element energy

# *Evidence gathering for electric heating options in off gas grid homes:*

## *Final Report*

**BEIS**
Research Paper
no: 2019/021

April 2019

Element Energy Limited
Suite 1
Bishop Bateman Court
Thompson's Lane
Cambridge CB5 8AQ

Tel: 01223 852499
Fax: 01223 353475

## Project team


| | |
|---|---|
| Sam Foster | sam.foster@element-energy.co.uk |
| Fiona Hughes | fiona.hughes@element-energy.co.uk |
| Ian Walker | ian.walker@element-energy.co.uk |

# Table of Contents

# 1 Executive Summary

This study provides evidence on the electric heating systems available on the UK market and their potential contribution to decarbonising rural off-gas grid dwellings in England and Wales. The heating systems considered include:

- Electric storage heaters
- Electric panel heaters and electric radiators
- Electric infrared heaters
- Electric underfloor heaters
- Electric boilers
- Hot water cylinders with electric immersion elements
- Hot water point-of-use systems

Information on the range of systems available, their costs and performance, and the installation process and associated challenges has been collected via the examination of prior literature, review of the current market, and engagement with relevant stakeholders including original equipment manufacturers (OEMs). The findings are used to inform a model of the uptake of electric heating systems in English and Welsh off-gas grid dwellings, which are currently heated using oil, liquified petroleum gas (LPG), solid fuel, and electric heaters. This model determines the size and number of systems required to heat each dwelling archetype and assesses the upfront and ongoing costs, installation barriers, potential carbon savings, and the impact of additional fabric efficiency measures. This allows the stock of dwellings which are suitable for electric heating to be determined and the uptake of systems under several potential scenarios to be estimated.

Only factors affecting the feasibility of installing and operating electric heating systems within individual dwellings are considered. Impacts on the electricity network and generation requirements will also affect the feasibility of widespread electric heating deployment but are outside the scope of the present study. The most significant factor governing the feasibility of electric heating systems in a given dwelling is the relative size of the dwelling's electricity connection and the peak power needed to heat the dwelling. The model results indicate that the electric heating technologies considered here are not technically feasible in 10% of the 1.3 million rural off-gas dwellings in England and Wales. In these dwellings, the peak power required is too great to be accommodated by a single-phase domestic electricity connection, even when the dwelling is well-insulated. Due to their large size, these dwellings are responsible for 20% of the carbon emissions from the off-gas grid housing stock. 85% of the dwellings in this category are large detached houses which are currently oil heated.

Approximately half of the housing stock is suitable for electric heating with the existing level of insulation. A quarter of the dwellings are not feasible in their current state but can be accommodated if the dwelling fuse is upgraded from 80 A to the maximum value available for a domestic dwelling, 100 A. A further 15% require a fuse upgrade plus additional fabric efficiency measures, such as loft, floor, and wall insulation. With these modifications, these dwellings are suitable for one or more of the electric heating systems considered. The analysed electric heating systems are not feasible in about 10% of dwellings even when these measures have been applied, unless the electricity supply is upgraded to a commercial three-phase connection. The breakdown of the housing stock in these feasibility categories is shown in Table 1-1. Constraints on the electricity LV and HV grids have not been considered and will likely pose an additional barrier to the uptake of electric heating systems[1].

[1] *Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings*, Delta EE for BEIS, Dec 2018.

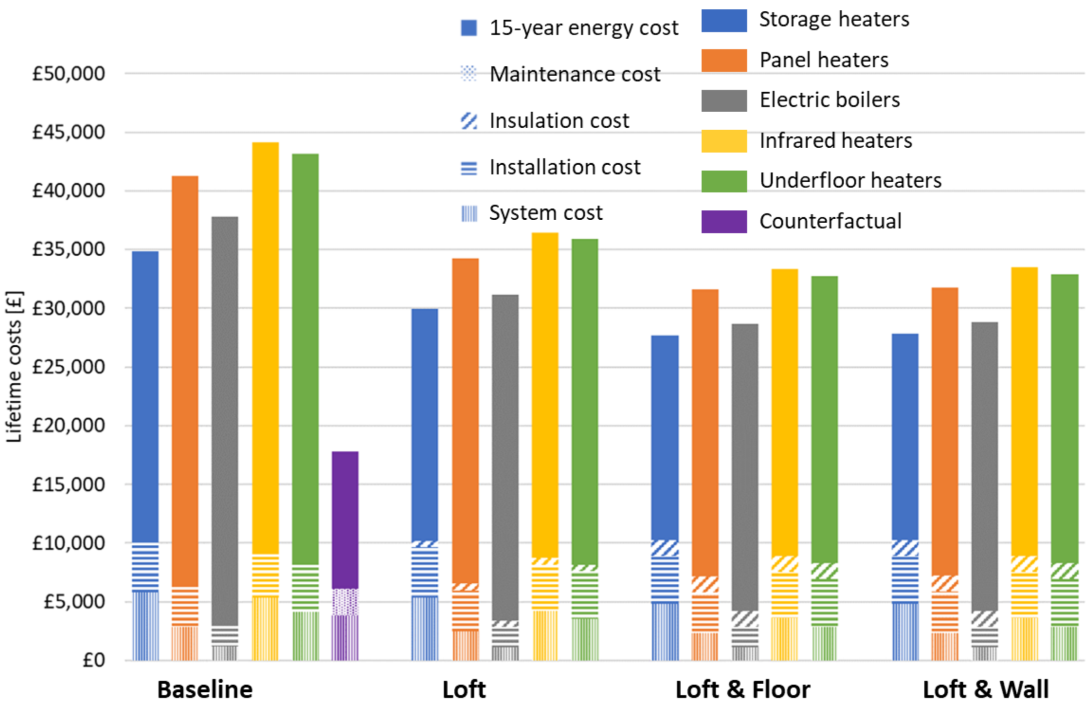
**Table 1-1 Steps required to facilitate use of electric heating in the off-gas grid housing stock**

| Category | Fraction of housing stock |
|---|---|
| Feasible with baseline insulation | 50% |
| Fuse upgrade to 100 A required | 25% |
| Fuse upgrade to 100 A and additional insulation required | 15% |
| Remaining unfeasible dwellings | 10% |

Figure 1-1 allows a comparison of the costs of the electric heating options in a dwelling with the median heat demand and floor area. This is a detached dwelling of 115 $m^2$ with un-insulated cavity walls currently heated by an oil boiler. Figure 1-1 presents the lifetime costs of the systems considered at several levels of insulation, and includes the system costs for each heater type, the installation process, any additional insulation measures, and the lifetime cost of energy. The lifetime of all systems is 15 years, which are assumed to occur between 2020 and 2035. A 3.5% discount rate is applied to all costs incurred after the first year.

Electric boilers have the lowest upfront cost for this dwelling as they can make use of the existing central heating system currently used by the oil boiler. The other systems require significant new wiring to bring power to the individual heaters distributed around the home. Storage heaters have the highest upfront cost of the candidate systems due to their high capital costs. The total system costs are dominated by the cost of electricity, even when additional insulation has reduced the dwelling's annual heat demand from 15 to 11 MWh/year. Storage heaters are the most cost effective in terms of lifetime cost, due to their ability to effectively use an Economy 7 tariff. The lifetime cost of storage heaters is similar to that of electric boilers in this dwelling when additional efficiency measures reduce the yearly heat demand and electricity bill. In larger dwellings where the heat demand is higher across all efficiency levels, the cost savings from storage heaters is more pronounced.

**Figure 1-1 Lifetime costs of electric heating systems in the median off-gas dwelling**



There is a significant increase in the lifetime cost of the electric heating systems over the oil counterfactual due to the high cost of electricity relative to domestic heating oil. This is reduced by the addition of further insulation but is still more than £10,000 when all insulation measures have been added. The median dwelling faces an increase of at least 50%, around £500 per year, in the cost of heat and hot water.

A possible distribution of electric heating systems across the full off-gas grid housing stock is shown in Table 1-2. This assumes that the type of electric heating system and any additional insulation measures are selected to minimise the lifetime cost in each dwelling. As for the median dwelling above, all systems have a 15-year lifetime which occurs between 2020 and 2035. For cavity wall dwellings, the lifetime cost is typically minimised when loft and wall insulation are added. Due to the much higher costs of wall insulation in solid wall dwellings, these typically adopt loft and floor insulation.

The floor area, lifetime costs, and carbon savings shown in Table 1-2 are the average for the dwellings adopting each system. As noted above, around 10% of the stock are not suitable for the installation of any electric heating system due to the heat demand exceeding the power available for domestic dwellings. Three quarters of the stock select storage heaters. This includes dwellings which were already using electric storage heaters as well as many dwellings similar to the median dwelling shown above which are converted from oil- and solid-fuelled systems. 15% of the dwellings select electric boilers, including around 20% of the oil- and solid-fuelled dwellings. In some cases, the high upfront cost of conversion to storage heaters does not “pay back” in reduced electricity costs over the 15-year system lifetime. Other larger dwellings adopt electric boilers because the peak power demand from storage heaters would breach the dwelling fuse limit. A small fraction made up of larger dwellings where all other systems would breach even a 100 A fuse limit select infrared heaters. Panel heaters and underfloor heating do not result in the lowest lifetime costs for any of the dwelling archetypes and therefore do not appear in this uptake scenario.

**Table 1-2 Electric heating system uptake across the stock based on lowest lifetime cost**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 962,361 | 0 | 196,969 | 33,399 | 0 | 116,458 |
| All dwellings fraction | 74% | 0% | 15% | 3% | 0% | 9% |
| Oil dwellings | 600,091 | 0 | 173,319 | 30,040 | 0 | 107,207 |
| Oil fraction | 66% | 0% | 19% | 3% | 0% | 12% |
| Solid dwellings | 68,460 | 0 | 17,867 | 3,359 | 0 | 151 |
| Solid fraction | 76% | 0% | 20% | 4% | 0% | 0% |
| Electric dwellings | 293,809 | 0 | 5,783 | 0 | 0 | 9,101 |
| Electric fraction | 95% | 0% | 2% | 0% | 0% | 3% |
| All dwellings | | | | | | |
| Floor area ($m^2$) | 116 | n/a | 143 | 235 | n/a | n/a |
| Lifetime cost | £29,500 | n/a | £36,300 | £74,500 | n/a | n/a |
| Lifetime cost over counterfactual | £9,970 | n/a | £17,100 | £44,300 | n/a | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2e$) | 32 | n/a | 49 | 89 | n/a | n/a |
| **Total carbon savings (Mt $CO_2e$)** | **31** | **n/a** | **10** | **3** | **n/a** | **n/a** |

Over the life of the systems, a total of 44 Mt $CO_2e$ are avoided due to the uptake of electric heating in this scenario, a 40% reduction in the carbon emissions due to heating and hot water provision in the rural off-gas grid housing stock[2].

Additionally, storage heaters have the potential to provide Demand Side Response services. In the scenario shown here, the aggregated energy storage capacity of storage heaters is 90 GWh. This rises to 100 GWh if storage heaters are adopted in the 83% of dwellings where they are feasible. An alternative uptake scenario considers the use of electric boilers as a stepping stone towards the future installation of heat pumps in the rural off-gas stock. Electric boilers are feasible for installation in 88% of the dwellings.

Electric heating is technically feasible in the majority of the stock when only building-level constraints are considered, but the significant increases in heating bills and the lifetime costs faced by the dwelling occupants may pose a barrier to the uptake of electric heating systems. High costs are compounded by several issues highlighted in previous studies on electric heating, including poor customer service for those using non-standard tariffs[3] and the higher burden of environmental and social levies on consumers with electric heating[4].

[2] Electricity carbon emissions follow *BEIS Energy and Emissions Projections: 2017*, Annex M. Oil and solid fuel emissions are from *HMT Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal*, BEIS, 2018.
[3] *False Economy: Missed opportunities and failures in the 'time of use' tariff market*. Future Energy Consumers Unit, Citizens Advice England, 2018, https://www.citizensadvice.org.uk/about-us/policy/policy-research-topics/energy-policy-research-and-consultation-responses/energy-policy-research/false-economy/
[4] *Insights paper on households with electric and other non-gas heating*, Ofgem Consumer Vulnerability Team, 2015.

### Acknowledgements

We would like to thank the stakeholders who provided key input to this project.

| Organisation | Stakeholders consulted |
|---|---|
| Aqualisa | Richard Pope |
| Atlantic Heat | John Lee |
| BEAMA | Kevin Ray<br>Yselkla Farmer<br>Adrian Regueira-Lopez<br>Simon Harpin |
| Climote | Eamon Conway<br>Derek Roddy<br>Ivor Roddy |
| Cotherm UK Ltd | Steve Bartholomew |
| Danfoss | Richard Boon |
| ECA | Luke Osborne |
| Electric Heating Company | Bill Walters |
| Flexel | George Graham |
| Gaia Climate Solutions | Chris Alecock<br>Steven Rooney |
| Geo | Rik Temmink<br>Patrick Caiger-Smith<br>Allan Turpie |
| Glen Dimplex | Rowena McCappin<br>Shaun Hurwurth<br>Alan McDonald<br>Matthew Maskell |
| Heatrae Sadia | Dylan Hearn<br>Alan Clarke<br>Anthony Gravestock |
| Herschel | Paul Morey<br>Richard Martin |
| Logicor | David Bowen |
| Mull & Iona Community Trust | Moray Finch |
| Vailliant | Mark Barson<br>Andrew Ireland |
| Volution Group | Steve Totman |
| Warmup | Antony White |

## Glossary

| | |
|---|---|
| BEAMA | British Electrotechnical and Allied Manufacturers Association |
| BEIS | Department for Business, Energy, and Industrial Strategy |
| CAE | Citizens Advice England |
| CAS | Citizens Advice Scotland |
| CHM | Cambridge Housing Model |
| CMA | Competitive Market Authority |
| DNO | Distribution network operator |
| DOM 8 | *DOM 8: Guide to the Design of Electric Space Heating Systems*, The Electric Heating & Ventilation Association, Feb 2006. |
| ECO | Energy Company Obligation |
| EED | Energy Efficiency Directive |
| EHS | English Housing Survey |
| EPBD | Energy Performance in Buildings Directive |
| EPC | Energy performance certificate |
| LGP | Liquified petroleum gas |
| LiW | Living in Wales (housing survey) |
| LV | Low voltage |
| NEA | National Energy Action |
| OEM | Original equipment manufacturer |
| Ofgem | Office of Gas and Electricity Markets |
| PEF | Primary energy factor |
| SAP | Standard Assessment Procedure |
| WHCS | Welsh Housing Conditions Survey |

# 2 Introduction

## 2.1 Context and objectives

The 2017 Clean Growth Strategy lays out the government's ambition to phase out the installation of high carbon fossil fuel heating in off-gas grid dwellings during the 2020s[5]. This effort will begin with new construction but will necessarily include existing dwellings as these make up the majority of the housing stock. It is unlikely that a single heating technology will be optimal across the range of off-gas dwellings, but rather a mix of solutions will be needed to accommodate dwellings of differing size, occupancy, and heat demand. The present study provides evidence on the electric heating systems available on the UK market and their applicability to the rural off-gas housing stock in England and Wales.

The heating systems considered include:

- Electric storage heaters
- Electric panel heaters and electric radiators
- Electric infrared heaters
- Electric underfloor heaters
- Electric boilers
- Electric convection heaters
- Hot water cylinders with electric immersion elements
- Hot water point-of-use systems

Heat pumps are excluded from the study as BEIS has previously collected sufficient evidence on systems already supported in current policy[6]. The electric heating systems analysed here are, with the exception of infrared heaters, established technologies that have been used in some form for several decades. However, more recent advancements in insulation, controls, and system construction have improved the performance relative to the older systems that many consumers may be familiar with. This study assesses the potential for modern electric heating systems to contribute to the decarbonisation of off-gas grid homes. The study seeks to fulfil the following objectives:

- **Review the range of products available** on the market for each electric heating option, their **performance**, the current state-of-the-art and the current sales volumes;

- Describe the **technical challenges** of installing these systems in off gas grid (mainly rural) properties;

- Assess the **cost** of each electric heating option, including the systems required to serve various types of household and any associated building renovation required;

- Estimate the **carbon savings** of the various electric heating technologies compared with various types of incumbent off-gas grid heating systems;

- Assess the **potential technology developments and innovations** that could lead to improvements in the suitability, cost, and/or carbon savings of these options.

[5] Clean Growth Strategy, BEIS, Oct 2017, https://www.gov.uk/government/publications/clean-growth-strategy
[6] *Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings*, Delta EE for BEIS, Dec 2018.

## 2.2 Methodology

The research and analysis for the present work was completed in four stages. The **Literature review**, presented in Chapter 3, discusses existing standards for electric heating systems in domestic dwellings and prior studies on the systems of interest. The existing standards cover the efficiency rating of electric heating and hot water systems under the EcoDesign Directive as well as the relevant safety standards. Although there is limited existing literature available, the reviewed studies discuss the running costs and level of comfort provided and the potential for electric storage heaters to provide flexibility services to the electricity networks.

The second stage comprised a **Market review** covering the systems available for sale in the UK. This was performed predominately on-line. Details of the products available on the websites of the consulted OEMs, other known manufacturers, and available from UK wholesalers are presented in Chapter 4. This includes the size, cost, features, and warranty of the available systems. The findings from the Market review are supplemented with further information obtained during the **Stakeholder consultation.** Electric heating manufacturers were contacted with the aid of BEAMA[7] and 90-minute teleconference discussions were held with all organisations wishing to provide input. The discussions covered the range of products available, the installation process and its challenges, system performance, control options, and the potential for future innovations. This information is presented in Chapters 4 and 5.

The final component of the study was the development of the **Electric Options in Off-gas Grid Dwellings model** which uses the collected information on sizing, costs, and the installation process to build a picture of the potential for electric heating to contribute to decarbonising off-gas grid dwellings. The modelling approach is discussed in Chapter 6 and results are shown in Chapters 7 and 8. Gaps in the evidence base presented are discussed in Chapter 9.

## 2.3 Technology definitions

The terminology used to describe electric heating options is somewhat varied between suppliers. For clarity, this section provides brief explanations of the technologies discussed in this report.

### Electric storage heaters

Electric storage heaters are used in combination with differential or time-of-use electricity tariffs such as Economy 7 and Economy 10. High thermal mass bricks are heated overnight by electric heating elements. During the following day, a fan blows air over the heated bricks, delivering heat to the room. The thermal bricks are typically made of clay or ceramic material, although in the past some models contained asbestos. Some storage heaters are able to supplement the stored heat with additional on-demand heating from the resistive elements. Storage heaters rest on the floor but are wall-mounted and have two fused connections to the mains electricity supply, one for charging the thermal bricks using off-peak electricity and one for the controls and the fan assist using peak time electricity. Storage heaters are typically controlled individually or on a room-by-room basis.

[7] British Electrotechnical and Allied Manufacturers' Association, http://www.beama.org.uk/

**Figure 2-1 Example storage heaters[8,9]**

### Electric panel heaters

Electric panel heaters are modular heaters for individual rooms that can be wall-mounted or free standing. They use electrically heated elements to heat the air directly (i.e. without the use of water or heat transfer fluid), creating passive convection currents which spread heat throughout the room. Electric panel heaters are also referred to as convector heaters due to their use of passive convection. They are used to provide on-demand heat and are typically controlled individually. Panel heaters can be plugged into a socket or use a hard-wired fused connection to the mains supply. In this report, electric panel heaters and electric radiators are considered together.

**Figure 2-2 Example panel heaters[10,11]**

8 http://quantum-heating.co.uk/

9 https://www.vent-axia.com/range/optimax-plus-storage-heaters

10 https://www.electricradiatorsdirect.co.uk/ecostrad-eco-6-electric-panel-radiator-600w/

11 https://www.adax.lt/en/1293-adax-clea-wifi.htmls

### Electric radiators

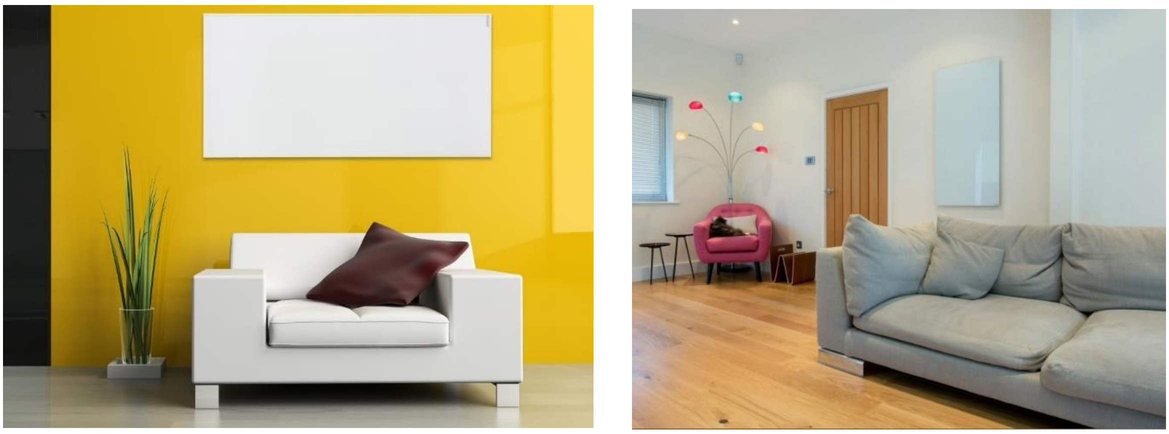
Electric radiators contain a heat transfer fluid which is heated by electric elements at the base of the heater, as shown in Figure 2-3. The warmed fluid expands and rises throughout the pipes within the radiator. Air is heated on contact with the radiator pipes, and passive convection distributes heat throughout the room. As with panel heaters, electric radiators can be free standing or wall-mounted and may be plugged into a socket or use a hard-wired fused connection to the mains supply. They are used to provide on-demand heat and are typically controlled individually. Electric radiators have greater thermal inertia than panel heaters and are more prevalent at the high end of the domestic market. Electric radiators are considered together with panel heaters in this report.

**Figure 2-3 Example electric radiators[12]**

### Electric infrared heaters

Infrared heaters (also called radiant heaters) for indoor use are flat panels which are heated to relatively high temperatures (typically over 80 °C) using resistive elements. Heat is transferred from the panels to the room, including the walls, occupants, and room furniture, predominantly via radiation, rather than convection. The air is heated indirectly via convection from the other surfaces in the room. Infrared heaters are mounted to the walls or ceiling and may use a socket or a hard-wired connection. They are typically individually controlled although they may require external controls and thermostats. Infrared heaters for outdoor and commercial use are also available but are outside the scope of the current study.

**Figure 2-4 Example infrared heaters[13]**



---

12 https://haverland.co.uk/electric-radiators/designerrctt/
13 https://www.herschel-infrared.co.uk/product-category/electric-panel-heaters/

### Electric underfloor heaters

Electric underfloor heaters consist of resistive elements arrayed under the primary floor covering (e.g. carpet, tile, etc.). They may be installed between layers of the floor construction or within a screed floor layer. Underfloor heaters are wired into the mains electricity supply and generally controlled on a room-by-room basis. A floor temperature sensor is typically included, while air thermostats and control systems are purchased separately.

**Figure 2-5 Example underfloor heaters[14,15]**

### Electric boilers

Electric boilers can provide space heating via a wet radiator system or wet underfloor heaters, or both heating and hot water if a hot water storage cylinder is present. They may be used in direct or indirect configurations with hot water cylinders. Electric boilers provide heat on-demand and typically use a Standard rate tariff.

**Figure 2-6 Example electric boilers[16],[17]**

[14] https://www.gaia.co.uk/products/electric-underfloor-heating/devimat-heating-mats/
[15] https://www.warmup.co.uk/underfloor-heating/electric/heating-mat
[16] https://www.electric-heatingcompany.co.uk/fusion-comet-electric-boiler/
[17] https://www.redring.co.uk/water-heating/flow-boilers

### Electric convection heaters

Electric convection heaters (also called fan heaters) provide on-demand heating using a fan to circulate air over the electric heating elements and into the room. They are often free standing and portable, although some wall-mounted and base unit systems are used to heat kitchens and bathrooms. Portable convection heaters provide top-up heating to draughty areas or on very cold days and are plugged into electric sockets. Installed systems have a fused connection to the mains supply and are also used for supplemental heating. Because they are not intended for use as primary heating, convection heaters are not considered further in this report.

**Figure 2-7 Example convection heaters[18,19]**

### Electric hot water cylinders

Electric hot water cylinders heat and store hot water for use in showers, baths, and basins. Hot water cylinders used in combination with boilers (of any type) will often feature an immersion heating element for back-up use. Electric cylinders typically contain two immersion elements: one each for off- and on-peak use. The electricity tariff used for hot water cylinders is typically determined by the preferred tariff for the dwelling's heating system.

**Figure 2-8 Example hot water cylinders[20,21]**


[18] https://www.dimplex.co.uk/convector-heaters
[19] https://www.dimplex.co.uk/product/bfhe-base-unit-heater
[20] http://rmcylinders.com/product/direct-stelflow-cylinder/
[21] https://www.heatraesadia.com/products/cylinders-and-hot-water/unvented-cylinders

### Point-of-use hot water systems

Point-of-use hot water systems are an alternative hot water solution that may be selected in smaller dwellings where space constraints prohibit installation of a hot water cylinder. Separate systems are installed in each shower and basin. Cold water is piped into the systems and heated instantaneously when the taps or shower is turned on. Some point-of-use systems for taps also store between 10 and 15 L hot water.

**Figure 2-9 Example point-of-use systems[22,23]**

[22] http://www.ariston.com/uk/Electric_Water_Heaters

[23] https://www.zipwater.co.uk/shop/hot-water/zip-aquapoint-unvented-water-heater-15-litres-ap3-15-ob

# 3 Literature review

The sections below review regulations and standards relevant to electric heating and prior studies on observed system performance and the experience of electric heating consumers. The presented evidence focuses on regulations and reports relevant to the UK market.

## 3.1 Review of standards

### EcoDesign Directive

The EU EcoDesign Directive (2009/125/EC) establishes a framework for setting mandatory energy efficiency measures for energy-using and energy-related products sold in the EU. Requirements for groups of products are specified in individual 'lots' under the wider directive. The burden is placed on manufacturers who must consider the energy consumption of their products during the design phase, while consumers are affected only through changes in the systems available for purchase. The EcoDesign Directive was brought into UK law under the Ecodesign for Energy-Related Products Regulations, 2010.

The Energy Labelling Directive (2010/30/EU) is a companion to the EcoDesign Directive which requires clear and consistent labelling of the relevant systems. This is reflected in the UK under the Energy Information Regulations, 2011.

There are several specific measures under the above Directives that affect electric heating technologies:

- Lot 1: space heaters and combination (space and water) heaters
- Lot 2: water heaters and hot water storage tanks
- Lot 20: local space heaters
- Lot 33: smart appliances (not yet implemented)

### Primary Energy Factor

The efficiency specifications in the EcoDesign Directive refer to the efficiency of primary energy consumption. For electric heaters, this depends on the primary energy factor (PEF), the assumed EU-average ratio of primary energy consumed for every unit of electricity produced. The relevant efficiency for electric heating systems is therefore

$$\eta = \frac{\eta_{system}}{PEF}.$$

Since the systems may be sold and installed anywhere in the EU, the EcoDesign Directive does not allow individual Member States to adjust this value based on the characteristics of local electricity production.

The PEF is currently set at 2.5, which means the maximum efficiency of electric heating systems is 40%. In November 2016[24], the European Commission proposed reducing the PEF to 2.0 as part of updates to the Energy Efficiency Directive. The rationale was that this would reflect the increasing share of renewables in electricity production. In March 2018, the European Parliament proposed a value of 2.3, with a further review in 2024. The trialogue between the European Parliament, European Commission, and European Council on this issue is ongoing. Any eventual decision to modify the PEF will directly affect the energy efficiency rating (A+++ to G) for all electric heating technologies.

[24] *Revision of the EU's EED*, EuroVent European Industry Association, 2018, https://eurovent.eu/?q=articles/revision-eu%E2%80%99s-energy-efficiency-directive-eed-gen-90400

### Lot 1: Space heaters and combination heaters

Lot 1 applies to space and combination (space and hot water) heaters with output less than 400 kW. The efficiency requirements in Lot 1 were updated in September 2017, and currently require the following:

- The seasonal space heating energy efficiency of space and combination heaters must be above 36%
- The water heating energy efficiency of combination heaters must be above 32%, with further requirements for some duty cycles rising as high as 38%

Lot 1 of the Energy Labelling Directive requires that systems be clearly labelled with the appropriate energy efficiency class, as defined in Table 3-1. Although electric boilers are nearly 100% efficient in producing heat from electricity, with a PEF of 2.5 they fall into Class D.

**Table 3-1 Efficiency classes of heaters under Lot 1**

Seasonal space heating energy efficiency classes of heaters, with the exception of low-temperature heat pumps and heat pump space heaters for low-temperature application

| Seasonal space heating energy efficiency class | Seasonal space heating energy efficiency $\eta_s$ in % |
|---|---|
| A+++ | $\eta_s \geq 150$ |
| A++ | $125 \leq \eta_s < 150$ |
| A+ | $98 \leq \eta_s < 125$ |
| A | $90 \leq \eta_s < 98$ |
| B | $82 \leq \eta_s < 90$ |
| C | $75 \leq \eta_s < 82$ |
| D | $36 \leq \eta_s < 75$ |
| E | $34 \leq \eta_s < 36$ |
| F | $30 \leq \eta_s < 34$ |
| G | $\eta_s < 30$ |

### Lot 2: Water heaters and hot water storage tanks

Lot 2 applies to hot water heaters with rated output less than 400 kW and with volume less than 2000 litres. The efficiency requirements were updated in September 2017 and currently require the following:

- The water heating energy efficiency of water heaters must be above 32%, with further requirements for some duty cycles rising as high as 38%
- Standing losses *S* (in Watts) from hot water storage tanks must be less than

$$S = 16.66 + 8.33V^{0.4},$$

where the volume *V* is measured in litres. The efficiency class ratings for Lot 2 also depend on the duty cycle and are not reproduced here. For the same reasons stated above relating to the PEF, electric water heaters typically fall into Class C.

### Lot 20: Local space heaters

Electric heating systems apart from electric boilers fall into Lot 20, which came into force on 1 January 2018. The energy efficiency requirements are listed in Table 3-2.

**Table 3-2 Lot 20 efficiency requirements**

| System | Minimum seasonal space heating energy efficiency |
|---|---|
| Electric portable space heaters | 36% |
| Electric fixed space heaters > 250 W | 38% |

| | |
|---|---|
| Electric fixed space heaters < 250 W | 38% |
| Electric storage heaters | 38.5% |
| Electric underfloor heaters | 38% |
| Electric radiant heaters | 35% |

In addition to the above efficiency requirements, there are several 'smart' control features which must be present on local electric space heaters. Lot 20 specifies that these should use existing, non-proprietary technologies and should therefore not increase the combined costs of purchasing and operating the systems.

**All heaters** falling within the scope of Lot 20 must now include **all** of the following features:

- Electronic room thermostat
- 24/7 programmable timing control
- Labelling specifying the power consumption for heating and for auxiliary systems (i.e. fans and controls)

In addition, **all direct-acting heaters** must include **at least one** of the following features:

- Open window sensing to cause the product to shut down if a sudden temperature reduction is measured
- Adaptive start control to initiate heating at the appropriate time to reach the desired set point at the desired time without overheating or reaching the set point too early
- Distance control to allow remote system interaction, e.g. via an app

**Infrared heaters** have **three additional** options for fulfilling this requirement:

- Presence detection to cause the product to shut down if no one is present in the room
- Black bulb sensor to measure the air and radiant temperatures
- Working time limitation to automatically shut down the product after a set time

**Storage heaters** must include **all** of the following features:

- Electronic heat charge control reacting to either the room or outdoor temperature
- Electronic room temperature control and 24/7 programmable timing control
- Fan assisted output

Further, all portable space heaters must feature a label stating "This product is only suitable for well insulated spaces or occasional use." The efficiency class of local space heaters depends on the rated efficiency, the PEF, and fulfilment of the above criteria.

### Lot 33 – Smart appliances

The regulations for Lot 33 have not yet been finalised, but will cover appliances that can provide demand side flexibility[25]. Space heaters, boilers, and buffered water heaters have been classified as "High flexibility potential," with few comfort and performance impacts from providing demand size flexibility. The regulations will provide guidance on the addition of smart functionality to existing systems and are expected to cover the following:

- Requirement to ensure the user's needs are met, including the ability to override DSR-related instructions from third parties
- Requirements related to communications protocols and interoperability
- Requirements for the user interface and provision of information to consumers

[25] http://www.eco-smartappliances.eu/Pages/projectsummary.aspx

### Energy Performance in Buildings Directive

The Energy Performance in Buildings Directive (EPBD) was originally approved in 2010 (2010/31/EU) but has been updated from July 2018 (2018/844/EU). Member States have 20 months to bring the regulations into national law. The EPBD requires Energy Performance Certificates (EPCs) for all buildings when they are commissioned, leased or sold, and lays out plans to achieve low and zero-emissions building stock by 2050. The EPBD is implemented in UK law by Part L of the Building Regulations.

Relevant to the current study, the 2018 update to the EPBD recommends the installation of devices to allow separate temperature regulation in individual rooms or heating zones of buildings, where economically feasible.

### SAP 2012 and SAP 10

The Standard Assessment Procedure (SAP) is the UK's government's national methodology for assessing the energy performance of buildings. As with the EcoDesign Directive, SAP uses factors to determine the amount of primary energy required to provide 1 kWh of energy to the end user. Table 3-3 presents the PEFs and emissions factors for electricity, heating oil, and house coal in SAP 2012[26] and in the proposed new version, SAP 10[27]. The primary energy and emissions intensity of electricity is appreciably reduced in the new version, while the primary energy factors for heating oil and house coal have been increased. SAP 2012 remains in force. A draft version of SAP 10 was released in July 2018; this will be revised following a consultation on Building Regulations Part L which is expected in Spring 2019.

**Table 3-3 SAP primary energy and emissions factors for electricity, oil, and solid fuel**

| | SAP 2012 | SAP 10 |
|---|---|---|
| Electricity PEF | 3.017 | 1.738 |
| Electricity emission factor | 0.519 $kgCO_2/kWh$ | 0.233 $kgCO_2/kWh$ |
| Heating oil PEF | 1.10 | 1.188 |
| Heating oil emission factor | 0.298 $kgCO_2/kWh$ | 0.298 $kgCO_2/kWh$ |
| House coal PEF | 1.00 | 1.101 |
| House coal emission factor | 0.394 $kgCO_2/kWh$ | 0.395 $kgCO_2/kWh$ |

### Safety standards

There are a number of safety standards that should be applied during the installation of electric heating systems. These will not be covered in detail here, but include the following:

- Building Regulations Part P, covering electrical safety in dwellings in the UK
- BS 7671, covering the safety of electrical installations (referenced in Part P)
- EN 60335, covering the safety of household and similar electric appliances in the EU
- Ingress Protection Marking, which indicates the level of resistance against water and how close to sinks and tubs electrical systems may be installed.

## 3.2 Prior studies

There are a limited number of previous studies relating to the electric heating systems described above. National Energy Action has completed five studies covering the user experience of electric heating technologies. Further reports by Citizens Advice England, Citizens Advice Scotland, and Ofgem have

[26] SAP 2012, BRE for DECC, Oct 2013, https://www.bre.co.uk/sap2012/page.jsp?id=2759
[27] SAP 10.0, BRE for BEIS, July 2018, https://bregroup.com/sap/sap10/

published reports on the consumer impacts of electric heating, energy efficiency schemes, and existing time-of-use tariffs. A report outlining policy recommendations from an industry organisation and a demonstration of Demand Side Response using storage heaters are also reviewed below.

### National Energy Action Studies

National Energy Action (NEA) is a national fuel poverty charity working across England and Wales. In April 2015, NEA launched a Technical Innovation Fund to provide grants supporting the installation of new technologies aimed at reducing fuel poverty. 44 trials were funded, and several projects relevant to the current study have been identified. The trials included some monitoring of system performance and collected feedback from participants.

#### Nottingham Community Housing Association and Dimplex Storage heaters[28]

Nottingham Community Housing Association and Greenvision Energy replaced 20-year old storage heaters with Dimplex Quantum storage heaters, and replaced 10-year old domestic hot water cylinders with Dimplex ECSd cylinders. 51 households had the installations and 11 received detailed monitoring.

The Technical Evaluation Report states that resident satisfaction increased in regards to the following statements, although the level of increase is not quantified:

- "How warm it gets when cold out"
- "How easy the system is to use",
- "Amount of control over the system"
- "Cost of running the system".

With the new systems, the average share of off-peak (Economy 7) electricity consumption increased from 53% to 66%. Plots of the energy used per day (kWh) vs heating degree days (HDD) per day were made for both the old and new systems, examples of which are shown in Figure 3-1. The level of correlation is much higher with the new system, indicating that the new systems are maintaining the indoor room temperature at a more consistent level. This was aided by the Quantum storage heaters' adaptive start functionality which eliminates the need for residents to manually adjust the input control each day.

**Figure 3-1 Energy vs HDD for the old and new storage heaters**

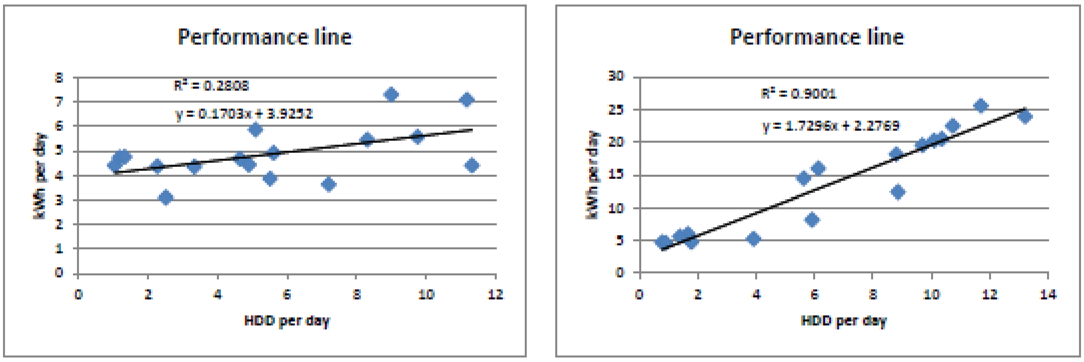



Figure 4.3 (a) pre install performance (T-30) Figure 4.3 (b) post install performance (T-30)

[28] *CP 744 Technical Evaluation Report: Dimplex storage heaters with water heaters and voltage optimisation*, Nottingham Community Housing Association and NEA, Oct 2017, https://www.nea.org.uk/hip/dimplex-storage-with-water-heaters-and-vpo-cp744/

### Aspire Housing Association and Dimplex Quantum storage heaters[29]

The project was delivered by Aspire Housing, who upgraded the electric heating systems in 32 dwellings. These had previously had general improvements to meet the Decent Homes Standard, but due to their old inefficient storage heating were still designated 'hard to heat'. This project replaced 20-year old storage heaters with Dimplex Quantum storage heaters and upgraded the domestic hot water tanks with 150 L Dimplex ECSd hot water cylinders. 6 of the installations had temperature and energy monitoring.

The properties involved in the study were mainly 1 and 2 bedroom flats but also included one semi-detached house and one semi-detached bungalow. Each property received 3 Dimplex Quantum storage radiators of differing sizes matched to the property's heat need - installed typically in the hall, living room and bedroom. After installation of the new heating measures, the majority of householders (7 of the 9 who responded) felt their home was warmer and more comfortable, and that it warmed up faster. 6 felt the heating was easier to use, and 5 said they had more control over it. 4 also felt their energy bills had reduced, but fewer (3) felt they were saving energy in the home.

The report also noted that the hot water tank should be suitably sized for the space available and likely hot water requirements. For example, a 150 L hot water tank may be too large for a flat with only a single electric shower and 1-2 residents, and an over-sized tank may increase costs by heating more water than is needed.

### Electric Boiler Assessment Project[30]

NEA was asked to evaluate the effectiveness of new electric boilers installed in a housing estate in central England. The temperature, humidity, and energy consumption were monitored in 10 households which had Heatrae Sadia's Amptec C1200 electric boiler installed to provide both space heating and hot water via a conventional wet radiator system and a hot water cylinder. The electric boiler replaced a solid fuel boiler in all cases. The Amptec C1200 consumes 12 kW and is not designed to make use of the Economy 7 tariff. Rather, hot water is produced instantaneously upon demand as in a combi boiler using combustion.

The NEA found significant evidence indicating that household energy costs nearly doubled with the new installations, making it more difficult for the householders to pay their bills and to heat their home as they would like. This was exacerbated by several residents' use of the Economy 7 tariff which was not appropriate for the new heating system. It was further noted that all households who participated in the survey were using alternative heating including portable electric and LPG heaters, in order to circumvent the dissatisfaction with the level of heat and the cost of using the new electric heating.

### Comparing advanced heating systems in Wakefield[31]

Eight different heating technologies were installed in social housing accommodation in Wakefield. The systems included heat pumps, hybrid heat pumps, modern storage heaters and Logicor's Clear Heater infrared system which was installed along with Logicor's InLine hot water system. In all cases the systems replaced existing storage heaters with immersion cylinders for hot water. The infrared heaters were installed in 4 semi-detached homes and 1 flat, with size ranging from 49 to 87 $m^2$.

The residents with newly installed infrared heating noted improved control over their heating and 3 of the 5 properties reduced their electricity use with the new system. Consumed energy per degree day was reduced by an average of 17% across the three properties. The fourth property saw a 15% increase in energy per degree day and the information was not available for the fifth property. However, all of the

[29] *CP 756 Technical Evaluation Report: Storage heaters for social tenants in Newcastle-under-Lyme*, Aspire Housing and NEA, Oct 2017, https://www.nea.org.uk/hip/newcastle-lymedimplex-tackling-fuel-poverty/

[30] *Electric Boiler Assessment Project*, NEA, June 2015.

[31] *CP 758 Technical Evaluation Report: Comparing advanced heating systems in Wakefield*, NEA, Oct 2018, https://www.nea.org.uk/hip/comparing-advanced-heating-systems-wakefield/

properties experienced increased heating costs due to switching from Economy 7 to a Standard tariff, and 4 of the 5 properties fell from EPC Band D into Band E. The manufacturer recommends that the system is left on all the time and the temperature varied as required using the built-in time controls, but residents did not vary the temperature during the trial. This contributed to the high heating costs observed but it is not known what reduction may have been possible if the temperature had been varied. NEA recommends that infrared heaters are installed only into well-insulated homes and are avoided where residents are at risk of fuel poverty. They also note that infrared heaters are more suitable for dwellings which do not need to be continually heated.

### Hybrid heat pumps, infrared radiators and Sunamp heat stacks in North Lincolnshire Ongo Homes[32]

Logicor Clear Heater infrared system was installed into 14 properties and 6 of these were monitored. The dwellings included 4 flats, 4 terraces, 5 semi-detached dwellings and 1 detached dwelling. The size of these homes ranged from 42 to 83 $m^2$. The infrared heaters replaced storage heaters in the majority of cases, although one dwelling previously used panel heaters and 4 previously used solid fuel.

The heating costs for the infrared heaters were observed to be more expensive than those of the previous storage heaters, but lower than those of the panel heaters and solid fuel heaters which they replaced. The residents noted improved control compared to the storage heaters and it was observed that the systems kept the dwelling room temperatures consistent and used electricity in proportion to the degree days. Of the 6 households that were monitored after installation, 4 were satisfied with their new heating systems while 2 were unhappy due to the higher costs and complained that they could no longer heat their houses to the temperature they preferred.

### Citizens Advice Scotland: Hot off the grid[33]

Both Citizens Advice Scotland (CAS) and Citizens Advice England (CAE) have published reports related to off-gas grid heating based on their experience assisting consumers. CAS's report *Hot off the grid* reviews existing energy efficiency schemes and their effectiveness in off-gas grid areas and investigates the impacts of heating system replacements in off-gas grid social housing. The study notes that the Energy Company Obligation (ECO) scheme has benefitted relatively few properties in rural areas despite the scheme being designed to avoid this issue. This is likely due to the economies of scale that can be realised in urban areas and the more mature supply chains in urban areas. It is therefore recommended that future schemes for energy efficiency and fuel poverty make an effort to directly target rural areas.

The report includes modelling results using the RdSAP software in three archetypical dwellings selected to represent the dwelling types most common in Scotland. The running costs calculated for six existing and six replacement heating systems are shown in Figure 3-2. Storage heaters and electric boilers are the most expensive to operate of the replacement heating systems although they are found to be comparable to air source heat pumps and are around 30% cheaper to operate than the existing, older storage heaters.

27 local authorities and social landlords were surveyed about their experiences with replacing heating systems in social housing. Their responses are shown in Figure 3-3 and Figure 3-4 below. The majority of landlords stated that they did not know the impact of new heating systems on their tenants' bills. Where landlords did express an opinion, 3 out of 4 felt that electric boilers had increased their tenants' costs a lot, while new 'smart' storage heaters were felt to reduce bills or to keep them the same. Landlords also noted that some parts of SAP were inaccurate and said in some cases they believed

[32] *CP 780 Technical Evaluation Report: Hybrid heat pumps, infrared radiators and Sunamp heat stacks in North Lincolnshire Ongo Homes*, NEA, Jan 2019, https://www.nea.org.uk/hip/hybrid-heat-pumps-infrared-radiators-sunamp-heat-stacks/

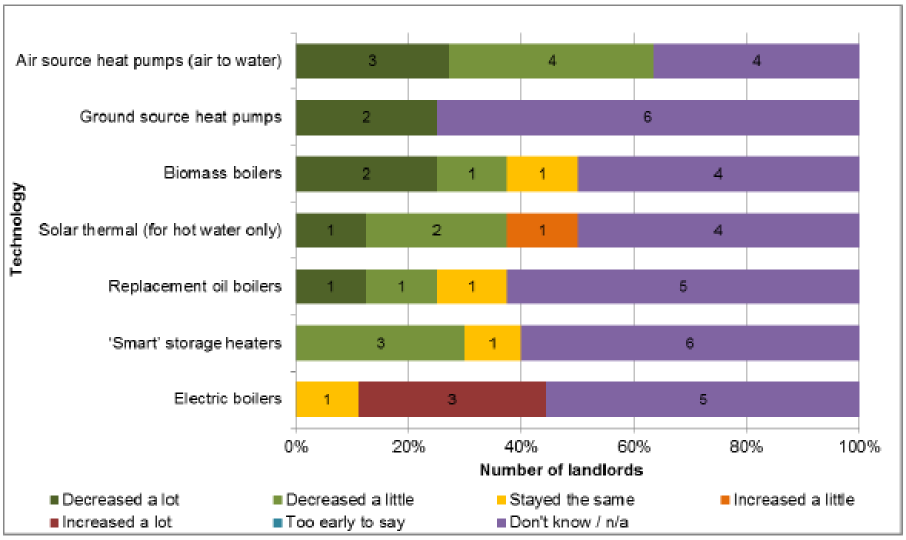
[33] *Hot off the Grid: Delivering energy efficiency to rural, off-gas Scotland*. Changeworks and CAG Consultants for Consumer Futures Unit, Citizens Advice Scotland, 2016.

that a move to increase the SAP score would actually increase their tenants' costs. Further details on this point were not provided.

**Figure 3-2 Estimated annual running costs in three archetypical off-gas Scottish dwellings**

| | Heating system | Detached solid stone | Semi-detached cavity | Detached timber frame |
|---|---|---|---|---|
| Existing | Open coal fire & portable heaters | £4,784 | £1,565 | £1,763 |
| | Electric storage heaters | £3,330 | £1,019 | £1,149 |
| | Bulk LPG boiler | £3,401 | £1,135 | £1,327 |
| | Auto feed solid fuel floor mounted boiler system | £2,037 | £665 | £766 |
| | Solid fuel open fire back boiler system | £2,852 | £953 | £1,038 |
| | Aga/ rayburn solid fuel boiler system | £3,124 | £948 | £1,090 |
| Improvements | Smart storage heaters | £2,331 | £769 | £894 |
| | Air source heat pump | £2,176 | £731 | £869 |
| | Ground source heat pump | £1,701 | £573 | £681 |
| | Biomass boiler | £1,750 | £542 | £628 |
| | Electric boiler | £2,227 | £696 | £805 |
| | Oil boiler | £1,664 | £539 | £629 |

**Figure 3-3 Survey responses: "How do landlords think that tenants' bills have changed since installation of the new heating systems?"**

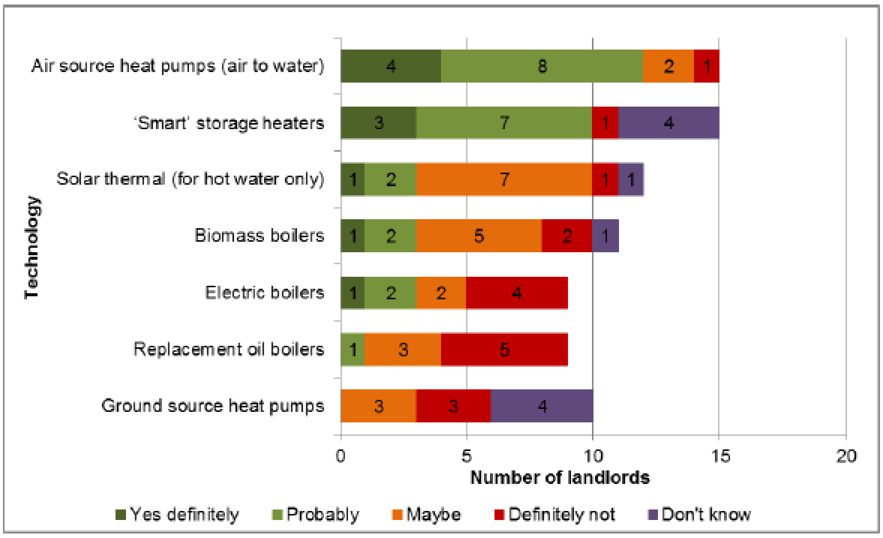



Out of 11 landlords who answered and expressed an opinion, only 1 would not install 'smart' storage heaters again while 10 would 'definitely' or 'probably' install them. The picture is more mixed for electric boilers, with 4 out of 9 landlords stating they would 'definitely not' install them again. 2 were unsure and 3 stated they would 'definitely' or 'probably' install them.

Additionally, a small number of tenants were interviewed regarding their experience of electric heating. The tenants with electric boilers stated that the systems were able to provide adequate warmth, although the tenants interviewed had turned their boilers off during on-peak electricity periods and when it was very cold in order to save money. They also noted that the installation of the wet heating system was very disruptive. Some tenants had moved out of their homes during the installation process and others expressed regret that they had not done so.

Tenants with storage heaters found them easy to use, but only 1 out of 4 interviewed felt that they provided adequate heat. It was noted that even the new heaters ran out of heat in the afternoon and evening. The installation process was straightforward as it was a like-for-like replacement of similar systems.

**Figure 3-4 Survey responses: "Would landlords install the same heating systems again?"**




### Citizens Advice England: False Economy[34]

In September 2018, the Future Energy Consumers Unit of Citizens Advice published a report on 'legacy' Time of Use (LToU) tariffs, including Economy 7, Economy 10, and restricted meter tariffs. With the deployment of smart meters, increased use of intermittent renewable electricity, and uptake of electric vehicles, new types of static and dynamic ToU tariffs are being considered by policy makers. Citizens Advice highlight the experience of existing customers of LToU tariffs and note that no meaningful improvement in their experience has occurred since their previous review in 2012. The 2012 study found that 25% of electrically heated households are dissatisfied with their heating compared with 10% of gas households. Citizens Advice feel it is likely that new ToU customers are likely to face similar problems if these issues are not resolved.

The primary issues faced by LToU customers are inadequate information provision and difficulty in switching suppliers. In a survey of 500 LToU customers, around a quarter were unsure of the hours when the cheaper off-peak rates were available. This could result in consumers inadvertently raising their costs when changing their usage patterns in an effort to save money. Citizens Advice recommends that energy suppliers regularly update their customers with the hours of the peak and off-peak rates, the tariffs applied during each window, and guidance on how a ToU tariff may or may not fit their lifestyle. The report notes, however, that some energy suppliers do not have detailed information about the meter and its settings for each of their customers. It is recommended that this is remedied during routine meter reading visits.

LToU customers also face barriers to switching suppliers and to switching tariff type. While 57% of customers with LToU tariffs are generally satisfied with their tariff and have not attempted to change, 4% of customers have tried to switch suppliers and were unable to do so. These consumers faced additional barriers relative to standard rate consumers, including suppliers being unable or unwilling to serve them, inability to find an attractive ToU deal, and being charged additional fees to replace meters. Switching suppliers and tariffs is particularly difficult for customers with restricted meters; these

[34] *False Economy: Missed opportunities and failures in the 'time of use' tariff market*. Future Energy Consumers Unit, Citizens Advice England, 2018, https://www.citizensadvice.org.uk/about-us/policy/policy-research-topics/energy-policy-research-and-consultation-responses/energy-policy-research/false-economy/

customers typically have two meters which are each hard-wired to only provide electricity at certain times of the day. Following the Competitive Market Authority's 2016 investigation into the energy market[35], energy suppliers are obliged to offer a standard rate tariff to customers with restricted meters and to provide a standard meter. However, they are not required to offer the same tariff and metering arrangements as the customer had previously.

### Ofgem: Insights paper on households with electric and other non-gas heating[36]

This report is part of Ofgem's Consumer Vulnerability Strategy and provides an evidence base on non-gas households and dwellings in Great Britain. Electric heating is currently present in 25% of flats and only 4% of houses in Great Britain. Storage heating is located disproportionately in social housing while direct-acting heating is predominately present in the private rented sector. In England, 23% of storage households and 25% of direct heating households find it difficult to meet their heating costs compared with 20% of households with mains gas heating. This is exacerbated by the poor energy efficiency ratings of electric dwellings. While only 2% of mains gas dwellings are rated F or G, 25% of electric dwellings are rated F or G, including 57% of those with direct-acting heating.

The report discusses the difficulties with changing tariffs and suppliers noted by Citizens Advice England above. Customers on non-standard tariffs also experience issues with electricity bills that are not faced by customers on standard tariffs. These include the suppliers reading the peak and off-peak meters backwards as well as faulty meters not accurately recording peak and off-peak usage and/or causing appliances to turn on at the wrong times. Additionally, social and environmental levies placed on electricity fall more heavily on households using electric heating. Ofgem cites a study which estimates that by 2020, households with electric heating will pay 19% of the levies but only receive 7% of the resulting benefits (e.g. energy efficiency measures).

### BEAMA: Heat electrification by design[37]

BEAMA, the industry organisation for manufacturers of electrical infrastructure products and systems, has published a series of papers with policy and market recommendations for the promotion of low-carbon electric systems. Several points and recommendations raised are relevant to the present study. It is noted that storage heaters can facilitate the development of 'smart grids,' providing flexibility that can allow higher penetration of renewable electricity production (see the NINES case study below).

The report explains that the general passivity of consumers with regards to heating systems is a barrier to the uptake of low-carbon systems. The typical supply route for new heating systems involves some internet searching and a call to an installer when the current system breaks down or becomes unreliable. BEAMA recommends an impartial, well-informed 'Information Hub' is created to develop buyers guides and provide information to consumers. They believe a local and regional, rather than national approach is needed, including regional targets for uptake of systems and efficiency measures and support for suppliers and installers. The Local Enterprise Partnerships and Local Energy Hubs are seen as a step in this direction although BEAMA feels more action is needed. They also recommend that the ECO scheme is extended to include high efficiency storage heaters and heat pumps. As noted by Ofgem above, off-gas electric households are supporting ECO through their heating bills but are less able to benefit from the scheme.

---

[35] *Energy market investigation: Overview*, CMA, 2016, https://www.gov.uk/government/publications/energy-market-investigation-overview

[36] *Insights paper on households with electric and other non-gas heating*, Ofgem Consumer Vulnerability Team, 2015.

[37] *Heat Electrification by Design*, BEAMA, June 2018, http://www.beama.org.uk/resourceLibrary/heat-electrification-by-design.html

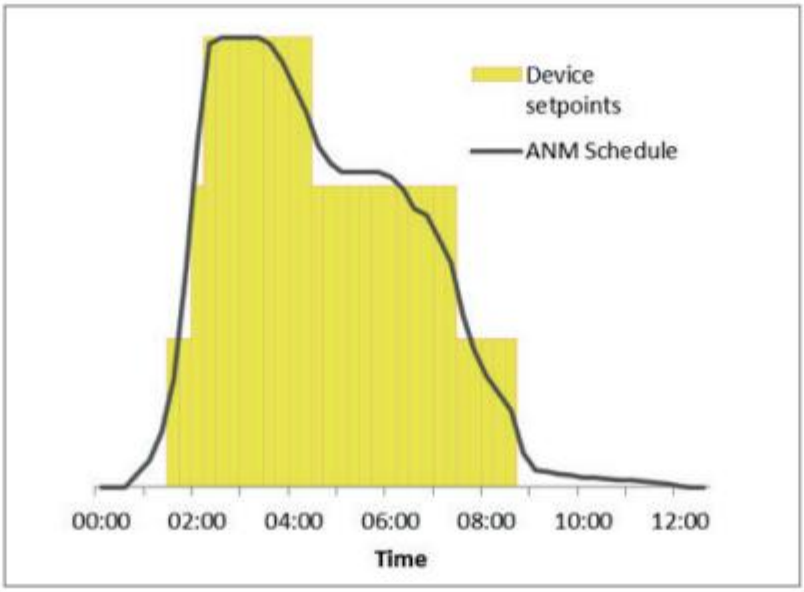
### Glen Dimplex and SSEN NINES project[38]

Glen Dimplex and Scottish and Southern Energy Networks installed a Demand Side Management system in the Shetlands as part of the Northern Isles New Energy Solutions (NINES) project. The goal of the study was to determine how domestic storage heaters could contribute to managing the electricity grid in the Shetlands, which is not connected to the wider GB grid and has a large fraction of intermittent electricity production.

Dimplex Quantum storage heaters were installed in 234 socially-owned houses between July 2013 and October 2014. In addition, an Active Network Management (ANM) system was installed in the dwellings and the local electricity grid in 2016. This included communications between individual heaters and a Glen Dimplex Home Hub installed in each property (via RF), and communication between the Home Hubs and a central Element Manager (via a wide-area network). The Element Manager then communicated with the Lerwick Power Station.

The ANM ensured the storage heaters received adequate energy over each night, but varied the power drawn in 15-minute intervals to match the current level of renewable electricity production. Figure 3-5 presents an example overnight charging schedule. This reduced the level of curtailment of local wind and tidal sources. The heat output of the storage heaters remained under the control of the residents.

**Figure 3-5 ANM generated schedule and the resulting storage heater setpoints**




This project provided a small-scale demonstration of smart grid control of electric storage heaters. Communications outages adversely affected the smart grid's performance and the need for further improvements in the in-house RF communications systems was noted. There was a high participation rate amongst the residents, and the 85% of the participating households remained on the scheme three years after its initiation. The trial did not require participants to change their behaviour and ensured that thermal comfort was maintained, leading to a high degree of satisfaction from the participating households.

[38] *NINES 1A Customer Impact Report and 1B DSM Infrastructure Report*, SSEN and University of Strathclyde Engineering Dept, 2017.

# 4 Market review

We have collected data on 114 products (with a larger number of products when accounting for different sizes) across the nine system categories defined in Section 2.3. These products are manufactured by 30 different companies. Table 4-1 indicates the different electric heating system categories produced by the manufacturers considered. The following sections present details on the systems analysed in this study and further information is presented in Section 11: Appendix 1 – Market review. The collected data is not exhaustive but covers the majority of electric heating products available in the UK and is representative of the UK market.

**Table 4-1 Manufacturers of electric heating systems by category**

| Company | Storage | Panel | Radiators | Infrared | Under-floor | Boilers | Hot water cylinders | Point-of-use systems | Control systems |
|---|---|---|---|---|---|---|---|---|---|
| Adax | | ✓ | | | | | | | |
| Aqualisa | | | | | | | | | ✓ |
| Ariston | | | | | | | | ✓ | ✓ |
| Atlantic Heat | | ✓ | ✓ | ✓ | | | | | |
| Creda | ✓ | | | | | | | | |
| Climote | | | | | | | | | |
| Cotherm UK Ltd | | | | | | | | | |
| Danfoss Ltd | | | | | ✓ | | | | |
| Ecostrad | | ✓ | ✓ | | | | | | |
| Electric Heating Company | | ✓ | ✓ | | | ✓ | | ✓ | |
| Elnur | ✓ | ✓ | | | | ✓ | | | |
| Fischer | ✓ | | | | | | ✓ | | |
| Flexel International | | ✓ | | ✓ | ✓ | | | | |
| Gaia Climate Solutions | | | | | ✓ | | | | |
| Geotogether | | | | | | | | | ✓ |
| Gledhill | | | | | | | | ✓ | |
| Glen Dimplex | ✓ | ✓ | | | | ✓ | ✓ | ✓ | |
| Heatrae Sadia | | | | | | ✓ | | ✓ | |
| Herschel | | | | ✓ | | | | | |
| Logicor | | | | ✓ | | | | | ✓ |
| nVent Thermal Management | | | | | ✓ | | | | |
| Osily | | ✓ | ✓ | ✓ | ✓ | | | | |
| Redring Xpelair Group | ✓ | | | | | ✓ | | | ✓ |
| RM Cylinders | | | | | | | | ✓ | |
| Rointe | | | ✓ | | ✓ | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vaillant | | | | | | | | | |
| Vent Axia | ✓ | ✓ | ✓ | | ✓ | | ✓ | | |
| Warmup Plc | | | | | ✓ | | | | |
| Zehnder Group UK | | ✓ | ✓ | | | | | | |
| Zip | | | | | | | | | ✓ |

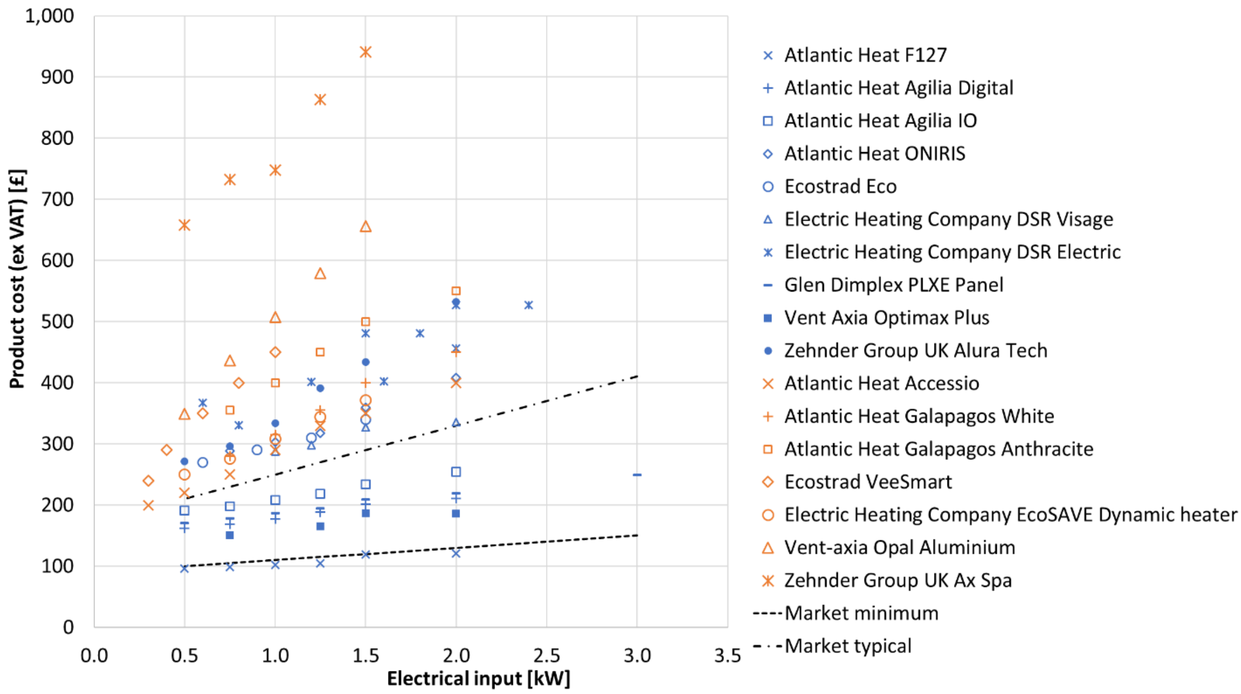
## 4.1 Electric panel heaters and electric radiators

Electric panel heaters are one of the most widely manufactured electric heating systems, and we have identified 31 products across 11 companies. Figure 4-1 presents the price of the products studied according to size (kW electrical input), where the price was available in the documentation, on retail websites, or during consultation with the manufacturers. Several manufacturers noted that they have no control and limited visibility of the actual costs paid by consumers because systems are sold to wholesalers and then to installers before the final purchase by the consumer. Wholesalers may apply trade and/or bulk discounts to installers, who may bundle the cost of the systems together with the installation. The prices below are RRPs and prices available to consumers online, but may differ from the price paid for systems purchased via an installer. This is a product cost only and excludes VAT, the cost of installation, and any additional or hidden costs that might be incurred.

The chart shows electric panel heaters in blue and electric radiators in orange. Panel heaters are generally lower cost than radiators although this is not universally the case. The products at the lower end of the price range feature the control options required by EcoDesign Lot 20 but have simple, “no-frills” designs and are available only in white. At the higher price points, systems may offer more sophisticated control options including integration with other systems across the home and may have more aesthetic options to choose from (e.g. aspect ratio, finish, and colour). The Zehnder Ax Spa is the most costly product; this is an electric version of a radiator also available for a wet heating system. Vent-axia’s Opal Aluminium system is at the higher end of their range, and its aluminium construction is highlighted in the product documentation. Detailed information on the electric panel heaters and electric radiators is presented in Section 11.1.

The two lines indicate the representative costs assumed during the modelling exercise discussed in Chapters 6 to 8 below. The lowest cost option available is shown in the dashed line (“Market minimum”) while a more typical median market cost is shown by the dash-dot line (“Market typical”). While some consumers may select systems primarily based on cost, it is likely many will consider other factors and purchase systems nearer to the market average cost.

**Figure 4-1 Product cost vs size for electric panel heaters (blue) and electric radiators (orange)**



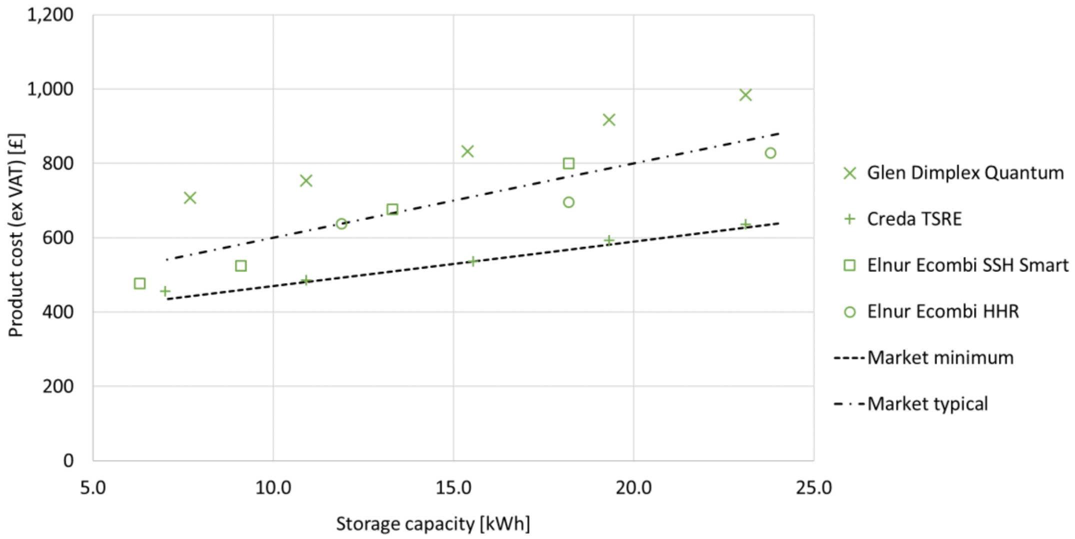

## 4.2 Electric storage heaters

We have identified 8 electric storage heating systems from 5 manufacturers, which are documented in detail in Section 11.2. The sizes of the systems identified, in terms of electric input, range from under 1 kW to nearly 3.5 kW, corresponding to stored energy range of about 7 kWh to 24 kWh. The storage media are similar across the products and is typically high-density bonded magnetite or a ceramic. As a result of the heat storage material, storage heaters are significantly heavier than most other electric heaters and are therefore always fixed to a wall with floor supports. Two connections to the mains electricity supply are required: one each for on- and off-peak usage.

A majority of the systems (7 out of 8) also feature a 'boost mode' to provide on-demand heat at a higher power rating, in addition to the release of stored heat. The boost mode power rating ranges from 0.34 kW to 1.38 kW.

The product cost data identified is presented in Figure 4-2. The systems are more expensive than electric panel heaters although the range of costs is not as wide. The more expensive products are marketed as high heat retention (HHR) storage heaters which offer improved insulation to reduce heat leakage and maintain the store of heat into the afternoon and evening.

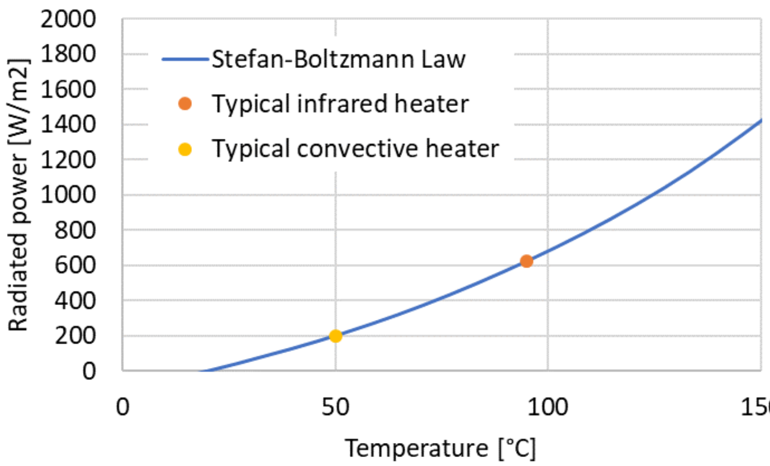
**Figure 4-2 Product cost vs size for electric storage heaters**




## 4.3 Electric infrared heaters

Electric infrared heaters deliver heat predominately via radiation, unlike the majority of electric heating systems which rely chiefly on convection. The surface temperatures of the infrared heaters reviewed for this study are typically around 90 °C (see Appendix 1, Section 11.3). The surface temperature governs the amount of heat that is radiated to the room relative to the amount that is convected to the air in a manner similar to electric panel heaters. Figure 4-3 plots the radiation from an idealised surface to a room at 20 °C as a function of temperature. Heaters in the typical temperature range for infrared heaters (around 90 °C) radiate around three times the amount of heat as convective heaters which have lower surface temperatures (around 50 °C).

**Figure 4-3 Radiated power from an idealised surface to a room at 20 °C[39]**



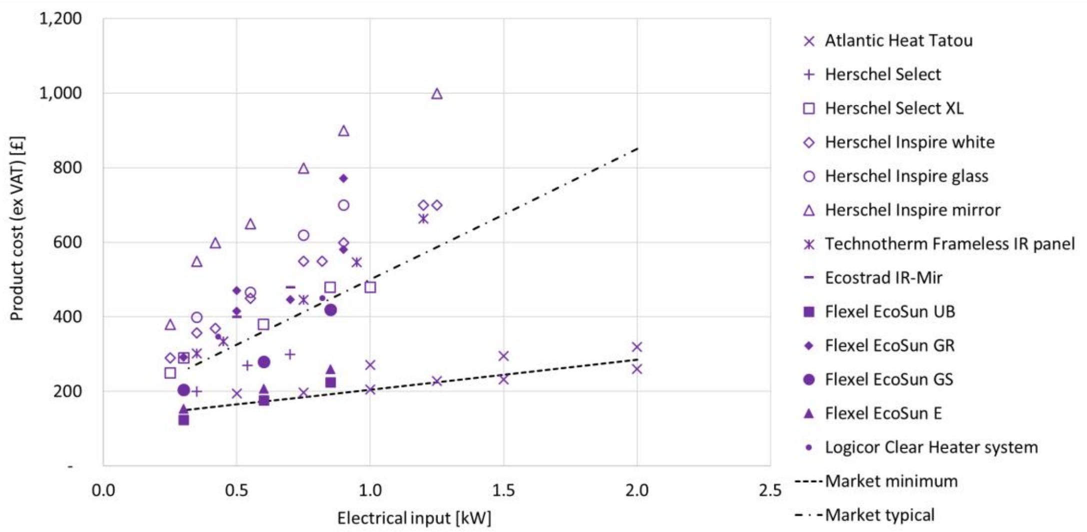

We have identified 16 electric radiant heating systems from 6 manufacturers. Figure 4-4 shows a significant cost range similar to that of electric panel heaters. This is mainly due to a difference in the materials used, visual appearance and style, and warranty. Herschel's Inspire range demonstrates this, with the 'mirror' finish appreciably more expensive than the simple white finishes in their Select range.

[39] Stefan, J. (1879). On the relation between heat radiation and temperature. *Proceedings of the Imperial Philosophical Academy of Vienna: Mathematical and Scientific Class* (in German). **79**: 391–428.

The more costly Herschel products, in the Inspire range, also have a longer warranty of 10 years versus 5 years in the Select range.

Radiant heaters are typically rated IPX4, meaning they are appropriate for installation in bathrooms. Radiant heating raises the temperature of walls and furniture above the ambient air temperature, which will reduce condensation and may prevent the growth of mould. Further details on electric infrared heaters are shown in Section 11.3.

**Figure 4-4 Product cost vs size for electric radiant heaters**




## 4.4 Electric underfloor heaters

We have identified 19 electric underfloor heating systems from 7 manufacturers, details of which are presented in Section 11.4. The products identified include systems appropriate for all types of floors, and for retrofits in addition to new construction. At the highest heat intensity, 200 W/m$^2$, systems are intended for use in a conservatory or to be supplemental heating for draughty rooms, and are designed to be used for under 6 hours per day. Systems of 150 W/m$^2$ or less may be used as the primary heating system for sufficiently well-insulated rooms.

Underfloor heaters include floor thermostats which will shut down the power to the heating elements if the floor temperature passes a set threshold, typically between 35 and 40°C. Room thermostats and other control mechanisms must be purchased separately but are often available from the same supplier. Control systems are discussed in more detail in Section 4.6 below.

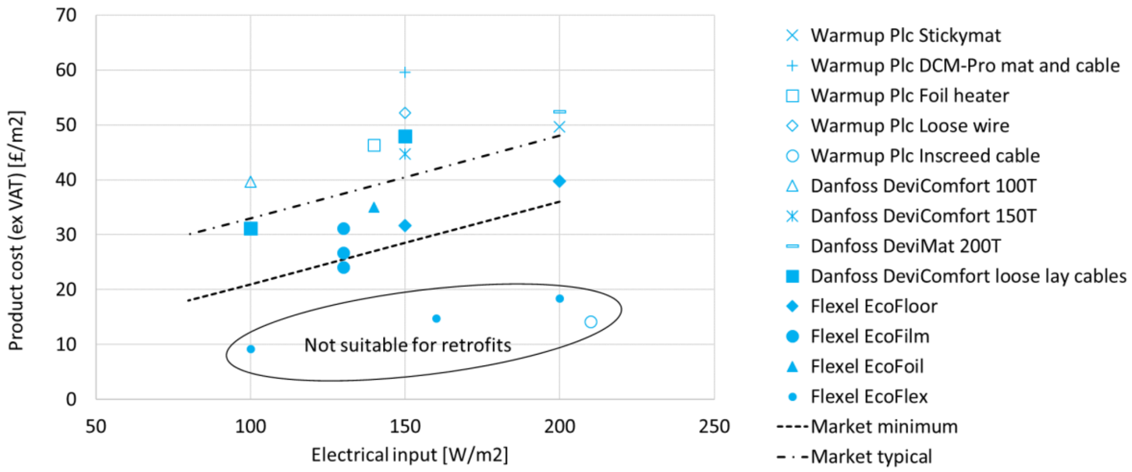
The electric underfloor heating products cover several different physical types:

- Heating mats, in which the bi-conductive heating elements are already attached to a mesh or mat which can be quickly rolled out during system installation, but which can only be applied over a rectangular area.
- Foil heaters, which are similar to the above but in which the heating elements are attached to a thermally conductive sheet of aluminium foil, which must also be applied over a rectangular area.
- Heating cables without any backing material. These can be arrayed over a floor of any shape, and must be arranged at the appropriate interval during installation. These are typically laid into a screed floor layer. As shown in Figure 4-5, the cable itself is less costly, but these have more extensive installation requirements. These systems may work as partial storage heaters if installed within a screed floor layer with a further 70 to 80 mm of concrete above the heating

elements. This allows fewer elements of higher capacity to be used as the concrete layer allows the heat to spread evenly across the floor. This system provides enhanced thermal inertia but is not appropriate for use as a true storage heater. It is also not generally appropriate for retrofits as the floor level must be raised by the height of the concrete layer.

Nearly all the systems require or recommend installation of insulation layers below the heating elements. The warranties for electric underfloor heating systems are notably longer than those of other electric heaters, between 10 years and a lifetime guarantee. Figure 4-5 presents the cost data collected on a per area basis.

**Figure 4-5 Product cost vs size for electric underfloor heaters**

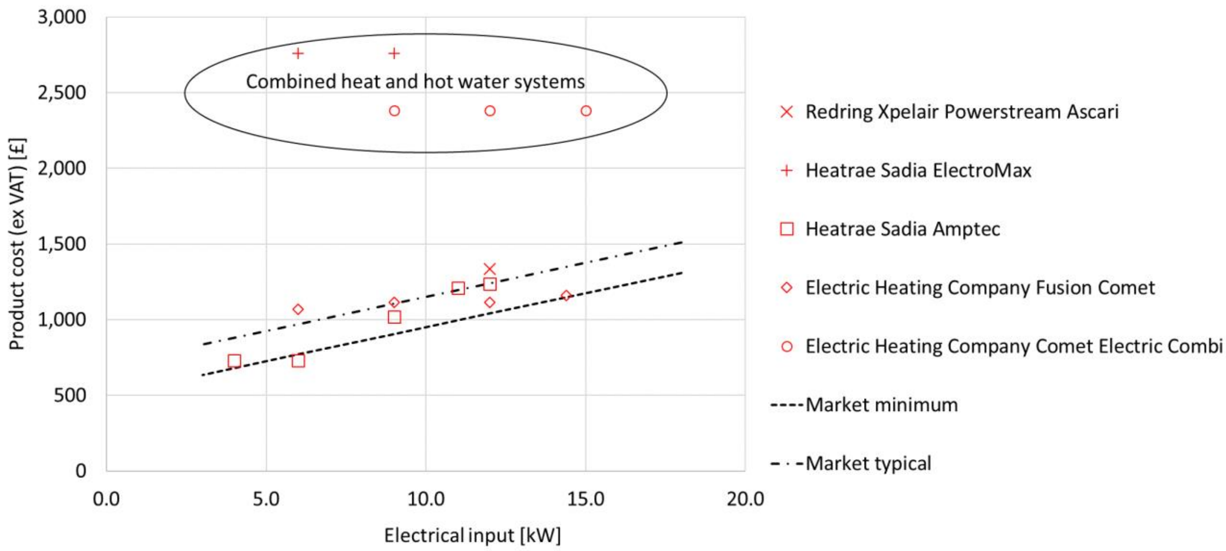



## 4.5 Electric boilers

We have identified 9 electric boiler systems from 5 manufacturers. Figure 4-6 presents the collected cost data for electric boilers, which falls into two distinct clusters. The costs above £2,000 are for systems that contain an integrated hot water cylinder and are designed to provide both heating and hot water. The lower cost systems do not contain integrated cylinders, but may provide hot water if connected to an external cylinder. The cost range for these systems is relatively small in percentage terms and there are minimal aesthetic differences between products. The Market minimum and Market typical costs are defined using only the standalone electric boilers. This allows heating and hot water to be considered separately in the subsequent modelling, as is the case for the other electric heating systems.

It should be noted that the required power and resulting fuse rating for electric boilers is significantly higher than that of the other systems noted above. The electric boilers have an EcoDesign rating of C and D. This is related to the PEF, as discussed in Section 3.1. Further details on the electric boilers are shown in Section 11.5.

**Figure 4-6 Product cost vs size for electric boilers**

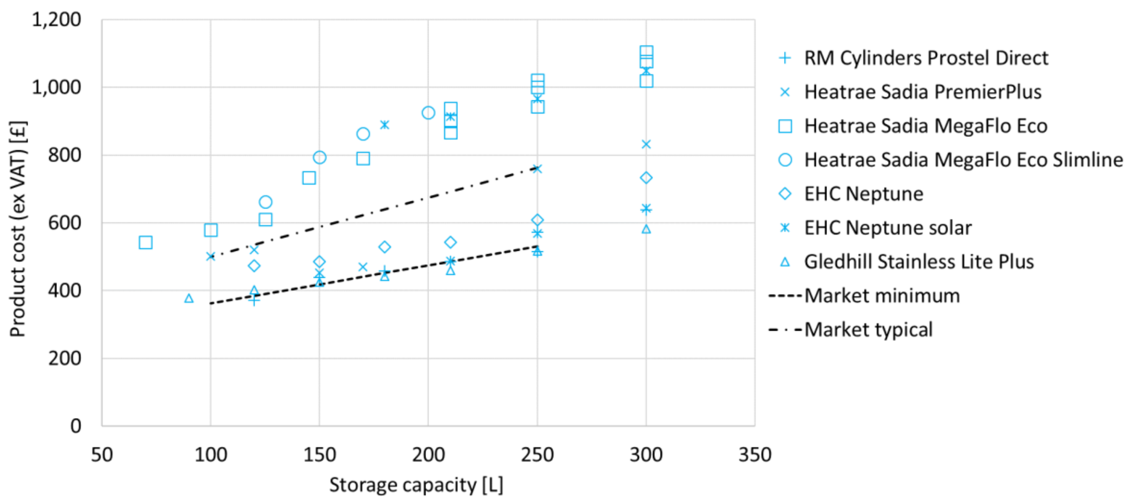



## 4.6 Hot water cylinders

Information on 11 hot water cylinders from 6 manufacturers has been collected and is shown in Section 11.6. The hot water cylinders documented range in size from 70 to 300 L. All of the immersion elements in the surveyed systems are rated at 3 kW. Some cylinders contain multiple immersion elements although these are generally intended for on- and off-peak rather than simultaneous use. The heat-up time increases linearly with the size of the tank. The EcoDesign rating of the systems depends on the level of insulation provided, as discussed above in Section 3.1, and ranges between A and D. The length of the warranties for hot water cylinders is typically at least 20 years.

The cost data for hot water cylinders is shown in Figure 4-7. The cost increases with cylinder size and depends on the level of insulation, quality of materials, and sophistication of the cylinder controls. The more expensive cylinders are more likely to contain control systems designed to learn and anticipate the household's hot water needs in order to reduce energy consumption.

**Figure 4-7 Product cost vs size for hot water cylinders**

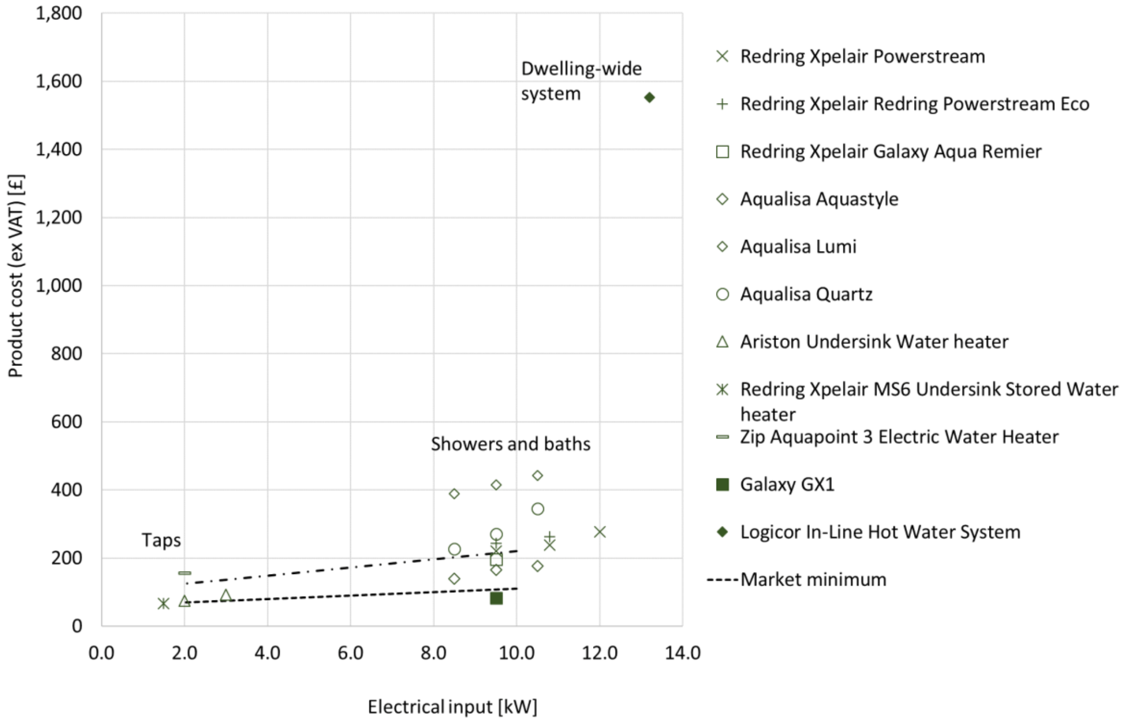


## 4.7 Point-of-use systems

We have documented 9 point-of-use systems from 5 manufacturers. The cost data collected for these systems is shown in Figure 4-8. The majority of the systems are designed to be installed under the sink or in the shower/bath. The Logicor Inline heating system provides on-demand hot water for the entire home from a single central location. This system has a higher power demand, as well as a higher cost, than the other systems. Because on-demand hot water systems heat only the water that is required by the household, there are no standing losses as with storage heaters. The systems can therefore achieve A and B EPC ratings. The warranties are shorter than those of hot water cylinders and are typically around 2 years. More details on the documented systems are shown in Section 11.7.

In Figure 4-8, the various types of systems are clustered in both size and cost. Hot water systems for taps are rated below 4 kW and cost less than £200. Systems for showers and baths are rated between 8 and 12 kW, while the Logicor systems which provides dwelling-wide hot water has a maximum power rating of 13 kW. This system is significantly more expensive but might replace 2 or more of the other system types.

**Figure 4-8 Product cost vs size for point-of-use hot water systems**




## 4.8 Electric heating system cost functions

The linear cost trends shown in Figure 4-1 to Figure 4-8 are presented numerically in Table 4-2, along with the size range over which the functions are valid.

**Table 4-2 Summary of linear cost functions used for each electric heating system**

| System type | Market typical | | Market minimum | | Range of relevance |
|---|---|---|---|---|---|
| | y-intercept | Slope | y-intercept | Slope | |
| Storage £/unit | £400 | £20/kWh | £350 | £12/kWh | 7 to 24 kWh |
| Panel £/unit | £170 | £80/kW | £90 | £20/kW | 0.25 to 3 kW |

| | | | | | |
|---|---|---|---|---|---|
| Infrared £/unit | £350 | £150/kW | £125 | £80/kW | 0.25 to 2 kW |
| Underfloor £/$m^2$ | £18 | £0.15/(W/$m^2$) | £6 | £0.15/(W/$m^2$) | 80 to 200 W/$m^2$ |
| Electric boiler £/unit | £700 | £45/kW | £500 | £45/kW | 3 to 18 kW |
| Hot water cylinder £/L | £325 | £1.75/L | £250 | £1.13/L | 100 to 250 L |
| Point of use system £/kW | £100 | £12/kW | £60 | £5/kW | 2 to 10 kW |

## 4.9 Controls

### Types of system controls

The electric heating systems presented in the above sections have a variety of control methods incorporating different levels of 'smart' technology. The analysis presented here is based on features that are advertised in the available product literature as well as information collected during manufacturer consultations. A table detailing each product presented above and the advertised control options is presented in Appendix 2 in Chapter 12.

The control options identified in the electric heating systems studied so far are described below:

- ***Temperature*** control indicates the presence of a room thermostat and the ability to set a target temperature. The heating system will then modulate its output accordingly. Many systems include additional internal thermostats to prevent overheating, but these are not sufficient to maintain a comfortable room temperature. This is now a requirement for all local space heaters under Lot 20 of the EcoDesign Directive.
- ***Timing and temperature*** control consists of a thermostat and an interface allowing the system to be programmed for a seven-day cycle at a minimum of hourly intervals. Some systems feature half hourly or 15 minute intervals and offer several pre-programmed settings such as 'home all day' and 'evening heat only.' However, the system must offer user customisation of the programmed schedules to fulfil this category. This is now a requirement for all local space heaters under Lot 20 of the EcoDesign Directive.
- ***Adaptive start*** is an enhanced feature of a programmable time and temperature control that uses the room temperature, the outside temperature, or weather reports obtained over WiFi to determine how to heat the room to ensure that the target temperature is achieved at the desired time. This avoids overheating and wasting energy by reaching the desired temperature too early. This is one of the features which fulfil the requirements of the EcoDesign Directive Lot 20.
- ***Open window detection*** is an enhanced feature of a temperature-controlled system. If the controller observes a sudden drop in room temperature despite no change in the power emitted by the heater, the heater will reduce the amount of heat emitted until the user pushes a button to indicate that the window or door has been closed. This is one of the features which fulfil the requirements of the EcoDesign Directive Lot 20.
- ***Frost protection*** mode maintains the dwelling at a temperature below the typical occupied target temperature but above 0°C, to prevent freezing when the dwelling is unoccupied for several days. This is typically a pre-programmed setting with a temperature of 7°C or less.
- ***Control from app*** typically requires the electric heater to be connected to WiFi and the installation of the manufacturer's app on the user's smart phone or tablet. The user is then able to remotely access most or all of the available system controls. This also enables house-wide control since multiple heating systems can be controlled via the same app.

- ***Motion detection*** enables systems to shut off or reduce their power level when they do not detect any motion in the room for a set length of time, typically 15 to 20 minutes.
- ***Geo-fencing*** requires that the electric heating system has smart phone control. It allows the heating system to react when the user (or more accurately their smart phone or tablet) is within a certain distance of their home. For example, the system might raise or lower the set temperature when the smart phone enters or leaves a region within 1 km of the dwelling. This is one of the features which fulfil the requirements of the EcoDesign Directive Lot 20.
- ***Load shedding*** allows the heating system to be powered down when the total power draw of the dwelling exceeds a value set by the user. This requires a passive current-measuring device to be installed at the home's connection to the electricity grid.

Table 4-3 below presents the prevalence of the above control options across the electric heating systems studied to date (which are listed in Appendix 1 in Section12) in summary form, for each electric heating system category. The table also includes the sample size for each category – it should be noted that the sample size is relatively small for several of the categories, so the results for those categories should be taken as indicative only.

**Table 4-3 Prevalence of control options in the documented systems**

| | | *Share of products with control capability* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N (sample size) | Temperature | Timing and temperature | Adaptive start | Open window detection | Frost protection | Control from app | Motion detection | Geo-fencing | Load shedding |
| Electric panel heater | 27 | 93% | 78% | 30% | 44% | 56% | 26% | 7% | 7% | 7% |
| Electric radiator | 8 | 88% | 88% | 13% | 63% | 63% | 63% | 13% | 0% | 13% |
| Electric storage heater | 7 | 86% | 86% | 71% | 43% | 57% | 14% | 0% | 0% | 0% |
| Electric convection heater | 2 | 50% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Electric radiant heater | 10 | 100% | 10% | 0% | 10% | 0% | 0% | 10% | 0% | 0% |
| Electric underfloor heater | 19 | 89% | 26% | 0% | 16% | 0% | 5% | 0% | 0% | 0% |
| Electric boiler | 17 | 100% | 65% | 12% | 0% | 6% | 0% | 0% | 0% | 0% |
| TOTAL | 90 | 92% | 57% | 18% | 27% | 28% | 16% | 4% | 2% | 3% |

The information gathered suggests that the majority of products have **Temperature** control, with the exception of a small number of products across several of the categories. All electric radiant heaters and electric boilers studied have this functionality. **Timing and temperature** control is a feature of just over half of the products studied. The majority of electric panel heaters, electric radiators, electric storage heaters and electric boilers have the option of this feature. However, only a small fraction of the electric radiant heater and electric underfloor heaters studied have timing and temperature control, and neither of the electric convection heaters studied have the feature.

**Adaptive start** is a prevalent feature among electric storage heaters, with more than 70% having this feature, but is only present in a small fraction of other heating systems. Less than one-third of electric panel heaters studied have this feature, while this share is even lower for the other system categories.

**Open window detection** is present in 27% of products studied, with more than half of the electric radiators, and nearly half of the electric panel heaters and electric storage heaters having this capability. Among the other product categories this is much less prevalent. **Frost protection** follows a similar trend across the product categories, being a feature of more than half of the electric panel heaters, radiators and storage heaters, but in very few of the other products.

**Control from app** is a feature mainly found in electric radiators, and in a smaller number of electric panel heaters and storage heaters. None of the electric convection heaters, radiant heaters or boilers studied have this capability. Across all the products studied only 16% have this control option.

The least prevalent control options are **Motion detection**, **Geofencing** and **Load shedding**, which are advertised in less than 5% of products studied. Two electric panel heaters, one electric radiator and one electric radiant heater were found to have Motion detection, two different panel heaters found to have Geofencing and Load shedding, and one different electric radiator to have Load shedding only.

## 4.10 Innovations in electric heating

During the stakeholder consultations, electric heating manufacturers anticipated relatively few innovations relating to the materials, manufacturing, and installation of the electric heating products. With the exception of infrared heaters which are relatively new to the UK market, electric heating systems are mature products which have been available in their current form for years and in some cases decades. The manufacturers of electric infrared heaters predict that costs will continue to fall as the supply chain and manufacturing process are further developed.

The majority of advancements in electric heating are expected to occur around control systems, including the development of dwelling-wide controls and DSR. Developments are anticipated in the following areas:

- **Integration across the home**: While many manufacturers offer apps for heating control, it is recognised that users ultimately will prefer to use one method (app) to control heat, lighting, appliances, home security, etc. rather than individual apps for each system.
- **Integration of renewables within the home**: Several manufacturers have or are developing electric heating and hot water systems that work in tandem with solar PV, solar thermal water heaters, and home batteries.
- **Demand side response**: Manufacturers feel that electric heating can provide benefits to the electricity grid and aid the penetration of renewables. With Lot 20, the electric heating systems and in-dwelling controls are largely ready for DSR, and the remaining steps will be around infrastructure development outside individual dwellings.
- **Energy as a service**: Two electric heating manufacturers have started energy companies, Fischer Future Heat and Logicor. Logicor offers their electric heating customers a flat monthly tariff for all electricity used.

# 5 Installation process and barriers

## 5.1 Installation process and costs

The installation process and resulting costs depend on the pre-existing heating system within a dwelling as well as on the type and number of systems to be installed. The following sections present the costs of installing distributed electric heating systems, central electric heating systems, and underfloor electric heating. All costs are exclusive of VAT and do not include component costs except where noted.

### Distributed electric heating

The installation process is broadly similar between the distributed electric heating systems: storage heaters, panel heaters, and infrared heaters. Table 5-1 presents the steps and range of costs for the installation of distributed electric heating systems in dwellings with existing electric heating. It is assumed that existing electric heating systems comprise a combination of storage and panel heaters, and that the required wiring is therefore already present in the locations where new storage and panel heaters are to be installed (near to the floor and typically underneath windows). Due to their high surface temperatures, infrared heaters are typically installed high on walls or on the ceiling where they are less likely to be touched. The previous heaters will not have been in these locations, and the cost of new fused connections is therefore included for infrared heaters. These are added to the ring circuit that was previously used for electric heating and new ring circuits are not required. It is currently more common for infrared heaters to be sold without integral thermostats and control systems; the additional cost of these components is also included in Table 5-1.

**Table 5-1 Installation process and costs for distributed systems in existing electric dwellings**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Storage | Installation when wiring present | £35 | £50 | £65 | # systems | EE assumption: Cost of replacing existing electric heaters is similar to Which? Trusted Traders cost for replacing an electric oven |
| Panel | Installation when wiring present | £35 | £50 | £65 | # systems | EE assumption: Cost of replacing existing electric heaters is similar to Which? Trusted Traders cost for replacing an electric oven |
| Infrared | New fused connections and heater installation | £110 | £150 | £200 | # systems | EE assumption: Fused connection cost similar to Which? Trusted Traders cost of new double socket |
| Infrared | Supply and installation of thermostats and controls | £40 | £50 | £60 | # systems | Stakeholder consultation and market review |

The installation costs of distributed heating systems are more substantial when they are installed in dwellings which previously had central heating with a wet distribution system. The process and cost of installation in this case are shown in Table 5-2 and Table 5-3 . The boiler and wet radiators are removed and the pipes of the wet distribution system are drained and capped. The cost of the removal process depends on the size of the dwelling as larger homes will have more radiators to be removed. New wiring must then be added to supply the distributed electric heaters. Storage heaters each require two power supplies: an off-peak connection for overnight charging and an on-peak connection to power the controls, fan, and peak-time top-up heating. Storage heaters are not typically connected to a ring circuit but are wired directly to the consumer unit, resulting in a higher wiring cost per unit. A new consumer unit for distributing and metering the off-peak electricity is also required.

Panel and infrared heaters require a single fused connection per unit and are typically connected to a ring circuit. In addition to the 3 A fuse at individual connections, each ring circuit is protected by a 30 A fuse. This places a 7 kW limit on the maximum power deliverable to all appliances on a given ring circuit. It is assumed that new ring circuits dedicated to electric heating will be installed to prevent the electric heaters from interfering with the use of other appliances. Where the combined power demand of the electric heaters exceeds 7 kW, multiple new ring circuits must be installed. As noted above, infrared heaters additionally require external thermostats and control systems.

**Table 5-2 Removal costs for wet heat distribution systems[40],[41]**

| Removal of wet distribution system | Low | Central | High |
|---|---|---|---|
| y-intercept (£) | £250 | £250 | £300 |
| slope (£/m$^2$) | £2 | £2.50 | £3 |
| **Dwelling floor area** | **Low** | **Central** | **High** |
| 50 m$^2$ | £350 | £375 | £450 |
| 80 m$^2$ | £410 | £450 | £540 |
| 125 m$^2$ | £500 | £563 | £675 |
| 175 m$^2$ | £600 | £688 | £825 |
| 250 m$^2$ | £750 | £875 | £1,050 |

**Table 5-3 Installation process and costs for distributed systems in existing oil and solid-fuelled dwellings**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Storage | New wiring and storage heater installation | £150 | £225 | £300 | # systems | EE assumption: Cost of wiring for storage heaters similar to Which? Trusted Traders cost of wiring for new electric shower |
| Storage | New distribution board for off-peak electricity | £450 | £500 | £550 | fixed | Which? Trusted Trader cost of replacing consumer unit |
| Panel and infrared | New fused connections and electric heater installation | £110 | £150 | £200 | # systems | EE assumption: Fused connection cost similar to Which? Trusted Traders cost of new double socket |

[40] *What does it cost to retrofit homes: Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling*, Cambridge Architectural Research for BEIS, Apr 2017
[41] Stakeholder consultation

| | | | | | | |
|---|---|---|---|---|---|---|
| Panel and Infrared | New ring circuits for electric heaters | £110 | £150 | £200 | power demand | EE assumption: Cost of connecting new fused connections to the consumer unit is similar to the cost of an additional fused connection |
| Infrared | Supply and installation of thermostats and controls | £40 | £50 | £60 | # systems | Stakeholder consultation and market review |

### Centralised electric heating

Electric central heating systems comprise the electric boiler and wet heat distribution system. The installation process and range of costs are shown in Table 5-4. Because it is assumed that existing electric dwellings have distributed heating systems, all new installations require a high power electricity connection for the boiler. The cost is similar to that of installing the boiler and plumbing it into the wet heat distribution system.

In existing electric dwellings where a wet heat distribution system is not already present, this must be newly installed. Table 5-5 presents a linear correlation between the area of a dwelling and the cost of supplying and installing a wet heat distribution system, as well as costs for several selected dwelling sizes. The cost of the wet heat distribution system, including radiators, pumps, and piping, is often two to three times the cost of the electric boiler itself.

**Table 5-4 Installation process and costs for centralised electric heating system**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Boiler | Dedicated high power supply for boiler | £150 | £225 | £300 | fixed | EE assumption: Cost of wiring for electric boiler similar to Which? Trusted Traders cost of wiring for new electric shower |
| Boiler | Boiler installation | £160 | £250 | £320 | fixed | EE assumption: Cost of installing electric boiler similar to Which? Trusted Traders cost of hot water cylinder replacement |
| Boiler | Supply and installation of wet distribution system | *See next table* | | | area of dwelling | Stakeholder consultation and market review |

**Table 5-5 Installation costs for wet heat distribution systems[42,43]**

| Supply and installation of wet distribution system | Low | Central | High |
|---|---|---|---|
| y-intercept (£) | £1,000 | £1,250 | £1,500 |
| slope (£/$m^2$) | £4 | £5 | £6 |
| **Dwelling floor area** | **Low** | **Central** | **High** |
| 50 $m^2$ | £1,200 | £1,500 | £1,800 |
| 80 $m^2$ | £1,320 | £1,650 | £1,980 |
| 125 $m^2$ | £1,500 | £1,875 | £2,250 |
| 175 $m^2$ | £1,700 | £2,125 | £2,550 |
| 250 $m^2$ | £2,000 | £2,500 | £3,000 |

### Electric underfloor heaters

The installation process for electric underfloor heaters and the associated costs are presented in Table 5-6. As described in Section 4.4 above, there are several types of underfloor electric heating systems available including loose cables to be installed in screed layers and electric heating mats and foils that can be laid directly underneath floor coverings. Because this study is focussed on options for retrofitting homes rather than new construction, the installation costs are for mats and foils that do not require any changes to the floor structure. The existing floor covering is removed and the mat is unrolled to cover the desired area. A thin layer of self-levelling compound (typically 10 mm or less) is laid over the heating mats which enables the floor coverings to be changed in future without damage to the heating system. The floor covering can then be replaced. Although underfloor heating is typically installed when the floor covering is being changed, the costs for new floor coverings are not considered as part of the heating system.

As with the other systems, several of the required installation steps depend on the previous heating system. If a wet heat distribution system was previously used, this is removed (see Table 5-2 above) and new fused connections and ring circuits are installed. If distributed electric heating was already present, the underfloor heaters can be connected to the available existing wiring. One electrical connection is required per room except for very large rooms where the heating system draws more than 3 A. Thermostats and controls must be purchased separately from the underfloor heaters; one is typically needed per room.

[42] *What does it cost to retrofit homes: Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling*, Cambridge Architectural Research for BEIS, Apr 2017
[43] *Hybrid Heat Pumps Study,* Element Energy for BEIS, 2018

**Table 5-6 Installation process and costs for underfloor electric heating**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Underfloor - all | Underfloor heating installation | £4 | £5 | £6 | area of heaters | Stakeholder consultation |
| Underfloor - all | Supply and installation of thermostats and controls | £40 | £50 | £60 | # rooms | Stakeholder consultation and market review |
| Underfloor - existing oil & solid | New fused connections for underfloor heating | £110 | £150 | £200 | # rooms | EE assumption: Fused connection cost similar to Which? Trusted Traders cost of new double socket |
| Underfloor - existing oil & solid | New ring circuits for underfloor heating | £110 | £150 | £200 | power demand | EE assumption: Cost of connecting new fused connections to consumer unit similar to cost of an additional fused connection |
| Underfloor - existing electric | Connection to existing wiring | £35 | £50 | £65 | # rooms | EE assumption: Cost of connecting to existing wiring is similar to Which? Trusted Traders cost for replacing an electric oven |

### Decommissioning and removal of oil tank

In addition to the steps described above, dwellings with existing oil heating require the oil tank to be decommissioned and removed. This cost has been estimated as part of a concurrent study on bioenergy options for off-gas grid homes and is presented in Table 5-7.

**Table 5-7 Cost of decommissioning and removing existing oil tank**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| All | Decommissioning and removal of oil tank | £1,000 | £1,000 | £1,000 | fixed | Bioenergy options for off-gas grid dwellings, NNFCC for BEIS, 2019. |

## 5.2 Options for hot water provision

The majority of off-gas houses in England and Wales have an existing hot water storage cylinder, as shown in Table 5-8. Dwellings with oil heating may contain combi boilers if a cylinder is not present, while solid-fuelled dwellings may use a back boiler. Electric dwellings without hot water cylinders are likely to be fitted with instantaneous electric hot water heaters.

**Table 5-8 Fraction of dwellings with existing hot water cylinders based on the dwelling type and existing heating system[44]**

| Existing system | Terrace | Semi-detached | Detached |
|---|---|---|---|
| Oil | 78% | 86% | 84% |
| Solid | 88% | 100% | 98% |
| Electric | 83% | 86% | 94% |
| Total dwellings with cylinders | 1,119,002 (85%) | | |
| Total dwellings without cylinders | 190,185 (15%) | | |

Existing hot water cylinders can be maintained in the dwelling when electric heating is installed. In the 15% of dwellings where hot water cylinders are not already present, one may be installed if space is available. In smaller houses where finding space is challenging, it may be preferable to install instantaneous point-of-use systems to provide hot water.

### Hot water cylinders

The installation process and associated costs for hot water cylinders are presented in Table 5-9 Installation process and costs for hot water cylinders. Where no hot water cylinder is present, the installation costs include both installing the cylinder and the addition of the electrical connection. If the existing cylinder does not contain an immersion heater (or if a second immersion is desired for use with an off-peak electricity tariff), this can usually be retrofit.

**Table 5-9 Installation process and costs for hot water cylinders**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Hot water cylinder | Hot water cylinder installation | £160 | £250 | £320 | fixed | Which? Trusted Traders cost of hot water cylinder replacement |
| Hot water cylinder and Immersion element | New electrical connection for hot water cylinder | £110 | £150 | £200 | fixed | EE assumption: Fused connection cost similar to Which? Trusted Traders cost of new double socket |
| Immersion element | Supply and installation of immersion element | £100 | £140 | £180 | fixed | Stakeholder consultation and market review |

44 English Housing Survey 2015-16: Special Access Housing Stock Data, MHCLG, 2016.

### Point-of-use systems

Table 5-10 presents the installation costs for point-of-use hot water systems. Electric showers and taps require both plumbing and electrical connections. It is assumed that where a hot water cylinder is not present and there is insufficient space to add one, the dwelling previously relied on a combi-boiler or back boiler and that no pre-existing electrical connections are available for these systems.

**Table 5-10 Installation process and costs for point-of-use systems**

| System type | Installation process | Low | Central | High | depends on: | Source |
|---|---|---|---|---|---|---|
| Electric shower | New wiring for electric shower | £150 | £225 | £300 | # systems | Which? Trusted Traders cost of wiring for new electric shower |
| Electric shower | Plumbing connection for electric shower | £120 | £180 | £240 | # systems | EE assumption: Cost of plumbing connection for electric shower similar to Which? Trusted Trader cost for changing bath taps |
| Electric tap | New wiring for electric tap | £110 | £150 | £200 | # systems | EE assumption: Fused connection cost similar to Which? Trusted Traders cost of new double socket |
| Electric tap | Plumbing connection for electric tap | £120 | £180 | £240 | # systems | EE assumption: Cost of plumbing connection for electric tap similar to Which? Trusted Trader cost for changing bath taps |

## 5.3 Dwelling fuse limit

Electric heating requires more power than other domestic appliances. The dwelling fuse limit can therefore pose a significant barrier to electric heating installation, especially in larger homes with higher peak heating demands. Table 5-11 presents typical power requirements for lighting and other appliances across the dwelling types of interest[45]. The demand during the evening peak (approximately 6 to 10 pm) is highest, followed by the day time demand and finally overnight demand. Larger dwellings with more rooms (and typically, more occupants) have a higher non-heat electricity demand and require a larger capacity to be kept in reserve. The night time limit is applied to storage heaters while the peak time limit is applied to all other systems as they provide heat on-demand.

**Table 5-11 Power required for lighting and appliance use[45]**

| Dwelling type | Peak time requirement | Day time requirement | Night time requirement |
|---|---|---|---|
| Terrace | 5.5 kW | 3.7 kW | 1.8 kW |
| Semi-detached | 6.3 kW | 4.2 kW | 2.1 kW |
| Detached | 6.6 kW | 4.4 kW | 2.2 kW |

In Great Britain, a single-phase domestic electricity connection can theoretically supply up to 100 A (23 kW). However, many dwellings have installed fuses of 80 A or, in older dwellings, 60 A. Electric heating manufacturers familiar with the installation process noted that DNOs will provide an upgrade to the

[45] *Household Electricity Survey*, Inertek for DECC, 2014.

dwelling fuse limit at no charge when electric heating is installed in a dwelling, provided that the cable supplying the dwelling is of sufficient size. While many dwellings are easily upgraded to 100 A fuses, some dwellings would require new cabling to reach this level and are otherwise limited to 80 A.

For this reason, a two-level fuse limit test is applied. Where the required buffer and heat demand can be supplied with 80 A, the electric heating system receives a "Pass" rating. If 100 A is required to accommodate both the heat demand and the buffer, the electric heating system receives a "Caution" rating. If greater than 100 A is required, the electric heating system is not feasible in the given dwelling and receives a "Fail" rating. Table 5-12 presents the power available for each type of electric heating system in the various dwelling types. Because storage heaters are charged overnight, they can demand more power without interfering with the use of lights and other appliances.

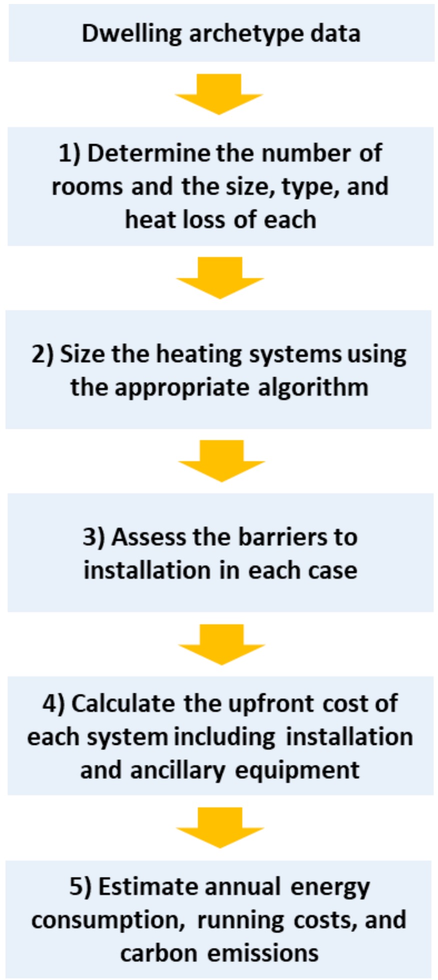
**Table 5-12 Power available for electric heating**

| **PASS 80 A** | Storage heaters | Panel heaters | Infrared heaters | Underfloor heating | Electric boilers |
|---|---|---|---|---|---|
| Terrace | 16.6 kW | 12.9 kW | 12.9 kW | 12.9 kW | 12.9 kW |
| Semi-detached | 16.3 kW | 12.1 kW | 12.1 kW | 12.1 kW | 12.1 kW |
| Detached | 16.2 kW | 11.8 kW | 11.8 kW | 11.8 kW | 11.8 kW |
| **CAUTION 100 A** | Storage heaters | Panel heaters | Infrared heaters | Underfloor heating | Electric boilers |
| Terrace | 21.2 kW | 17.5 kW | 17.5 kW | 17.5 kW | 17.5 kW |
| Semi-detached | 20.9 kW | 16.7 kW | 16.7 kW | 16.7 kW | 16.7 kW |
| Detached | 20.8 kW | 16.4 kW | 16.4 kW | 16.4 kW | 16.4 kW |

# 6 Modelling approach

This section describes the modelling methodology used to assess the challenges, costs, and reduction in carbon emissions resulting from the installation of electric heating systems in the rural off-gas grid dwellings in England and Wales, which is outlined in Figure 6-1.

**Figure 6-1 Modelling approach for assessing the costs and reduction in carbon emissions from electric heating systems**




## 6.1 Off-gas grid dwelling archetypes

A set of 703 archetypes are used to approximate housing stock of 1.3 million dwellings. The archetypes were developed as part of a previous study[46] and are based on the Cambridge Housing Model[47] (CHM), with updated stock data from the 2015-16 English Housing Survey[48] and the 2008 Living in Wales[49] survey.

Table 6-1 presents the set of attributes defined for each archetype. In addition to the dwelling type, wall type, floor area, and existing heating system, the location of each archetype in the Government Office Regions (GOR) is specified along with the average winter minimum temperature in each Region. The

[46] *Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings*, Delta EE for BEIS, 2018.
[47] *Cambridge Housing Model*, Cambridge Architectural Research for DECC, 2010, https://www.gov.uk/government/publications/cambridge-housing-model-and-user-guide
[48] *English Housing Survey: End User Housing Stock Data*, MHCLG, 2016.
[49] *Living in Wales Property Survey 2008*, Wales Local Government Data Unit, 2010.

current demand for space heating and energy consumption resulting from this demand and the efficiency of the existing heating system have been calculated using the CHM. The impact of three types of additional fabric efficiency measures is also included for each archetype. These are also listed in Table 6-1.

**Table 6-1 Properties of the off-gas grid dwelling archetypes**

| Attribute | | Possible values or unit |
|---|---|---|
| Dwelling type | | Terraced, Semi-detached, Detached |
| Wall type | | Un-insulated cavity, Insulated cavity, Solid |
| Existing fuel type | | Electric, Oil, Solid |
| Location | | Government office region (GOR) |
| Minimum external temperature | | ° C |
| Floor area | | $m^2$ |
| Baseline space heating demand | | kWh/year and kW peak |
| Baseline space heating energy consumption | | kWh/year and kW peak |
| Space heating demand with additional insulation | Loft | kWh/year and kW peak |
| | Loft & Floor | kWh/year and kW peak |
| | Loft & Wall | kWh/year and kW peak |

An indicative cost estimate of the additional efficiency measures is included in the model to allow a cost-benefit analysis of the increase in dwelling energy efficiency. The costs are based on a 2017 survey of installers and have been correlated with dwelling floor area as shown in Table 6-2. Solid wall insulation is significantly more expensive than the other measures available.

**Table 6-2 Indicative costs for additional insulation measures[50]**

| Supply and installation of additional insulation | Loft | Floor | Cavity wall | Solid wall |
|---|---|---|---|---|
| y-intercept (£) | £200 | £250 | £250 | £4000 |
| slope (£/$m^2$) | £3 | £5 | £5 | £60 |
| **Dwelling floor area** | **Loft** | **Floor** | **Cavity wall** | **Solid wall** |
| 50 $m^2$ | £350 | £500 | £500 | £7,000 |
| 80 $m^2$ | £440 | £650 | £650 | £8,800 |
| 125 $m^2$ | £575 | £875 | £875 | £11,500 |
| 175 $m^2$ | £725 | £1,125 | £1,125 | £14,500 |
| 250 $m^2$ | £950 | £1,500 | £1,500 | £19,000 |

The average impact of the additional measures on the space heating demand across the housing stock can be seen in Table 6-3. The average cost of the measures in the dwellings with each wall type is also shown. This varies across the wall types due to the mix of house sizes in each category and the cost of the insulation measures.

[50] *What does it cost to retrofit homes: Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling*, Cambridge Architectural Research for BEIS, Apr 2017

**Table 6-3 Average space heating demand and cost for additional insulation measures**

| | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|
| Average space heating demand (kWh/year) | 13,942 | 12,753 | 11,852 | 10,147 |
| Average cost of additional insulation | | | | |
| Un-insulated cavity | n/a | £618 | £1,560 | £1,560 |
| Insulated cavity | n/a | £587 | £1,480 | £587 |
| Solid | n/a | £659 | £1,680 | £13,800 |

Distributed electric heating systems are sized to accommodate the peak heat demand in the individual rooms in which they are placed. The number of bedrooms and total rooms in each dwelling is determined using floor area thresholds shown in Table 6-4, which have been derived from the EHS 2015-16 data set excluding dwellings with gas heating.

**Table 6-4 Floor area thresholds for dwelling bedrooms and total rooms**

| | House type and floor area | | |
|---|---|---|---|
| # Bedrooms | Terrace | Semi-detached | Detached |
| 5 | > 250 $m^2$ | > 250 $m^2$ | > 250 $m^2$ |
| 4 | 250 $m^2$ | 250 $m^2$ | 250 $m^2$ |
| 3 | 150 $m^2$ | 130 $m^2$ | 150 $m^2$ |
| 2 | 70 $m^2$ | 50 $m^2$ | 70 $m^2$ |
| 1 | 40 $m^2$ | 40 $m^2$ | 40 $m^2$ |
| # Total rooms | Terrace | Semi-detached | Detached |
| 8 | > 150 $m^2$ | > 200 $m^2$ | > 225 $m^2$ |
| 7 | 150 $m^2$ | 200 $m^2$ | 225 $m^2$ |
| 6 | 140 $m^2$ | 130 $m^2$ | 120 $m^2$ |
| 5 | 110 $m^2$ | 100 $m^2$ | 100 $m^2$ |
| 4 | 70 $m^2$ | 50 $m^2$ | 60 $m^2$ |
| 3 | 40 $m^2$ | 40 $m^2$ | 40 $m^2$ |

Several of the sizing algorithms described in Sections 4.1 to 4.5 above depend on the type of room as well as the heat loss rate. Table 6-5 presents the assumed use of the rooms other than the bedrooms and the number of halls and landings. Smaller dwellings have a single hall, a combined living and dining area that also contains the kitchen and a single bathroom. In larger dwellings, there are two halls or landings, and the living space, dining room, and kitchen are each in separate rooms. The EHS 2015-16 data set extends only to 5 bedrooms and 8 rooms in total. The largest 5% of the dwellings in the archetype set are over 300 $m^2$ and are likely to have more than 8 rooms in total. However, as there is no significant difference between installing multiple distributed heating systems in a single large room and in several smaller rooms, this does not impact the model results.

The assumed relative size of each room type is shown in Table 6-6. These size factors are used to apportion the floor area and the heat loss across the rooms of each dwelling. Once the peak heat loss rate in each room is known, the electric heating systems required in each room can be determined.

**Table 6-5 Assumed relationships between the number and type of dwelling rooms**

<table>
<tr><th># Non-bedrooms</th><th># Living/dining rooms</th><th># Kitchens</th><th># Bathrooms</th></tr>
<tr><td>4</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>3</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>2</td><td>1</td><td>0</td><td>1</td></tr>
<tr><th># Bedrooms</th><th colspan="3"># Halls/landings</th></tr>
<tr><td>5</td><td colspan="3">2</td></tr>
<tr><td>4</td><td colspan="3">2</td></tr>
<tr><td>3</td><td colspan="3">2</td></tr>
<tr><td>2</td><td colspan="3">1</td></tr>
<tr><td>1</td><td colspan="3">1</td></tr>
</table>

**Table 6-6 Assumed relative sizes of dwelling rooms**

| Room | Size factor |
|---|---|
| Bedroom | 1 |
| Living/Dining | 1.8 |
| Kitchen | 1 |
| Bathroom | 0.6 |
| Hall/Landing | 0.6 |

### Analysis of updated Welsh housing data

As discussed above, the dwelling archetypes used in the present study are based on housing stock data from the 2015-16 English Housing Survey[51] and the 2008 Living in Wales[52] survey. The 2018 Welsh Housing Conditions Survey[53] provides an updated view of the housing stock in Wales and the characteristics relevant to the present study. The following tables compare the new housing stock data with that used to create the archetypes.

Table 6-7 presents the distribution of heating fuels in houses in Wales in 2008 and 2018. There are 32,000 additional houses while the off-gas stock has reduced by 43,000 houses. The fraction of electric dwellings has remained constant at 4% of the total stock and the share of oil and solid-fuelled dwellings has reduced. The majority of off-gas houses in Wales are detached. Between 2008 and 2018, the share of semi-detached dwellings has increased by 3% while the shares of terrace and detached homes have slightly reduced. However, the number of semi-detached homes has reduced overall as off-gas dwellings have been connected to the gas network or demolished.

[51] *English Housing Survey: End User Housing Stock Data*, MHCLG, 2016.
[52] *Living in Wales Property Survey 2008*, Wales Local Government Data Unit, 2010.
[53] *Welsh Housing Conditions Survey 2017-18*, Statistics for Wales, 2018.

**Table 6-7 Heating fuels and dwelling types in Welsh houses in 2008 and 2018**

| | Living in Wales 2008 | Welsh Housing Conditions Survey 2018 |
|---|---|---|
| **Number of Welsh houses** | **1,162,144** | **1,194,104** |
| Gas | 78% | 83% |
| Oil | 14% | 11% |
| Solid | 3% | 2% |
| Electric | 4% | 4% |
| **Number of off-gas houses** | **246,846** | **203,322** |
| Off-gas terrace | 18% | 17% |
| Off-gas semi-detached | 24% | 27% |
| Off-gas detached | 58% | 56% |

The wall types present in Welsh houses are shown in Table 6-8. The fractions of un-insulated cavity walls and un-insulated solid walls in 2008 have been estimated assuming the fraction of cavity and solid-walled dwellings remain constant between 2008 and 2018. Cavity wall insulation was present in 25% of all Welsh houses in 2008 and in 2018 has been installed in 36% of Welsh houses. There were virtually no houses with insulated solid walls in 2008, but by 2018 solid wall insulation was added to 8% of the total housing stock. The yearly energy demand in dwellings which have received these insulation measures will have been reduced by around 30%[54]. This will increase the number of dwellings which are suitable for electric heating in their current state, reducing the requirement for fuse upgrades and further insulation measures.

**Table 6-8 Outer wall insulation in Welsh off-gas houses in 2008 and in 2018**

| Wall type | Living in Wales 2008 | Welsh Housing Conditions Survey 2018 |
|---|---|---|
| Cavity un-insulated | 29% (estimated) | 18% |
| Cavity insulated | 25% | 36% |
| Solid wall un-insulated | 46% (estimated) | 38% |
| Solid with external insulation | 0% | 8% |

Data on the prevalence of hot water storage cylinders in Wales is shown in Table 6-9. The fractions of English dwellings with hot water cylinders (as documented in the EHS 2015-16) are included in the table as a point of comparison. Oil-heated dwellings in Wales have seen a marked reduction in the usage of hot water cylinders between 2008 and 2018, with less than half currently containing a cylinder. This is significantly less than the 84% of English oil dwellings with hot water cylinders. The English and Welsh values are more similar for solid and electric dwellings. These houses have had little reduction in cylinder usage since 2008. In aggregate, around a third of Welsh dwellings would have to either give up space to install a hot water cylinder or install point-of-use hot water systems when converting to electric heating, compared with less than 15% of English dwellings. These dwellings will face a higher upfront cost of conversion, as discussed in Section 6.2 Hot water cylinders below.

[54] This is the mean reduction due to wall insulation seen in the relevant subset of the dwelling archetypes used in the study.

**Table 6-9 Prevalence of hot water cylinders in off-gas houses in England and Wales**

| Dwellings with hot water cylinder | Living in Wales 2008 | Welsh Housing Conditions Survey 2018 | EHS 2015-16 |
|---|---|---|---|
| Oil | 63% | 48% | 84% |
| Solid | 98% | 100% | 96% |
| Electric | 98% | 96% | 88% |
| Total | 76% | 68% | 86% |

## 6.2 Sizing algorithms for electric heating systems

### DOM 8 sizing for storage and panel heaters

*DOM 8: Guide to the Design of Electric Space Heating Systems*[55] provides guidance on the sizing of electric storage heaters and electric panel heaters in domestic dwellings. Storage heaters are sized to provide the 24-hour energy requirement on the design (coldest) day. DOM 8 provides correlations between the seasonal use of peak-time heating and its use on the coldest day. This peak-time heating is provided by the storage heaters themselves using "top-up" charging or the "boost" mode outside of the off-peak window. In the present study it is assumed that peak-time charging provides 10% of the seasonal heat demand, which corresponds to 19% of the heat consumed on the coldest day. DOM 8 also includes heat gain and infiltration factors for each room type to represent heat gained from the occupants and other appliances. The seasonal heat factor $y$ and the heat gain factor z are multiplied by the heat loss rate $H$ to determine the energy requirement for each room:

$$E = 24Hzy.$$

For electric panel heaters, DOM 8 specifies an oversizing factor based on the room type and the building construction; these are shown in Table 6-10. This is multiplied by the design heat loss rate to determine the power required in each room. Masonry construction is assumed for all dwellings and new masonry construction is considered as a sensitivity in Chapter 8.

**Table 6-10 Oversizing factors for panel heaters as specified in DOM 8**

| Room | Masonry construction | New masonry construction | Timber frame construction |
|---|---|---|---|
| Bedrooms | 1.5 | 1.3 | 1.1 |
| Living/dining | 1.7 | 1.5 | 1.2 |
| Kitchen | 1.5 | 1.3 | 1.1 |
| Hall/landing | 1.5 | 1.3 | 1.1 |
| Bathroom | 2 | 2 | 2 |

### Electric infrared heaters

The other types of electric heaters are not covered in DOM 8 and the sizing algorithms used have been developed based on consultations with system manufacturers. Electric infrared heaters are sized to match the heat loss rate in each room without oversizing. This is due to the nature of radiant heat delivery; heat is delivered directly to the room and items and occupants within the room rather than to the air. This allows a cold room to feel warm more quickly without oversizing the heaters.

### Electric underfloor heating

Electric underfloor heating is sized to cover 75% of the floor area of each room because the systems cannot be placed under cabinets, bookshelves, and other furniture that it is direct contact with the floor.

[55] *DOM 8: Guide to the Design of Electric Space Heating Systems*, The Electric Heating & Ventilation Association, Feb 2006.

Additionally, the maximum acceptable floor temperature places a limit on the amount of heat that can be comfortably delivered. When a room is steady at a comfortable temperature (18-21 °C), underfloor heating can provide 120 W/m$^2$ via convection to the room air if the floor surface is at 30 °C, the maximum allowable temperature for carpet and wood floor coverings. If this is insufficient to match the room's heat loss rate, underfloor heating is not appropriate without additional insulation measures. If the steady state heat loss can be matched without exceeding the floor temperature limit, then manufacturers recommend oversizing the system by 25 W/m$^2$ to allow rapid warming from cold temperatures.

### Electric boilers

The manufacturers of electric boilers recommend that systems are oversized by 15% relative to the dwelling's design day heat loss rate.

### Hot water cylinders

A dwelling's hot water demand depends on the number of occupants rather than the dwelling size. The number of occupants is assumed to be one greater than the number of bedrooms. The hot water demand in litres is calculated using a formula developed by the Energy Saving Trust[56], where *n* is the number of occupants:

$$L = 46 + 26 \times n$$

This gives very similar results to the formula specified in SAP 2012. Electric hot water cylinders generally have two immersion elements of 3 kW each for on- and off-peak use. Where an immersion element is retrofit to a cylinder previously used with a solid fuel or oil boiler, a single element of 3 kW is assumed.

### Hot water point-of-use systems

Point-of-use systems for taps are typically between 2 and 3 kW while those for showers and baths are between 8.5 and 10.5 kW. In the present study, 3 kW is assumed for taps and 10 kW for showers and baths. The size assumptions, capital, and installation costs for hot water systems are shown in Table 6-11.

**Table 6-11 Applicability and costs for hot water cylinders and point-of-use systems**

| | Hot water cylinder | Immersion element | Electric shower | Electric tap |
|---|---|---|---|---|
| Where applicable | Default option where cylinder not present | Default option where cylinder present | Sensitivity for small dwellings without existing cylinder | Sensitivity for small dwellings without existing cylinder |
| Preferred electricity tariff | Selected by heating system | Selected by heating system | Selected by heating system | Selected by heating system |
| Annual maintenance cost | £0 | £0 | £0 | £0 |
| Size range | 100 to 210 L | 6 kW | 10 kW | 3 kW |
| Market minimum cost range | £363 to £486 | £25 | £110 | £75 |
| Market typical cost range | £500 to £693 | £25 | £220 | £136 |
| Stock-wide average installation cost | £400 | £265 | Whole dwelling: £1230<br>Cost per electric shower: £405<br>Cost per electric tap: £330 | |

[56] *Measurement of Domestic Hot Water Consumption in Dwellings*, Energy Saving Trust, 2008

## 6.3 Upfront costs and disruption level

The above sizing procedures are repeated at each level of insulation shown previously in Table 6-2. The capital cost of the systems (as detailed in Chapter 4) is added to the installation cost (as detailed in Section 5.1). The counterfactual upfront cost is also assessed using the correlations presented in Table 6-12[57]. For dwellings with existing electric heating, electric storage heaters are considered as the counterfactual case. The annual maintenance cost of oil and solid-fuelled boilers is also shown; electric heating systems do not require annual maintenance.

**Table 6-12 Indicative costs for the counterfactual heating systems**

| Supply and installation of counterfactual heating systems | Oil[57] | Solid[58] |
|---|---|---|
| y-intercept (£) | £1500 | £2000 |
| slope (£/m²) | £20 | £5 |
| **Dwelling floor area** | **Oil** | **Solid** |
| 50 m² | £2,500 | £2,250 |
| 80 m² | £3,100 | £2,400 |
| 125 m² | £4,000 | £2,625 |
| 175 m² | £5,000 | £2,875 |
| 250 m² | £6,500 | £3,250 |
| Annual maintenance cost | 5% of cap ex | 5% of cap ex |

In addition to the cost of conversion, the level of disruption caused by the installation is also assessed for each dwelling and each type of heating system according to **Error! Reference source not found.**. The lowest level of disruption occurs when central or distributed heating is maintained before and after the conversion and no additional efficiency measures or fuse upgrade is required. The second level involves changing from a distributed heating system to a centralised system or vice versa without the need for additional efficiency measures or a fuse upgrade. In these cases, the installation process is more involved and will involve lifting floor coverings and creating holes in the wall, floors, and potentially ceilings to install electrical wiring or the wet heat distribution system. Disruption level 3 comprises homes which would fall into the previous two categories but are currently without a hot water storage cylinder. Some loss of space may be required to add a hot water cylinder, or further disruption for the installation of point-of-use systems.

**Table 6-13 Levels of dwelling disruption due to electric heating installation**

| Level of disruption | Description |
|---|---|
| 1 | No notable barriers based on existing fuel type |
| 2 | Installation will cause some internal disruption based on existing fuel type |
| 3 | No existing hot water cylinder – a hot water solution is required |
| 4 | Fuse upgrade to 100 A required to avoid breach of the fuse limit |
| 5 | Cavity wall & loft insulation are required to avoid breach of the fuse limit |
| 6 | Solid wall & loft insulation are required to avoid breach of the fuse limit |
| 7 | Remainder – the current system is not feasible for this archetype |

[57] *What does it cost to retrofit homes: Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling*, Cambridge Architectural Research for BEIS, Apr 2017
[58] EE assumption based on a review of solid fuel boilers for central heating available on the UK market.

Level 4 includes dwellings in which the peak heat demand cannot be met without upgrading the dwelling fuse limit to 100 A. At levels 5 and 6, additional wall and loft insulation is required to reduce the dwelling heat demand such that it can be met with an electric heating system that does not breach the 100 A limit. Because cavity wall insulation is cheaper and simpler to install than solid wall insulation, solid wall dwellings are given a higher disruption level. Any dwellings where the heat demand cannot be supplied with 100 A even after additional fabric efficiency measures are installed fall into the last category.

### 6.4 Running costs and carbon intensity

The annual space heating demand for the dwelling archetypes at each insulation level is provided as part of the inputs from the CHM (see Table 6-1). The energy demand for hot water is added to this assuming an average temperature rise of 45 °C. The electric heating systems are assumed to be 100% efficient, while the counterfactual oil and solid-fuelled systems operate at the efficiency prescribed in the CHM inputs for each archetype.

Table 6-14 presents the most appropriate tariff for each type of electric heating system, and the assumed on- and off-peak fractions for each system if used with an Economy 7 tariff. The on- and off-peak fractions do not impact the electricity cost under a Standard tariff. Off- and on-peak times vary by region and by electricity supplier; typical Economy 7 off-peak hours are from 12:30 or 1:00 am to 7:30 or 8:00 am.

**Table 6-14 Preferred tariff for each electric heating system and the assumed on-peak/off-peak split when used with an Economy 7 tariff[59]**

| System | Tariff | % off-peak | % on-peak |
|---|---|---|---|
| Panel heaters | Standard | 30% | 70% |
| Storage heaters | Economy 7 | 90% | 10% |
| Infrared heaters | Standard | 30% | 70% |
| Underfloor heating | Standard | 30% | 70% |
| Electric boilers | Standard | 30% | 70% |
| Hot water cylinder | Economy 7 | 80% | 20% |
| Point-of-use systems | Standard | 30% | 70% |

A 15-year lifetime is assumed for all systems. Projections of residential energy prices including VAT are shown in Figure 6-2 from the present to 2035. A discount rate of 3.5% is applied to all costs outside of the initial investment. The carbon intensity of the fuels is presented in Figure 6-3. While electricity is currently comparable to burning oil, it is projected to drop to around one third of its current carbon intensity by 2035.

[59] The on- and off-peak fractions are based on DOM 8 and consultation with OEMs

**Figure 6-2 Projected residential prices of electricity[60], oil[60], and solid fuel[61] to 2035**

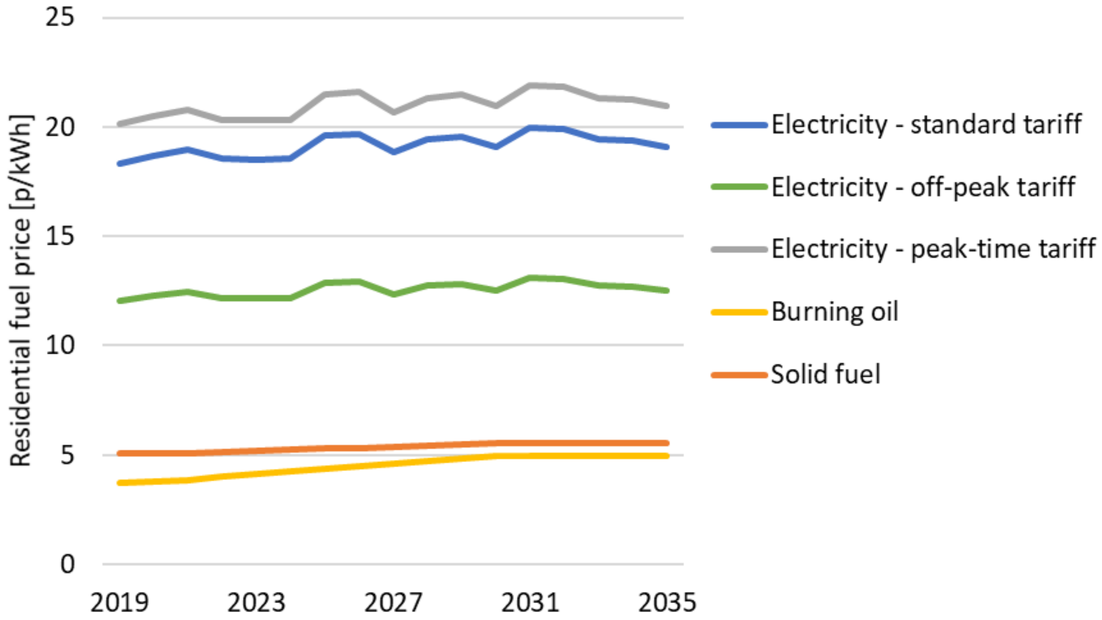
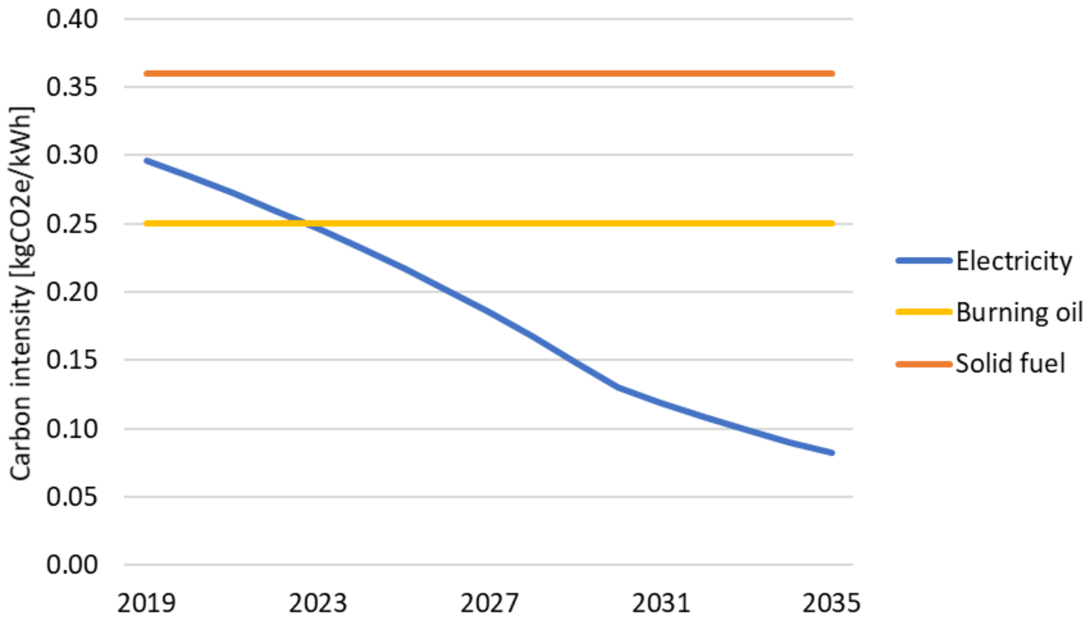



**Figure 6-3 Projected carbon intensity of electricity, oil, and solid fuel to 2035[62]**




[60] *BEIS Energy and Emissions Projections: 2017*, Annex M for Standard tariff and Market review for Economy 7 on- and off-peak tariffs

[61] *HMT Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal*, BEIS, 2018

[62] *HMT Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal*, BEIS, 2018

# 7 Results for selected archetypes

This section presents detailed results for two archetypes selected to illustrate how system sizing, the installation process, and lifetime costs differ based on the features of each dwelling. Results for the full off-gas housing stock are discussed in Section 8 below. Table 7-1 presents the characteristics of the selected dwellings. Dwelling A is a solid-walled terrace at the 14th percentile for floor area amongst the off-gas grid housing stock. The counterfactual system is electric heating, which is assumed to be electric storage heaters. Dwelling B is a detached dwelling with un-insulated cavity walls at the 73rd percentile for floor area. Dwelling B is currently heated using an oil boiler. Both homes are assumed to contain hot water cylinders.

**Table 7-1 Properties of two selected archetypes**

| | Dwelling A | Dwelling B |
|---|---|---|
| |  |  |
| Dwelling type | Terrace | Detached |
| Existing fuel type | Electric | Oil |
| Wall type | Solid | Un-insulated cavity |
| Floor area | 73 $m^2$ | 174 $m^2$ |
| # Dwelling rooms | 5 | 7 |
| # Bedrooms | 3 | 5 |
| Cylinder present? | Yes | Yes |
| Maximum heat loss rate – Baseline | 6.8 kW | 12.4 kW |
| Maximum heat loss rate – Loft & wall insulation | 4.8 kW | 8.6 kW |
| Yearly space heating energy demand – Baseline | 9.4 MWh | 17.9 MWh |
| Yearly space heating energy demand – Loft & wall insulation | 6.3 MWh | 12.1 MWh |
| Yearly hot water energy demand | 3.3 MWh | 3.9 MWh |

## 7.1 Dwelling A - Electric-heated terrace with solid walls

Cost, energy consumption, and carbon results are shown below for electric heating systems in Dwelling A: storage heaters (the counterfactual), panel heaters, an electric boiler, and infrared heaters. The required size and cost of these heating systems at two levels of dwelling fabric insulation are shown in Table 7-2. This includes only the heating systems themselves, while the installation process and associated cost are shown in Table 7-3.

The installed capacity varies with the type of heating system due to the sizing methodologies described in Section 6.2 above. Panel heaters have the highest power demand to allow the dwelling to be rapidly heated when cold, while infrared heaters are most closely sized to the dwelling's peak heat loss rate.

### Table 7-2 Size and cost of electric heating systems for Dwelling A

| | Baseline | Loft & Wall insulation |
|---|---|---|
| # Dwelling rooms | 5 | |
| Peak heat loss rate(kW) | 7 | 5 |
| **# Storage heaters** | 8 | 7 |
| Combined storage capacity (kWh) | 84 | 70 |
| Market minimum cost | £3,570 | £3,040 |
| Market typical cost | £4,730 | £4,020 |
| **# Panel heaters** | 8 | 8 |
| Combined capacity (kW) | 13 | 9 |
| Market minimum cost | £985 | £895 |
| Market typical cost | £2,420 | £2,060 |
| **Electric boiler** capacity (kW) | 9 | 6 |
| Market minimum cost | £905 | £770 |
| Market typical cost | £1,110 | £970 |
| **# Infrared heaters** | 8 | 7 |
| Combined capacity (kW) | 8 | 5 |
| Market minimum cost | £1,640 | £1,300 |
| Market typical cost | £4,000 | £2,890 |

In the Market typical cost scenario, the capital cost of storage heaters is around twice that of panel heaters and four times more than an electric boiler. The capital cost of infrared heaters is close to twice the cost of panel heaters in both the Market typical and Market minimum cost scenarios. Although electric boilers have the lowest system capital cost, the cost of supplying and installing a wet heat distribution system to the dwelling adds significantly to the upfront cost of the electric boiler. In dwellings where electric heating was already present, the installation cost for storage heaters and panel heaters is similar. Panel heaters have the lowest total upfront cost which is under £3,000, followed by electric boilers. Storage heaters and infrared heaters both have upfront costs over £5,000. For storage heaters this is due primarily to the high system costs, while for infrared heaters both the capital and installation costs contribute. Infrared heaters are typically mounted high on walls or on the ceiling while the previous storage heaters would have been located on the floor. The installation cost therefore includes relocating fused connections which is not required for the other distributed heaters.

### Table 7-3 Installation process and costs for Dwelling A

| Storage heaters | Required? | Central cost – Baseline | Low to High range – Baseline |
|---|---|---|---|
| Removal of wet heating system | × | × | × |
| Decommissioning of oil tank | × | × | × |
| New fused connections and installation of storage heaters and bathroom panel heater | × | × | × |
| New distribution board for off-peak electricity | × | × | × |
| Installation of storage heaters and bathroom panel heater when wiring already present | ✓ | £400 | £280 to £520 |
| **Total installation cost** | | **£400** | **£280 to £520** |
| **Total upfront cost – system (Market typical) and installation** | | **£5,130** | **£5,010 to £5,250** |

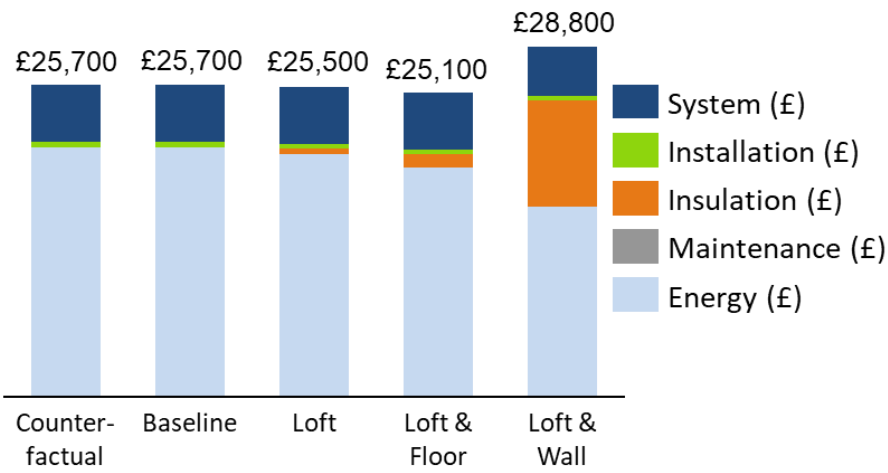
| Panel heaters | Required? | Central cost - Baseline | Low to High range - Baseline |
|---|---|---|---|
| Removal of wet heating system | × | × | × |
| Decommissioning of oil tank | × | × | × |
| New fused connections and installation of panel heaters | × | × | × |
| New ring circuits for panel heaters | × | × | × |
| Installation of panel heaters when wiring already present | ✓ | £400 | £280 to £520 |
| **Total installation cost** | | **£400** | **£280 to £520** |
| **Total upfront cost – system (Market typical) and installation** | | **£2,820** | **£2,700 to £2,940** |
| Electric boiler | Required? | Central cost – Baseline | Low to High range – Baseline |
| Decommissioning of oil tank | × | × | × |
| Dedicated high power supply for boiler | ✓ | £225 | £150 to £300 |
| Boiler installation | ✓ | £250 | £160 to £320 |
| Supply and installation of wet distribution system | ✓ | £1,610 | £1,290 to £1,940 |
| **Total installation cost** | | **£2,090** | **£1,600 to £2,560** |
| **Total upfront cost – system (Market typical) and installation** | | **£3,190** | **£2,710 to £3,660** |
| Infrared heaters | Required? | Central cost - Baseline | Low to High range - Baseline |
| Removal of wet heating system | × | × | × |
| Decommissioning of oil tank | × | × | × |
| New fused connections and installation of infrared heaters | ✓ | £1,200 | £880 to £1,600 |
| New ring circuits for infrared heaters | × | × | × |
| Supply and installation of thermostats and controls | ✓ | £400 | £320 to £480 |
| **Total installation cost** | | **£1,600** | **£1,200 to £2,080** |
| **Total upfront cost – system (Market typical) and installation** | | **£5,600** | **£5,200 to £6,080** |

Table 7-4 and Figure 7-1 present the lifetime costs of storage heaters in Dwelling A at the Baseline and with additional fabric efficiency measures. A system lifetime of 15 years, occurring between 2020 and 2035, is assumed for all systems. As mentioned above, storage heaters at the Baseline insulation level are considered as the counterfactual for existing electric dwellings. The annual electricity cost is discounted at 3.5% and makes up the bulk of the lifetime cost. Although there is a significant reduction in energy consumption and electricity cost with the addition of solid wall insulation, it is not cost-effective within the 15-year lifetime of the storage heaters due to the large capital cost. The other, less costly efficiency measures are cost-effective although their impact is more marginal. Because storage heaters are also the counterfactual, the only reduction in carbon emissions arises due to reduced energy consumption as the dwelling becomes more energy efficient.

**Table 7-4 Energy consumption and costs, including hot water, for storage heaters in Dwelling A**

| Storage heaters | Counter-factual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | PASS | PASS | PASS | PASS | PASS |
| Yearly energy consumption | 12.8 MWh | 12.8 MWh | 12.4 MWh | 11.8 MWh | 9.7 MWh |
| Year 1 energy cost | £1,670 | £1,670 | £1,620 | £1,540 | £1,270 |
| System cost (Market typical) | £4,730 | £4,730 | £4,730 | £4,730 | £4,020 |
| Installation cost (Central) | £400 | £400 | £400 | £400 | £350 |
| Added insulation cost | £0 | £0 | £418 | £1,030 | £8,800 |
| Discounted lifetime maintenance cost | £0 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £20,500 | £20,500 | £20,000 | £18,900 | £15,600 |
| **Lifetime cost** | **£25,700** | **£25,700** | **£25,500** | **£25,100** | **£28,800** |
| **Lifetime emissions (tonnes $CO_2e$)** | **38** | **38** | **37** | **35** | **29** |

**Figure 7-1 Lifetime costs of storage heaters in Dwelling A at several insulation levels**

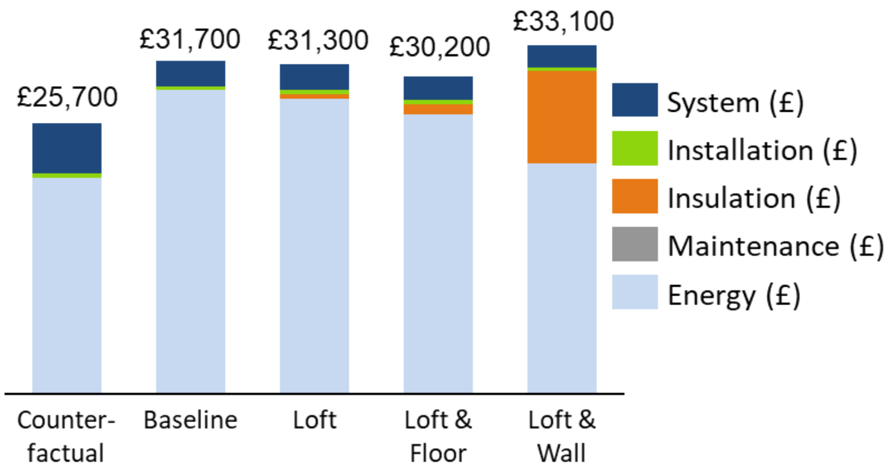



The energy, lifetime costs and carbon emissions of panel heaters in Dwelling A are shown in Table 7-5 and the lifetime costs are plotted in Figure 7-2. In the Baseline and Loft insulation cases, the maximum power demand of the panel heaters cannot be accommodated with an 80 A fuse and an upgrade to 100 A is required. The reduced upfront cost of panel heaters relative to storage heaters does not cause a reduction in lifetime costs because the use of a Standard tariff rather than Economy 7 increases the annual electricity bill. Again, solid wall insulation is not cost-effective during the system lifetime.

**Table 7-5 Energy consumption and costs, including hot water, for panel heaters in Dwelling A**

| Panel heaters | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | PASS | CAUTION | CAUTION | PASS | PASS |
| Yearly energy consumption | 12.8 MWh | 12.8 MWh | 12.4 MWh | 11.8 MWh | 9.7 MWh |
| Year 1 energy cost | £1,670 | £2,340 | £2,280 | £2,150 | £1,780 |
| System cost (Market typical) | £4,730 | £2,420 | £2,420 | £2,220 | £2,060 |
| Installation cost (Central) | £400 | £400 | £400 | £400 | £400 |
| Added insulation cost | £0 | £0 | £418 | £1,030 | £8,800 |
| Discounted lifetime maintenance cost | £0 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £20,500 | £28,800 | £28,000 | £26,500 | £21,800 |
| **Lifetime cost** | **£25,700** | **£31,700** | **£31,300** | **£30,200** | **£33,100** |
| **Lifetime emissions (tonnes $CO_2e$)** | **38** | **38** | **37** | **35** | **29** |

**Figure 7-2 Lifetime costs of panel heaters in Dwelling A at several insulation levels**




The electric boiler results in Table 7-6 and Figure 7-3 are substantially similar to those for panel heaters above. A fuse upgrade is not required to accommodate the electric boiler. Despite the low cost of the electric boiler, the wet heat distribution system and the higher electricity tariff make the lifetime cost higher than the storage heater counterfactual at all insulation levels.

**Table 7-6 Energy consumption and costs, including hot water, for electric boilers in Dwelling A**

| Electric boilers | Counter-factual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | PASS | PASS | PASS | PASS | PASS |
| Yearly energy consumption | 12.8 MWh | 12.8 MWh | 12.4 MWh | 11.8 MWh | 9.7 MWh |
| Year 1 energy cost | £1,670 | £2,340 | £2,280 | £2,150 | £1,780 |
| System cost (Market typical) | £4,730 | £1,110 | £1,110 | £1,110 | £970 |
| Installation cost (Central) | £400 | £2,090 | £2,090 | £2,090 | £2,090 |
| Added insulation cost | £0 | £0 | £418 | £1,030 | £8,800 |
| Discounted lifetime maintenance cost | £0 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £20,500 | £28,800 | £28,000 | £26,500 | £21,800 |
| **Lifetime cost** | **£25,700** | **£32,000** | **£31,700** | **£30,700** | **£33,700** |
| **Lifetime emissions (tonnes $CO_2$e)** | **38** | **38** | **37** | **35** | **29** |

**Figure 7-3 Lifetime costs of electric boilers in Dwelling A at several insulation levels**

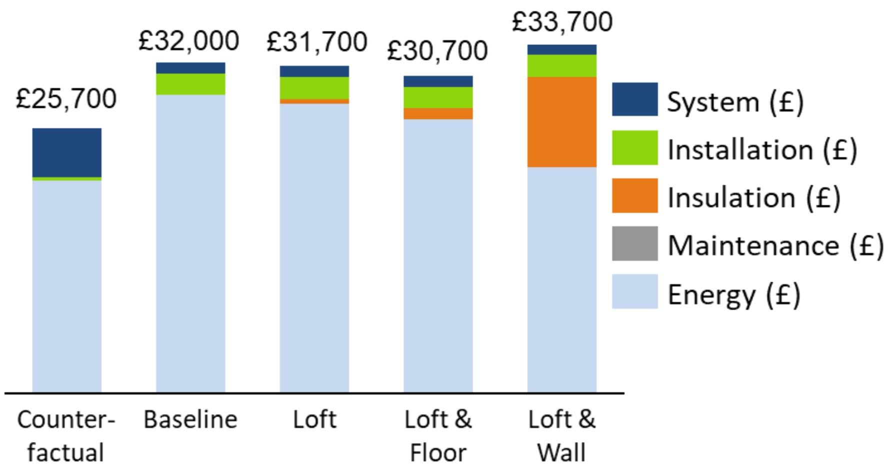
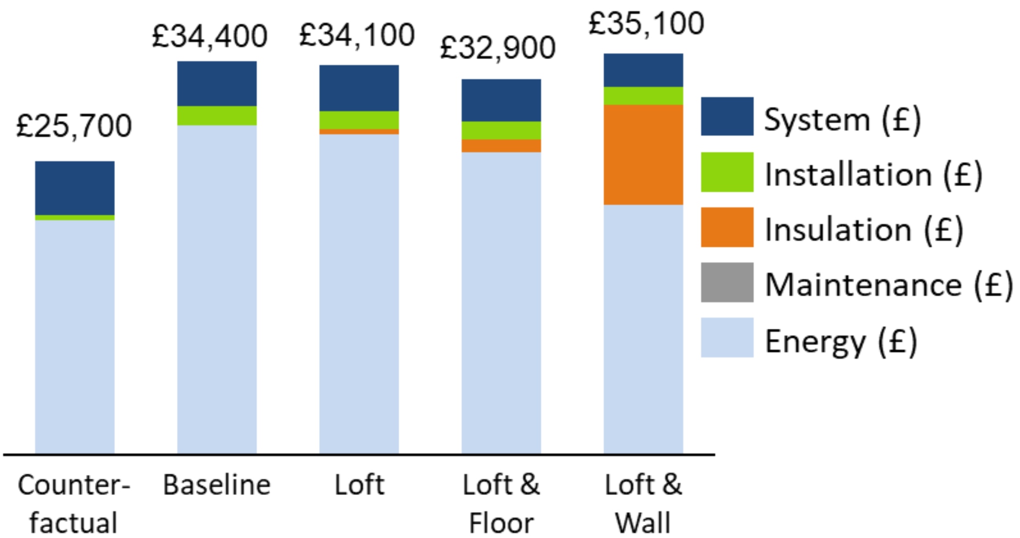



Table 7-7 and Figure 7-4 present the lifetime energy consumption, costs, and carbon emissions for infrared heaters in Dwelling A. Infrared heaters are the most expensive of the four systems examined. They have the highest upfront cost and use the Standard electricity tariff. The yearly energy consumption is assumed to be the same as for the other electric heating systems, but it is possible that this may be reduced due to the highly modular nature of infrared heaters. Where multiple heaters are present in a room, a single heater may be used to heat only the occupied portion of the room. The potential reduction in energy use has not been quantified and is likely to require frequent interaction from the user or sophisticated controls including continuous motion detection.

**Table 7-7 Energy consumption and costs, including hot water, for infrared heaters in Dwelling A**

| Infrared heaters | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | PASS | PASS | PASS | PASS | PASS |
| Yearly energy consumption | 12.8 MWh | 12.8 MWh | 12.4 MWh | 11.8 MWh | 9.7 MWh |
| Year 1 energy cost | £1,670 | £2,340 | £2,280 | £2,150 | £1,780 |
| System cost (Market typical) | £4,730 | £4,000 | £4,000 | £3,738 | £2,888 |
| Installation cost (Central) | £400 | £1,600 | £1,600 | £1,600 | £1,550 |
| Added insulation cost | £0 | £0 | £418 | £1,030 | £8,800 |
| Discounted lifetime maintenance cost | £0 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £20,500 | £28,800 | £28,000 | £26,500 | £21,800 |
| **Lifetime cost** | **£25,700** | **£34,400** | **£34,100** | **£32,900** | **£35,100** |
| **Lifetime emissions (tonnes $CO_2e$)** | **38** | **38** | **37** | **35** | **29** |

**Figure 7-4 Lifetime costs of infrared heaters in Dwelling A at several insulation levels**



### 7.2 Dwelling B - Oil-heated detached with un-insulated cavity walls

The same electric heating systems discussed above are now examined in Dwelling B, a larger detached dwelling with an oil counterfactual system. The required capacity and capital costs of each system are shown in Table 7-8 while the installation process and costs are shown in Table 7-9. The grey values in Table 7-8 and further below indicate where the system requires greater than 100 A and is therefore not feasible without upgrading to a three-phase electricity connection. Assumptions relating to the dwelling fuse limit and the power required for uses other than heating can be found in Section 5.3 above.

**Table 7-8 Size and cost of electric heating systems for Dwelling B. Grey values indicate where the system is not feasible due to breaching a 100 A fuse limit.**

| | Baseline | Loft & Wall insulation |
|---|---|---|
| # Dwelling rooms | 7 | |
| Peak heat loss rate (kW) | 12 | 9 |
| **# Storage heaters** | 10 | 10 |
| Combined capacity (kWh) | 172 | 109 |
| Market minimum cost | £5,330 | £4,560 |
| Market typical cost | £7,330 | £6,020 |
| **# Panel heaters** | 13 | 10 |
| Combined capacity (kW) | 22 | 17 |
| Market minimum cost | £1,610 | £1,250 |
| Market typical cost | £3,970 | £3,080 |
| **Electric boiler** capacity (kW) | 15 | 12 |
| Market minimum cost | £1,180 | £1,040 |
| Market typical cost | £1,380 | £1,240 |
| **# Infrared heaters** | 10 | 10 |
| Combined capacity (kW) | 14 | 11 |
| Market minimum cost | £2,330 | £2,090 |
| Market typical cost | £6,630 | £5,180 |

As with Dwelling A, panel heaters have the highest combined power capacity while infrared heaters are the nearest to the dwelling's peak heat loss rate. Storage heaters have the highest system cost followed by infrared heaters, panel heaters, and finally electric boilers. The installation cost for the distributed systems is now substantially higher than for the electric boiler. The electric boiler is able to re-use the existing wet heat distribution system including the piping and radiators, while extensive new wiring must be installed for each of the distributed systems. All systems require decommissioning and removal of the existing oil tank. The upfront cost of storage heaters is over £10,000, while an electric boiler can be supplied and installed for less than £3,000.

**Table 7-9 Installation process and costs for Dwelling B**

| Storage heaters | Required? | Central cost - Loft & Wall | Low to High range - Loft & Wall |
|---|---|---|---|
| Removal of wet heating system | ✓ | £686 | £599 to £823 |
| Decommissioning of oil tank | ✓ | £1,000 | £1,000 |
| New fused connections and installation of storage heaters and bathroom panel heater | ✓ | £2,180 | £1,460 to £2,900 |
| New distribution board for off-peak electricity | ✓ | £500 | £450 to £550 |
| Installation of storage heaters and bathroom panel heater when wiring already present | × | × | × |
| **Total installation cost** | | **£4,360** | **£3,510 to £5,270** |
| **Total upfront cost – system (Market typical) and installation** | | **£10,380** | **£9,530 to £11,290** |
| Panel heaters | Required? | Central cost - Loft & Wall | Low to High range - Loft & Wall |
| Removal of wet heating system | ✓ | £686 | £599 to £823 |
| Decommissioning of oil tank | ✓ | £1,000 | £1,000 |
| New fused connections and installation of panel heaters | ✓ | £1,950 | £1,430 to £2,600 |
| New ring circuits for panel heaters | ✓ | £450 | £330 to £600 |
| Installation of panel heaters when wiring already present | × | × | × |
| **Total installation cost** | | **£4,090** | **£3,360 to £5,020** |
| **Total upfront cost – system (Market typical) and installation** | | **£7,170** | **£6,440 to £8,100** |
| Electric boiler | Required? | Central cost – Loft & Wall | Low to High range – Loft & Wall |
| Decommissioning of oil tank | ✓ | £1,000 | £1,000 |
| Dedicated high power supply for boiler | ✓ | £225 | £150 to £300 |
| Boiler installation | ✓ | £250 | £160 to £320 |
| Supply and installation of wet distribution system | × | × | × |
| **Total installation cost** | | **£1,480** | **£1,310 to £1,620** |
| **Total upfront cost – system (Market typical) and installation** | | **£2,720** | **£2,550 to £2,860** |
| Infrared heaters | Required? | Central cost – Loft & Wall | Low to High range – Loft & Wall |
| Removal of wet heating system | ✓ | £686 | £599 to £823 |
| Decommissioning of oil tank | ✓ | £1,000 | £1,000 |
| New fused connections and installation of infrared heaters | ✓ | £1,500 | £1,100 to £2,000 |
| New ring circuits for infrared heaters | ✓ | £300 | £220 to £400 |
| Supply and installation of thermostats and controls | ✓ | £500 | £400 to £600 |
| **Total installation cost** | | **£3,990** | **£3,320 to £4,820** |
| **Total upfront cost – system (Market typical) and installation** | | **£9,160** | **£8,490 to £10,000** |

The energy, carbon, and lifetime costs for storage heaters in Dwelling B are shown in

Table 7-11 and Figure 7-5. The lifetime for all systems is 15 years, assumed to occur between 2020 and 2035. Storage heaters will breach even a 100 A fuse with Baseline and Loft insulation but are feasible with Loft and Floor as well as Loft and Wall insulation. The additional levels of insulation are cost-effective within the lifetime of the electric heating systems, with cavity wall insulation providing the most significant lifetime cost reduction. The lifetime costs of the storage heaters are approximately double that of the counterfactual in some insulation cases. This is predominately due to the high cost of electricity relative to oil, even with the use of an Economy 7 electricity tariff. The lifetime carbon emissions are reduced by between 40% and 60% relative to the oil counterfactual.

**Table 7-10 Energy consumption and costs, including hot water, for storage heaters in Dwelling B. Grey values indicate where the system is not feasible due to breaching a 100 A fuse limit.**

| Storage heaters | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | n/a | FAIL | FAIL | CAUTION | PASS |
| Yearly energy consumption | 30.0 MWh | 21.9 MWh | 21.1 MWh | 20.0 MWh | 16.0 MWh |
| Year 1 energy cost | £1,120 | £2,840 | £2,741 | £2,600 | £2,082 |
| System cost (Market typical) | £4,990 | £7,330 | £6,830 | £6,590 | £6,020 |
| Installation cost (Central) | £0 | £4,650 | £4,650 | £4,650 | £4,650 |
| Added insulation cost | £0 | £0 | £723 | £1,850 | £1,850 |
| Discounted lifetime maintenance cost | £2,950 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £15,500 | £34,900 | £33,700 | £32,000 | £25,600 |
| **Lifetime cost** | **£23,500** | **£46,900** | **£45,900** | **£45,100** | **£38,100** |
| **Lifetime emissions (tonnes $CO_2e$)** | **113** | **65** | **63** | **59** | **47** |

**Figure 7-5 Lifetime costs of storage heaters in Dwelling B at several insulation levels**

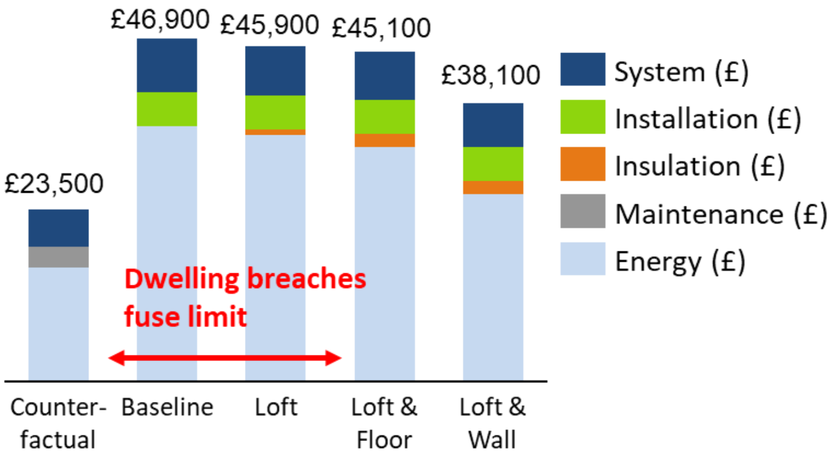
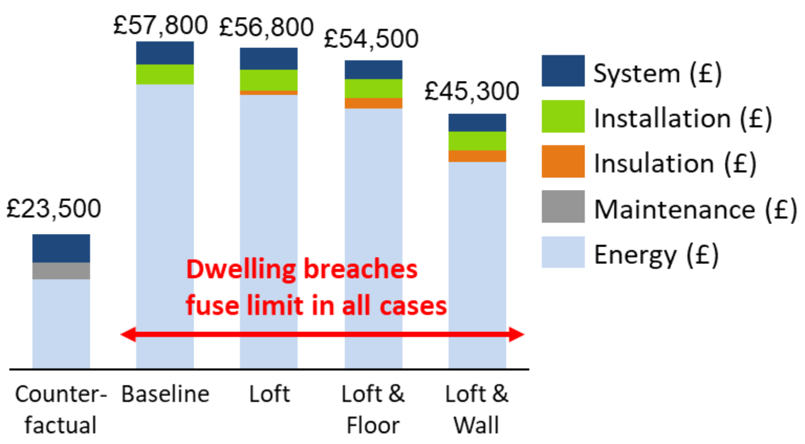


Table 7-11 and Figure 7-6 present the same results for panel heaters in Dwelling B. Panel heaters are not feasible at any of the insulation levels considered due to their high peak-time power requirement in this large home. If panel heaters were technically feasible, their lifetime costs would be higher than electric boilers and storage heaters.

**Table 7-11 Energy consumption and costs, including hot water, for panel heaters in Dwelling B. Grey values indicate where the system is not feasible due to breaching a 100 A fuse limit.**

| Panel heaters | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | n/a | FAIL | FAIL | FAIL | FAIL |
| Yearly energy consumption | 30.0 MWh | 21.9 MWh | 21.1 MWh | 20.0 MWh | 16.0 MWh |
| Year 1 energy cost | £1,120 | £4,000 | £3,870 | £3,670 | £2,930 |
| System cost (Market typical) | £4,990 | £3,970 | £3,930 | £3,180 | £3,080 |
| Installation cost (Central) | £0 | £4,530 | £4,530 | £4,380 | £4,380 |
| Added insulation cost | £0 | £0 | £723 | £1,850 | £1,850 |
| Discounted lifetime maintenance cost | £2,950 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £15,500 | £49,300 | £47,600 | £45,100 | £36,000 |
| **Lifetime cost** | **£23,500** | **£57,800** | **£56,800** | **£54,500** | **£45,300** |
| **Lifetime emissions (tonnes $CO_2$e)** | **113** | **65** | **63** | **59** | **47** |

**Figure 7-6 Lifetime costs of panel heaters in Dwelling B at several insulation levels**



Electric boilers are feasible in Dwelling B if a fuse upgrade to 100 A is possible, as shown in Table 7-12 and Figure 7-7. Despite the low upfront cost, the lifetime cost is higher in all efficiency cases than for storage heaters due to the Standard rate electricity tariff, and significantly higher than for the oil counterfactual. The annual energy cost for heat and hot water increases by nearly a factor of four in the Baseline case, falling to just below a factor of three with Loft & Wall insulation.

**Table 7-12 Energy consumption and costs, including hot water, for electric boilers in Dwelling B. A fuse upgrade to 100 A is required at all insulation levels.**

| Electric boilers | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | n/a | CAUTION | CAUTION | CAUTION | CAUTION |
| Yearly energy consumption | 30.0 MWh | 21.9 MWh | 21.1 MWh | 20.0 MWh | 16.0 MWh |
| Year 1 energy cost | £1,120 | £4,000 | £3,870 | £3,670 | £2,930 |
| System cost (Market typical) | £4,990 | £1,380 | £1,380 | £1,380 | £1,240 |
| Installation cost (Central) | £0 | £1,770 | £1,770 | £1,770 | £1,770 |
| Added insulation cost | £0 | £0 | £723 | £1,850 | £1,850 |
| Discounted lifetime maintenance cost | £2,950 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £15,500 | £49,300 | £47,600 | £45,100 | £36,000 |
| **Lifetime cost** | **£23,500** | **£52,500** | **£51,500** | **£50,100** | **£40,900** |
| **Lifetime emissions (tonnes $CO_2$e)** | **113** | **65** | **63** | **59** | **47** |

**Figure 7-7 Lifetime costs of electric boilers in Dwelling B at several insulation levels. A fuse upgrade is required at all levels of insulation.**

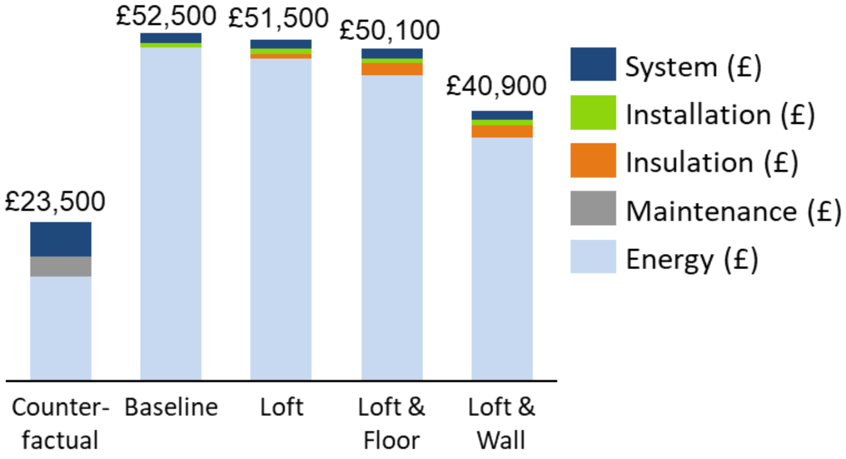
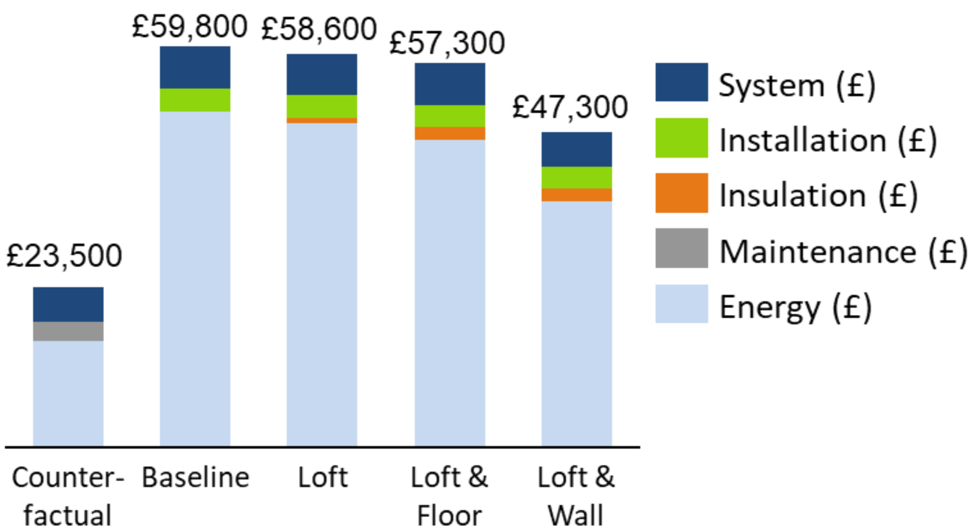


Table 7-13 and Figure 7-8 present the lifetime results for infrared heaters. A fuse upgrade to 100 A is required at all levels of insulation apart from Loft & Wall insulation. As noted for Dwelling A, the yearly electricity costs are unchanged from the other on-demand heaters. The use of the Standard electricity tariff and the high upfront costs result in the highest lifetime costs of the four systems examined.

**Table 7-13 Energy consumption and costs, including hot water, for infrared heaters in Dwelling B. A fuse upgrade is required at all levels of insulation except for Loft & Wall.**

| Infrared heaters | Counterfactual | Baseline | Loft | Loft & Floor | Loft & Wall |
|---|---|---|---|---|---|
| Fuse rating test | n/a | CAUTION | CAUTION | CAUTION | PASS |
| Yearly energy consumption | 30.0 MWh | 21.9 MWh | 21.1 MWh | 20.0 MWh | 16.0 MWh |
| Year 1 energy cost | £1,120 | £4,000 | £3,870 | £3,670 | £2,930 |
| System cost (Market typical) | £4,990 | £6,225 | £6,050 | £6,050 | £5,175 |
| Installation cost (Central) | £0 | £3,276 | £3,276 | £3,276 | £3,276 |
| Added insulation cost | £0 | £0 | £723 | £1,850 | £1,850 |
| Discounted lifetime maintenance cost | £2,950 | £0 | £0 | £0 | £0 |
| Discounted lifetime energy cost | £15,500 | £49,300 | £47,600 | £45,100 | £36,000 |
| **Lifetime cost** | **£23,500** | **£59,800** | **£58,600** | **£57,300** | **£47,300** |
| **Lifetime emissions (tonnes $CO_2e$)** | **113** | **65** | **63** | **59** | **47** |

**Figure 7-8 Lifetime costs of infrared heaters in Dwelling B at several insulation levels. A fuse upgrade is required except with Loft & Wall insulation.**

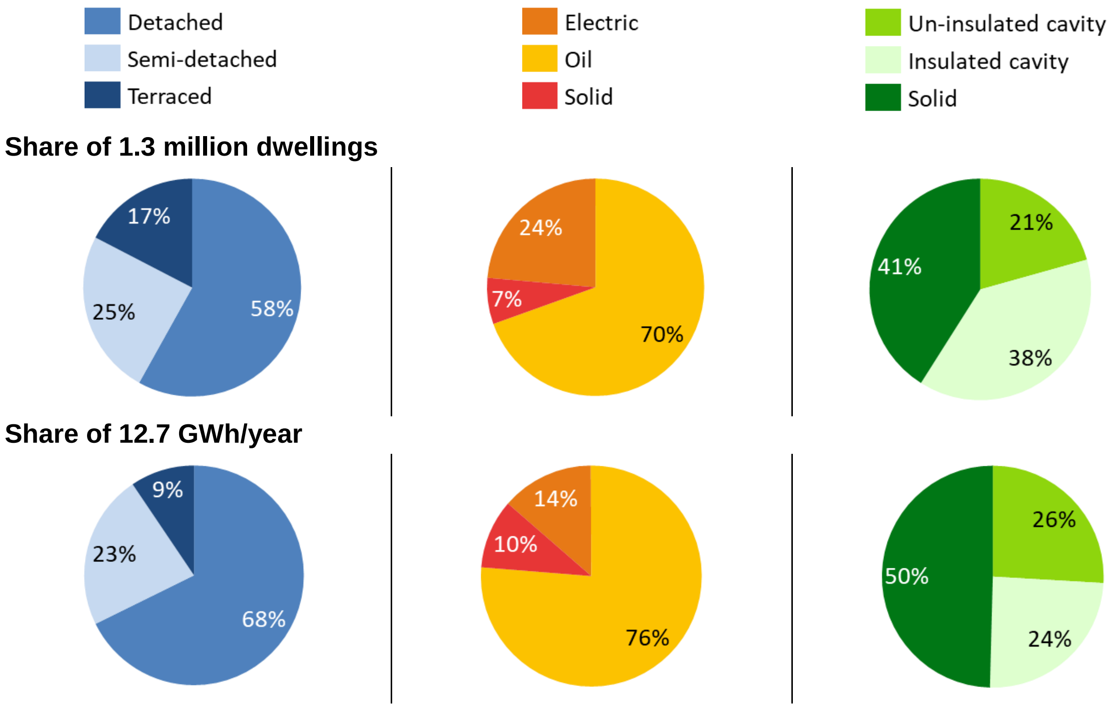



The analysis presented here for Dwellings A and B has been applied across the full set of off-gas grid house archetypes. Results for the entire stock are discussed in Chapter 8.

# 8 Stock-wide results

The 1.3 million off-gas grid houses in England and Wales consume 12.7 GWh annually for heating. The dwelling stock and energy consumption is divided by dwelling type, existing fuel, and wall type in Figure 8-1. Detached houses make up over half of the stock and are responsible for two thirds of the energy consumed. Oil boilers are similarly dominant, making up over 75% of the energy demand. Solid wall and insulated cavity wall dwellings each comprise around 40% of the housing stock, but the energy consumption of solid wall dwellings is twice that of insulated cavity dwellings.

**Figure 8-1 Breakdown of the off-gas grid dwellings by number and energy consumption**




## 8.1 Technical feasibility

The results of the modelling procedure described in Chapter 6 are presented below for each type of electric heating system. The technical barriers to system installation are described as 7 levels of increasing disruption discussed in Section 6.3 above and shown in Table 8-1. The dwellings are grouped according to what steps are required to allow successful installation of the given electric heating system.

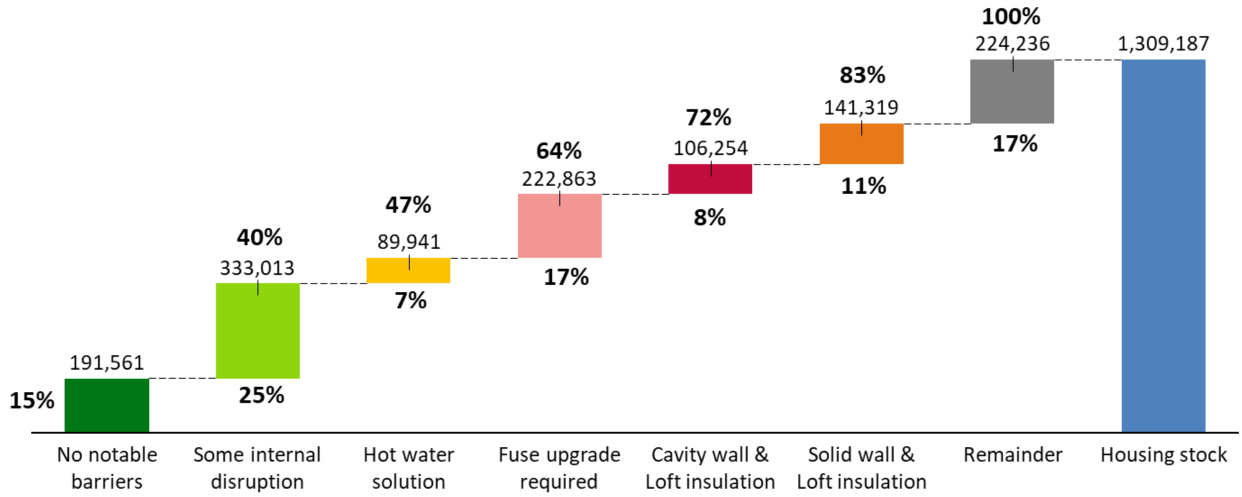
**Table 8-1 Levels of dwelling disruption due to electric heating installation**

| Level of disruption | Description |
|---|---|
| 1 | No notable barriers based on existing fuel type |
| 2 | Installation will cause some internal disruption based on existing fuel type |
| 3 | No existing hot water cylinder – a hot water solution is required |
| 4 | Fuse upgrade to 100 A required to avoid breach of the fuse limit |
| 5 | Cavity wall & loft insulation are required to avoid breach of the fuse limit |
| 6 | Solid wall & loft insulation are required to avoid breach of the fuse limit |
| 7 | Remainder – the current system is not feasible for this archetype |

Waterfall diagrams are used below to present the number of dwellings falling into each disruption category. The diagram for storage heaters is shown in Figure 8-2. The installation process is most straightforward for dwellings in the lower left and is more complicated towards the right of the figure.

Note that the disruption levels are cumulative. For example, a house falling in Level 6 will require a fuse upgrade (Level 4) and may experience some internal disruption (Level 2) in addition to needing solid wall insulation. 15% of the stock face no notable barriers to the installation of storage heaters. This is less than the 24% shown to be electrically heated in Figure 8-1. These dwellings may already have a 100 A fuse while 80 A has been assumed in the present study, or they may be currently experiencing some underheating. Just under half of the stock can be accommodated with some internal disruption (to replace a central heating system with the distributed storage heaters) and with the addition of a hot water cylinder or point-of-use systems. 17% of the stock are suitable for storage heaters if the dwelling fuse is upgrade from 80 A to 100 A. A further 18% can be accommodated if wall and loft insulation are installed. The installation of storage heaters is found to be feasible in 83% of the total stock when all supporting measures have been taken.

**Figure 8-2 Disruption levels across the off-gas grid housing stock for storage heaters**




***Waterfall diagram – Electric heating system feasibility***

A series of waterfall diagrams have been created to allow a comparison of the feasibility of the five electric heating systems considered across the off-gas housing stock in England and Wales. In each diagram, a single type of heating system is deployed across the housing stock. The dwellings are divided into seven categories based on the barriers to installing the heating system of interest:

- 1 - No notable disruption
- 2 - Some internal disruption
- 3 - Hot water solution required
- 4 - Fuse upgrade required
- 5 - Cavity wall insulation required
- 6 - Solid wall insulation required
- 7 - Remainder

The installation process is most straightforward for dwellings in the lower left of the figure and is more complicated towards the right of the figure. Smaller and better-insulated dwellings with lower peak heat demands occur in the lower categories, while larger dwellings with high peak heat demands require additional steps to allow this demand to be accommodated. Level 7 – Remainder contains the largest dwellings that cannot be accommodated with the measures considered. Dwellings at level 2 – Some internal disruption, are being converted from central to distributed heating systems (or vice versa). The internal disruption will typically include lifting floor coverings and creating holes in the dwelling walls.

Table 8-2 presents quantitative results for the dwellings which fall into each of the seven disruption categories. The average floor area, lifetime costs, and carbon savings of the dwellings within each category are shown to indicate how these vary across the categories. Dwellings at Level 1 have an average size of 76 $m^2$, notably smaller than the stock-wide median of 114 $m^2$. The average size of the remaining unfeasible houses (Level 7) is 269 $m^2$, more than double the stock-wide median.

The lifetime cost of storage heaters increases with the level of disruption. This is due not only to the additional measures required, but also due to the higher average size of the dwellings in the higher categories. These larger dwellings have a higher energy demand and higher lifetime electricity cost. The carbon savings per dwelling also increase with disruption level for the same reason. Dwellings at Level 1 see no savings relative to the counterfactual which is also storage heaters. Over the lifetime of the systems, 31 Mt $CO_2$e is avoided across the off-gas stock.

**Table 8-2 Stock-wide cost and carbon results for storage heaters**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 191,561 | 333,013 | 89,941 | 222,863 | 106,254 | 141,319 | 224,236 |
| Dwelling fraction | 15% | 25% | 7% | 17% | 8% | 11% | 17% |
| Cumulative fraction | 15% | 40% | 47% | 64% | 72% | 83% | 100% |
| **Average dwelling results at each disruption level** | | | | | | | |
| Floor area ($m^2$) | 76 | 97 | 89 | 131 | 170 | 156 | 269 |
| Heating systems | £4,060 | £4,680 | £4,430 | £5,340 | £6,290 | £6,020 | n/a |
| Hot water systems | £0 | £290 | £773 | £231 | £266 | £248 | n/a |
| Installation | £346 | £3,530 | £2,510 | £3,200 | £3,870 | £3,640 | n/a |
| Additional insulation | £0 | £0 | £0 | £0 | £1,380 | £14,000 | n/a |
| Year 1 energy cost | £1,350 | £1,490 | £1,410 | £1,660 | £2,040 | £1,970 | n/a |
| 15-year energy cost (discounted) | £16,700 | £18,400 | £17,300 | £20,500 | £25,100 | £24,200 | n/a |
| **Total lifetime cost** | **£21,100** | **£26,900** | **£25,000** | **£29,200** | **£36,900** | **£48,100** | **n/a** |
| Cost over counterfactual | £0 | £13,700 | £9,030 | £14,600 | £13,300 | £22,600 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | 0 | 25 | 15 | 28 | 57 | 62 | n/a |
| **Sum of dwelling results at each disruption level** | | | | | | | |
| Total carbon savings (Mt $CO_2$e) | 0 | 9 | 1 | 6 | 6 | 9 | n/a |
| **Cumulative carbon savings (Mt $CO_2$e)** | **0** | **9** | **10** | **16** | **22** | **31** | **31** |

To allow a visual comparison of the feasibility results for all of the electric heating systems, the waterfall plots presented in this section are combined into a single plot in Figure 8-3. A similar figure presenting results for oil-heated dwellings only is shown in Figure 8-4. The number of dwellings at Levels 1 to 3 varies across the heating systems due to how the systems are sized to accommodate the peak heat demand of each dwelling. Electric boilers have highest proportion of dwellings at Level 1; these are oil and solid fuelled dwellings which already have wet heat distribution systems and have peak heat demands which can be accommodated without the need for additional insulation or fuse upgrades. For the other systems, dwellings at Level 1 are existing electric dwellings. Dwelling fuse upgrades to 100 A allow the conversion of between 13% and 25% of the housing stock. Infrared heaters and electric boilers have the smallest fraction of dwellings which are unsuitable for electric heating (Level 7 – Remainder), while over 30% of dwellings are unsuitable for panel heaters. For 3% of dwellings, infrared heaters are the only feasible option, while a further 5% have the choice only between electric boilers and infrared heaters. The waterfall plots for each heating system are presented individually and further discussed below.

**Figure 8-3 Disruption levels across the complete housing stock for each electric heating system considered**

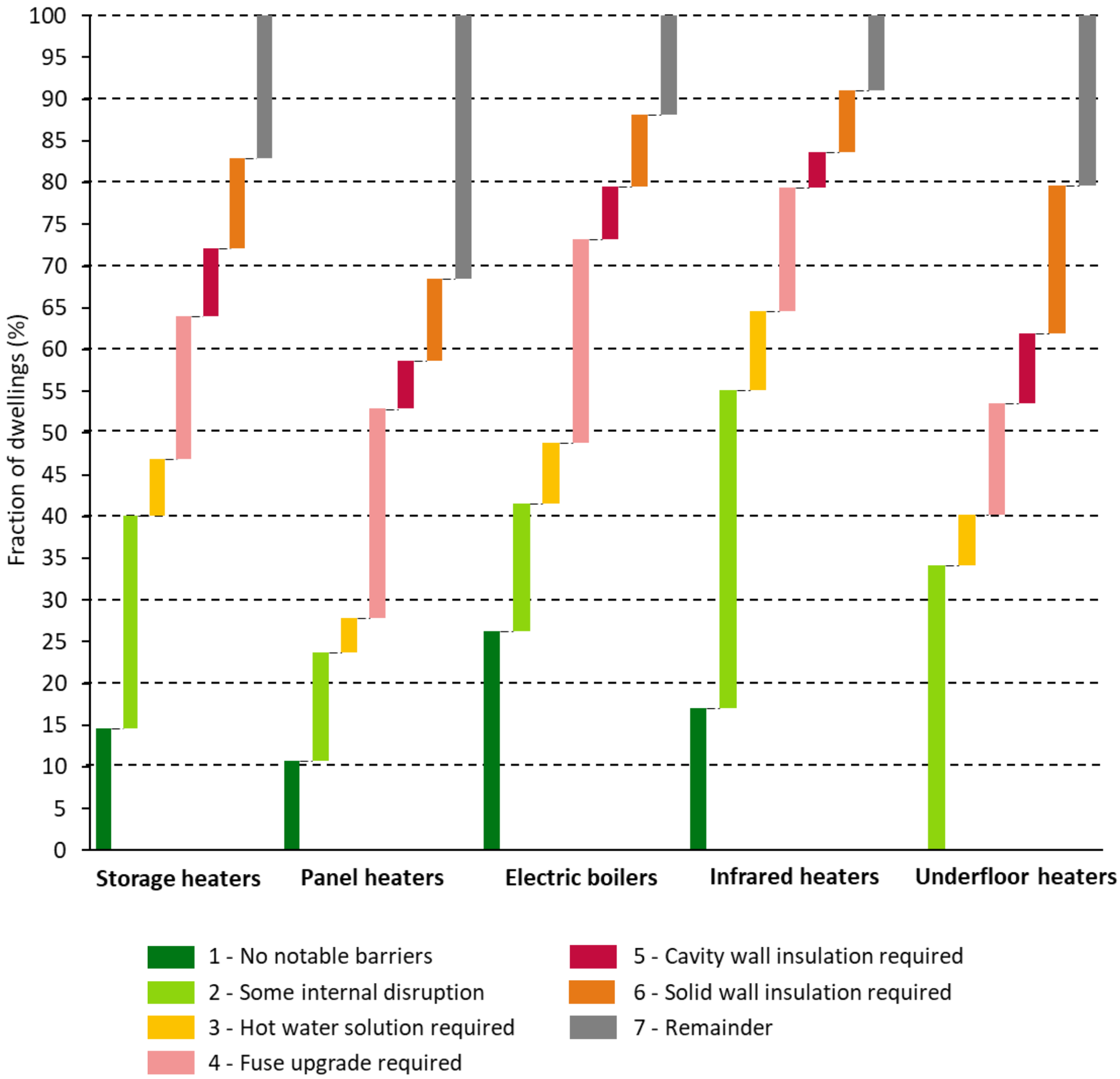



Figure 8-4 considers only oil-heated dwellings, which make up 70% of the off-gas stock and are generally larger than electric and solid-heated dwellings. Electric boilers are the only system that allow a conversion at Level 1 as the other, distributed heating systems involve considerable upheaval within the home to remove the wet central heating system and install the necessary electric connections. Two thirds of existing oil dwellings can be converted to electric boilers with a fuse upgrade but without requiring additional insulation measures. The fraction of unsuitable dwellings is slightly higher in oil dwellings than amongst the stock as a whole, with 12% of dwellings unsuitable for any system compared with 9% across the entire stock.

**Figure 8-4 Disruption levels across the stock of oil dwellings for each electric heating system considered**

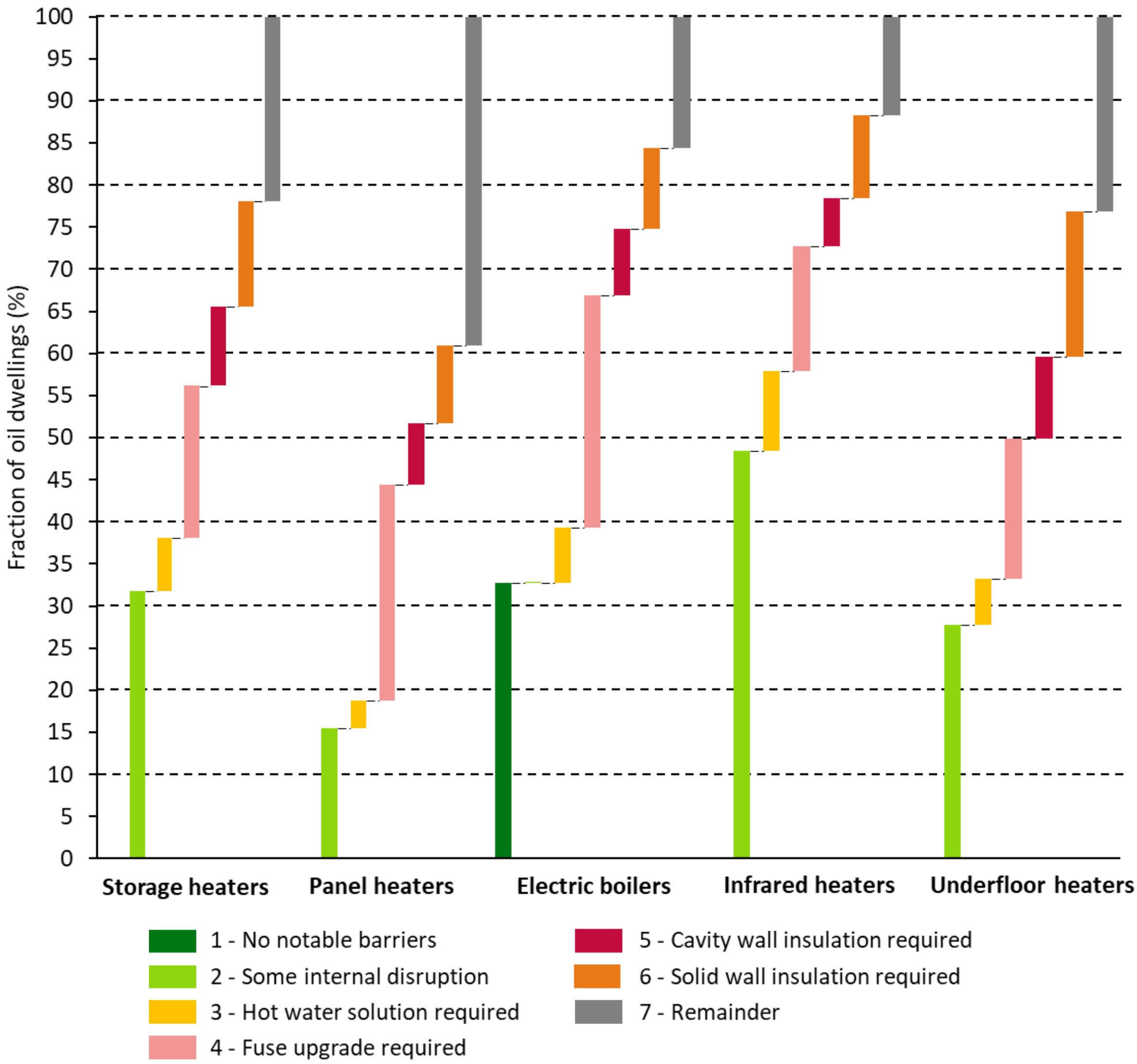
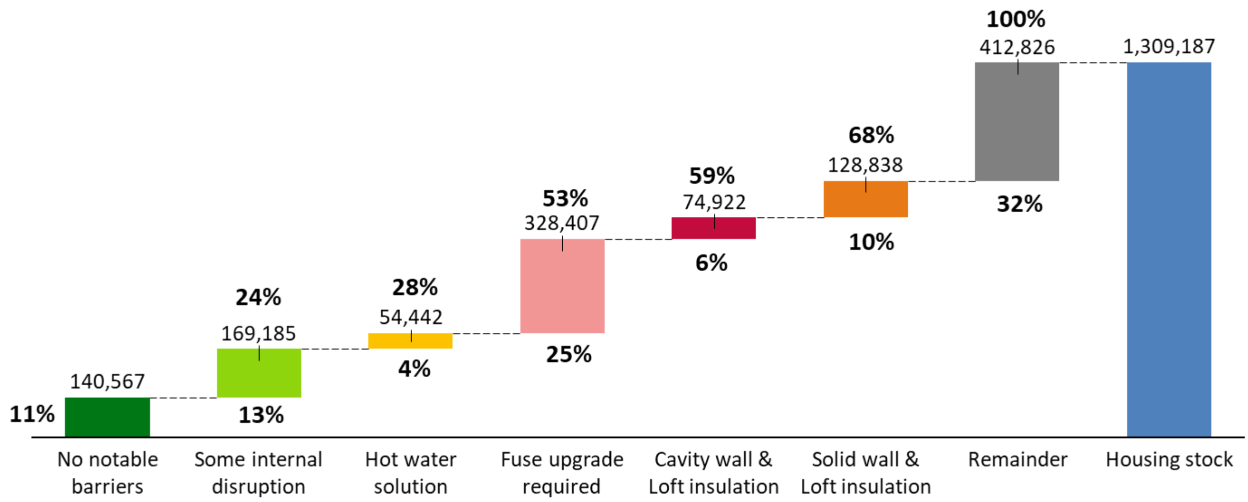



Figure 8-5 and Table 8-3 present the stock-wide results for electric panel heaters. Due to their usage at peak times when a higher power buffer for other uses is needed and the oversizing factors discussed in Section 6.2, nearly one third of dwellings are not feasible for panel heaters even with all supporting measures deployed. A sensitivity on the oversizing assumptions is shown in Section 8.4. 28% of the stock can be accommodated with some disruption and the installation of a hot water solution, rising to 53% with a fuse upgrade and 68% when additional insulation measures are added.

**Figure 8-5 Disruption levels across the off-gas grid housing stock for panel heaters**



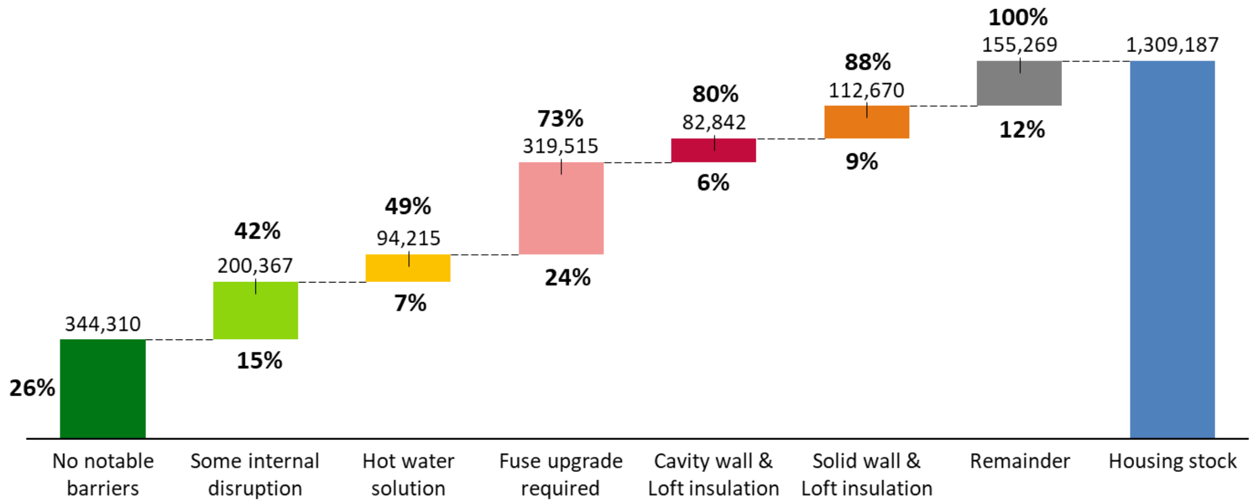

Average lifetime cost again increases with disruption level but is not uniformly higher than that of storage heaters at the same level. This is due to the different mix of dwellings at each level in the two cases as evidenced in the different floor areas. A reduced amount of carbon savings, 22 Mt $CO_2$e is achieved because of the higher number of dwellings which are unfeasible.

**Table 8-3 Stock-wide cost and carbon results for panel heaters**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 140,567 | 169,185 | 54,442 | 328,407 | 74,922 | 128,838 | 412,826 |
| Dwelling fraction | 11% | 13% | 4% | 25% | 6% | 10% | 32% |
| Cumulative fraction | 11% | 24% | 28% | 53% | 59% | 68% | 100% |
| **Average dwelling results at each disruption level** | | | | | | | |
| Floor area ($m^2$) | 70 | 82 | 76 | 108 | 137 | 126 | 230 |
| Heating systems | £1,840 | £2,060 | £1,950 | £2,380 | £2,710 | £2,590 | n/a |
| Hot water systems | £0 | £290 | £736 | £225 | £258 | £223 | n/a |
| Installation | £348 | £2,740 | £1,740 | £2,500 | £3,300 | £2,750 | n/a |
| Additional insulation | £0 | £0 | £0 | £0 | £1,060 | £12,100 | n/a |
| Year 1 energy cost | £1,710 | £1,770 | £1,700 | £2,010 | £2,390 | £2,360 | n/a |
| 15-year energy cost (discounted) | £21,100 | £21,800 | £20,900 | £24,700 | £29,400 | £29,000 | n/a |
| **Total lifetime cost** | **£23,300** | **£26,900** | **£25,300** | **£29,800** | **£36,700** | **£46,700** | **n/a** |
| Cost over counterfactual | £4,140 | £15,300 | £10,200 | £17,900 | £16,100 | £23,100 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | 0 | 23 | 10 | 22 | 44 | 52 | n/a |
| **Sum of dwelling results at each disruption level** | | | | | | | |
| Total carbon savings (Mt $CO_2$e) | 0 | 4 | 1 | 7 | 3 | 7 | n/a |
| **Cumulative carbon savings (Mt $CO_2$e)** | **0** | **4** | **5** | **12** | **15** | **22** | **22** |

The disruption levels, costs, and carbon savings across the stock for electric boilers are shown in Figure 8-6 and Table 8-4. For electric boilers, the 26% of dwellings that present no notable barriers are dwellings which already have wet heat distribution systems installed. With the installation of wet heat distribution systems and hot water solutions, nearly half of the stock can be accommodated. Insulation measures and fuse upgrades bring the feasible portion of the stock up to 88%.

**Figure 8-6 Disruption levels across the off-gas grid housing stock for electric boilers**



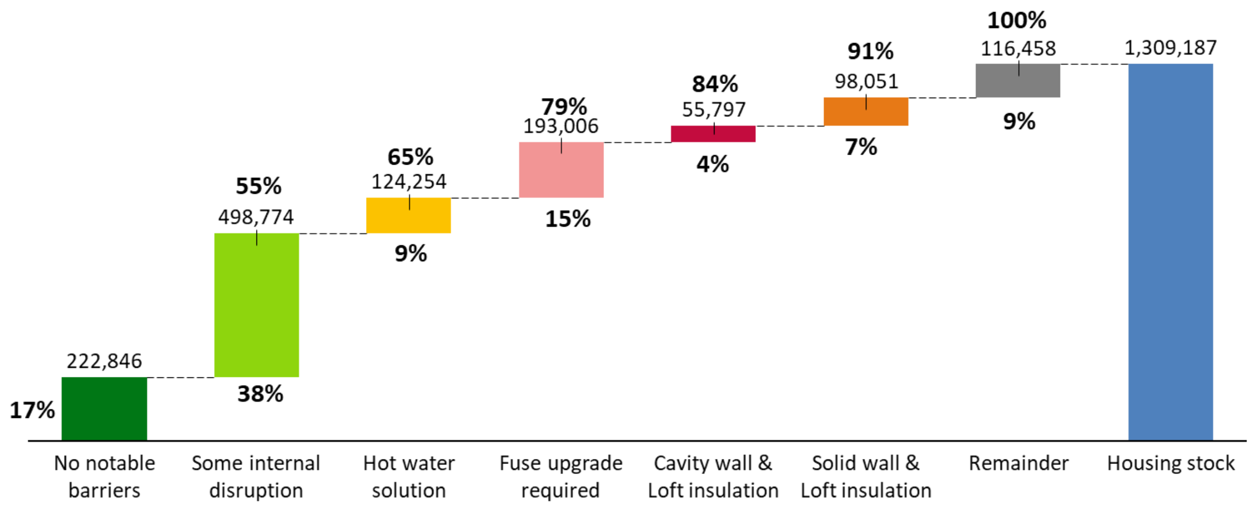

In this case, dwellings at Level 2 do not see any carbon savings as their counterfactual is already electric. The stock-wide carbon savings is 36 Mt $CO_2$e, an increase over the storage heater case due to the lower number of unfeasible dwellings.

**Table 8-4 Stock-wide cost and carbon results for electric boilers**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 344,310 | 200,367 | 94,215 | 319,515 | 82,842 | 112,670 | 155,269 |
| Dwelling fraction | 26% | 15% | 7% | 24% | 6% | 9% | 12% |
| Cumulative fraction | 26% | 42% | 49% | 73% | 80% | 88% | 100% |
| **Average dwelling results at each disruption level** | | | | | | | |
| Floor area ($m^2$) | 94 | 79 | 88 | 143 | 191 | 177 | 301 |
| Heating systems | £1,100 | £1,050 | £1,080 | £1,200 | £1,330 | £1,280 | n/a |
| Hot water systems | £290 | £0 | £770 | £249 | £274 | £247 | n/a |
| Installation | £1,340 | £2,120 | £1,680 | £1,530 | £1,460 | £1,540 | n/a |
| Additional insulation | £0 | £0 | £0 | £0 | £1,510 | £15,300 | n/a |
| Year 1 energy cost | £2,120 | £1,960 | £2,020 | £2,490 | £3,130 | £3,090 | n/a |
| 15-year energy cost (discounted) | £26,100 | £24,100 | £24,900 | £30,700 | £38,500 | £38,100 | n/a |
| **Total lifetime cost** | **£28,800** | **£27,300** | **£28,400** | **£33,700** | **£43,000** | **£56,500** | **n/a** |
| Cost over counterfactual | £14,734 | £5,559 | £11,360 | £19,720 | £16,532 | £26,296 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | 26 | 0 | 14 | 32 | 68 | 83 | n/a |
| **Sum of dwelling results at each disruption level** | | | | | | | |
| Total carbon savings (Mt $CO_2$e) | 9 | 0 | 1 | 10 | 6 | 9 | n/a |
| **Cumulative carbon savings (Mt $CO_2$e)** | **9** | **9** | **11** | **21** | **26** | **36** | **36** |

Figure 8-7 and Table 8-5 present the stock-wide results for infrared heaters. Infrared heaters have the lowest proportion of unfeasible dwellings at 9%. This is because the systems have been matched to the peak dwelling heat loss rate without oversizing. This also contributes to the large fraction of dwellings (65%) which can be accommodated without fuse upgrades or additional insulation measures. Over half of the existing non-electric stock fall into Level 2 and do not require supporting measures beyond the new wiring.

**Figure 8-7 Disruption levels across the off-gas grid housing stock for infrared heaters**




The high capital cost of infrared heaters and their use of Standard electricity tariffs contribute to the high lifetime costs seen in Table 8-5. The energy costs may vary from those shown here if the modular use of infrared heaters enables a reduction in energy consumption. This possibility is discussed further in Section 9.3 below. The low number of unfeasible dwellings results in the highest carbon savings of 37 Mt $CO_2$e.

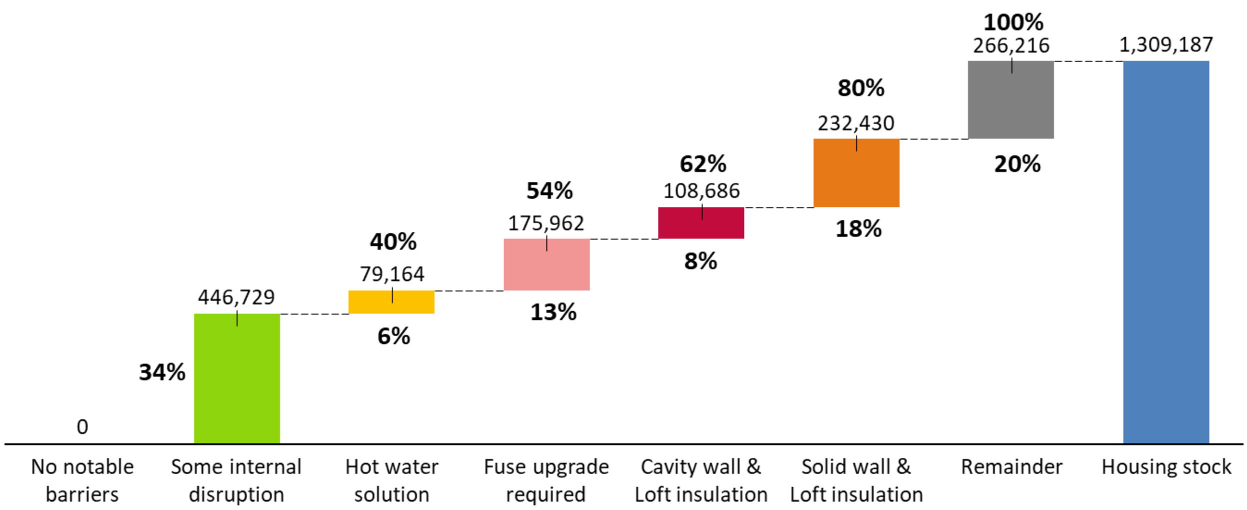
**Table 8-5 Stock-wide cost and carbon results for infrared heaters**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 222,846 | 498,774 | 124,254 | 193,006 | 55,797 | 98,051 | 116,458 |
| Dwelling fraction | 17% | 38% | 9% | 15% | 4% | 7% | 9% |
| Cumulative fraction | 17% | 55% | 65% | 79% | 84% | 91% | 100% |
| Average dwelling results at each disruption level | | | | | | | |
| Floor area ($m^2$) | 81 | 105 | 98 | 167 | 220 | 203 | 322 |
| Heating systems | £3,460 | £4,220 | £3,970 | £5,290 | £6,210 | £5,980 | n/a |
| Hot water systems | £0 | £290 | £795 | £231 | £284 | £285 | n/a |
| Installation | £1,460 | £3,340 | £2,870 | £3,640 | £4,690 | £4,620 | n/a |
| Additional insulation | £0 | £0 | £0 | £0 | £1,730 | £17,000 | n/a |
| Year 1 energy cost | £2,060 | £2,350 | £2,220 | £2,870 | £3,420 | £3,460 | n/a |
| 15-year energy cost (discounted) | £25,400 | £28,900 | £27,300 | £35,300 | £42,100 | £42,600 | n/a |
| **Total lifetime cost** | **£30,300** | **£36,800** | **£35,000** | **£44,500** | **£55,000** | **£70,500** | **n/a** |
| Cost over counterfactual | £7,530 | £22,300 | £18,100 | £30,500 | £27,200 | £41,000 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | 0 | 28 | 18 | 37 | 78 | 96 | n/a |

| Sum of dwelling results at each disruption level | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total carbon savings ($Mt\ CO_2e$) | 0 | 14 | 2 | 7 | 4 | 9 | n/a |
| **Cumulative carbon savings ($Mt\ CO_2e$)** | **0** | **14** | **16** | **23** | **28** | **37** | **37** |

Stock-wide results for underfloor heaters are shown in Figure 8-8 and Table 8-6. Due to the disruption involved with installing underfloor heating systems, no dwellings are present at Level 1. Underfloor heaters can be installed in 40% of dwellings without the need for additional insulation measures, and in over 80% of dwellings with additional insulation and fuse upgrades.

**Figure 8-8 Disruption levels across the off-gas grid housing stock for underfloor heaters**




The fraction of dwellings unsuitable for underfloor heating is 20%, similar to that of storage heaters. 31 Mt $CO_2e$ are avoided over the lifetime of the heaters. The lifetime costs are higher than those of panel heaters due to the higher cost of installation. Underfloor heaters are used with a Standard electricity tariff.

**Table 8-6 Stock-wide cost and carbon results for underfloor heaters**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 0 | 446,729 | 79,164 | 175,962 | 108,686 | 232,430 | 266,216 |
| Dwelling fraction | 0% | 34% | 6% | 13% | 8% | 18% | 20% |
| Cumulative fraction | 0% | 34% | 40% | 54% | 62% | 80% | 100% |
| **Average dwelling results at each disruption level** | | | | | | | |
| Floor area ($m^2$) | n/a | 91 | 91 | 149 | 138 | 122 | 253 |
| Heating systems | n/a | £2,720 | £2,700 | £3,940 | £3,910 | £3,410 | n/a |
| Hot water systems | n/a | £187 | £770 | £258 | £258 | £219 | n/a |
| Installation | n/a | £2,840 | £2,910 | £3,660 | £3,570 | £3,190 | n/a |
| Additional insulation | n/a | £0 | £0 | £0 | £1,180 | £11,900 | n/a |
| Year 1 energy cost | n/a | £1,970 | £1,930 | £2,480 | £2,490 | £2,350 | n/a |
| 15-year energy cost (discounted) | n/a | £24,300 | £23,800 | £30,500 | £30,700 | £29,000 | n/a |
| **Total lifetime cost** | **n/a** | **£30,000** | **£30,200** | **£38,400** | **£39,600** | **£47,700** | **n/a** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cost over counterfactual | n/a | £14,300 | £14,200 | £25,400 | £18,400 | £25,000 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | n/a | 16 | 14 | 29 | 50 | 52 | n/a |
| **Sum of dwelling results at each disruption level** | | | | | | | |
| Total carbon savings (Mt $CO_2$e) | 0 | 7 | 1 | 5 | 5 | 12 | n/a |
| **Cumulative carbon savings (Mt $CO_2$e)** | **0** | **7** | **8** | **13** | **19** | **31** | **31** |

## 8.2 Scenarios for stock-wide uptake

Four potential scenarios for the uptake of electric heating systems across the off-gas grid housing stock have been analysed to understand what systems are likely to be adopted depending on the preferences of individual dwelling owners.

### Scenario 1 - Lowest lifetime costs

In the first scenario, dwelling owners select the electric heating system and additional insulation measures that result in the lowest lifetime cost. The distribution of heating systems across the stock and amongst dwellings with different existing heating systems is shown in Table 8-7. Nearly 75% of the dwellings use storage heaters despite their high upfront cost as the Economy 7 tariff reduces the annual cost of electricity for heating and hot water. 15% of dwellings install electric boilers while a small fraction install infrared heaters and 9% remain without a feasible solution. Two thirds of dwellings with existing oil heating select storage heaters while nearly 20% maintain a central wet heating system and select electric boilers. Over 90% of the unsuitable dwellings have existing oil heating.

**Table 8-7 Electric heating system uptake across the stock based on lowest lifetime cost**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 962,361 | 0 | 196,969 | 33,399 | 0 | 116,458 |
| All dwellings fraction | 74% | 0% | 15% | 3% | 0% | 9% |
| Oil dwellings | 600,091 | 0 | 173,319 | 30,040 | 0 | 107,207 |
| Oil fraction | 66% | 0% | 19% | 3% | 0% | 12% |
| Solid dwellings | 68,460 | 0 | 17,867 | 3,359 | 0 | 151 |
| Solid fraction | 76% | 0% | 20% | 4% | 0% | 0% |
| Electric dwellings | 293,809 | 0 | 5,783 | 0 | 0 | 9,101 |
| Electric fraction | 95% | 0% | 2% | 0% | 0% | 3% |
| **Average dwelling results for the those selecting each system** | | | | | | |
| Floor area ($m^2$) | 116 | n/a | 143 | 235 | n/a | n/a |
| Lifetime cost | £29,500 | n/a | £36,300 | £74,500 | n/a | n/a |
| Lifetime cost over counterfactual | £9,970 | n/a | £17,100 | £44,300 | n/a | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2$e) | 32 | n/a | 49 | 89 | n/a | n/a |
| **Total carbon savings (Mt $CO_2$e)** | **31** | **n/a** | **10** | **3** | **n/a** | **n/a** |

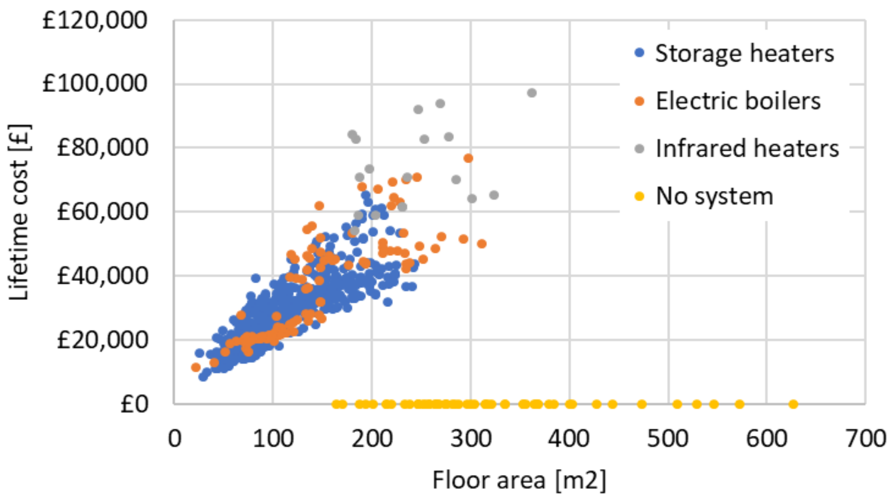
The average dwelling selecting each system faces an appreciable cost increase relative to the counterfactual, with the largest increase seen for infrared heaters which are selected by the largest dwellings. The cost increases occur despite the widespread uptake of additional efficiency measures, shown in Table 8-8. This scenario has the highest carbon reduction of 44 Mt $CO_2$e due to the uptake of efficiency measures.

**Table 8-8 Uptake of insulation measures in Scenario 1 – Lowest lifetime costs**

| Insulation level | Baseline | Loft insulation | Loft & Floor Insulation | Wall & Loft Insulation |
|---|---|---|---|---|
| All dwellings | 131,956 | 46,346 | 637,823 | 376,604 |
| All dwellings fraction | 10% | 4% | 49% | 29% |

The dwellings with electric boilers fall into two groups as can be seen in Figure 8-9. There is a tight cluster of electric boiler dwellings centred around 100 m$^2$ with lifetime costs below about £30,000. These are smaller oil- and solid-fuelled dwellings where the cost of conversion to storage heaters is not regained from the reduced cost of using the Economy 7 electricity tariff. There is also a broader distribution of larger dwellings with higher lifetime costs which are predominately dwellings where storage heaters are not feasible. Infrared heaters are selected in 3% of dwellings where they are the only feasible electric heating option. No cost value is shown for the remainder of dwellings in which no electric options are feasible, and the large size of these dwellings is apparent.

**Figure 8-9 Dwelling floor area vs lifetime cost for the systems selected in Scenario 1**




### Scenario 2 - Least disruption and lowest upfront costs

The second scenario seeks to estimate the uptake of different systems when consumers prioritise lack of disruption and low upfront cost rather than lowest lifetime cost. In this case, dwelling owners will select a system at Disruption Level 1 if such an option is available. If no such option is available, they select the electric heating system and additional efficiency measures with the lowest upfront cost. This results in previously oil and solid-fuelled dwellings with central heating systems selecting electric boilers or infrared heaters. Only dwellings with existing electric heating select storage heaters.

The lifetime cost of the average dwelling with each system is not uniformly higher than that in Scenario 1 due to the changed composition of the dwellings selecting each system. However, the costs shown in Figure 8-10 increase more steeply with floor area than those in Figure 8-9. Dwellings selecting storage heaters do not see a cost increase as storage heaters are also their counterfactual. Dwellings with electric boilers and infrared heaters again have significant increases in cost. The total carbon savings is reduced to 37 Mt $CO_2e$ due to lower uptake of efficiency measures, as shown in Table 8-10.

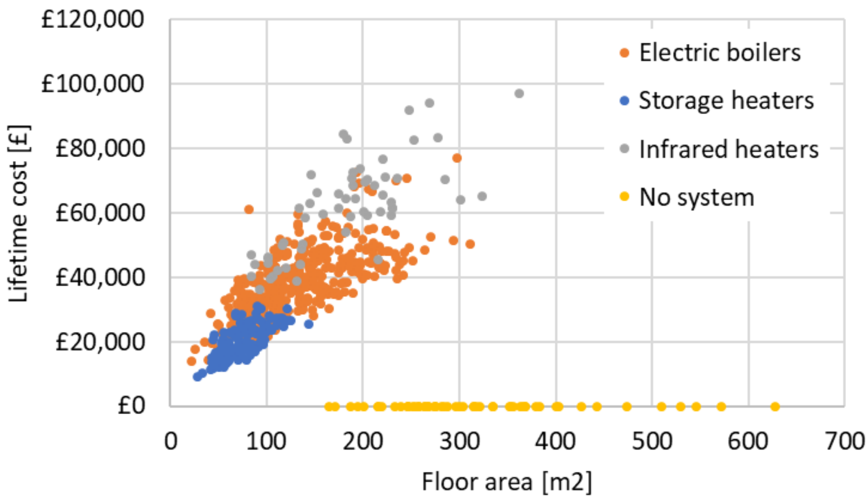
**Table 8-9 Electric heating system uptake across the stock based on least disruption and lowest upfront cost**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 222,295 | 0 | 864,001 | 106,433 | 0 | 116,458 |
| All dwellings fraction | 17% | 0% | 66% | 8% | 0% | 9% |
| Oil dwellings | 0 | 0 | 737,120 | 66,331 | 0 | 107,207 |
| Oil fraction | 0% | 0% | 81% | 7% | 0% | 12% |
| Solid dwellings | 0 | 0 | 86,327 | 3,359 | 0 | 151 |
| Solid fraction | 0% | 0% | 96% | 4% | 0% | 0% |
| Electric dwellings | 222,295 | 0 | 40,554 | 36,744 | 0 | 9,101 |
| Electric fraction | 72% | 0% | 13% | 12% | 0% | 3% |
| **Average dwelling results for the those selecting each system** | | | | | | |
| Floor area ($m^2$) | 76 | n/a | 128 | 181 | n/a | 322 |
| Lifetime cost | £21,000 | n/a | £36,700 | £61,300 | n/a | n/a |
| Lifetime cost over counterfactual | £0 | n/a | £18,500 | £31,200 | n/a | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2e$) | 0 | n/a | 37 | 49 | n/a | n/a |
| **Total carbon savings (Mt $CO_2e$)** | **0** | **n/a** | **32** | **5** | **n/a** | **n/a** |

**Table 8-10 Uptake of insulation measures in Scenario 2 – Least disruption and lowest upfront cost**

| Insulation level | Baseline | Loft insulation | Loft & Floor Insulation | Wall & Loft Insulation |
|---|---|---|---|---|
| All dwellings | 961,132 | 83,458 | 53,913 | 94,225 |
| All dwellings fraction | 73% | 6% | 4% | 7% |

**Figure 8-10 Dwelling floor area vs lifetime cost for the systems selected in Scenario 2**



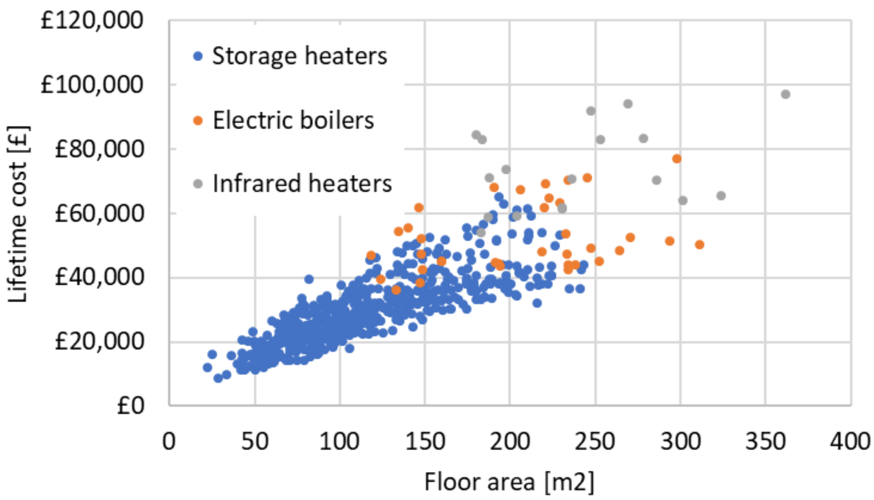
### Scenario 3 - Flexibility preferred

The third scenario estimates the maximum potential uptake of storage heaters. In this case, all dwellings select storage heaters where they are feasible, and select the insulation level leading to the lowest lifetime cost. Where storage heaters are not feasible, the system and insulation level with the lowest lifetime cost are chosen. The cost and carbon results are shown in Table 8-11 and the floor area and lifetime costs are plotted in Figure 8-11. 83% of the dwelling stock install storage heaters leading to an aggregated storage capacity of 100 GWh which could potentially be available to provide services to the electricity grid. Only larger dwellings with high heat loss select other systems; this includes 14% of solid-fuelled dwellings and 9% of oil dwellings. The total carbon savings and uptake of efficiency measures are similar to those in Scenario 1.

**Table 8-11 Electric heating system uptake across the stock when storage heaters are preferred**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 1,092,825 | 0 | 66,505 | 33,399 | 0 | 116,458 |
| All dwellings fraction | 83% | 0% | 5% | 3% | 0% | 9% |
| Oil dwellings | 718,613 | 0 | 54,797 | 30,040 | 0 | 107,207 |
| Oil fraction | 79% | 0% | 6% | 3% | 0% | 12% |
| Solid dwellings | 77,053 | 0 | 9,274 | 3,359 | 0 | 151 |
| Solid fraction | 86% | 0% | 10% | 4% | 0% | 0% |
| Electric dwellings | 297,158 | 0 | 2,434 | 0 | 0 | 9,101 |
| Electric fraction | 96% | 0% | 1% | 0% | 0% | 3% |
| Average dwelling results for the those selecting each system | | | | | | |
| Floor area ($m^2$) | 115 | n/a | 204 | 235 | n/a | 322 |
| Lifetime cost | £29,500 | n/a | £51,900 | £74,500 | n/a | n/a |
| Lifetime cost over counterfactual | £10,500 | n/a | £23,900 | £44,300 | n/a | n/a |
| Carbon savings (tonnes $CO_2e$) | 32 | n/a | 88 | 89 | n/a | n/a |
| **Total carbon savings (Mt $CO_2e$)** | **35** | **n/a** | **6** | **3** | **n/a** | **n/a** |

**Figure 8-11 Dwelling floor area vs lifetime cost for the systems selected in Scenario 3**



### Scenario 4 - Central heating preferred

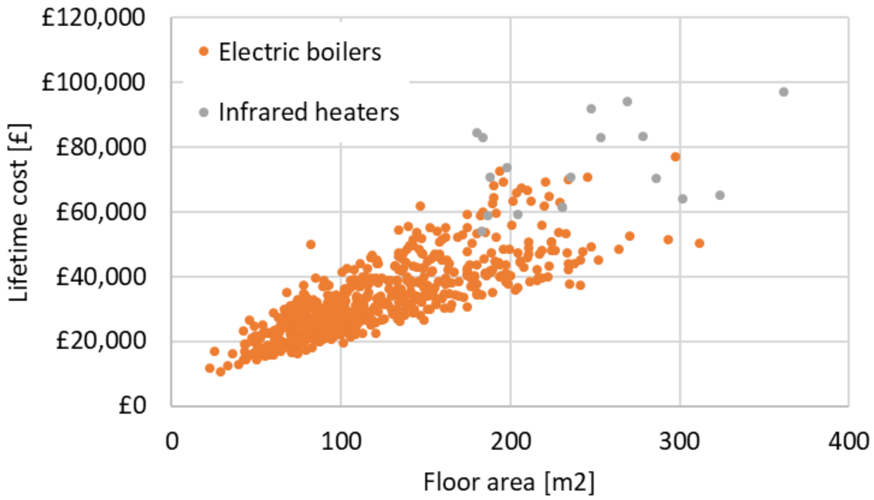
The final scenario prioritises central heating systems and aims to maintain and install wet heat distribution systems in all dwellings where it is feasible. This may be of interest if electric boilers are used before the dwellings are later transitioned to heat pumps. As in Scenario 3, the insulation level is selected based on the lowest lifetime cost. Nearly 90% of the stock is suitable for electric boilers with the remainder selecting infrared heaters or being unsuitable for any electric heating system. The carbon savings achieved and the uptake of efficiency measures are similar to those in Scenario 1 and 3.

**Table 8-12 Electric heating system uptake across the stock when central heating is prioritised**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 0 | 0 | 1,159,330 | 33,399 | 0 | 116,458 |
| All dwellings fraction | 0% | 0% | 89% | 3% | 0% | 9% |
| Oil dwellings | 0 | 0 | 773410 | 30040 | 0 | 107207 |
| Oil fraction | 0% | 0% | 85% | 3% | 0% | 12% |
| Solid dwellings | 0 | 0 | 86327 | 3359 | 0 | 151 |
| Solid fraction | 0% | 0% | 96% | 4% | 0% | 0% |
| Electric dwellings | 0 | 0 | 299592 | 0 | 0 | 9101 |
| Electric fraction | 0% | 0% | 97% | 0% | 0% | 3% |
| Average dwelling results for the those selecting each system | | | | | | |
| Floor area ($m^2$) | n/a | n/a | 120 | 235 | n/a | 322 |
| Lifetime cost | n/a | n/a | £33,100 | £74,500 | n/a | n/a |
| Lifetime cost over counterfactual | n/a | n/a | £13,600 | £44,300 | n/a | n/a |
| Carbon savings (tonnes $CO_2e$) | n/a | n/a | 35 | 89 | n/a | n/a |
| **Total carbon savings (Mt $CO_2e$)** | **n/a** | **n/a** | **41** | **3** | **n/a** | **n/a** |

Figure 8-12 shows the distribution of floor area and lifetime cost in Scenario 4. All but the largest dwellings are able to install electric boilers. Dwellings which are unsuitable for electric heating are not shown but are the same as in Figure 8-9.

**Figure 8-12 Dwelling floor area vs lifetime cost for the systems selected in Scenario 4**



## 8.3 Market size comparison

Table 8-13 allows a comparison between the existing size of the UK electric heating market and the maximum potential market for each system as determined by the technical feasibility assessment in Section 8.1. The maximum number of dwellings that could adopt each system is listed on the first line. The conversions per year is calculated assuming that the systems are adopted over the course of 15 years as the existing heating systems fail.

The current market size is estimated based on information received during the stakeholder consultation. These should be treated as order of magnitude estimates only. It is difficult to estimate the number of electric underfloor heating systems sold annually in the UK as the size of the systems purchased varies widely and includes both top-up and primary heating systems. The potential market size is several times larger than the existing market in all cases; this is most significant for infrared heaters. In the stakeholder consultations, the manufacturers did not mention any fundamental barriers to increasing the number of units produced, but did note that capacity increases take time especially when a complex supply chain is present. A number of manufacturers sell systems elsewhere in Europe and further afield; a large increase in the UK market would therefore represent a smaller increase in their overall market. As noted by BEAMA in Section 3.2, the sales route through wholesalers and installers will also need to expand as the market grows. Support for installers may be needed to avoid an increase in installation costs if the demand for electric heating increases.

**Table 8-13 Potential and current market sizes for the electric heating systems**

| | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating |
|---|---|---|---|---|---|
| Maximum uptake (dwellings) | 1,084,951 | 896,361 | 1,153,919 | 1,192,729 | 1,042,971 |
| Conversions per year (dwellings) | 72,330 | 59,757 | 76,928 | 79,515 | 69,531 |
| Average systems per dwelling | 9 | 10 | 1 | 9 | 6 (1 per room) |
| **Resulting market size (units per year)** | **650,000** | **600,000** | **80,000** | **725,000** | **425,000** |
| Estimated current UK market size (units per year) | 100,000 | 400,000 | 20,000 | 15,000 | -- |

## 8.4 Selected sensitivities

This selection presents several sensitivities that impact the lifetime cost of the systems. Results are presented for each type of heating system according to the disruption levels used in Section 8.1 above. Table 8-14 presents the system cost for the average dwelling in each disruption category for both the Market typical and Market minimum cost scenarios. The costs of individual systems in each scenario are shown in Chapter 4. The composition of the dwellings in each category and their thermal demand are unchanged between the two cases. The largest cost variation is seen in infrared heaters where the Market typical systems are between £2,000 and £4,000 more than the Market minimum. The least variation occurs in electric boilers where the difference is just £200. This effect is partly due to the aesthetic options available for different system types. Storage, panel, and infrared heaters come in a range of finishes that can be matched to each room as well as in more functional designs at lower cost. This range of options is not present for electric boilers. Dwelling owners concerned with the aesthetics of their systems may purchase heaters at or above the Market typical price point, while those concerned primarily with cost will select systems nearer to the Market minimum.

**Table 8-14 Impact of the system cost scenario on the average cost of electric heating systems in dwellings at each disruption level**

| System type | Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Storage heaters | Market typical | £4,060 | £4,680 | £4,430 | £5,340 | £6,290 | £6,020 |
| | Market minimum | £3,050 | £3,520 | £3,330 | £4,020 | £4,700 | £4,510 |
| Panel heaters | Market typical | £1,850 | £2,080 | £1,970 | £2,400 | £2,780 | £2,630 |
| | Market minimum | £791 | £883 | £836 | £1,010 | £1,130 | £1,090 |
| Electric boilers | Market typical | £1,100 | £1,050 | £1,080 | £1,200 | £1,330 | £1,280 |
| | Market minimum | £904 | £852 | £883 | £995 | £1,130 | £1,080 |
| Infrared heaters | Market typical | £3,460 | £4,220 | £3,970 | £5,290 | £6,210 | £5,980 |
| | Market minimum | £1,450 | £1,730 | £1,640 | £2,110 | £2,380 | £2,320 |
| Underfloor heaters | Market typical | n/a | £2,720 | £2,700 | £3,940 | £3,910 | £3,410 |
| | Market minimum | n/a | £1,910 | £1,890 | £2,600 | £2,670 | £2,320 |

Table 8-15 presents Low, Central, and High scenarios for installation cost. The installation cost assumptions are described above in Section 5.1. The cost in a particular dwelling depends not only on the system being installed and the existing system but also on the wall type, age of the dwelling, and the age and quality of the existing electrics. For relatively straightforward installations at Disruption Level 1, the uncertainty can be as low as £200. At Level 2 where central heating or extensive wiring must be installed, the cost variation is between £1,000 and £1,500. Dwellings at higher disruption levels tend to be larger and will have a higher number of systems installed leading to greater uncertainty in the installation cost.

**Table 8-15 Impact of the installation cost scenario on the average system installation cost in dwellings at each disruption level**

| System type | Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Storage heaters | Low | £242 | £2,890 | £2,050 | £2,580 | £3,100 | £2,920 |
| | Central | £346 | £3,530 | £2,510 | £3,200 | £3,870 | £3,640 |
| | High | £449 | £4,240 | £3,010 | £3,860 | £4,710 | £4,410 |
| Panel heaters | Low | £243 | £2,310 | £1,460 | £2,090 | £2,740 | £2,250 |
| | Central | £348 | £2,740 | £1,740 | £2,500 | £3,300 | £2,750 |
| | High | £452 | £3,310 | £2,100 | £3,040 | £4,040 | £3,390 |
| Electric boilers | Low | £1,180 | £1,620 | £1,400 | £1,310 | £1,270 | £1,310 |
| | Central | £1,340 | £2,120 | £1,680 | £1,530 | £1,460 | £1,540 |
| | High | £620 | £2,592 | £1,310 | £943 | £768 | £965 |
| Infrared heaters | Low | £1,100 | £2,800 | £2,380 | £2,960 | £3,820 | £3,760 |
| | Central | £1,460 | £3,340 | £2,870 | £3,640 | £4,690 | £4,620 |
| | High | £1,900 | £4,040 | £3,500 | £4,480 | £5,770 | £5,680 |
| Underfloor heaters | Low | n/a | £2,320 | £2,400 | £3,050 | £2,960 | £2,630 |
| | Central | n/a | £2,840 | £2,910 | £3,660 | £3,570 | £3,190 |
| | High | n/a | £3,460 | £3,540 | £4,420 | £4,310 | £3,870 |

Three electricity cost scenarios have been taken from the BEIS Energy and Emissions Projections[63]; these are Low Prices, Reference, and High Prices (see Figure 6-2 above). A fourth scenario, DSR tariff, has been added to estimate the potential impact of a tariff that rewards consumers for flexible electricity usage. This is based on the projected Low Prices scenario, with the tariff rate reduced by 70% during selected periods to encourage the shifting of electricity demand.

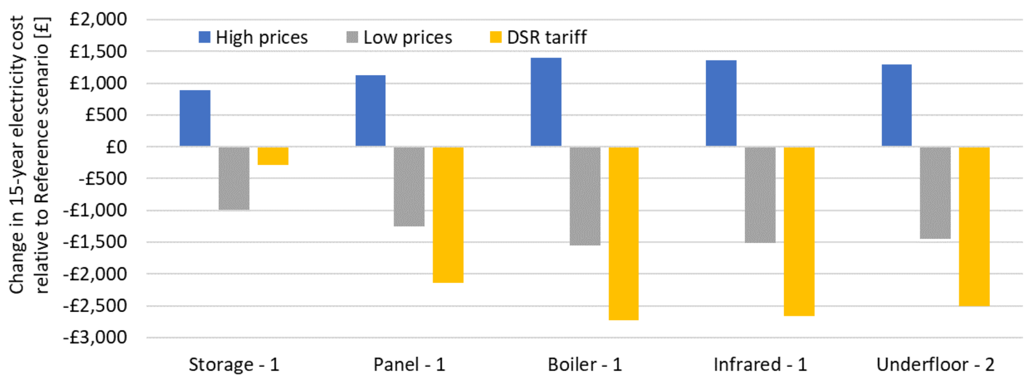
In 2015, Ofgem estimated that 2.2 million households use the Economy 7 tariff in the UK[64]. In Scenario 3 above (where storage heaters are preferred), an additional 700,000 households previously using fossil fuels would switch to Economy 7 tariffs, an increase of over 30%. More advanced DSR tariffs may be substituted for Economy 7 to support electricity grid balancing if many households switch to storage heating and seek non-standard tariffs. Table 8-16 presents the fraction of yearly energy consumption that each system can shift to the low-cost time periods.

**Table 8-16 Ability of electric heating systems to utilise a DSR tariff[65]**

| System | Fraction of energy consumed during low-cost DSR time periods |
|---|---|
| Storage heaters | 50% |
| Panel heaters | 10% |
| Electric boilers | 10% |
| Infrared heaters | 10% |
| Underfloor heaters | 10% |
| Hot water cylinders | 10% |
| Point-of-use systems | 0% |

Figure 8-13 shows the difference in the 15-year electricity cost between the other scenarios and the Reference scenario for dwellings at Disruption Level 1 except for underfloor heaters where Level 2 is shown. Storage heaters benefit less than other systems from the DSR tariff under the current assumptions. This is because storage heaters consume 90% of their electricity on the low rate under the Economy 7 tariff but only 50% on the low rate under the DSR tariff. Dwellings at low disruption levels see a lifetime cost reduction of between £2,000 and £3,000 on the DSR tariff with systems other than storage heaters.

**Figure 8-13 Change in 15-year electricity cost relative to the Reference scenario**




[63] *BEIS Energy and Emissions Projections: 2017*, Annex M for Standard tariff and Market review for Economy 7 on- and off-peak tariffs
[64] Insights paper on households with electric and other non-gas heating, Ofgem Consumer Vulnerability Team, 2015.
[65] EE assumption based on stakeholder consultation and the flexibility of each system type.

Table 8-17 presents the 15-year electricity cost in each of the four scenarios at all disruption levels. The cost variation is lowest for storage heaters where it ranges between £2,000 and £2,500. The lifetime electricity cost for the other heating systems varies by between £4,000 and £7,000. The variation is highest for electric boilers and infrared heaters which can be installed into larger dwellings with higher energy consumption.

**Table 8-17 Impact of the electricity cost scenario on the average 15-year space heating cost in dwellings at each disruption level**

| System type | Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Storage heaters | High prices | £17,600 | £19,300 | £18,200 | £21,500 | £26,500 | £25,500 |
| | Reference | £16,700 | £18,400 | £17,300 | £20,500 | £25,100 | £24,200 |
| | Low Prices | £15,700 | £17,300 | £16,300 | £19,200 | £23,600 | £22,800 |
| | DSR tariff | £16,400 | £18,000 | £17,000 | £19,900 | £24,200 | £23,300 |
| Panel heaters | High prices | £22,200 | £22,900 | £22,000 | £26,000 | £31,000 | £30,500 |
| | Reference | £21,100 | £21,800 | £20,900 | £24,700 | £29,400 | £29,000 |
| | Low Prices | £19,800 | £20,500 | £19,600 | £23,200 | £27,600 | £27,300 |
| | DSR tariff | £18,900 | £19,600 | £18,800 | £22,100 | £26,300 | £25,900 |
| Electric boilers | High prices | £27,500 | £25,400 | £26,200 | £32,300 | £40,500 | £40,100 |
| | Reference | £26,100 | £24,100 | £24,900 | £30,700 | £38,500 | £38,100 |
| | Low Prices | £24,500 | £22,700 | £23,400 | £28,900 | £36,200 | £35,800 |
| | DSR tariff | £23,300 | £21,600 | £22,300 | £27,400 | £34,300 | £33,900 |
| Infrared heaters | High prices | £26,700 | £30,400 | £28,800 | £37,200 | £44,400 | £44,900 |
| | Reference | £25,400 | £28,900 | £27,300 | £35,300 | £42,100 | £42,600 |
| | Low Prices | £23,800 | £27,200 | £25,700 | £33,200 | £39,600 | £40,100 |
| | DSR tariff | £22,700 | £25,800 | £24,500 | £31,500 | £37,500 | £38,000 |
| Underfloor heaters | High prices | n/a | £25,600 | £25,100 | £32,200 | £32,300 | £30,500 |
| | Reference | n/a | £24,300 | £23,800 | £30,500 | £30,700 | £29,000 |
| | Low Prices | n/a | £22,800 | £22,400 | £28,700 | £28,900 | £27,200 |
| | DSR tariff | n/a | £21,800 | £21,300 | £27,300 | £27,400 | £25,900 |

The cost of the counterfactual fuels is another area of uncertainty. The costs relative to the counterfactual options shown in Section 8.1 rely on the BEIS Energy and Emissions Projections for both electricity and fossil fuel costs. If the fossil fuel costs are higher than projected, electric heating systems may be more economically feasible even if the electricity costs remain at the Reference scenario rate. Figure 8-14 shows the cost over the counterfactual in the Reference scenario and in a scenario where fossil fuel prices are 50% higher than projected. Dwellings at Disruption Level 2 are shown (with the exception of electric boilers) as these have a fossil fuel counterfactual.

Results for all disruption levels are shown in Table 8-18. The cost over the counterfactual is reduced by around £4,000 at the low disruption levels, rising to between £6,000 and £10,000 for the large dwellings at high disruption levels. In all cases electric heating systems are more expensive than their fossil fuel counterfactuals in the average dwelling in each disruption category even when the fossil fuel prices are raised.

**Figure 8-14 Cost of electric heating over the counterfactual in two scenarios**

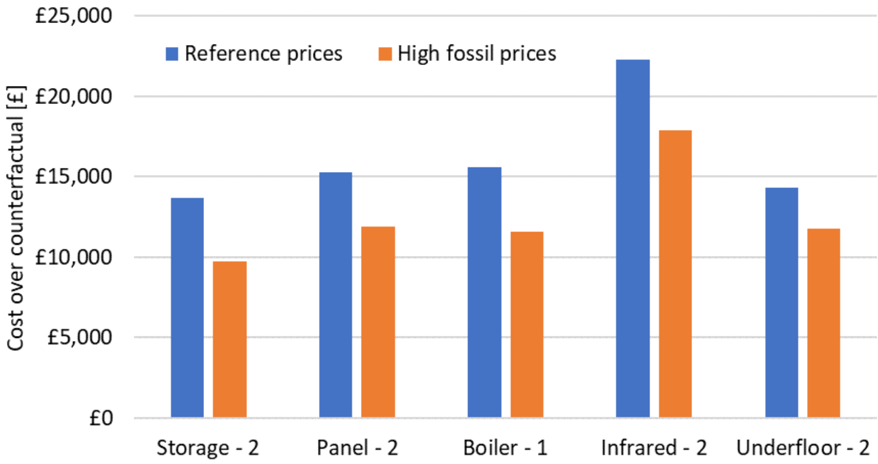



**Table 8-18 Impact of the counterfactual fuel cost on the lifetime cost relative to the counterfactual in dwellings at each disruption level**

| System type | Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Storage heaters | Reference | £0 | £13,700 | £9,030 | £14,600 | £13,300 | £22,600 |
| | High fossil prices | £0 | £9,710 | £6,570 | £10,300 | £6,660 | £16,000 |
| Panel heaters | Reference | £4,140 | £15,300 | £10,200 | £17,900 | £16,100 | £23,100 |
| | High fossil prices | £4,140 | £11,900 | £8,490 | £14,400 | £10,900 | £18,200 |
| Electric boilers | Reference | £15,600 | £5,560 | £12,000 | £20,500 | £17,400 | £27,100 |
| | High fossil prices | £11,600 | £5,560 | £9,540 | £15,500 | £9,620 | £18,900 |
| Infrared heaters | Reference | £7,530 | £22,300 | £18,100 | £30,500 | £27,200 | £41,000 |
| | High fossil prices | £7,530 | £17,900 | £15,000 | £25,100 | £18,200 | £31,000 |
| Underfloor heaters | Reference | n/a | £14,300 | £14,200 | £25,400 | £18,400 | £25,000 |
| | High fossil prices | n/a | £11,800 | £11,900 | £20,500 | £12,700 | £19,800 |

Figure 8-15 and Table 8-19 present a sensitivity on the oversizing assumptions for panel heaters. As described in Section 6.2, DOM 8 prescribes oversizing factors based on the wall type. These factors are reduced if new masonry construction is assumed (as shown in Table 6-10), but the age limit on new masonry construction is not specified. If the reduced oversizing factors are used, the proportion of dwellings that are unsuitable for panel heaters is reduced from 32% to 25% and the cumulative lifetime carbon savings increases from 22 $MtCO_2e$ to 26 $MtCO_2e$.

**Figure 8-15 Disruption levels across the off-gas grid housing stock for panel heaters when sized assuming new masonry construction**

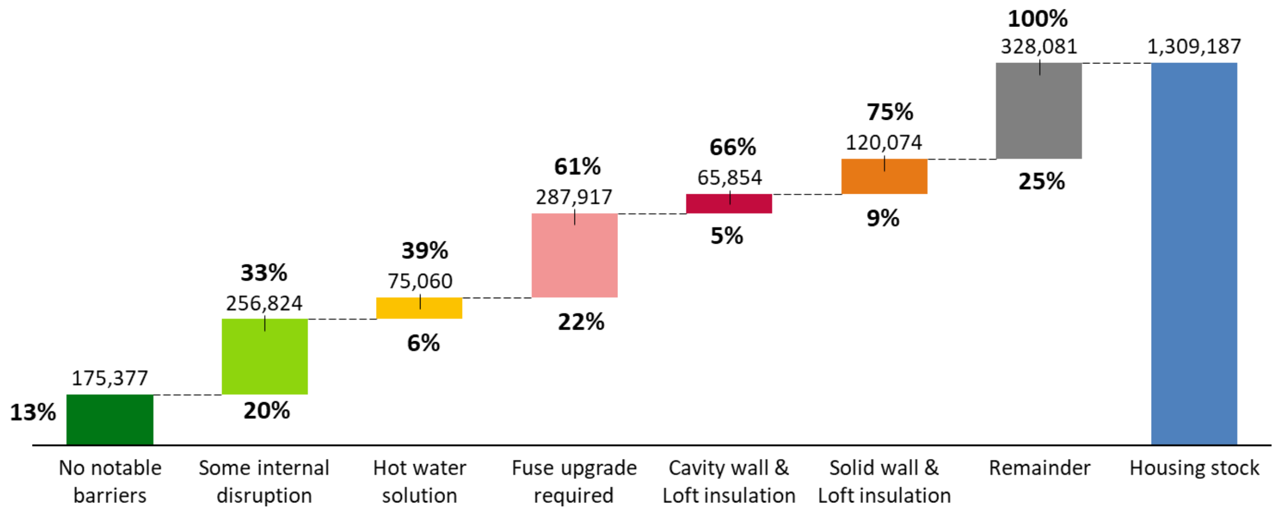



**Table 8-19 Stock-wide cost and carbon results for panel heaters when sized assuming new masonry construction**

| Disruption level: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dwellings | 175,377 | 256,824 | 75,060 | 287,917 | 65,854 | 120,074 | 328,081 |
| Dwelling fraction | 13% | 20% | 6% | 22% | 5% | 9% | 25% |
| Cumulative fraction | 13% | 33% | 39% | 61% | 66% | 75% | 100% |
| **Average dwelling results at each disruption level** | | | | | | | |
| Floor area ($m^2$) | 75 | 89 | 83 | 118 | 154 | 143 | 247 |
| Heating systems | £1,850 | £2,080 | £1,970 | £2,400 | £2,780 | £2,630 | n/a |
| Hot water systems | £0 | £290 | £757 | £238 | £257 | £241 | n/a |
| Installation | £354 | £2,810 | £1,920 | £2,660 | £3,260 | £3,020 | n/a |
| Additional insulation | £0 | £0 | £0 | £0 | £1,320 | £13,200 | n/a |
| Year 1 energy cost | £1,830 | £1,940 | £1,850 | £2,170 | £2,670 | £2,530 | n/a |
| 15-year energy cost (discounted) | £22,500 | £23,800 | £22,700 | £26,700 | £32,800 | £31,100 | n/a |
| **Total lifetime cost** | **£24,700** | **£29,000** | **£27,400** | **£32,000** | **£40,500** | **£50,200** | **n/a** |
| Cost over counterfactual | £4,340 | £16,700 | £11,800 | £20,300 | £17,200 | £25,700 | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2e$) | 2 | 23 | 12 | 27 | 55 | 61 | n/a |
| **Sum of dwelling results at each disruption level** | | | | | | | |
| Total carbon savings (Mt $CO_2e$) | 0 | 6 | 1 | 8 | 4 | 7 | n/a |
| **Cumulative carbon savings (Mt $CO_2e$)** | **0** | **6** | **7** | **15** | **18** | **26** | **26** |

## 9 Gap analysis

Several areas have been identified where further information would increase the clarity of the results presented above. Additional investigation of these topics would provide greater insight into the likely costs of converting oil and solid fuelled dwellings to electric heating. These areas are described briefly below.

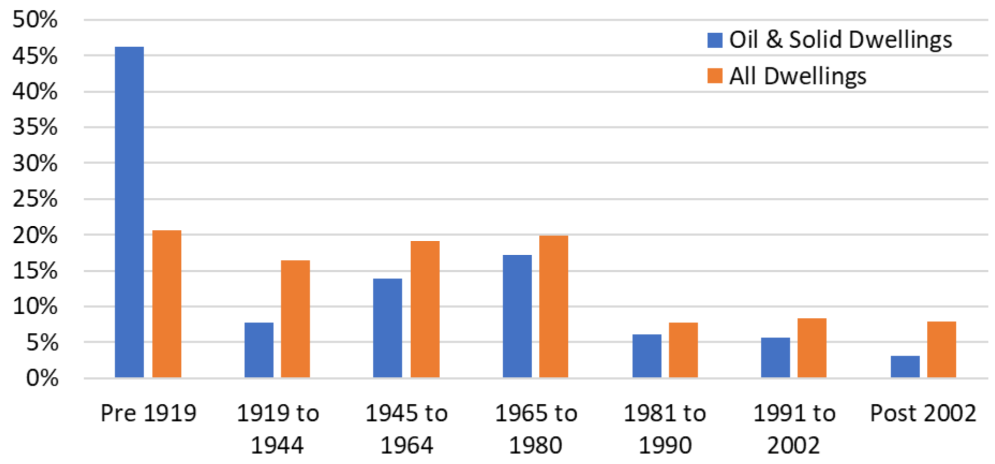
### 9.1 Existing fuse limits and potential for upgrades

As explained in Section 5.3, we assumed an 80 A fuse limit across the off-gas grid housing stock. This is based on conversations with DNOs and electric heating manufacturers who are familiar with the installation process and typical barriers. While this is a reasonable assumption across the bulk of the off-gas grid housing stock, more detailed information on how this varies with existing fuel type, house size, and region would allow a more accurate estimate of the cost of conversion.

Figure 9-1 presents the age distribution of dwellings in England according to the 2015-16 EHS**Error! Bookmark not defined.**. While 20% of all English dwellings were constructed before 1919, over 45% of oil and solid fuelled dwellings fall in this age category. There are also relatively few oil and solid fuelled dwellings constructed after 1980. Older dwellings are more likely to have a 60 A fuse, as are (anecdotally) dwellings in former coal mining areas which are more likely to use solid fuel. Dwellings with existing electric heating are more likely to already have a fuse of 100 A.

A related issue is the cost and complexity of upgrading the fuse limit. If the electricity supply cable to the dwelling is of sufficient size, the DNOs will provide a fuse upgrade free of charge when electric heating is installed in a dwelling. However, if the supply cable is not sufficient to handle the increased amperage, the cost of the new supply cable must be paid by the dwelling owner. The cost of this is expected to be similar to that of a new connection to a domestic dwelling, which is quoted at a standard rate of £1,100 for a 15 m connection across the DNOs (e.g. Ref. 66). More isolated dwellings may have a higher charge as a longer connection cable will be needed.

**Figure 9-1 Age distribution of oil and solid fuelled dwellings and all dwellings**[67]




If a large number of dwellings are converted to electric heating, upgrades to the low voltage network are likely to be also required. A previous study[68] analysed the increase in LV network loads likely to occur if a large number of rural dwellings install heat pumps. It was found that on the average peak

[66] *Statement of methodology and charges for connection to Western Power Distribution (East Midlands) Plc's Electricity distribution system*, Nov. 2018, https://www.westernpower.co.uk/downloads/2936
[67] *English Housing Survey 2015-16: Housing Stock Data*, MHCLG, 2016.
[68] *Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings*, Delta EE for BEIS, Dec 2018.

winter day, the LV network could support heat pumps operating in 82% of dwellings. This was reduced to 41% of dwellings on a 1-in-20 winter peak day when direct electric heaters are required to provide back-up heating for air source heat pumps. 70% of LV substations required reinforcement to accommodate the additional load from electric heating. The level of reinforcement may be somewhat reduced if a large number of dwellings adopt storage heaters rather than direct electric heating as the maximum heat demand will not coincide with the peak electricity demand for other uses. Nevertheless, significant investment in electricity network reinforcement is likely to be required, although these costs will be socialised across the population of electricity users and will not fall wholly to the converted households.

## 9.2 Quality and age of existing wiring

The quality and age of the existing wiring in individual dwellings will also impact the cost of conversion. New consumer units and extensive re-wiring may be needed in dwellings where these are no longer compliant with building regulations. Table 9-1 presents estimated costs for replacing a consumer unit and for completely re-wiring dwellings of various size. Re-wiring will approximately double the installation cost in many cases and will increase the system lifetime costs by around 10% (cf. Table 8-2 and Table 8-4), although the dwelling occupants may experience some ancillary benefits from the improvements. This may affect a substantial fraction of the off-gas grid stock as over 50% of oil- and solid-fuelled dwellings in England were constructed before 1945. Some of these dwellings may already have had substantial improvements to their original wiring. Further detail on the state of the wiring in the off-gas grid stock would allow a more detailed assessment of the likely upgrade costs.

**Table 9-1 Estimated costs of electrical upgrades[69]**

| | House type | Cost range | Days to complete |
|---|---|---|---|
| New consumer unit | n/a | £450 to £550 | 0.5 to 1 day |
| Complete re-wire | 2 bed terrace | £2,400 to £3,500 | 5 to 8 days |
| Complete re-wire | 3 bed semi-detached | £3,000 to £4,500 | 6 to 10 days |
| Complete re-wire | 4 bed detached | £3,750 to £5,500 | 10 to 15 days |

## 9.3 Variations in energy consumption

The annual energy consumption for heating has not been varied across the types of electric heating systems. The results presented in Sections 7 and 8 assume that a dwelling's heat demand is not affected by whether heat is delivered via centralised or modular heating systems. Modular heating systems have the potential to deliver the same level of thermal comfort while using less energy. Users may heat only the rooms occupied at a given time of day, and with infrared heaters may heat only part of the occupied rooms. Conversely, storage heaters typically experience some inefficiencies due to imperfect matching between the heat stored overnight and the following day's heat demand. However, the impact of these effects has not been quantified, and is likely to vary significantly with the sophistication of system controls and decisions made by the end user. While system manufacturers have developed in-house figures for the benefit offered by modular heating and smart controls, an independent study of these factors would provide further insight in this area.

[69] *Cost guide: electricians*, Which? Trusted Traders, Jan 2018, https://trustedtraders.which.co.uk/articles/cost-guide-electricians/

# 10 Conclusions

The most significant factor governing the feasibility of electric heating systems within a given dwelling is the relative size of the dwelling's electricity connection and the peak power needed to heat the dwelling. The results presented here indicate that electric heating is not technically feasible in 10% of the 1.3 million rural off-gas dwellings in England and Wales. In these dwellings, the peak power required is too great to be accommodated by a single-phase domestic electricity connection, even when the dwelling is well-insulated. 85% of the dwellings in this category are large detached houses which are currently oil heated.

Approximately half of the housing stock is suitable for electric heating with the existing level of insulation. A quarter of the dwellings are not feasible in their current state but can be accommodated if the dwelling fuse is upgraded from 80 A to the maximum value available for a domestic dwelling, 100 A. A further 15% require a fuse upgrade plus additional fabric efficiency measures, such as loft, floor, and wall insulation. With these modifications, these dwellings are suitable for one or more of the electric heating systems considered. Electric heating is not feasible in about 10% of dwellings even when these measures have been applied. The breakdown of the housing stock in these feasibility categories is shown in Table 10-1. Constraints on the electricity LV and HV grids have not been considered in the present study, but may pose a barrier to the uptake of electric heating systems in up to 60% of rural off-gas dwellings[70].

**Table 10-1 Steps required to facilitate use of electric heating in the off-gas grid housing stock**

| Category | Fraction of housing stock |
|---|---|
| Feasible with baseline insulation | 50% |
| Fuse upgrade to 100 A required | 25% |
| Fuse upgrade to 100 A and additional insulation required | 15% |
| Remaining unfeasible dwellings | 10% |

The high lifetime costs of electric heating systems may also be a significant deterrent to the uptake of electric heating systems. The lifetime costs and cost over the counterfactual are shown in Table 10-2 for the lowest lifetime cost scenario. The average dwelling adopting storage heaters faces a cost increase of nearly £10,000 over the 15-year system lifetime. The costs increase further when consumers select heating systems based on lower upfront costs and reduced disruption rather to minimise overall costs. The high cost is compounded by the issues highlighted in previous studies documented in Section 3.2. These include poor customer service for those using non-standard tariffs and the higher burden of environmental and social levies on electric heating consumers.

[70] *Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings*, Delta EE for BEIS, Dec 2018.

**Table 10-2 Electric heating system uptake across the stock based on lowest lifetime cost**

| Selected system: | Storage heaters | Panel heaters | Electric boilers | Infrared heaters | Underfloor heating | No system |
|---|---|---|---|---|---|---|
| All dwellings | 962,361 | 0 | 196,969 | 33,399 | 0 | 116,458 |
| All dwellings fraction | 74% | 0% | 15% | 3% | 0% | 9% |
| Oil dwellings | 600,091 | 0 | 173,319 | 30,040 | 0 | 107,207 |
| Oil fraction | 66% | 0% | 19% | 3% | 0% | 12% |
| Solid dwellings | 68,460 | 0 | 17,867 | 3,359 | 0 | 151 |
| Solid fraction | 76% | 0% | 20% | 4% | 0% | 0% |
| Electric dwellings | 293,809 | 0 | 5,783 | 0 | 0 | 9,101 |
| Electric fraction | 95% | 0% | 2% | 0% | 0% | 3% |
| Average dwelling results for the those selecting each system | | | | | | |
| Floor area ($m^2$) | 116 | n/a | 143 | 235 | n/a | n/a |
| Lifetime cost | £29,500 | n/a | £36,300 | £74,500 | n/a | n/a |
| Lifetime cost over counterfactual | £9,970 | n/a | £17,100 | £44,300 | n/a | n/a |
| Lifetime carbon savings per dwelling (tonnes $CO_2e$) | 32 | n/a | 49 | 89 | n/a | n/a |
| **Total carbon savings (Mt $CO_2e$)** | **31** | **n/a** | **10** | **3** | **n/a** | **n/a** |

# 11 Appendix 1 – Market review

## 11.1 Electric panel heaters and electric radiators

The characteristics of the panel heaters studied are documented in Table 11-1, including:

- kW rating (electrical)
- Material
- Colours
- Installed or portable
- Plug-in or permanent
- Warranty.

The same details are presented for electric radiators in Table 11-2. 11 products from 7 manufacturers have been documented.

Several products are marketed as “hybrid” systems containing features typical of other types of electric heating systems. Electric Heating Company’s DSR Electric panel heater is a partial storage heater containing ceramic tablets to increase its thermal inertia, although these are significantly smaller than would be required in a true storage heater. Similarly, the Glen Dimplex Q-Rad (cost data not shown) is a combined panel heater and infrared heater. It has the design of a typical panel heater with fins to promote passive convection, combined with a radiant panel on the front of the system. The Solius panel heater from Flexel International is similar.

**Table 11-1 Details of electric panel heaters**

| Company | System name | kW rating | Material | Colours | Installed or portable | Plug-in or permanent | Warranty |
|---|---|---|---|---|---|---|---|
| Atlantic Heat | F127 | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | both | 2 years |
| Atlantic Heat | Agilia Digital | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | both | 2 years |
| Atlantic Heat | Agilia IO | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | both | 2 years |
| Atlantic Heat | ONIRIS | 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | both | 2 years |
| Adax | VP10 | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 2.0 | steel | white | both | both | 5 years |
| Adax | VP11 | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5 | steel | white | both | both | 5 years |
| Adax | Clea, Neo | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 2.0 | glass | white, black | both | both | 5 years |
| Adax | VSP9, VSP10 | 0.3, 0.4, 0.6, 0.8, 1.0, 1.2 | steel | white | installed | both | 5 years |
| Adax | Glamox H30 H | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 2.0 | steel | 4 | both | both | 5 years |
| Adax | Glamox TPA | 0.4, 0.6, 0.8, 1.0, 1.5, 2.0 | steel | white | both | both | 5 years |
| Adax | Glamox TLO | 0.25, 0.5, 0.75, 1.0, 1.4 | steel | white | both | both | 5 years |
| Adax | Glamox TVPD | 0.4, 0.6, 0.8, 1.0 | aluminium | white | installed | both | 5 years |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Adax | Norel PM/LM | 0.25, 0.5, 0.7, 1.0, 1.2, 1.5, 2.0 | steel | white | installed | both | 5 years |
| Ecostrad | Eco | 0.6, 0.9, 1.2, 1.5 | steel | white | both | plug-in | 2 years |
| Electric Heating Company | DSR Visage | 1, 1.2, 1.5, 2 | aluminium | RAL colours | both | both | 5 years |
| Electric Heating Company | DSR Electric | 0.6, 0.8, 1.2, 1.5, 1.6, 1.8, 2.0, 2.4 | ceramic | white | both | both | 5 years, 2 years thermostat |
| Elnur | Diligens | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | permanent | 5 years electronics |
| Elnur | RXE Plus | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white | installed | permanent | 5 years electronics |
| Elnur | Nexiun | 0.5, 1.0, 1.5, 2.0 | aluminium | white | installed | permanent | 5 years electronics |
| Flexel Int. | Solius | 0.75, 1.0, 1.5, 2.0 | steel | white | installed | permanent | 2 years |
| Glen Dimplex | PLXE Panel | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 3.0 | steel | white | installed | both | 2 years |
| Glen Dimplex | Girona | 0.5, 0.75, 1.0, 1.5, 2.0 | glass or steel | white, black | installed | both | 2 years |
| Glen Dimplex | Monterey | 0.5, 0.75, 1.0, 1.5, 2.0 | steel | white | installed | both | 2 years |
| Glen Dimplex | Q-Rad | 0.5, 0.75,1.0, 1.5, 2.0 | steel, aluminium | white | installed | permanent | 2 years |
| Glen Dimplex | Saletto | 0.5, 0.75, 1.0, 1.5 | steel | white | installed | both | 2 years |
| Osily | Inertia radiator | 1.0, 1.5, 2.0 | aluminium, steatite | white | installed | -- | 3 years |
| Osily | NEF | 0.5, 0.75, 1.0, 1.25, 1.5 2.0 | steel | white | installed | permanent | 3 years |
| Vent Axia | Optimax Plus | 0.75, 1.25, 1.5, 2.0 | steel | white | installed | permanent | -- |
| Zehnder Group UK | Alura Tech | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | 52 | installed | permanent | 2 years |
| Zehnder Group UK | Fare Tech | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | -- | -- | -- | -- | 2 years |

## Table 11-2 Details of electric radiators

| Company | System name | kW rating | Material | Colours | Installed or portable | Plug in or permanent | Warranty |
|---|---|---|---|---|---|---|---|
| Atlantic Heat | Accessio | 0.3, 0.5, 0.75, 1.0,1.25, 1.5, 2.0 | aluminium | white | installed | permanent | 2 years |
| Atlantic Heat | Galapagos White | 0.75, 1.0,1.25, 1.5, 2.0 | aluminium | white | installed | permanent | 2 years |
| Atlantic Heat | Galapagos Anthracite | 0.75, 1.0,1.25, 1.5, 2.0 | aluminium | grey | installed | permanent | 2 years |
| Ecostrad | VeeSmart | 0.3, 0.4, 0.6, 0.8, 1.0 | steel | white, black | installed | -- | 2 years on heater, 8 years on finish |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Electric Heating Company | EcoSAVE Dynamic heater | 0.5, 0.75, 1.0, 1.25, 1.5 | aluminium | RAL colours | installed | both | 10 years on body, 2 years on electric components |
| Osily | e-KETSCH connected radiator | 0.6, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | white, black | -- | -- | 3 years |
| Rointe | D series | 0.33, 0.55, 0.77, 0.99, 1.21, 1.43, 1.60 | aluminium body, steel elements | RAL colours | installed | -- | 20 years on body, 3 years on electrics |
| Rointe | Kyros | 0.33, 0.55, 0.77, 0.99, 1.21, 1.43, 1.60 | aluminium body, steel elements | white | installed | -- | 20 years on body, 3 years on electrics |
| Vent-axia | Opal Aluminium | 0.5, 0.75, 1.0, 1.25, 1.5 | aluminium | white | installed | plug in | -- |
| Zehnder Group UK | Ax spa | 0.5, 0.75, 1.0, 1.25 | -- | 52 | installed | -- | 2 years |
| Zehnder Group UK | Charleston | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | -- | 52 | installed | -- | 2 years |

## 11.2 Electric storage heaters

We have identified 8 electric storage heating systems from 5 manufacturers. The characteristics of these products are documented in Table 11-3, including:

- kW electric input
- kWh heat storage
- kW electric in boost mode
- Fan assist
- Body material
- Warranty.

**Table 11-3 Details of electric storage heaters**

| Company | System name | kW electric input | kWh heat storage | kW boost mode | Fan assist? | Body material | Warranty |
|---|---|---|---|---|---|---|---|
| Creda | TSRE | 1.1, 1.56, 2.2, 2.76, 3.3 | 7.7, 10.9, 15.4, 19.3, 23.1 | 0.63, 0.88, 1.13, 1.38 | y | steel | 1 year |
| Elnur | Ecombi HHR | 1.74, 2.63, 3.48 | 12.2, 18.3, 24.4 | 0.55, 0.82, 1.12 | y | steel | 12 years |
| Elnur | Ecombi SSH smart | 0.975, 1.3, 1.95, 2.6 | 7.4, 9.9, 14.9, 19.8 | 0.45, 0.6, 0.9, 1.2 | -- | steel | 5 years |
| Elnur | ADL | 2, 3, 4 | 14, 21, 28 | 0.178, 0.267, 0.355 | y | -- | 5 years |
| Glen Dimplex | Quantum | 1.1, 1.56, 2.2, 2.76, 3.3 | 7.7, 10.9, 15.4, 19.3, 23.1 | 0.63, 0.88, 1.13, 1.38 | y | steel | 2 years |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Glen Dimplex | XLE Slimline | 1.02, 1.56, 2.22, 2.76, 3.3 | 7.14, 10.92, 15.54, 19.32, 23.1 | 0.34, 0.52, 0.74, 0.92, 1.1 | y | steel | 2 years |
| Redring Xpelair Group | Creda TSRE Slimline | 1.02, 1.56, 2.22, 2.76, 3.3 | 7.14, 10.92, 15.5, 19.3, 23.1 | 0.34, 0.52, 0.74, 0.92, 1.1 | -- | -- | 2 years |
| Vent Axia | Optimax Plus | -- | 6, 12, 18, 24 | none | y | -- | -- |

### 11.3 Electric infrared heaters

We have identified 16 electric radiant heating systems from 6 manufacturers. These products are documented in Table 11-4, including:

- kW rating (electrical)
- Material
- Surface temperature
- Ceiling or wall-mounted
- Colours
- Plug in or permanent
- Warranty.

**Table 11-4 Details of electric infrared heaters**

| Company | System name | kW rating | Material | Surface temp. | Ceiling or wall | Colours | Plug in or permanent | Warranty |
|---|---|---|---|---|---|---|---|---|
| Atlantic Heat | Tatou Horizontal | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | aluminium | -- | wall | white | permanent | 2 years |
| Atlantic Heat | Tatou Vertical | 1, 1.5, 2.0 | aluminium | -- | wall | white | permanent | 2 years |
| Ecostrad | IR-mir | 0.35, 0.5, 0.54, 0.7 | aluminium, glass | 85 to 95 C | both | white, mirror | both | 5 years |
| Flexel Int. | EcoSun UB | 0.3, 0.6, 0.85 | steel | max 90 C | ceiling | white | both | 5 years |
| Flexel Int. | EcoSun GS | 0.3, 0.5, 0.6, 0.85 | glass, steel, quartz crystals | max 90 C | both | white, black, mirror, with print | both | 2 years |
| Flexel Int. | EcoSun GR | 0.3, 0.5, 0.7, 0.9 | glass, steel | max 90 C | wall | 5 | plug in | 2 years |
| Flexel Int. | EcoSun E | 0.3, 0.6, 0.85 | steel, aluminium | max 90 C | both | white | both | 2 years |
| Herschel | Select | 0.35, 0.54, 0.7 | aluminium | 85 to 95 C | both | white | permanent | 5 years |
| Herschel | Select XL | 0.25, 0.3, 0.6, 0.85, 1.0 | aluminium, glass | 85 to 95 C | both | white, black, glass, mirror | permanent | 5 years |
| Herschel | Inspire white | 0.25, 0.35, 0.42, 0.55, 0.75, 0.82, 0.9, 1.2, 1.25 | aluminium | 85 to 95 C | both | white | permanent | 10 years |
| Herschel | Inspire glass | 0.35, 0.55, 0.75, 0.9 | ESG safety glass | 85 to 95 C | wall | white, black | permanent | 10 years |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Herschel | Inspire mirror | 0.25, 0.35, 0.42, 0.55, 0.75, 0.9, 1.25 | mirror safety glass | 85 to 95 C | wall | mirror | permanent | 10 years |
| Herschel | Inspire picture | 0.25, 0.35, 0.42, 0.55, 0.75, 0.9, 1.25 | ESG safety glass | 85 to 95 C | wall | customised with picture | permanent | 10 years |
| Herschel | Inspire blackboard | 0.75, 0.9, 1.15 | ESG safety glass | 85 to 95 C | wall | matt black chalkboard finish | permanent | 10 years |
| Logicor | Clear Heater System | 0.43, 0.82 | glass, ceramic | 40 to 60 C | wall | white | plug in | 20 years |
| Osily | Radiant panels | 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 | steel | -- | -- | white | permanent, also pilot wire | 3 years |

## 11.4 Electric underfloor heaters

We have identified 19 electric underfloor heating systems from 7 manufacturers. These products are documented in Table 11-5, including:

- W/m$^2$ rating (electrical)
- Area in m$^2$
- Material
- Thickness
- Floor type
- Insulation layer
- Warranty
- Suitability for retrofits

**Table 11-5 Details of electric under floor heaters**

| Company | System name | kW/m2 rating | Material | Thickness | Floor type | Warranty | Suitable for retrofit? |
|---|---|---|---|---|---|---|---|
| Danfoss Ltd | EcMat | 100, 150, 200 | -- | 5.5 mm | tile, stone, laminate, wood, carpet, vinyl | 20 years | ✓ |
| Danfoss Ltd | DEVImat | 70, 100, 150, 200 | bi-conductive cabling and mesh | 3.5 mm | flexible except for 200, tiles and stone only | 20 years | ✓ |
| Danfoss Ltd | DEVIflex heating tables | 10, 20 W/m | bi-conductive cabling | 4 to 7 mm | screed floor | 20 years | × |
| Flexel Int. | EcoFilm F | 40, 60, 80 | silver coated copper strips within polyester foil | 0.4 mm | carpet, laminate | 10 years | ✓ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flexel Int. | Ecofloor heating cable | 5, 10, 15, 18 W/m | -- | -- | tiles | 10 years | × |
| Flexel Int. | EcoFloor heating cable for semi-storage | 5, 10, 15, 18 W/m | -- | -- | carpet, laminate, tile, PVC | 10 years | × |
| nVent thermal management | Nuheat mat | 130 | bi-conductive with mat | 3.2 mm | tile, stone, laminate, wood | 25 years, 3 years on thermostats | ✓ |
| nVent thermal management | RAYCHEM T2Quicknet | 90, 160 | fluoropolymer with fibreglass mat | 3 mm | tile, marble, stone | 12 years, 20 if certified installer | ✓ |
| Osily | Sweet Up | 120 | bi-conductive cabling and mesh | | tile, screed floors | -- | × |
| Osily | Thintherm | 80, 120 | -- | 2.8 mm | laminate, wood, linoleum | -- | ✓ |
| Rointe | Atria Ultra thin | 150 | bi-conductive cabling and mesh | 2 mm | ceramic | 10 years | ✓ |
| Rointe | Milos PVC | 150 | bi-conductive cabling and fibreglass mesh | 4 mm | ceramic | 10 years | ✓ |
| Rointe | Erko foil | 140 | foil, aluminium | 1 mm | laminate, wood, carpet, vinyl, linoleum | 10 years | ✓ |
| Vent-axia | Bluethermal electric | 100, 150 | cable with fibreglass net | 4mm | 100 - any floor 150 - non-combustible | 10 years | ✓ |
| Warmup Plc | Stickymat | 150, 200 | bi-conductive fluoropolyer cabling and mesh | 3 mm | carpet, tile, wood, linoleum | Lifetime | ✓ |
| Warmup Plc | DCM-Pro mat and cable | 150 | bi-conductive fluoropolyer cabling and polypropylene membrane | 5.5 mm | ceramic, stone | Lifetime | ✓ |
| Warmup Plc | Foil heater | 140 | foil, aluminium | 3 mm | wood, laminate, vinyl, carpet | Lifetime | ✓ |
| Warmup Plc | Loose wire | 150 | bi-conductive cabling | 1.8 mm | ceramic, stone | Lifetime | × |
| Warmup Plc | Inscreed cable | 100 to 210 | bi-conductive cabling | 6 mm cable, 50 to 100 mm screed layer | all types, new construction | 10 years | × |

## 11.5 Electric boilers

We have identified 9 electric boiler systems from 5 manufacturers. These products are documented in Table 11-6, including:

- Heat or hot water provision
- kW input (electrical)
- Rated current (A)
- Cylinder size (L)
- Heat-up time
- Energy Performance Certificate (EPC)
- Warranty

**Table 11-6 Details of electric boilers**

| Company | System name | Heat or hot water | kW input | Rated current A | Cylinder size L | Heat-up time | EPC | Warranty |
|---|---|---|---|---|---|---|---|---|
| Electric Heating Company | Fusion Comet | both w/ cylinder | 6, 9, 12, 14.4 | 32, 50, 63, 80 | 150, 180, 210 | n/a | D | 2 years |
| Electric Heating Company | Comet combi boiler | both | 9, 12, 14.4 | 50, 63, 80 | 140 | 29 to 62 mins | C for water, D for heat | cylinder 10 years, electrics 2 years |
| Electric Heating Company | SlimJim Flow boiler | both w/ cylinder | 4, 7, 10, 12, 14.4 | 17.4, 30.9, 43.4, 52.5, 62.6 | 120, 150, 180 or 210 | n/a | D | 2 years |
| Elnur | Mattira | both | 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15 | 17.4, 21.7, 26.1, 30.4, 34.8, 39.1, 43.5, 47.8, 52.2 | 50 | n/a | D | 5 years |
| Glen Dimplex | Quantum Water cylinder | both | -- | -- | 125, 150, 210, 250, 300 | 122 to 313 mins | C | cylinder 25 years, immersion 2 years |
| Glen Dimplex | Quantum slim water cylinder | both | -- | -- | 135, 180 | 200 mins | D | cylinder 25 years, immersion 2 years |
| Heatrae Sadia | ElectroMax | both | 6, 9 | -- | 180 | 180 mins | C for water, D for heat | cylinder 10 years, electrics 2 years |
| Heatrae Sadia | Amptec | heat | 4, 6, 9, 11, 12 | -- | n/a | n/a | D | 2 years |
| Redring Xpelair Group | Redring Powerstream Ascari | both | 12 | -- | -- | -- | -- | -- |

## 11.6 Hot water cylinders

Information on 11 hot water cylinders from 6 manufacturers is shown in Table 11-7. The following information is presented for each system:

- Cylinder size (L)
- Heat-up time
- Details of the immersion heating element
- Energy Performance Certificate (EPC)
- Warranty.

**Table 11-7 Details of hot water cylinders**

| Company | System name | Cylinder size L | Heat-up time | Immersion heater | EPC | Warranty |
|---|---|---|---|---|---|---|
| Electric Heating Company | Neptune | 120, 150, 180, 210, 250, 300 | -- | -- | B | 25 years |
| Electric Heating Company | Neptune solar | 180, 210, 250, 300 | -- | -- | B | 25 years |
| Gledhill | Stainless Lite Plus | 90, 120, 150, 180, 210, 250, 300 | 1 min per litre | 2 x 3 kW | C | 25 years |
| Glen Dimplex | ECSd | 100, 125, 150, 175, 210, 250, 300 | -- | 2 x 3 kW | C | cylinder 25 years, immersion 2 years |
| Heatrae Sadia | Megaflow Eco | 70, 125, 145, 170, 210, 250, 300 | -- | optional | B or C | Lifetime |
| Heatrae Sadia | Megaflo Eco Slimline | 100, 125, 150, 170, 200 | 109 to 218 mins | 1 x 3 kW | B | Lifetime |
| Heatrae Sadia | Megalife HE | 100, 120, 150, 170, 210 | -- | 2 x 3 kW | C | 25 years |
| Heatrae Sadia | PremierPlus | 100, 120, 150, 170, 210, 250, 300 | -- | 1, 2, or 3 x 3 kW | B or C | 30 years |
| Logicor | In Line Heating system | n/a | n/a | n/a | A | 20 years |
| RM Cylinders | Prostel Direct | 120, 150, 180, 210, 250 | 76 to 323 mins | 2 x 3 kW | D | -- |
| RM Cylinders | Stelflow Direct | 250, 300 | 248 to 323 mins | 2 x 3 kW | D | -- |

## 11.7 Point-of-use systems

Table 11-8 presents the characteristics of 9 point-of-use systems from 5 manufacturers. Information is presented on

- Use with taps or showers
- kW input (electrical)
- Rated current (A)
- Energy Performance Certificate (EPC)
- Warranty.

**Table 11-8 Details of hot water point-of-use systems**

| Company | System name | Tap or shower | kW input | Rated current A | EPC | Warranty |
|---|---|---|---|---|---|---|
| Aqualisa | Aquastyle | Shower | 9, 10, 11 | 35, 40, 44 | -- | 2 years |
| Aqualisa | Lumi | Shower | 9, 10, 11 | 35, 40, 44 | A | 2 years |
| Aqualisa | Quartz | Shower | 9, 10, 11 | 35, 40, 44 | A | 2 years |
| Ariston | Undersink Water heater | Tap | 2, 3 | 9, 13 | A | 4 years |
| Logicor | Inline Heating system | Both | 13 | 56 | A | 20 years |
| Redring Xpelair Group | Redring Powerstream | Shower | 9.5, 10.8, 12.0 | 40, 45, 50 | A | -- |
| Redring Xpelair Group | Redring Powerstream Eco | Shower | 9.5, 10.8 | 40, 45 | A | -- |
| Redring Xpelair Group | Redring Powerstream EW, MW, MS, etc | Shower | 3 | 13 | B | -- |
| Redring Xpelair Group | Galaxy Aqua Remier | Shower | 9.5 | 45 | A | -- |
| Zip | Aquapoint 3 | Tap | 2 | 9 | A | 1 year |
| Aqualisa | Aquastyle | Shower | 9, 10, 11 | 35, 40, 44 | -- | 2 years |

# 12 Appendix 2 – Controls by heating system

| Category | Company | System name | Temperature | Timing and temperature | Adaptive start | Open window | Frost protection | Control from app | House-wide coordination | Motion detection | Geo-fencing | Load shedding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric panel heater | Adax | VP10 | x | | | | | y | | | | |
| Electric panel heater | Adax | VP11 | x | | | | | y | | | | |
| Electric panel heater | Adax | Clea, Neo | x | x | | | | x | | | | |
| Electric panel heater | Adax | VSP9, VSP10 | x | | | | | | | | | |
| Electric panel heater | Adax | Glamox H30 H | x | x | | | | | | | | |
| Electric panel heater | Adax | Glamox TPA | | | | | | | | | | |
| Electric panel heater | Adax | Glamox TLO | y | | | | | | y | | | |
| Electric panel heater | Adax | Glamox TVPD | x | x | | | | | | | | |
| Electric panel heater | Adax | Norel PM/LM | x | y | | | | y | | | | |
| Electric panel heater | Ecostrad | Eco | x | x | | | x | | | | | |
| Electric panel heater | Electric Heating Company | DSR Visage | x | x | x | x | x | y | | | y | y |
| Electric panel heater | Electric Heating Company | DSR Electric | x | x | x | x | x | y | y | | y | y |
| Electric panel heater | Elnur | Diligens | x | x | x | x | x | y | | | | |
| Electric panel heater | Elnur | RXE Plus | x | x | x | x | x | | | | | |
| Electric panel heater | Elnur | Nexiun | y | y | | | y | | y | | | |
| Electric panel heater | Fenix | Solius | x | x | | | x | | | | | |
| Electric panel heater | Fischer | elektrostore | | | | | | | | | | |
| Electric panel heater | Glen Dimplex | PLXE Panel | x | x | x | x | x | | | | | |
| Electric panel heater | Glen Dimplex | Girona | x | x | x | x | x | | | | | |
| Electric panel heater | Glen Dimplex | Monterey | x | x | x | x | x | | | | | |
| Electric panel heater | Glen Dimplex | Q-Rad | x | x | x | x | x | | y | | | |
| Electric panel heater | Glen Dimplex | Saletto | x | x | | | x | | x1 | | | |
| Electric panel heater | Osily | Inertia radiator | x | x | | x | x | | x1 | x | | |
| Electric panel heater | Osily | NEF | x | x | | x | x | | x1 | x | | |
| Electric panel heater | Vent Axia | Optimax Plus | x | x | | | x | | | | | |
| Electric panel heater | Zehnder Group UK | Alura Tech | x | x | | x | | | | | | |
| Electric panel heater | Zehnder Group UK | Fare Tech | x | x | | x | | | | | | |
| Electric radiator | Ecostrad | VeeSmart | x | x | | | | x | | | | |
| Electric radiator | Electric Heating Company | EcoSAVE Dynamic heater | x | x | x | x | x | y | | | | y |
| Electric radiator | Osily | e-KETSCH connected radiator | x | x | | x | x | x | | x | | |
| Electric radiator | Rointe | D series | x | x | | x | x | x | | | | |
| Electric radiator | Rointe | Kyros | x | x | | x | x | y | | | | |
| Electric radiator | Vent-axia | Opal Aluminium | x | x | | | x | | | | | |
| Electric radiator | Zehnder Group UK | Ax spa | x | x | | x | | | | | | |
| Electric radiator | Zehnder Group UK | Charleston | | | | | | | | | | |
| Electric storage heater | Elnur | Ecombi HHR | x | x | x | x | x | | | | | |
| Electric storage heater | Elnur | Ecombi SSH smart | x | x | x | x | x | y | | | | |
| Electric storage heater | Elnur | ADL | y | y | | | | | y | | | |
| Electric storage heater | Glen Dimplex | Quantum | x | x | x | | x | | | | | |
| Electric storage heater | Glen Dimplex | XLE Slimline | x | x | x | x | x | | | | | |
| Electric storage heater | Redring Xpelair Group | Creda TSRE Slimline | | | | | | | | | | |
| Electric storage heater | Vent Axia | Optimax Plus | x | x | + | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric convection heater | Glen Dimplex | BFHE Base Unit heater | | | | | | | | | | |
| Electric convection heater | Vent Axia | Plinth heater | x | | | | | | | | | |
| Electric radiant heater | Flexel International | EcoSun | y | | | | | | | | | |
| Electric radiant heater | Flexel International | GR | y | | | | | | | | | |
| Electric radiant heater | Herschel | Select | y | | | | | | | | | |
| Electric radiant heater | Herschel | Select XL | y | | | | | | | | | |
| Electric radiant heater | Herschel | Inspire white | y | | | | | | | | | |
| Electric radiant heater | Herschel | Inspire glass | y | | | | | | | | | |
| Electric radiant heater | Herschel | Inspire mirror | y | | | | | | | | | |
| Electric radiant heater | Herschel | Inspire picture | y | | | | | | | | | |
| Electric radiant heater | Herschel | Inspire blackboard | y | | | | | | | | | |
| Electric radiant heater | Osily | Radiant panels | x | x | | x | | | | + | | |
| Electric underfloor heater | Danfoss Ltd | Ecmat | y | | | | | | | | | |
| Electric underfloor heater | Flexel International | EcoFilm F | x | x | | | | | | | | |
| Electric underfloor heater | Flexel International | Ecofloor heating cable | y | | | | | | | | | |
| Electric underfloor heater | Flexel International | EcoFloor heating cable for semi-storage | x | | | | | | | | | |
| Electric underfloor heater | Gaia Climate Solutions | DEVImat | y | | | | | | | | | |
| Electric underfloor heater | Gaia Climate Solutions | DEVIflex heating tables | y | | | | | | | | | |
| Electric underfloor heater | nVent thermal management | Nuheat mat | y | | | | | | | | | |
| Electric underfloor heater | nVent thermal management | RAYCHEM T2Quicknet | y | | | | | | | | | |
| Electric underfloor heater | Osily | Sweet Up | | | | | | | | | | |
| Electric underfloor heater | Osily | Thintherm | | | | | | | | | | |
| Electric underfloor heater | Rointe | Atria Ultra thin | y | y | | y | | y | y | | | |
| Electric underfloor heater | Rointe | Milos PVC | y | y | | y | | | | | | |
| Electric underfloor heater | Rointe | Erko foil | y | y | | y | | | | | | |
| Electric underfloor heater | Vent-axia | Bluethermal electric | y | y | | | | | | | | |
| Electric underfloor heater | Warmup Plc | Stickymat | y | | | | | | | | | |
| Electric underfloor heater | Warmup Plc | DCM-Pro mat and cable | y | | | | | | | | | |
| Electric underfloor heater | Warmup Plc | Foil heater | y | | | | | | | | | |
| Electric underfloor heater | Warmup Plc | Loose wire | y | | | | | | | | | |
| Electric underfloor heater | Warmup Plc | Inscreed cable | y | | | | | | | | | |
| Electric boiler | Electric Heating Company | Fusion Comet | x | x | x | | | | | | | |
| Electric boiler | Electric Heating Company | Comet combi boiler | x | x | | | | | | | | |
| Electric boiler | Electric Heating Company | SlimJim Flow boiler | x | x | | | | | | | | |
| Electric boiler | Elnur | Mattira | x | x | x | | x | | | | | |
| Electric boiler | Glen Dimplex | ECSd | x | | | | | | | | | |
| Electric boiler | Glen Dimplex | Quantum Water cylinder | x | x | | | | | | | | |
| Electric boiler | Glen Dimplex | Quantum slim water cylinder | x | x | | | | | | | | |
| Electric boiler | Heatrae Sadia | ElectroMax | x | x | | | | | | | | |
| Electric boiler | Heatrae Sadia | Amptec | x | x | | | | | | | | |
| Electric boiler | Heatrae Sadia | Megaflow Eco | x | x | | | | | | | | |
| Electric boiler | Heatrae Sadia | Megaflo Slimline | x | x | | | | | | | | |
| Electric boiler | Heatrae Sadia | Megalife HE | x | x | | | | | | | | |
| Electric boiler | Redring Xpelair Group | Redring Powerstream Ascari | x | | | | | | | | | |
| Electric boiler | Redring Xpelair Group | Redring Powerstream | x | | | | | | | | | |
| Electric boiler | Redring Xpelair Group | Redring Powerstream Eco | x | | | | | | | | | |
| Electric boiler | Redring Xpelair Group | Redring Powerstream EW, MW, MS, etc | x | | | | | | | | | |
| Electric boiler | Redring Xpelair Group | Galaxy Aqua Remier | x | | | | | | | | | |
| | | | (y) if purchase thermostat sold separately | | | | | | | | | |
| | | | (+) system option | | | | | | | | | |
| | | | (x1) controllable via pilot wire | | | | | | | | | |