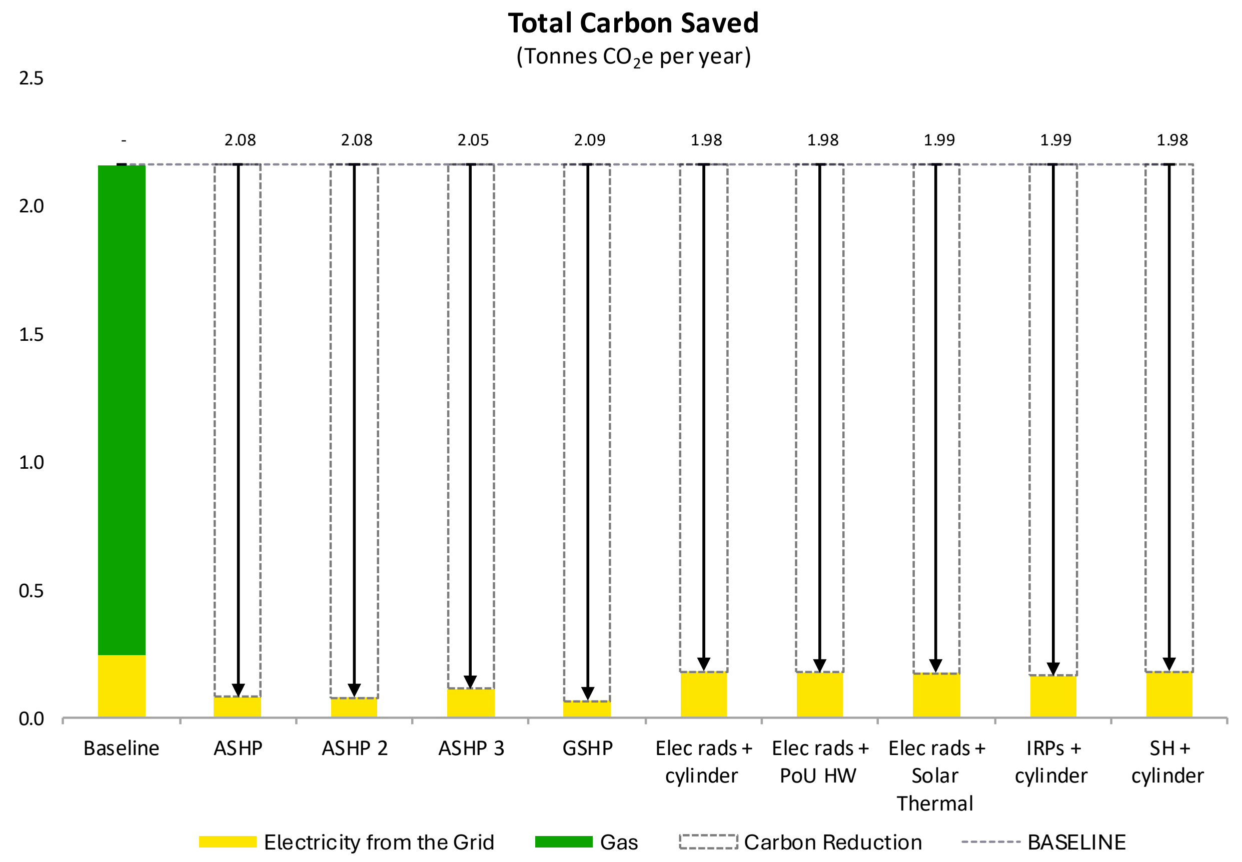


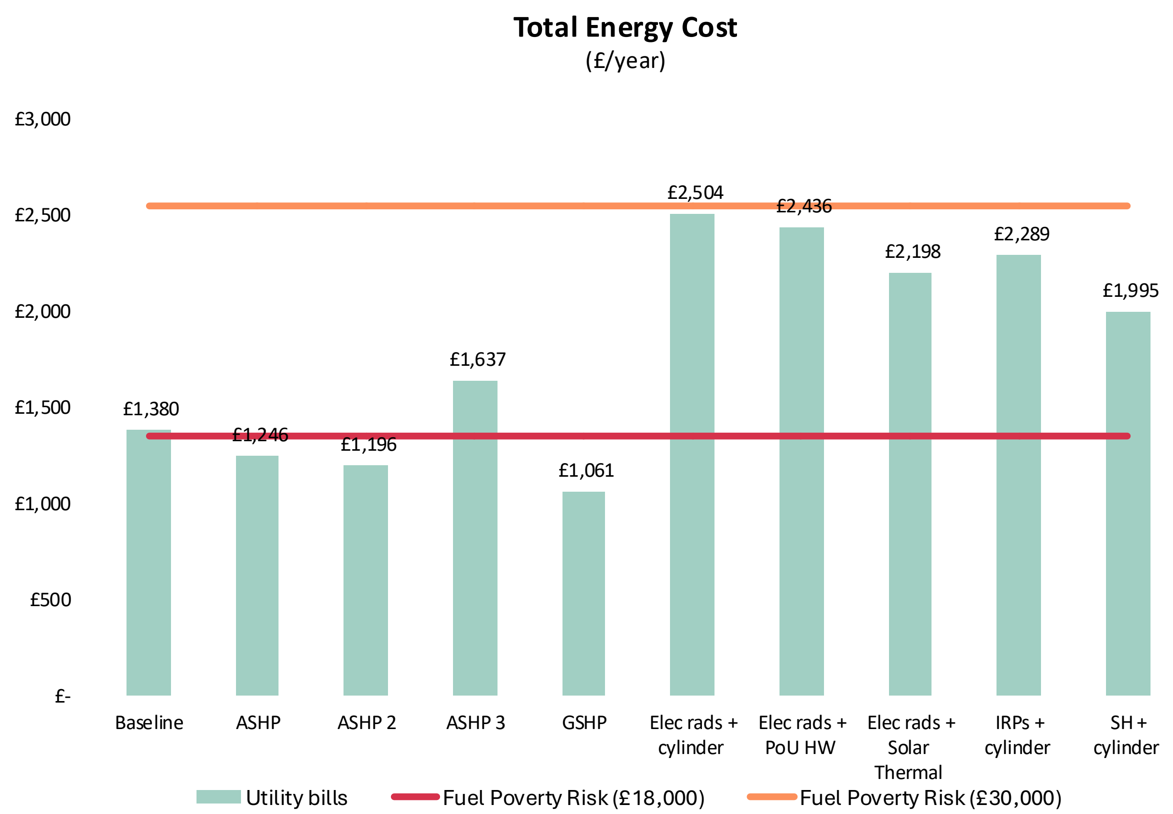


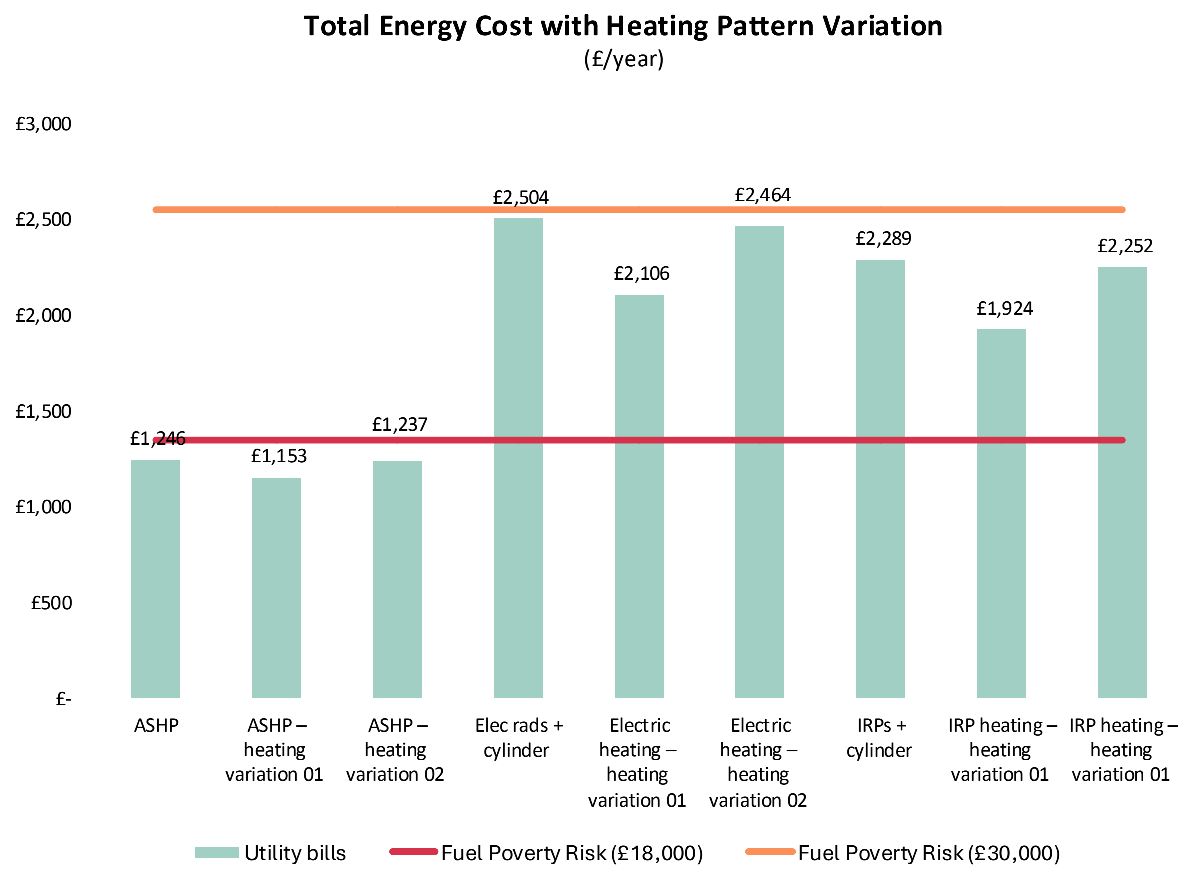
Property Type 8 - Small sized, average fabric efficiency

50m² Floor area, 120kWh/m²/year Space Heating Demand



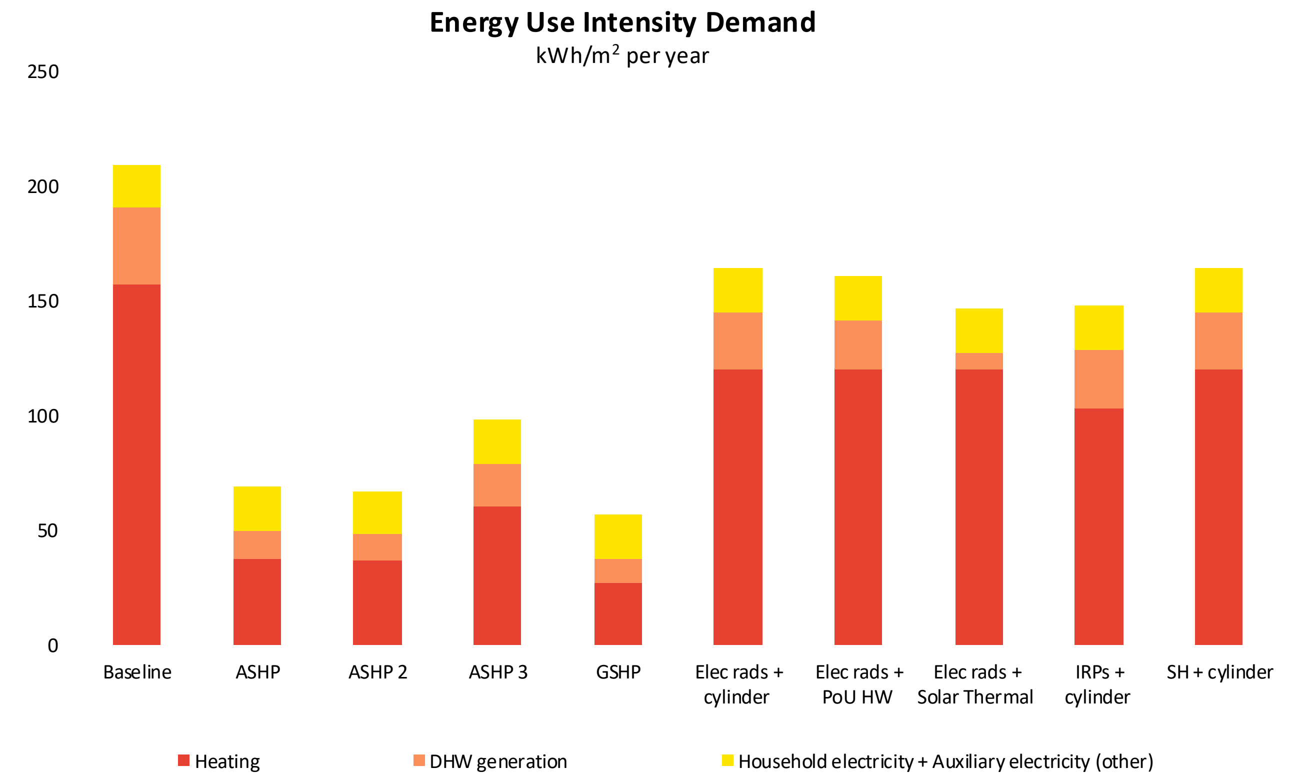


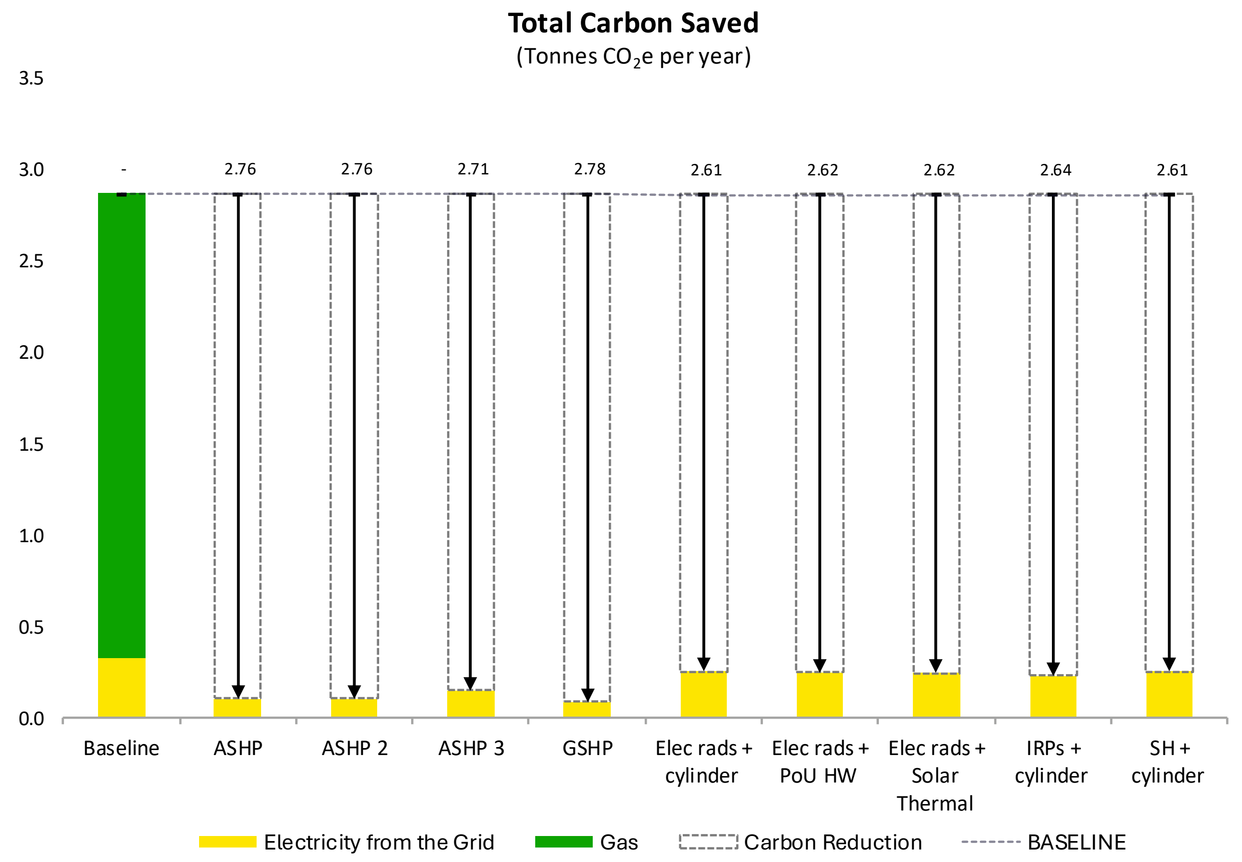


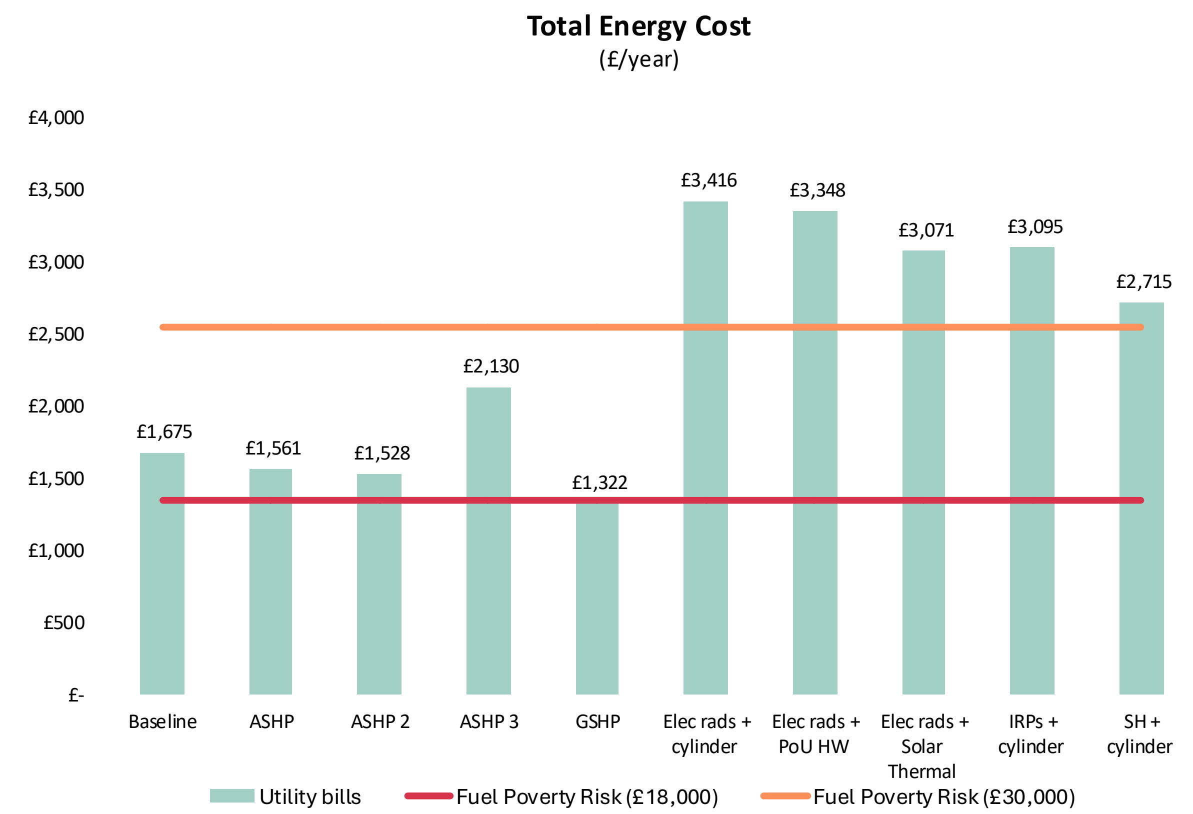


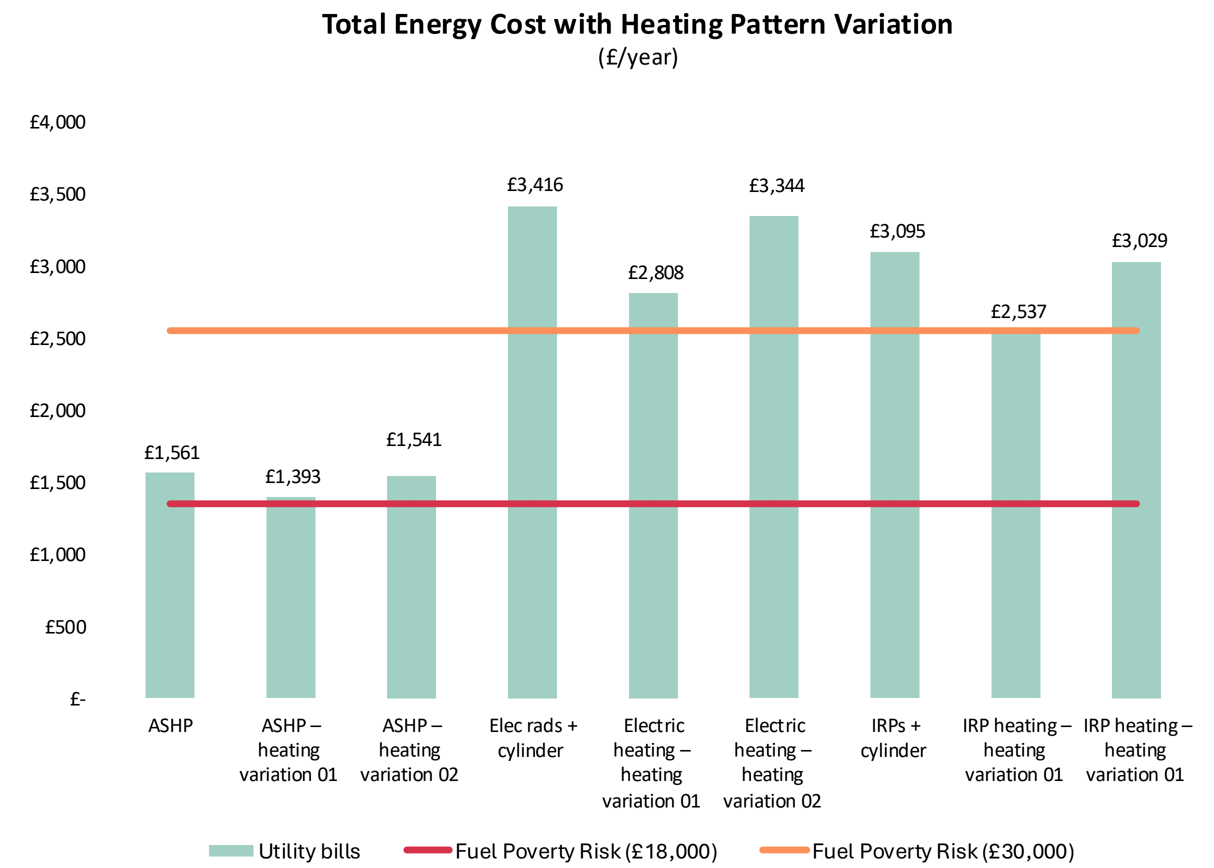
Property Type 9 - Medium sized, average fabric efficiency

75m² Floor area, 120kWh/m²/year Space Heating Demand



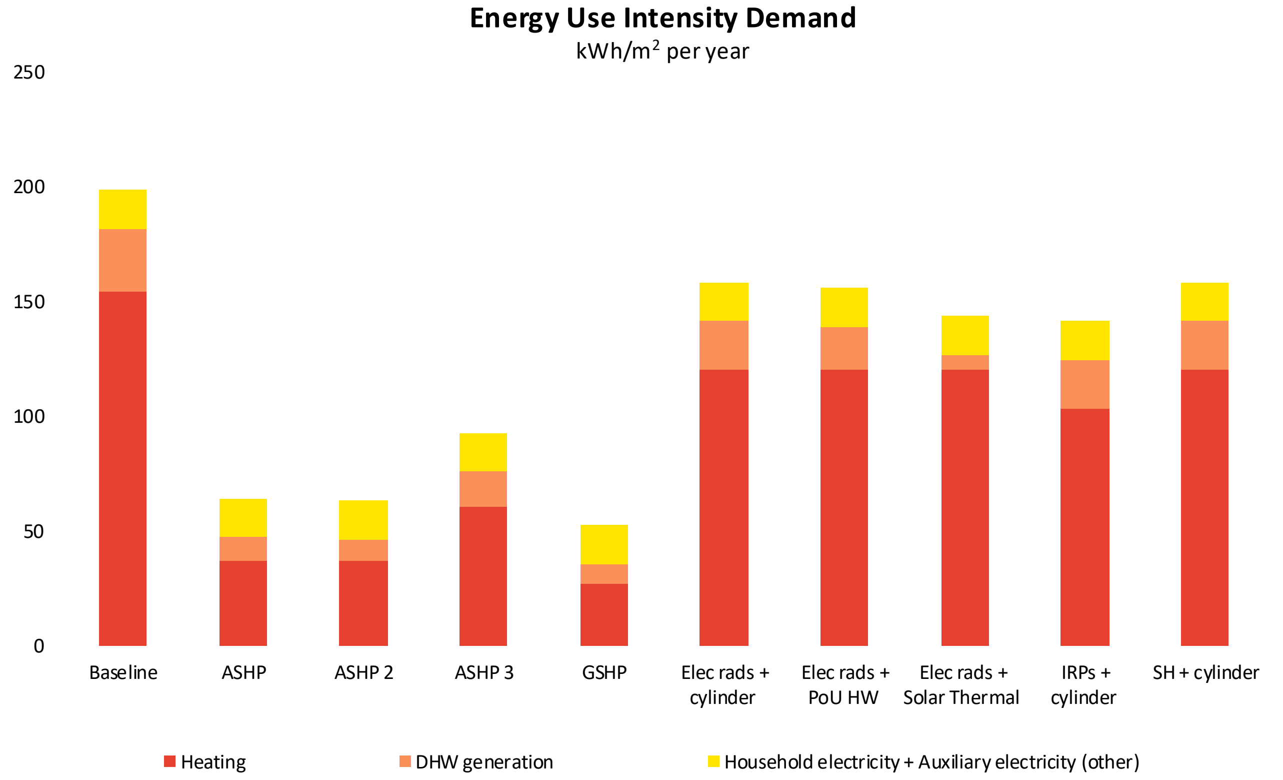


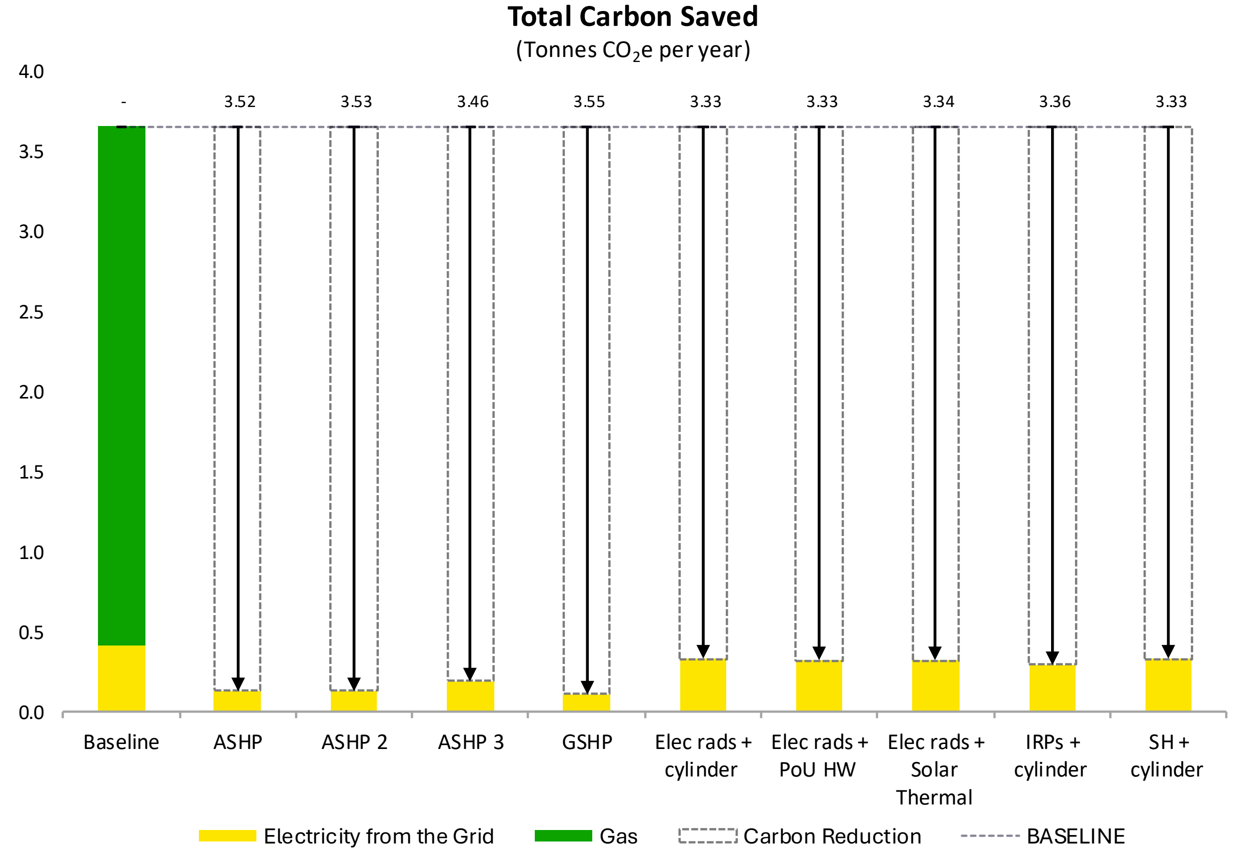


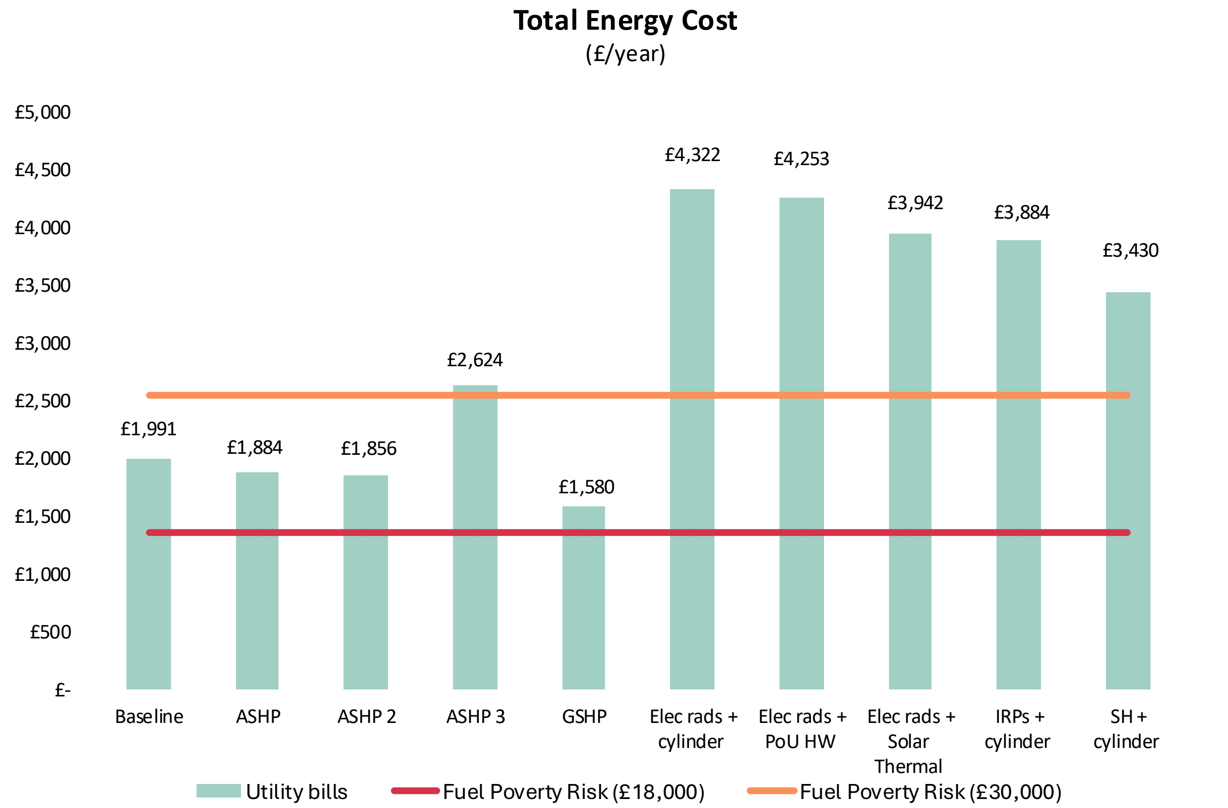


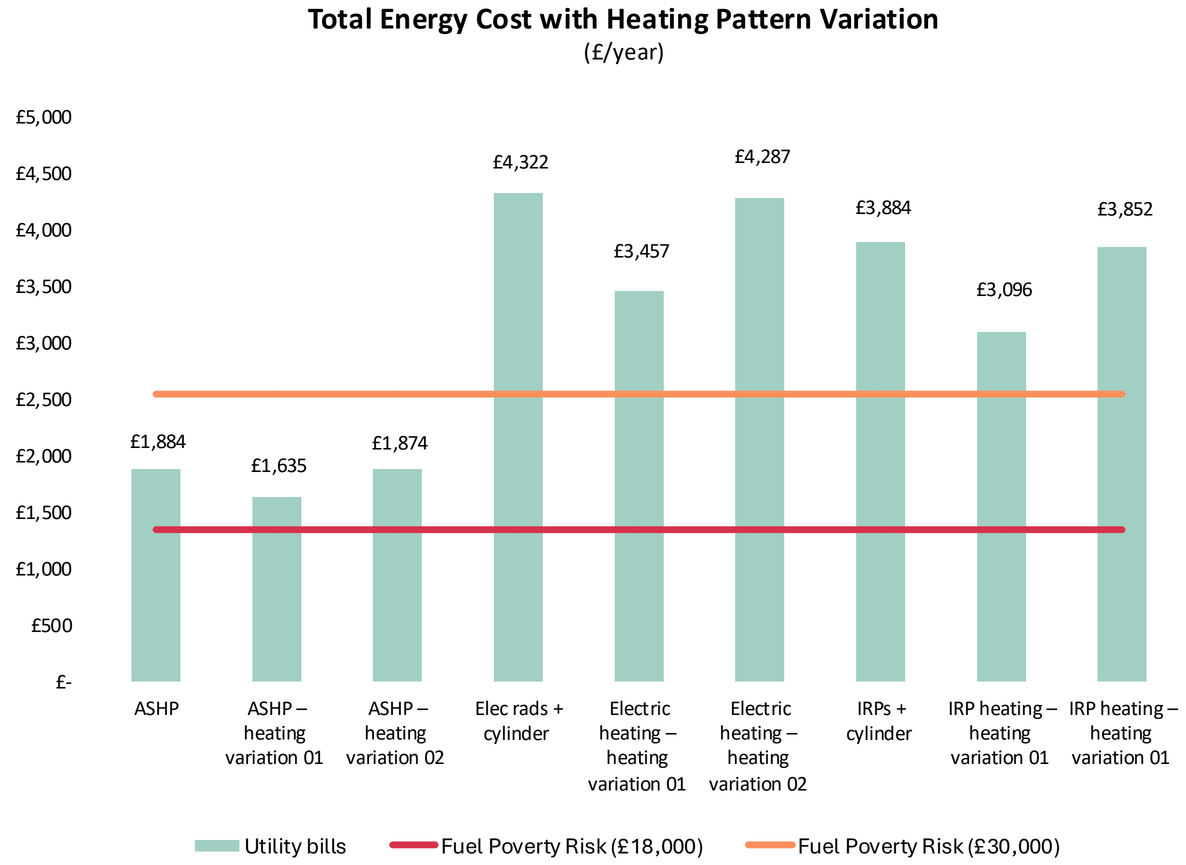
Property Type 10 - Large sized, average fabric efficiency

100m² Floor area, 120kWh/m²/year Space Heating Demand



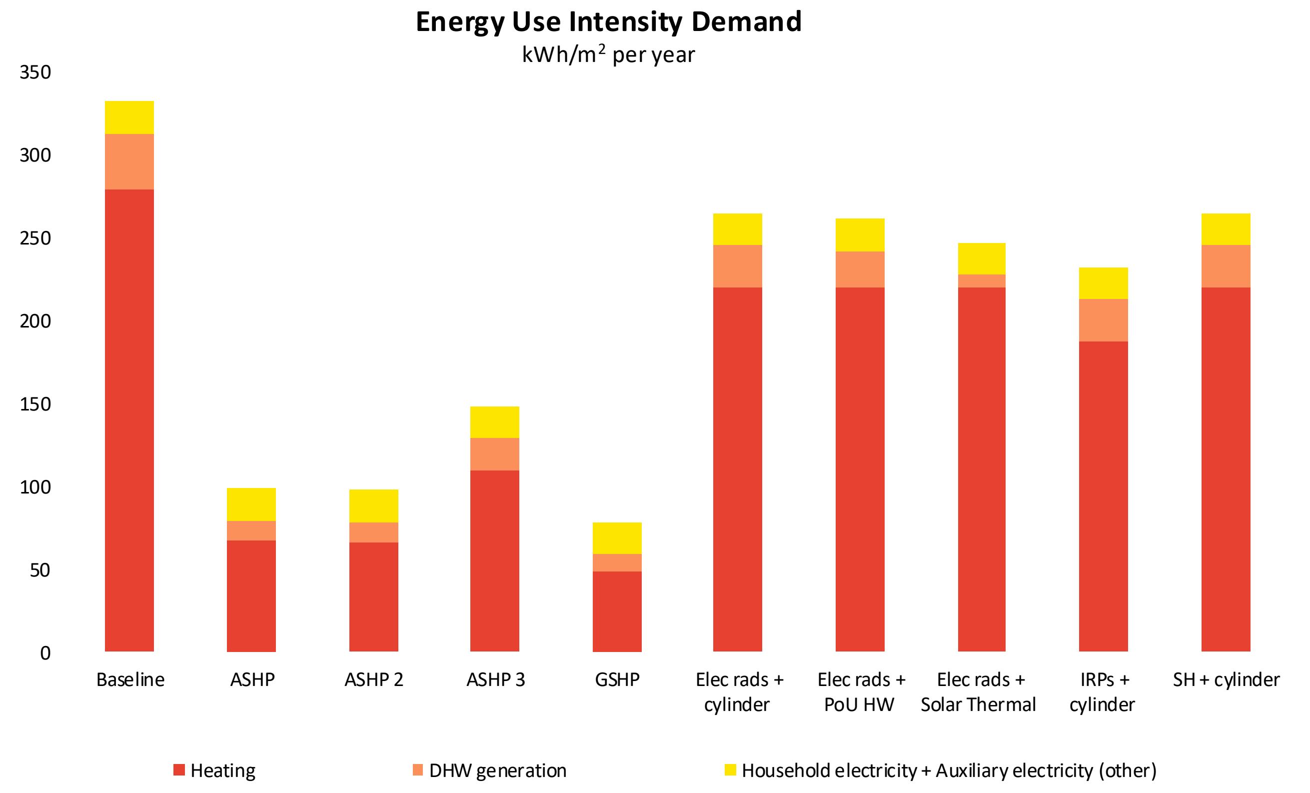


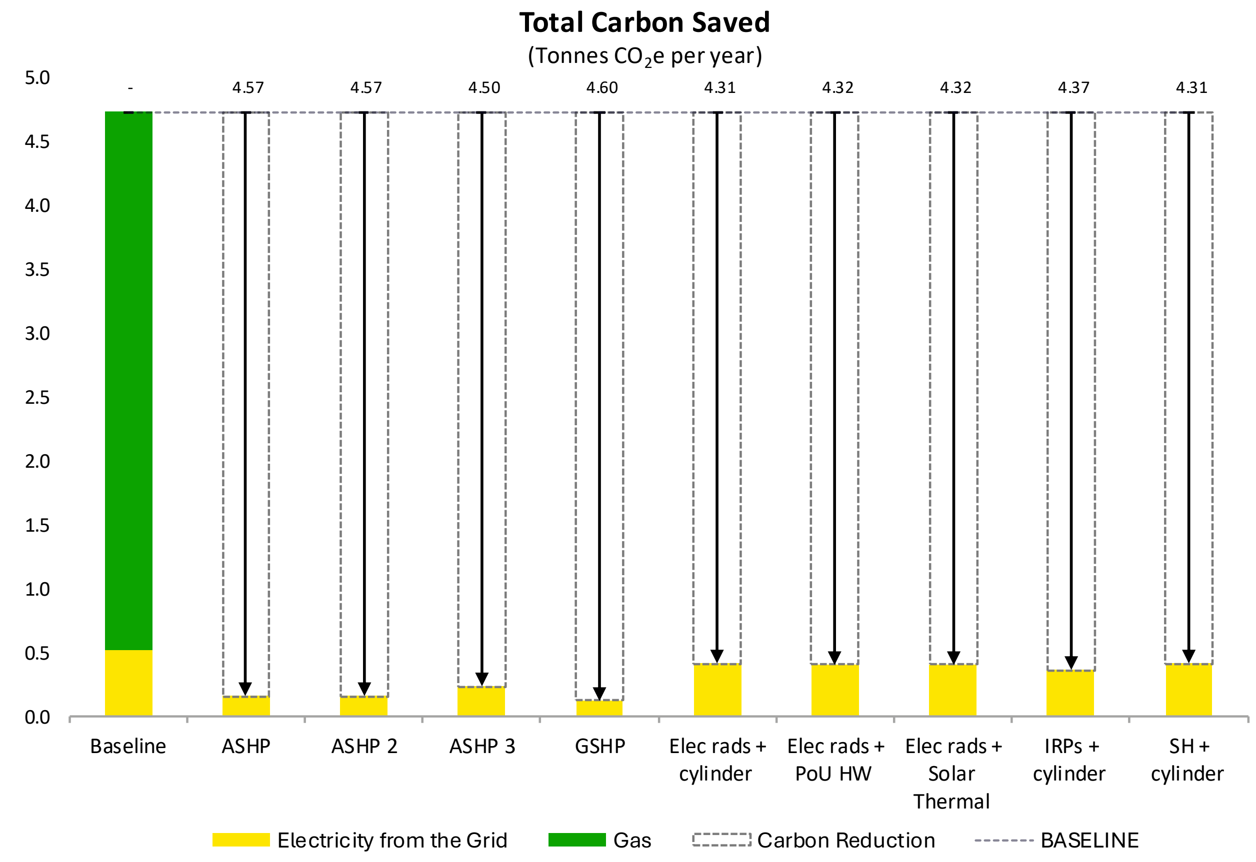


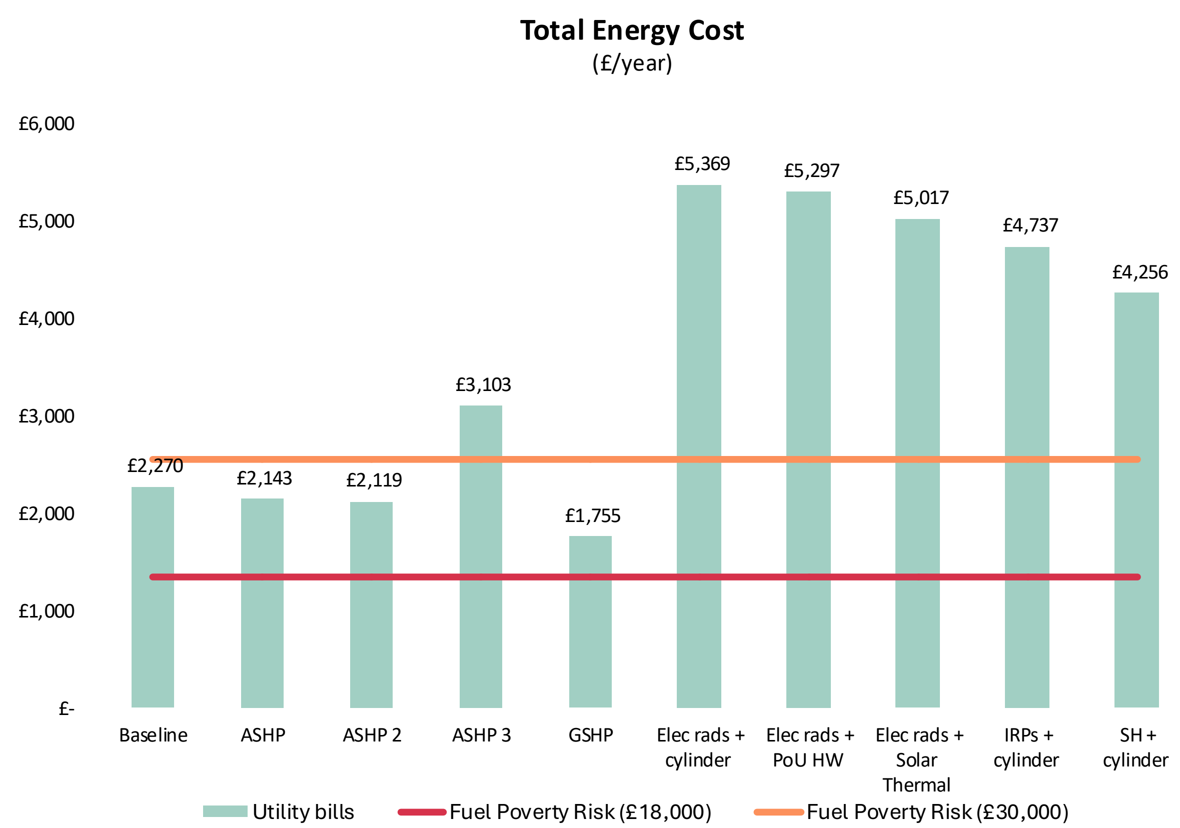


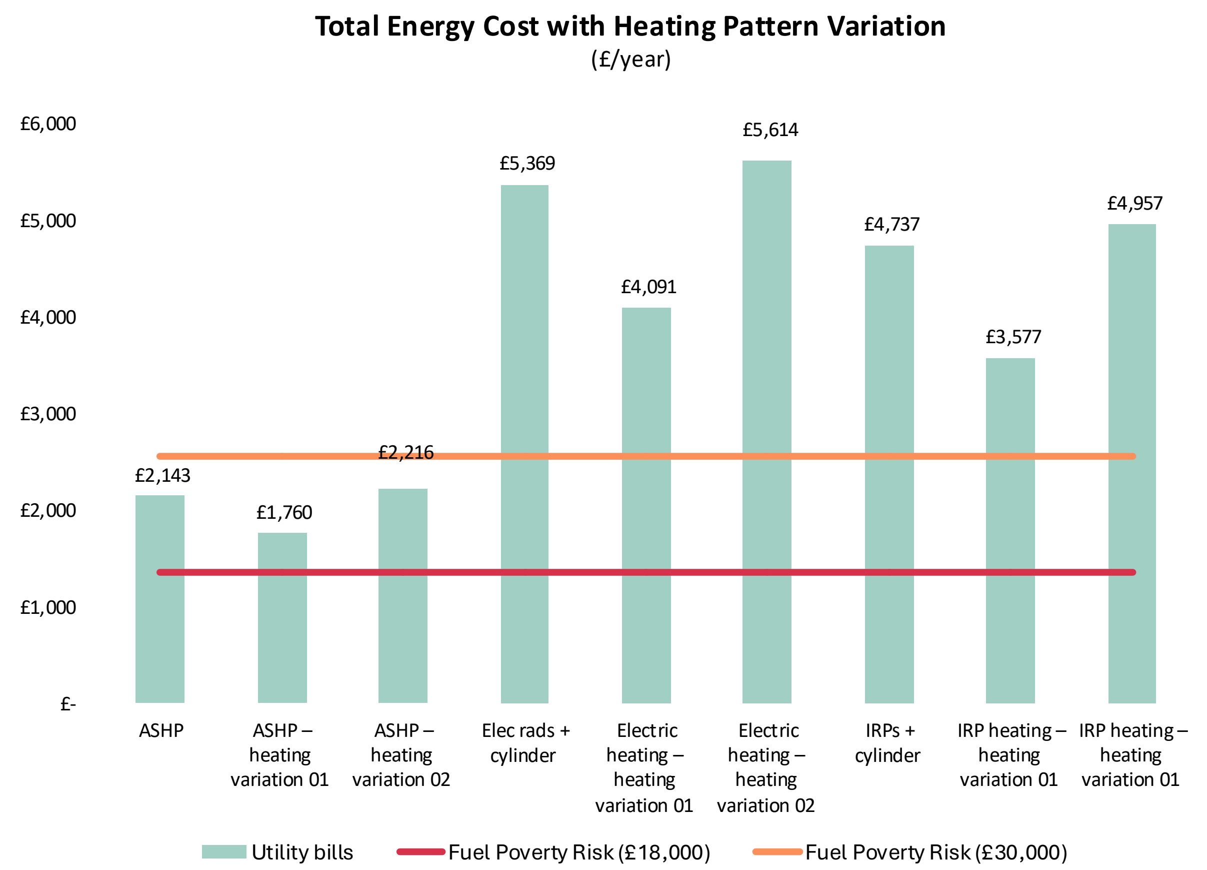
Property Type 11 - Medium sized, poor fabric efficiency

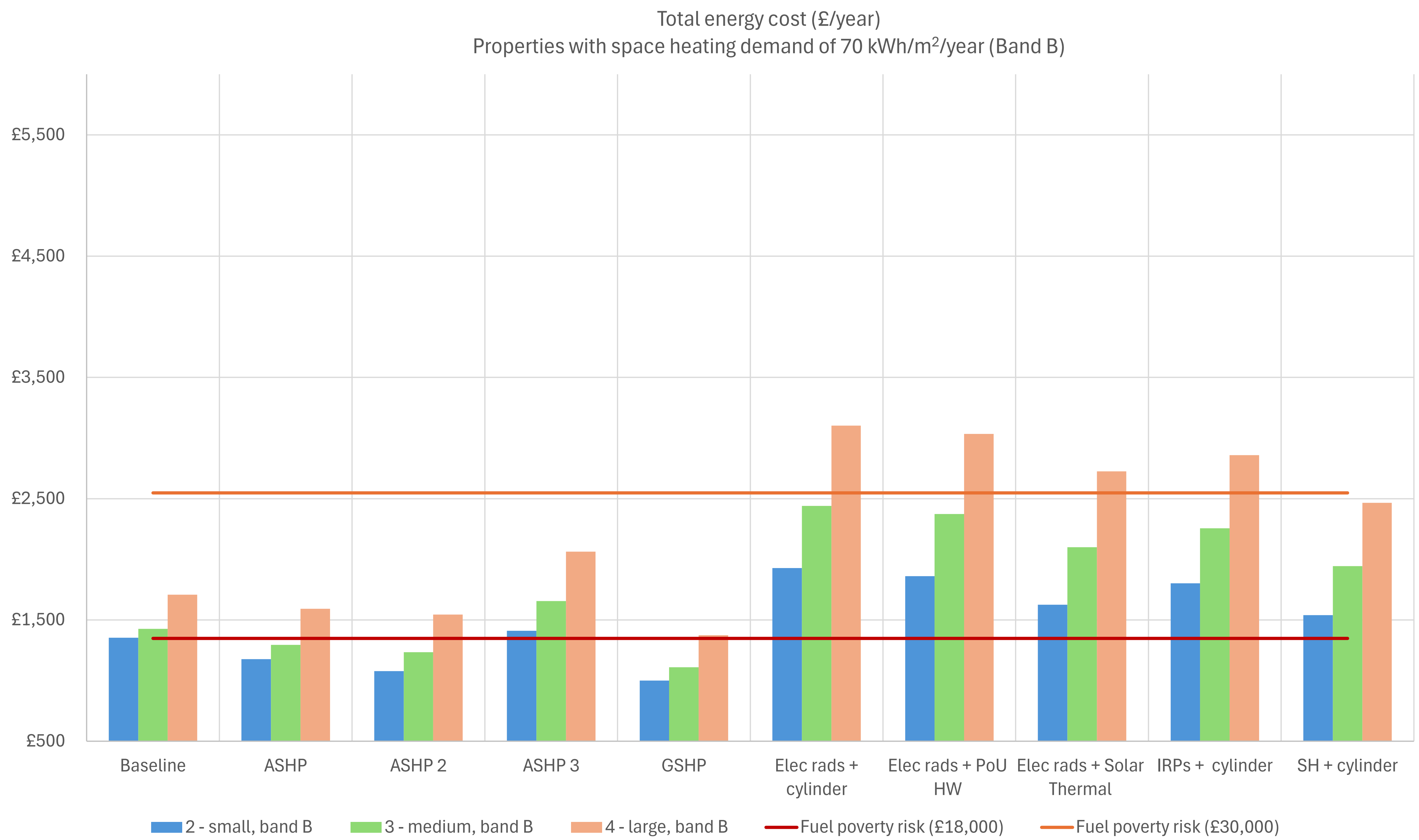
75m² Floor area, 220kWh/m²/year Space Heating Demand

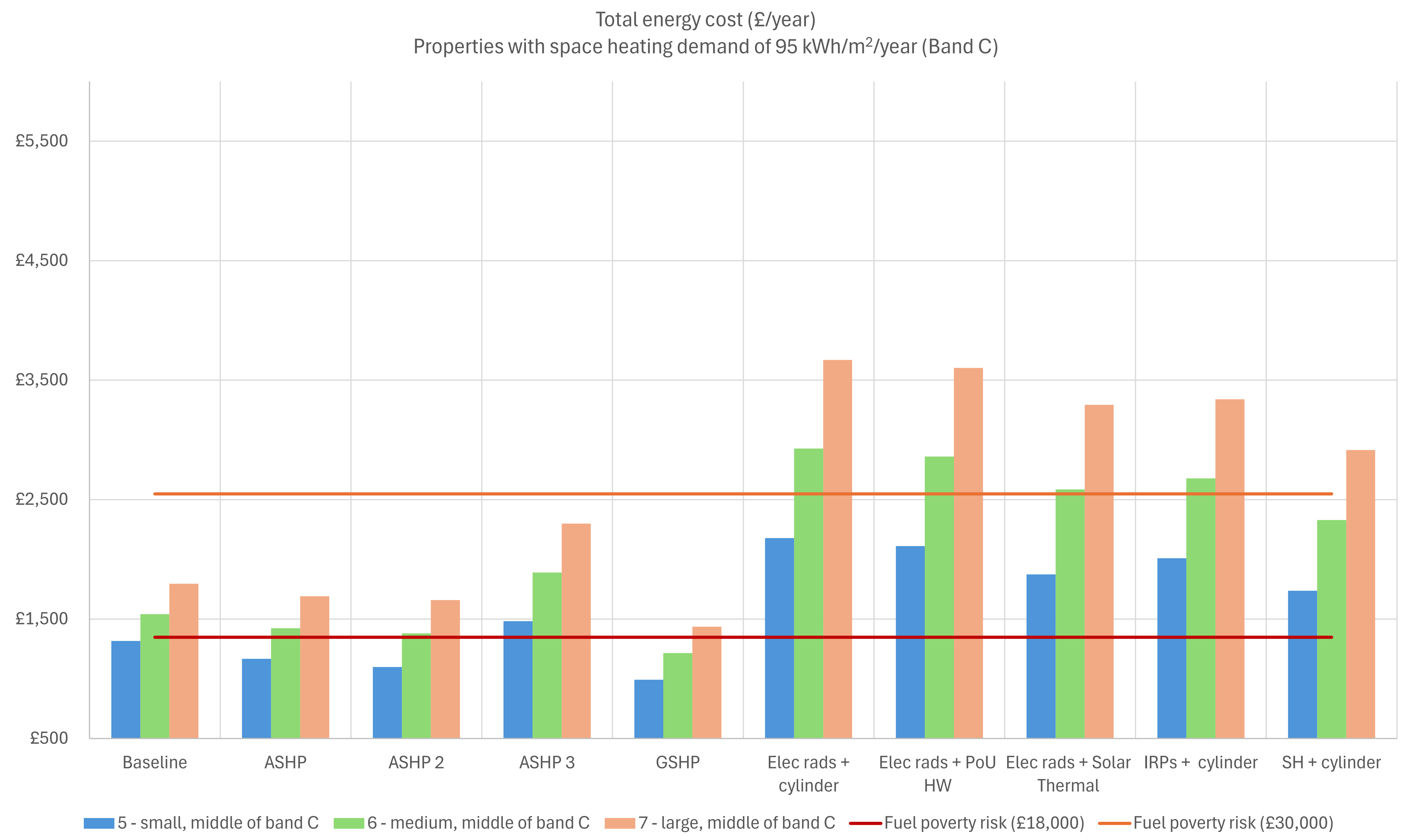


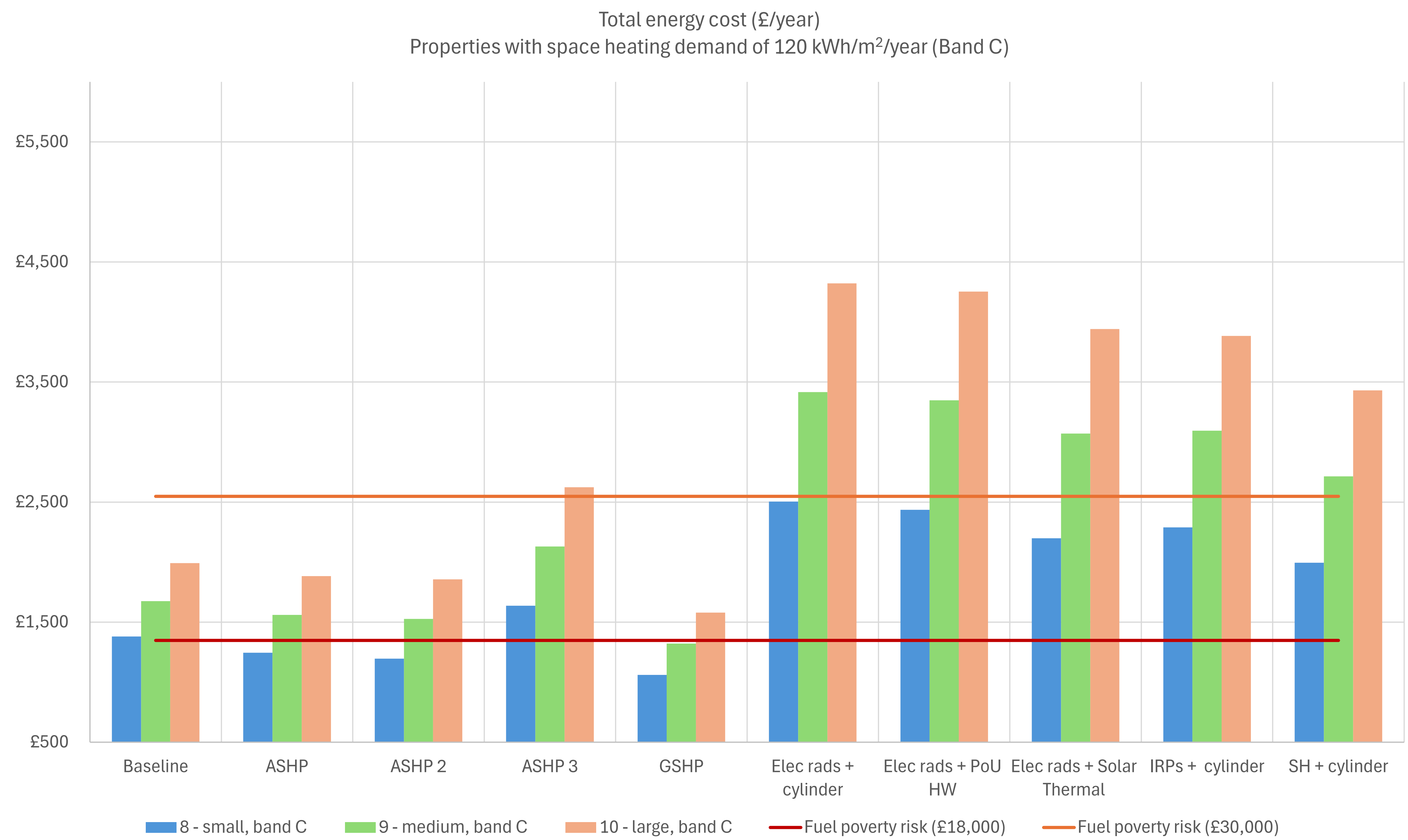







Total energy cost (£/year)
Properties with space heating demand of 70 kWh/m2/year (Band B)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
Baseline
ASHP
ASHP 2
ASHP 3
GSHP
Elec rads + cylinder
Elec rads + PoU HW
Elec rads + Solar Thermal
IRPs + cylinder
SH + cylinder
2 - small, band B
3 - medium, band B
4 - large, band B
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)


Total energy cost (£/year)
Properties with space heating demand of 95 kWh/m²/year (Band C)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
Baseline
ASHP
ASHP 2
ASHP 3
GSHP
Elec rads + cylinder
Elec rads + PoU HW
Elec rads + Solar Thermal
IRPs + cylinder
SH + cylinder
5 - small, middle of band C
6 - medium, middle of band C
7 - large, middle of band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)


Total energy cost (£/year)
Properties with space heating demand of 120 kWh/m2/year (Band C)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
Baseline
ASHP
ASHP 2
ASHP 3
GSHP
Elec rads + cylinder
Elec rads + PoU HW
Elec rads + Solar Thermal
IRPs + cylinder
SH + cylinder
8 - small, band C
9 - medium, band C
10 - large, band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)

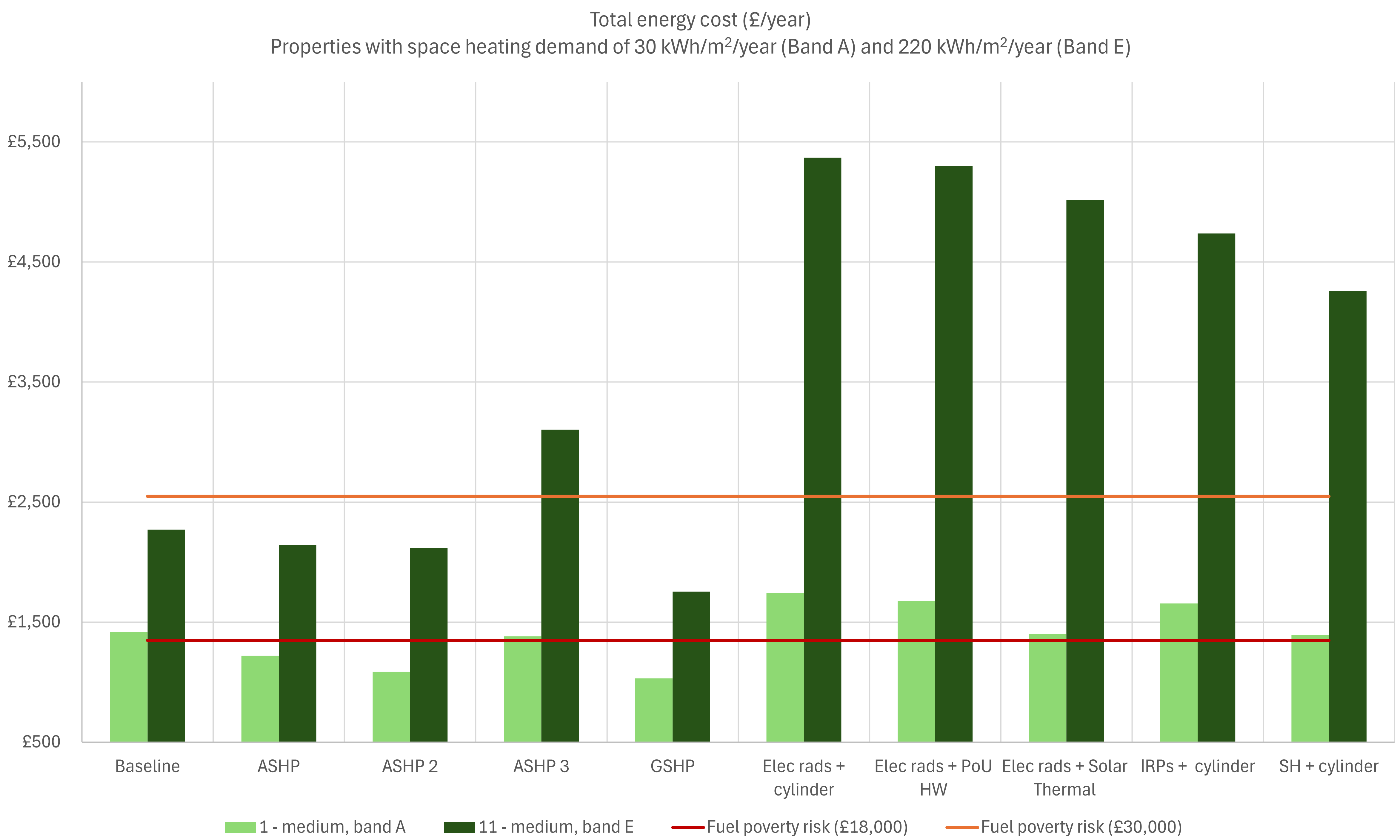
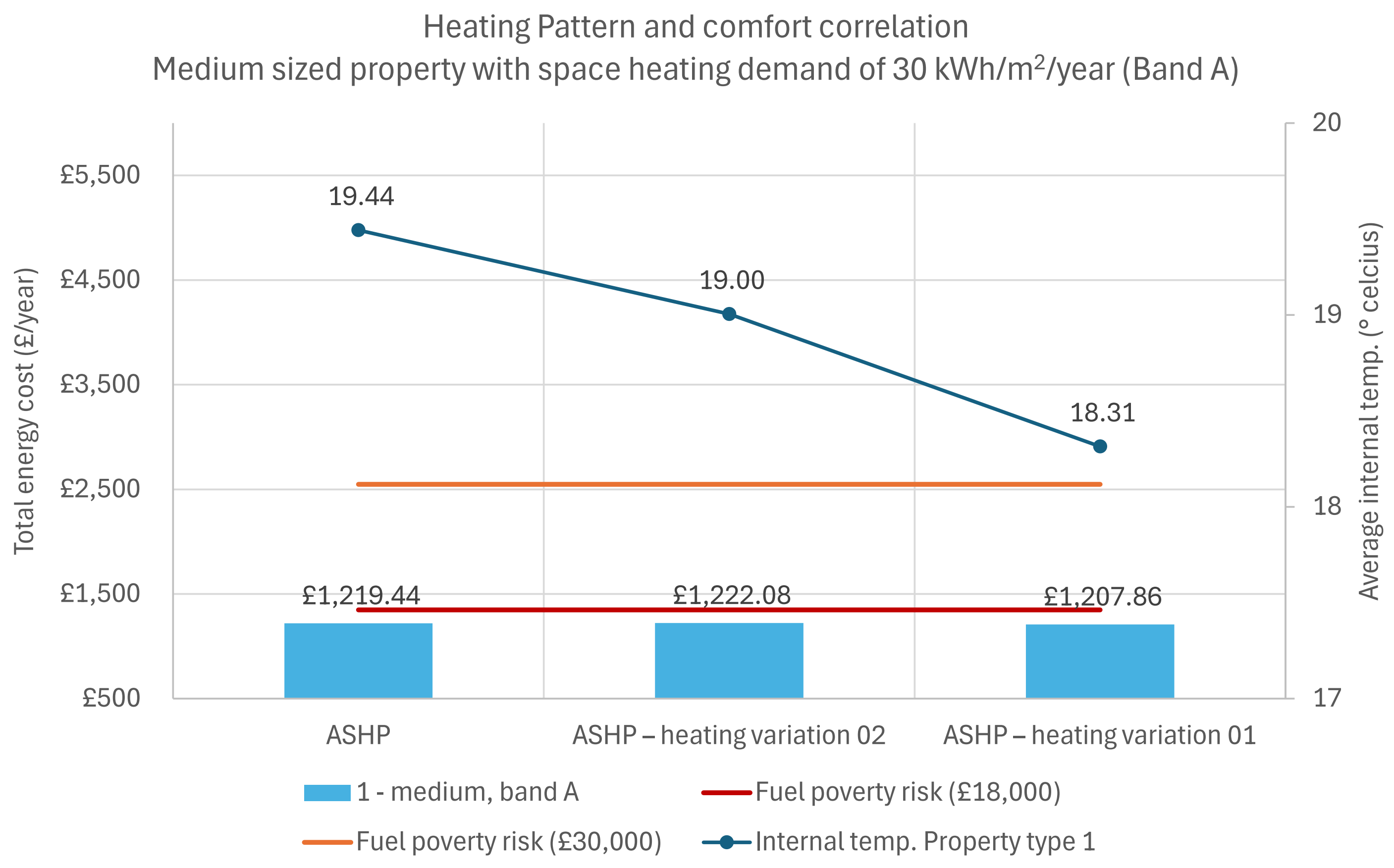
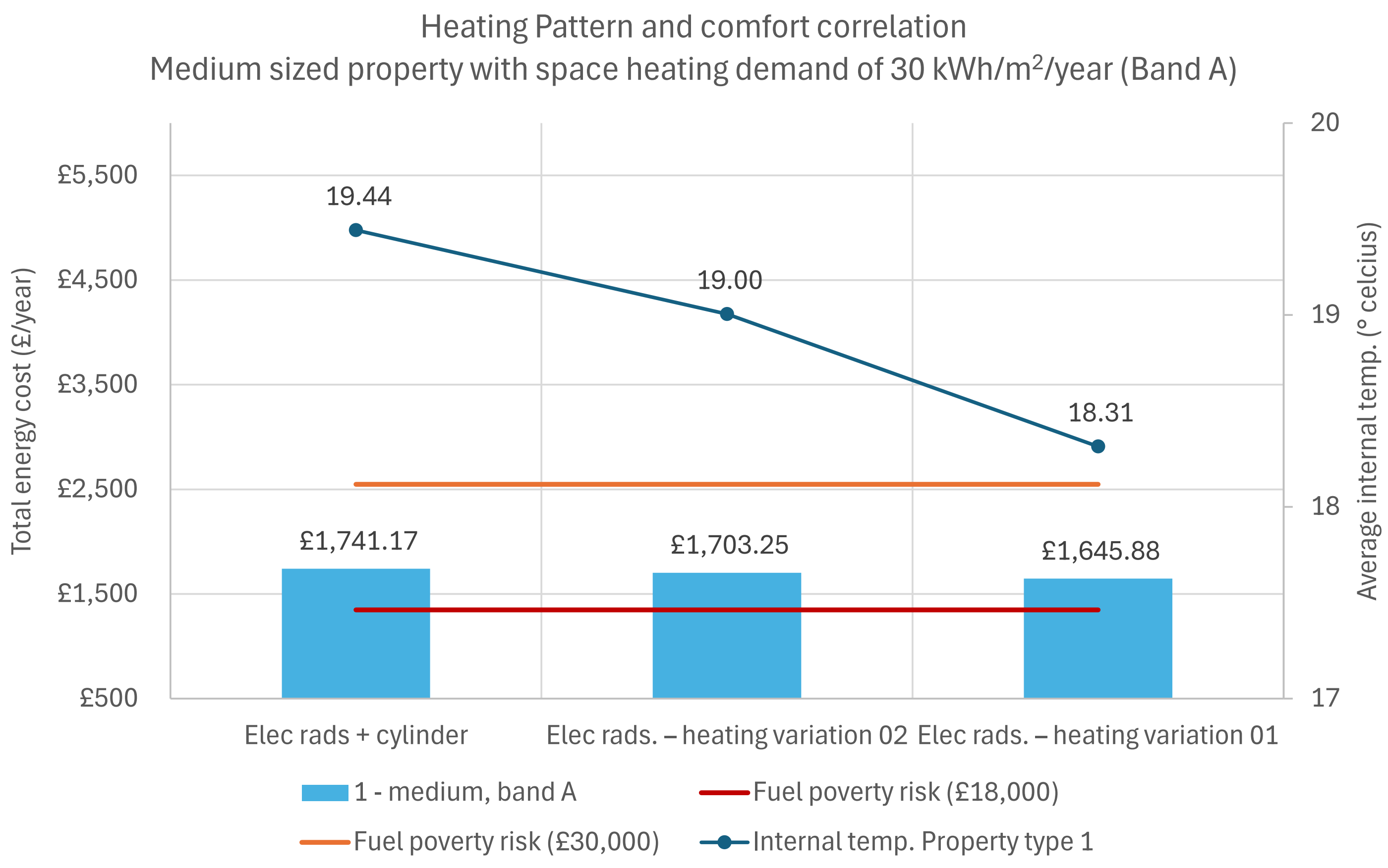
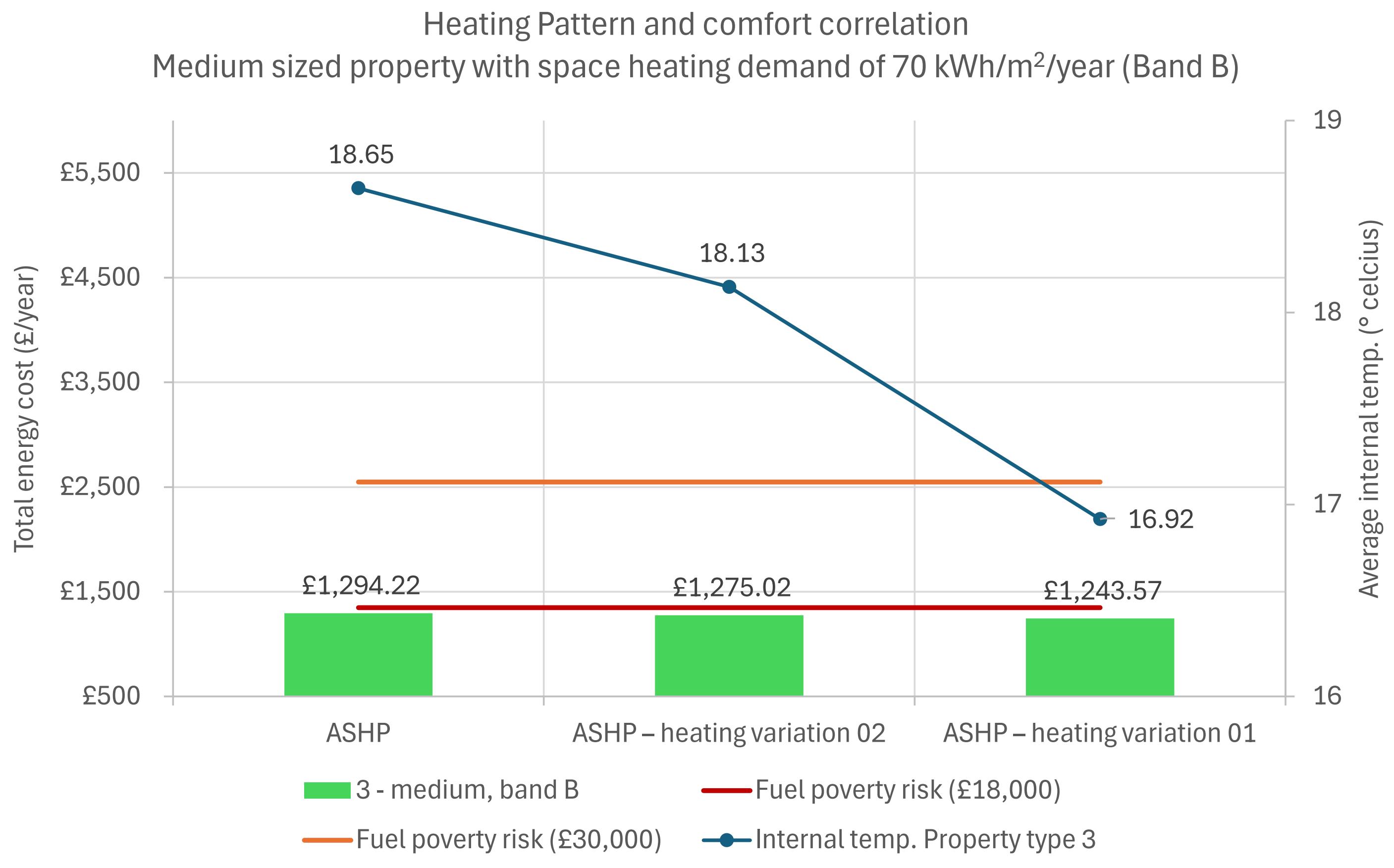

Total energy cost (£/year)
Properties with space heating demand of 30 kWh/m2/year (Band A) and 220 kWh/m2/year (Band E)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
Baseline
ASHP
ASHP 2
ASHP 3
GSHP
Elec rads + cylinder
Elec rads + PoU HW
Elec rads + Solar Thermal
IRPs + cylinder
SH + cylinder
1 - medium, band A
11 - medium, band E
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)

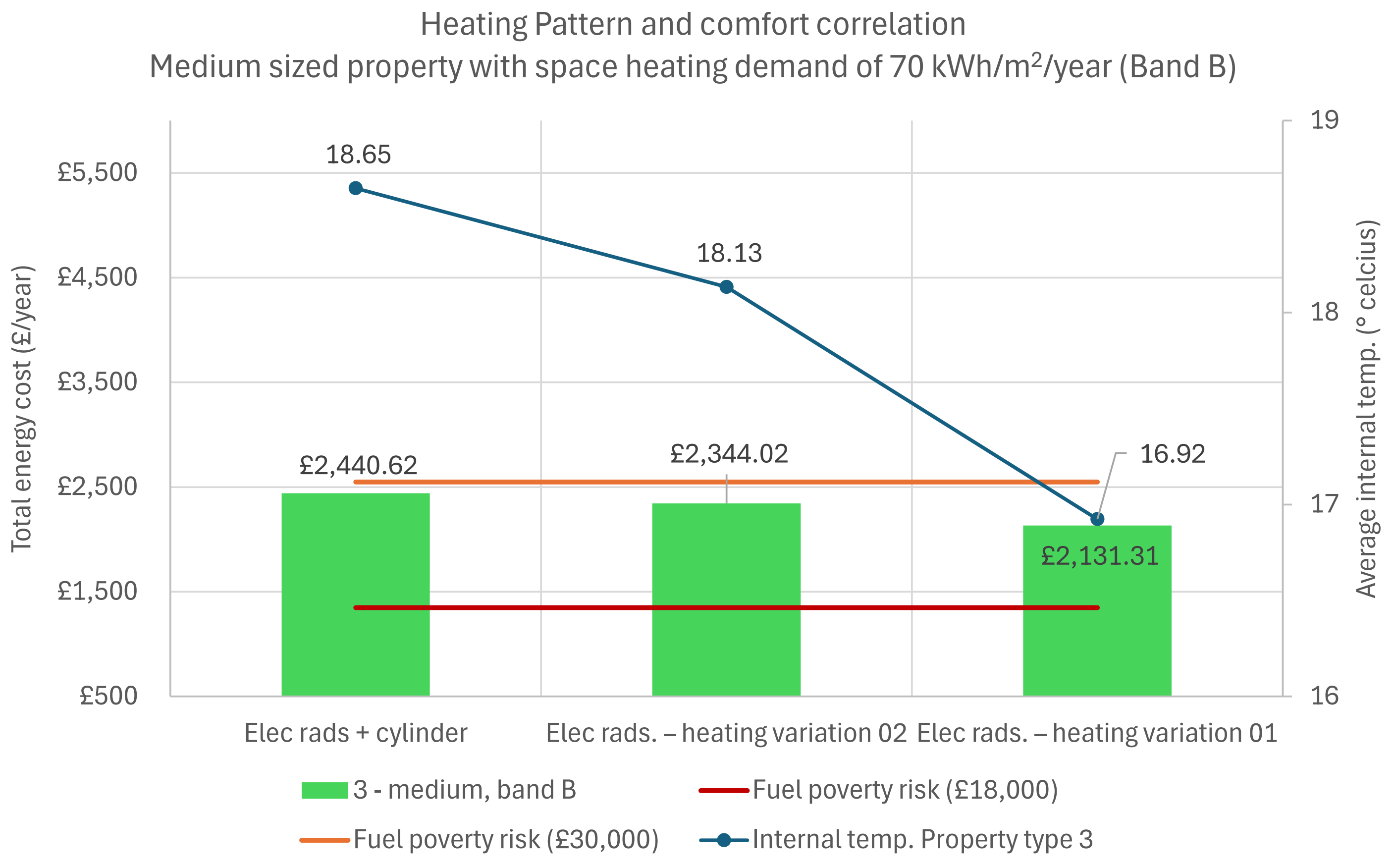
Table 33: Modelled heating regimes

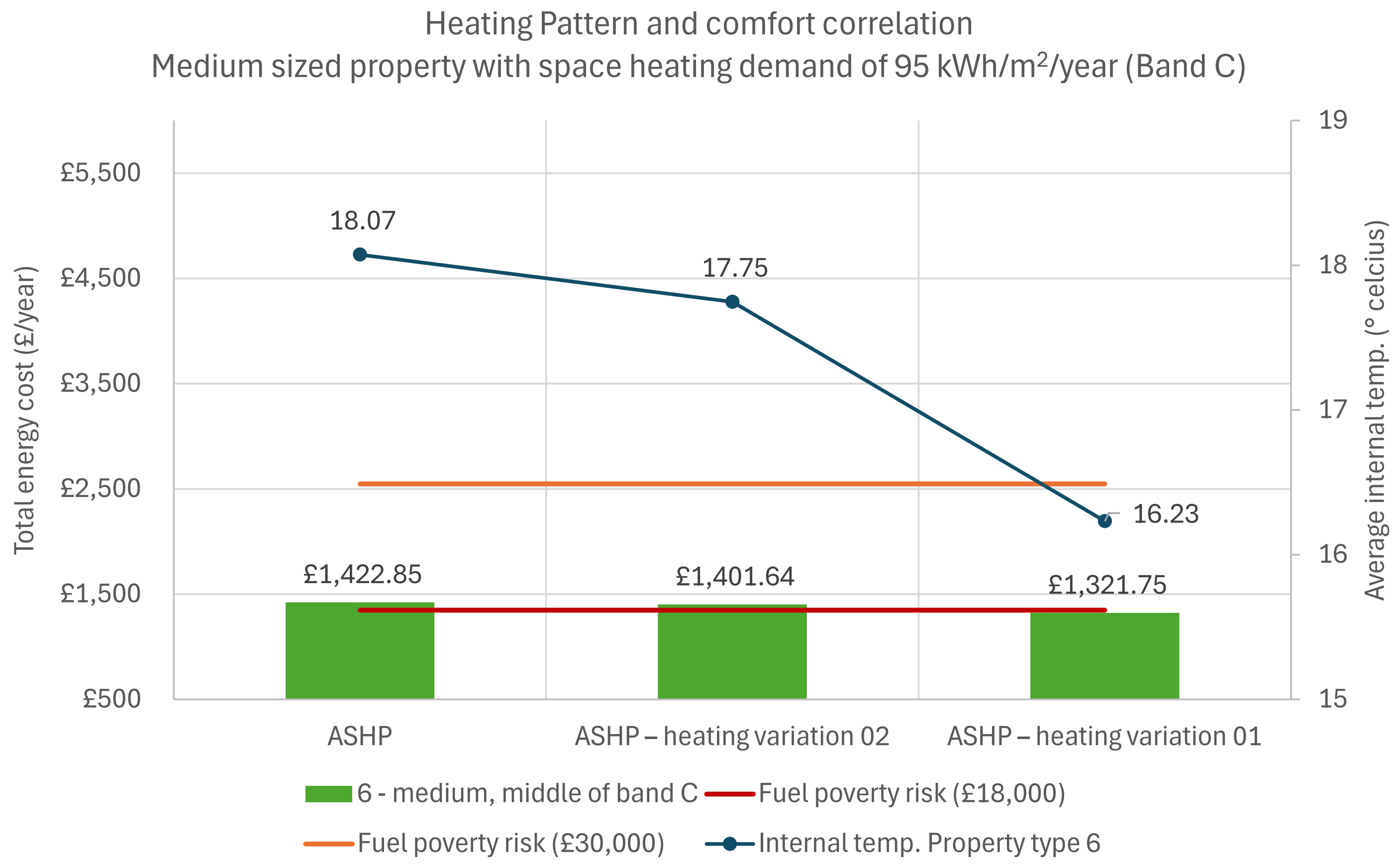
Heating Regime	Hours per day	Temperature of living areas
Standard	8 hours	21 °C
Variation 1	6 hours	20 °C
Variation 2	14 hours	20 °C

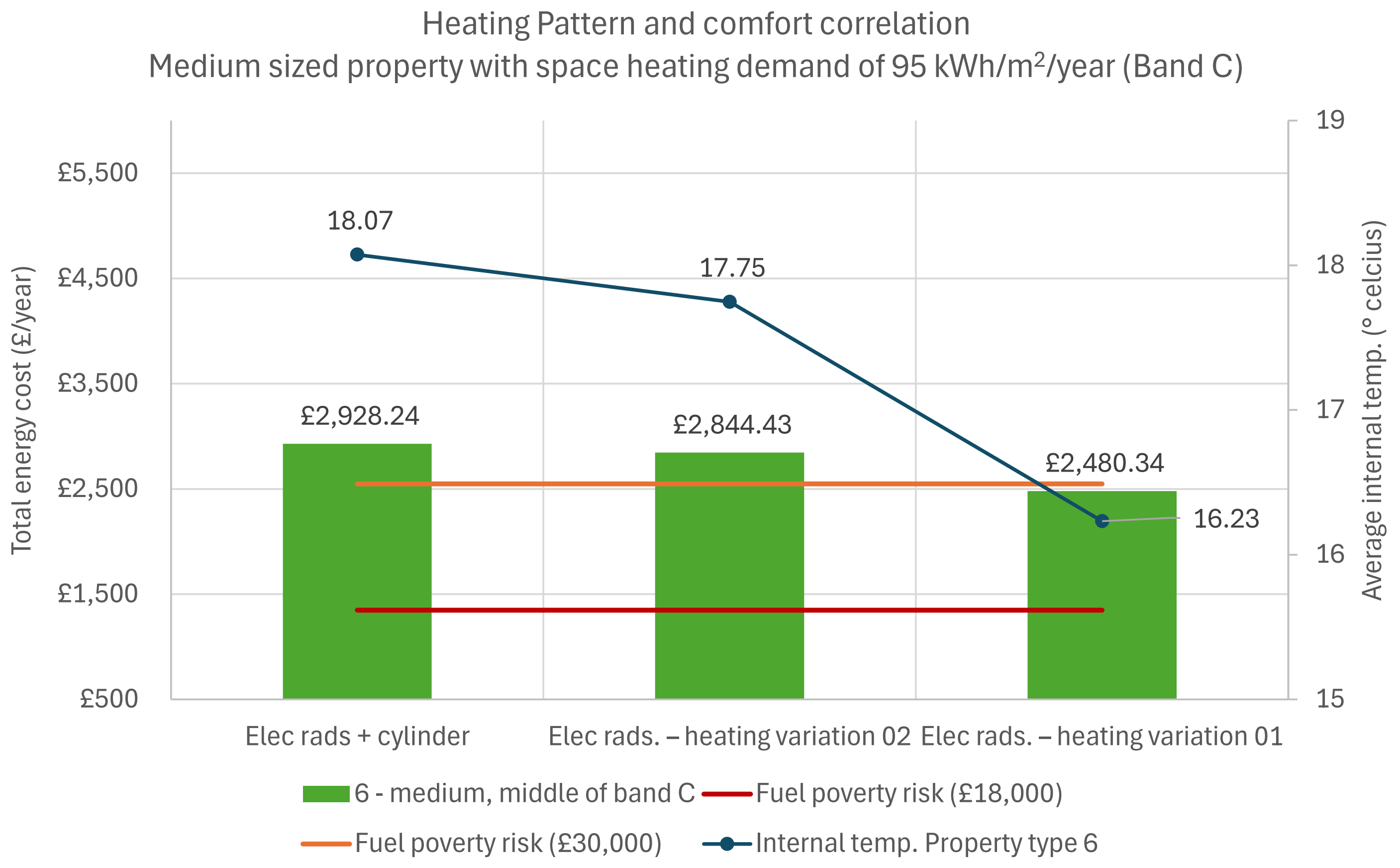


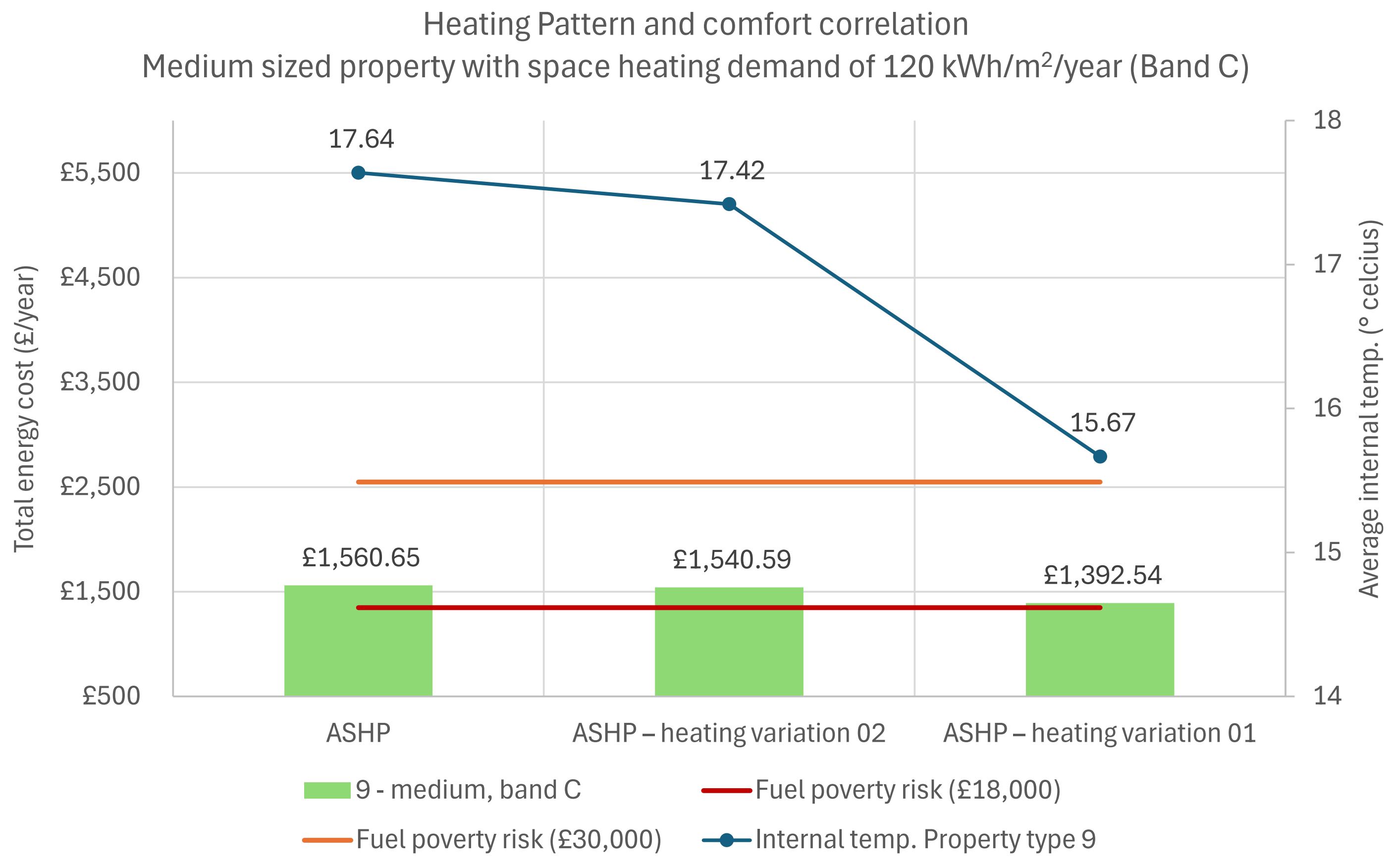



Heating Pattern and comfort correlation
Medium sized property with space heating demand of 70 kWh/m²/year (Band B)
Total energy cost (£/year)
Average internal temp. (° celcius)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
19
18
17
16
18.65
18.13
16.92
£1,294.22
£1,275.02
£1,243.57
ASHP
ASHP – heating variation 02
ASHP – heating variation 01
3 - medium, band B
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 3

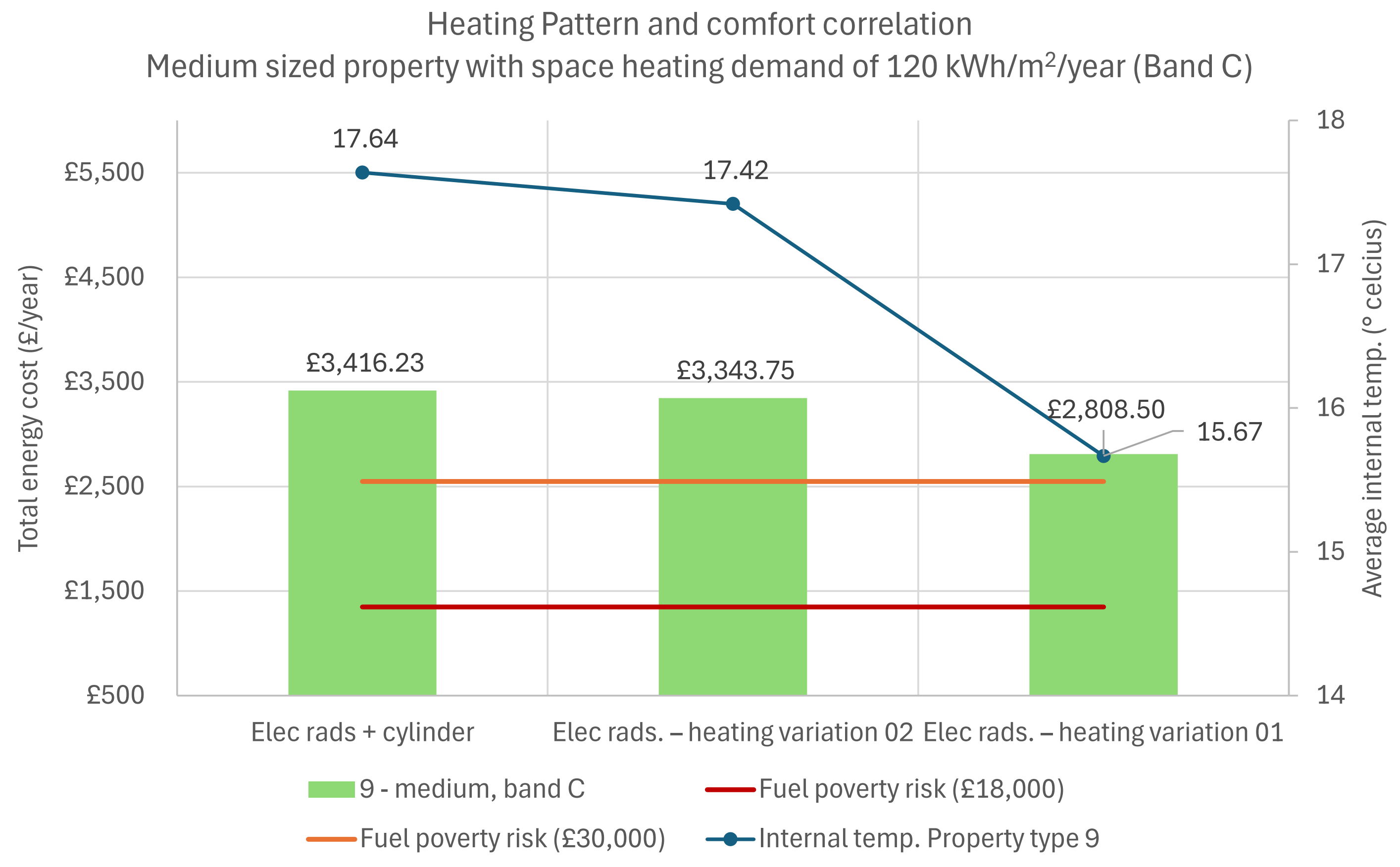

Heating Pattern and comfort correlation
Medium sized property with space heating demand of 70 kWh/m²/year (Band B)
Total energy cost (£/year)
Average internal temp. (° celcius)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
19
18
17
16
18.65
18.13
16.92
£2,440.62
£2,344.02
£2,131.31
Elec rads + cylinder
Elec rads. – heating variation 02
Elec rads. – heating variation 01
3 - medium, band B
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 3


Heating Pattern and comfort correlation
Medium sized property with space heating demand of 95 kWh/m²/year (Band C)
Total energy cost (£/year)
Average internal temp. (° celcius)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
19
18
17
16
15
18.07
17.75
16.23
£1,422.85
£1,401.64
£1,321.75
ASHP
ASHP – heating variation 02
ASHP – heating variation 01
6 - medium, middle of band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 6

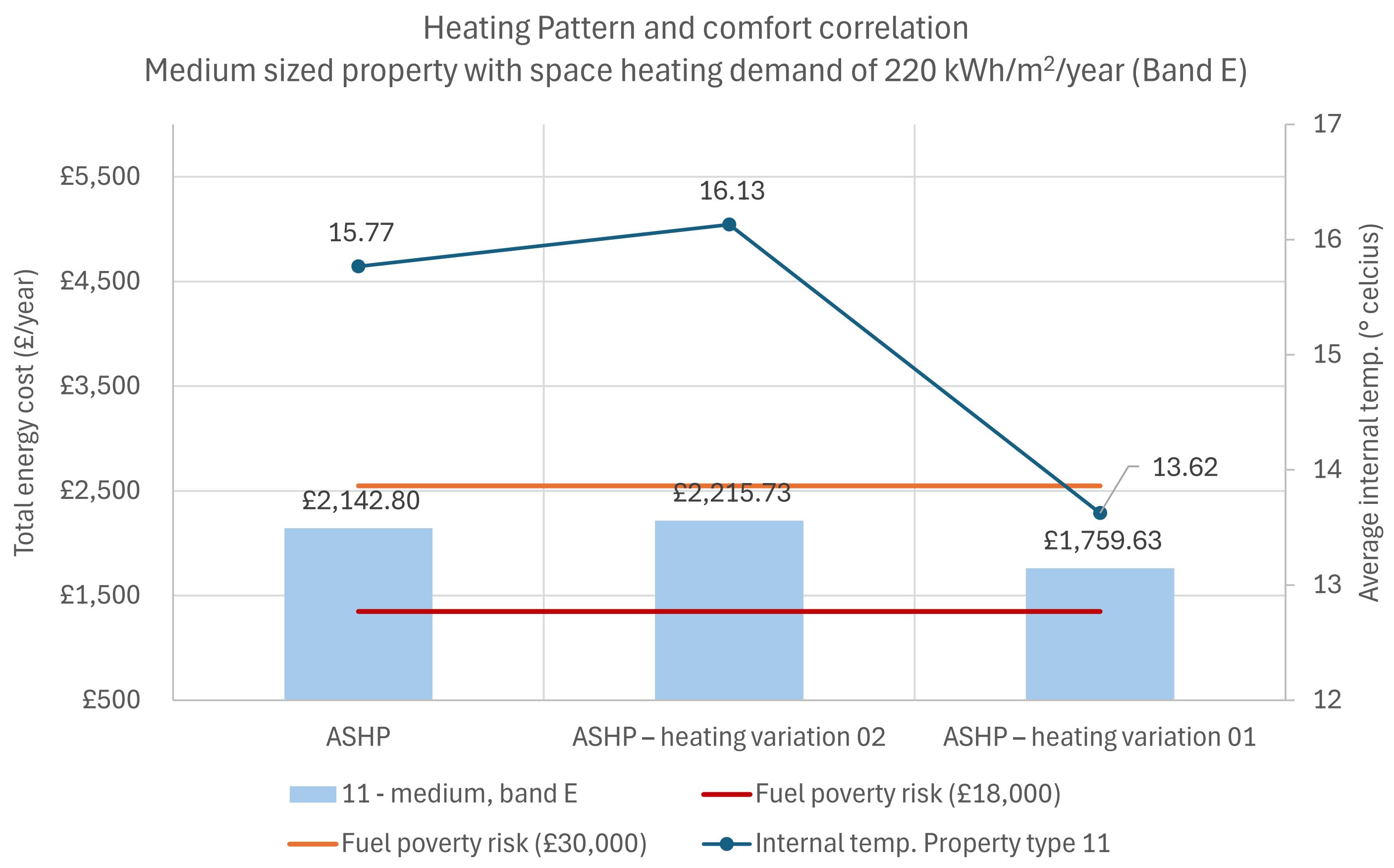

Heating Pattern and comfort correlation
Medium sized property with space heating demand of 95 kWh/m²/year (Band C)
Total energy cost (£/year)
Average internal temp. (° celcius)
£5,500
£4,500
£3,500
£2,500
£1,500
£500
19
18
17
16
15
18.07
17.75
16.23
£2,928.24
£2,844.43
£2,480.34
Elec rads + cylinder
Elec rads. – heating variation 02
Elec rads. – heating variation 01
6 - medium, middle of band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 6



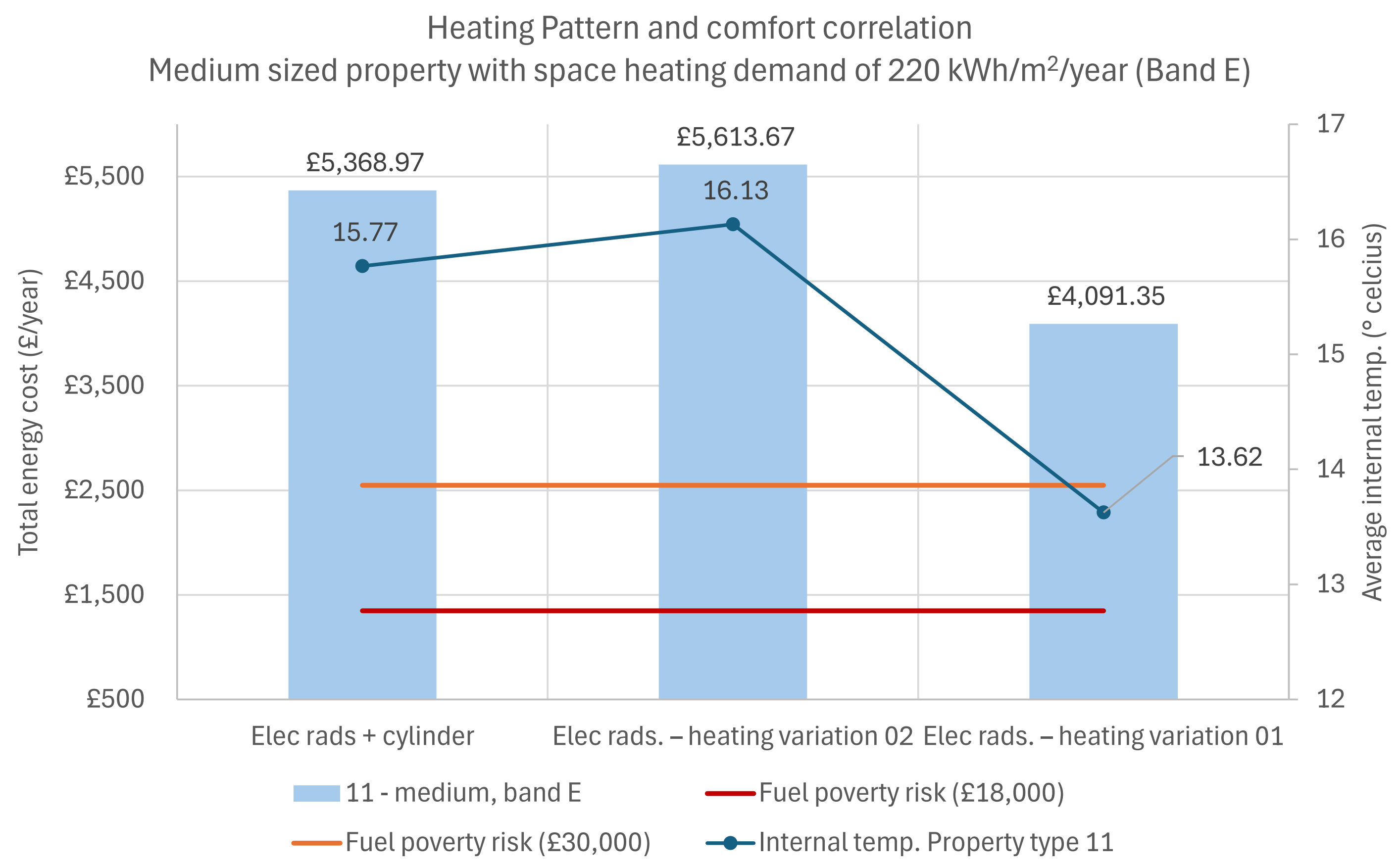
Heating Pattern and comfort correlation
Medium sized property with space heating demand of 120 kWh/m2/year (Band C)
Total energy cost (£/year)
Average internal temp. (° celcius)
17.64
17.42
15.67
£1,560.65
£1,540.59
£1,392.54
ASHP
ASHP – heating variation 02
ASHP – heating variation 01
9 - medium, band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 9



Heating Pattern and comfort correlation
Medium sized property with space heating demand of 120 kWh/m2/year (Band C)
Total energy cost (£/year)
Average internal temp. (° celcius)
17.64
17.42
15.67
£3,416.23
£3,343.75
£2,808.50
Elec rads + cylinder
Elec rads. – heating variation 02
Elec rads. – heating variation 01
9 - medium, band C
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 9



Heating Pattern and comfort correlation
Medium sized property with space heating demand of 220 kWh/m2/year (Band E)
Total energy cost (£/year)
Average internal temp. (° celcius)
15.77
16.13
13.62
£2,142.80
£2,215.73
£1,759.63
ASHP
ASHP – heating variation 02
ASHP – heating variation 01
11 - medium, band E
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 11



Heating Pattern and comfort correlation
Medium sized property with space heating demand of 220 kWh/m2/year (Band E)
Total energy cost (£/year)
Average internal temp. (° celcius)
£5,368.97
£5,613.67
£4,091.35
15.77
16.13
13.62
Elec rads + cylinder
Elec rads. – heating variation 02
Elec rads. – heating variation 01
11 - medium, band E
Fuel poverty risk (£18,000)
Fuel poverty risk (£30,000)
Internal temp. Property type 11

Changeworks has been leading the way in delivering high impact solutions for low-carbon living for over 35 years.
Get in touch with the team to discuss how we can help you.

Approved by : Fabrice Leveque

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Email consultancy@changeworks.org.uk

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