Peak Heat WP2: Electric heat market landscape

Peak Heat Project

Western Power Distribution

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Delta-EE is a leading European research and consultancy company providing insight into the energy transition. Our focussed research services include Connected Home, Electrification of Heat, Electric Vehicles, New Energy Business Models, Digital Customer Engagement and Local Energy Systems. We also provide consultancy for clients including networking companies and policymakers. Delta-EE's mission is to help our clients successfully navigate the change from 'old energy' to new energy.

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List of acronyms

ASHP	Air source heat pump
a/w HP	Air to water heat pump (a sub-type of air source heat pump (hydronic))
B2C	Business to customer
B2B2C	Business to business to customer
BEIS	Department for Business, Energy & Industrial Strategy
CHeSS	Central Heating System Specification
COP	Coefficient of Performance
DNO	Distribution Network Operator
DSR	Demand side response
DSO	Distribution System Operator
DFES	Distribution Future Energy Scenarios
DHW	Domestic hot water
DUoS	Distribution Use of System (charges)
ECO	Energy Company Obligation
EHS	English Housing Survey
ESO	Electricity System Operator
FEES	Fabric Energy Efficiency Standard
FES	Future Energy Scenarios
FFR	Fast Frequency Response
FHS	Future Homes Standard
GDN	Gas Distribution Network
GSHP	Ground source heat pump
HaaS	Heat as a service
HPs	Heat pump(s)
HIU	Heat Interface Unit
HT	High Temperature
LPG	Liquefied Petroleum Gas
LT	Low Temperature
LV	Low voltage
MFH	Multi-family home
OEM	Original Equipment Manufacturer
PCM	Phase Change Material
ToU	Time of use (tariff)
UFH	Underfloor heating

WPD	Western Power Distribution
ZEB	Zero Emission Boiler

Executive Summary

Changes to the domestic heat market - with increasing electrification, the use of thermal storage, and the ways these technologies could be operated more flexibly - could have a significant impact on electricity networks

A major challenge for electricity network operators is the uncertainty around what the future heat market will look like. It is likely that large scale and fast changes in the heating market will be required to achieve the UK's net zero by 2050 target and therefore early decisions will need to be taken by network operators to adapt and meet the needs of the changing market.

Domestic heat electrification could have a major impact on Low Voltage (LV) and Medium Voltage (MV) distribution network peak loads by adding a significantly larger load than the network was designed for. There is currently a range of uncertainties which need to be explored to inform distribution network operators' (DNOs) future network investment plans:

- What the load profiles of these new electricity loads, and technology shifts will look like
- Evaluating the role of thermal storage, its impacts, and potential benefits for network operators
- Determining the inherent flexibility in domestic heating and understanding how this can be used to the network's advantage

This report forms the 'landscaping' element of the Peak Heat project – outlining how the heating market is changing and will likely change in future (both qualitatively and quantitively), how and where domestic thermal storage might be used, and how these technologies might be used to provide flexibility.

This work will inform the wider Peak Heat project, which will help DNOs understand the impacts of electric heating loads, and the role that flexibility (including thermal storage) could take in helping to mitigate network impacts.

Anticipated large uptake of heat pumps, plus an uptick in domestic thermal storage (mainly hot water tanks)

Although decarbonisation scenarios vary in their estimated level of domestic heat electrification, several drivers including high policy ambition and new building regulations will mean we are likely to see high uptake of heat pumps (HP) by 2030. Delta-EE estimates that the installed base of heat pumps could grow from ~250,000 today to ~1.6 million (mostly low-temperature air to water) units by 2030 across the UK through new build and retrofit, based on current drivers.

Most of this growth will be seen in highly efficient, well insulated homes (likely with underfloor heating and/or large radiators) – much of which will be new build. This growth has the potential to be higher with further policy support. Some significant uptake will also be seen in retrofit (we estimate ~100,000/ year in 2028).

Delta-EE's projection for HP uptake on WPD's network is lower than the expected HP uptake by 2030 compared to some of the more ambitious 2020 Future Energy Scenarios (FES) from Regen, with Western Power Distribution's (WPD's) most ambitious Distribution Future Energy Scenario (DFES) estimating ~1.6 million units installed on WPD's network alone (see Figure 1). The reasons for the differences between these projections is as follows:

- Delta-EE's 'Central' scenario is based on considerations around the existing and future housing stock and assessing the likely future impact of announced policies (not including government 'ambitions') on both new build and retrofit properties. This outlook is also based on current levels of awareness and appeal of heat pumps, CAPEX not significantly reducing and OPEX not significantly reducing vs other alternatives. See 2.5 for full details of drivers considered.
- We have also included a scenario in Figure 1 that includes many of the same drivers but with these adjusted so that the government's ambition of 600,000 heat pump installs per year is by 2028 is achieved, and what this would likely look like on WPD's network.
- The two highest uptake scenarios (Consumer Transformation and Leading the Way) assume very rapid customer adoption of new technologies, with consumers highly engaged in acting to shift to electric heat pumps.

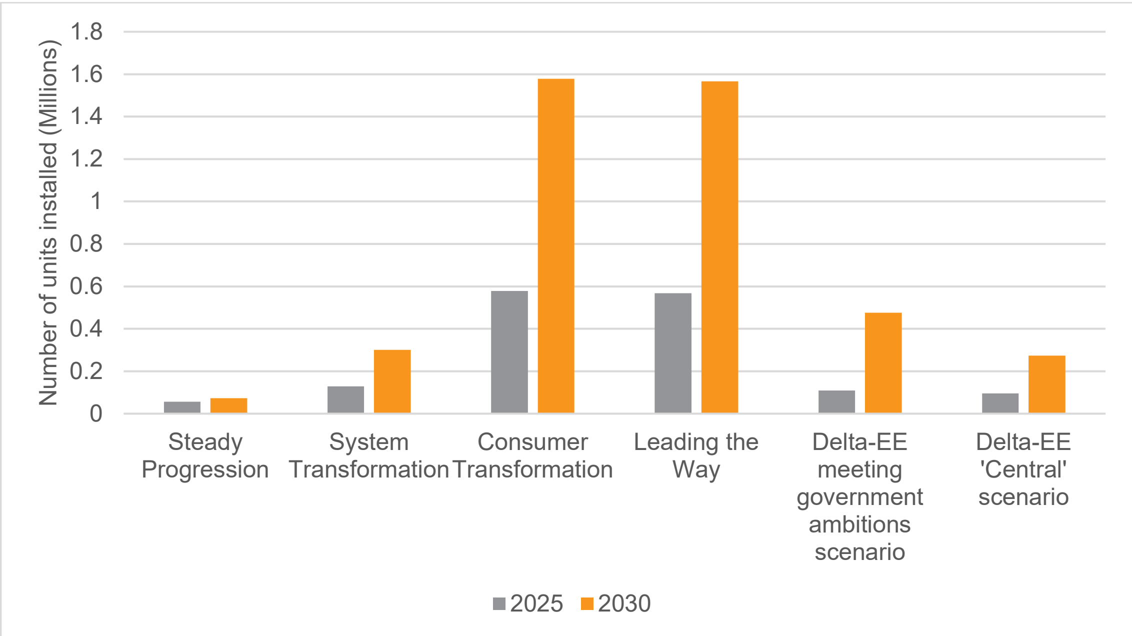


Figure 1. WPD DFES and Delta-EE scenarios for heat pump uptake on WPD's network (Regen for WPD, 2020)

The wider Peak Heat project will look to identify the potential for domestic flexibility (with a focus on heat pumps) on WPD's network. We want to give a range of possible values, including what might be the impact of flexibility under a scenario for highest potential heat pump uptake (a 'worst case' scenario), as well as the potential for demand reduction at a lower heat pump uptake (one could argue more realistic) scenario. For these reasons, the two scenarios that will be taken forward and form the basis of heat pump uptake in subsequent modelling will be the Consumer Transformation (CT) and System Transformation (ST) DFES. As can be seen from Figure 1, CT to 2030 has very similar uptake to that of Leading the Way (LTW), however CT sees a larger impact from domestic heat pumps on the distribution network (both in terms of peak demand and annual energy demand), due to differing assumptions between scenarios (e.g., LTW assumes higher and faster energy efficiency and insulation improvements to homes). ST is also chosen as a much lower uptake scenario as, as can be seen from Figure 1, it is most similar to Delta-EE's expectation of reality (Delta-EE's 'Central' scenario).

Heat pumps have several features that allow for flexibility in their operation (and potentially the avoidance of correspondingly large co-incident additional peak demand). They typically have some thermal storage ability which allows more constant HP operation against a changing load. HP flexibility can also be improved with a buffer tank; however, these are likely to remain niche in the UK due to their high costs and large size for UK homes.

Most of these heat pumps will have their own integrated control systems for space, hot water heat demand and internal HP management, and any signals for changing operation will likely come from external controllers, relaying smart grid 'requests'. However built-in connectivity for hydronic[1] heat pumps is becoming increasingly common, meaning they will increasingly be available to use for demand side flexibility.

Other flexible electric heating solutions include smart storage heaters and direct electric heaters, both of which could see increasing sales but whose market is quite limited to either replacements or highly efficient, new build homes. Other more novel solutions such as heat batteries and electric zero emission boilers could be used to provide flexibility to the electricity network; however, these options are likely to remain niche by 2030.

Most heat pumps will require a modern hot water cylinder (compatible with a heat pump) to store and provide hot water. These heat pump cylinders will have larger coil capacities (to allow for lower flow temperatures), meaning cylinders for heat pumps tend to be sized larger. These could be used with heat pumps to provide load shifting over certain periods of time, however, to accommodate this, they will potentially need to be sized even larger, meaning their suitability may be limited to certain house types. There are also opportunities to flex cylinders used with heat pumps in other ways – for example shifting the timing of when the immersion heater is used to periodically to heat the tank to 60°C to satisfy legionella guidelines.

This trend in increasing heat pumps will also therefore likely boost domestic hot water tank sales – potentially increasing the impact on the network, as these tanks tend to have electric immersion heater elements which are used to top up the hot water available. However, these tanks are also increasingly being recognised as a key solution to provide flexibility – with innovative new smart products and retrofittable smart controls emerging at a fast pace.

[1] A hydronic (or wet) heating system utilizes heated water to distribute warmth throughout a building

The other key domestic thermal storage technology will likely be phase change material (PCM) technologies. PCM has strong uptake potential in the UK, due to its characteristics (relatively fast demand side flexibility capability), size (it can displace a larger hot water tank) and availability in the UK via a domestic producer. These products have many advantages over domestic hot water (DHW) tanks – with much higher efficiencies, lower heat loss rates and can also be used to provide system flexibility.

This uptake in electric heating load will increase demand on the network at peak times. Emerging approaches utilising flexibility in electric heating and thermal storage could help soften peak impacts, but they could also exacerbate them

The highest potential heat pump uptake scenario as outlined above (Consumer Transformation) could result in an uptake of ~1.6 million units on WPD's network. Owing to their method of operation, the performance characteristics of HPs will differ significantly from conventional boilers. However, the highest demands will still occur in the coldest conditions, when HPs perform least efficiently. Additionally, there may be limited diversity associated with heat, and absolute power values are much higher than for non-heat demands. Given this, if HPs run without any operating constraints, the network may eventually become overloaded.

Assuming no reductions from co-incident peak demand from flexibility measures or thermal storage, an increase of 1.6 million heat pumps on WPD's network could add an additional ~4.8GW onto peak demand. Assuming the price of increased peak demand at the LV level of £350/kW, this could result in additional cost of ~£1.7 billion to WPD. In order to minimise the cost of supporting this additional heat pump uptake, WPD needs to develop a more granular understanding of:

- Where on the network heat pumps will be located. This will depend mostly on the suitability of the buildings. Since heat pumps are best suited to well-insulated properties with sufficient outdoor space, initial uptake is likely to be concentrated in new-build single-family housing developments. In contrast, heat pump uptake will probably be limited in densely populated areas with less outdoor space and poorly insulated older properties.
- How much more efficiently those heat pumps can be operated to minimise demand on the network, particularly during peak periods. Factors impacting efficiency include; improving insulation levels to reduce flow temperature requirements, ensuring the design and commissioning are done optimally, or modifying the control strategy to avoid short cycling.
- How much flexibility there potentially is to shift when the heat pumps operate in order to limit peak demand on the network. This depends on the thermal storage capacity of the system, and can be increased by, for example, adding insulation to reduce building heat loss rates, or adding some kind of heat store that can be charged during off-peak periods. For WPD, the questions are how to incentivise the uptake of such measures, and what kind of control algorithms and associated signals are needed to optimise the use of thermal storage and hybrid heating systems across the network.

There is also a large potential opportunity for DSOs to mitigate the cost of heat electrification through use of flexibility in existing UK domestic thermal storage. With a hot water cylinder in roughly one in three UK homes today, provision of enhanced control and flexibility using these cylinders represents a combined thermal storage capacity, and shiftable load of 100GWh, even before we consider the number of new homes set to be built over the period to 2030 (USER Project, 2020). This is a capacity equivalent to 6 million Tesla Powerwall units, facilitated at potentially a fraction of the cost (USER Project, 2020) when using retrofit add-on devices (with relatively small changes in heating system hardware). Emerging solutions thus offer a promising opportunity for DSOs to mitigate network congestion and constraints.

More modern, highly efficient hot water tanks and storage devices (such as PCM) could also help the local network by reducing overall consumption at times of peak demand. This is reflected in the much higher efficiencies of these devices (compared to older models), which affords customers much lower levels of heat loss, and saving on the number of times these thermal stores need to be ‘charged’. However, if these technologies are to provide significant flexibility services to the DSO, they will likely need additional support to encourage further uptake.

Although buffer tanks are unlikely to be a key domestic thermal storage technology going forward due to their size and high cost, it may be that this is an option DSOs could consider supporting the roll out to homes where they can fit, as these technologies provide further opportunities around thermal storage and hence larger potential to reduce peak load.

The increasing ‘smartness’ and connectivity of these electric heating loads provides a large opportunity for this increase in peak demand to be avoided or at least softened. However, most emerging propositions that utilise this smartness optimise according to ancillary or wholesale market signals rather than for the benefit of the local network. The benefits from these propositions are shared with customers through sharing revenue, providing a cheaper tariff, via an upfront cost saving, through improved control or through providing a guaranteed outcome (such as a set level of heat). However the way these propositions impact electric heating operation profiles will largely follow operation under a dynamic ToU tariff (such as the profile below) or more unpredictably if providing ancillary services to the ESO.

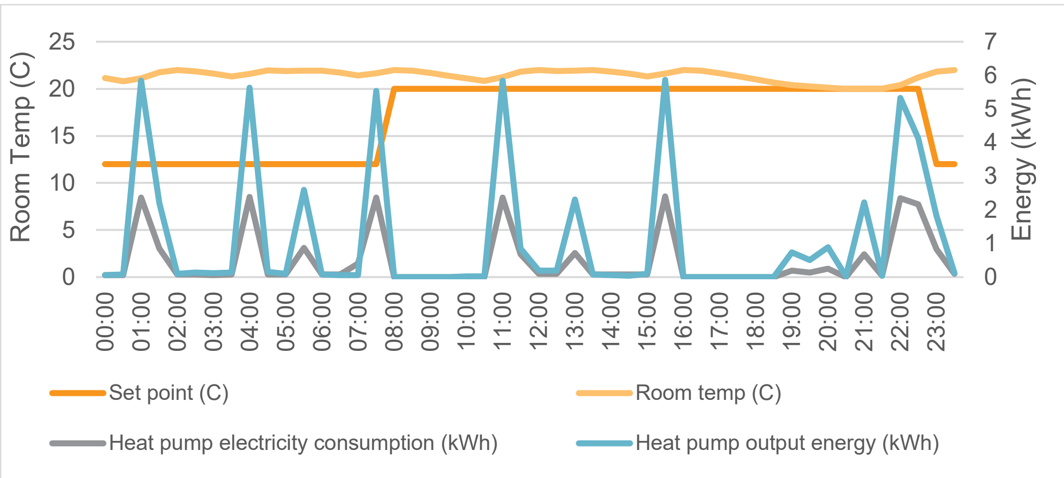


Figure 2. Average February weekday ASHP consumption profile on agile half-hourly tariff (source: Delta-EE & Passiv Systems, 4D Heat project, 2020)

Figure 2 shows how a heat pump is likely to operate on a dynamic ToU tariff – here the Agile tariff from Octopus Energy. Under this tariff the heat pump avoids consuming at peak rate times when the wholesale electricity price is high and when DUoS charges are high (which in this example is between 8am and 10am and 4pm and 7pm), and instead overheats the room overnight to allow reduced power consumption later on at morning peak, 'topping up' heat during cheap morning periods before morning peak, and ramping up just before 4pm to allow reduced power consumption thereafter during evening peak. For a heat pump, it is much more efficient to maintain a steady room temperature rather than allowing the temperature to drop and then ramping up for the high demand period. The heat pump will also take advantage of short periods of very low and negative pricing – spiking to boost temperature during these periods. Both factors go towards explaining why in the above figure, you see 'spikey' heat pump activity during the overnight period.

The tendency of flexibility propositions so far to follow wholesale market or ancillary service market signals (and follow a profile like the one above) may not favour the local distribution network positively. Indeed, in highly constrained areas of the local electricity network, there may be instances where optimising against these values streams (at the national level) may cause problems for the DSO at the local level. If, for example, customers are within constrained areas of the network and the ESO or supplier is sending signals to the heat pump to turn up (reacting to weather or system shock events) during the evening peak, this could cause challenges for the DSO. There may be conflict between national needs and DSO needs when for example nationally the system is long (more generation than demand – e.g. in instances of high wind) and there is high local demand. With increasing load on the local network via rising numbers of electric vehicles and heat pumps, these potential conflicts will likely be exacerbated and could cause new problems for the local network. For example, high levels of EVs/HPs reacting to a dynamic tariff such as the one above risks creating new overnight peaks, or peaky demand on either side of current morning/evening peaks. New constraints may also be created if an aggregator wants to dispatch a large amount of load (responding to wholesale or ESO market signals for example) outside of traditional DUoS/E7/E10 tariff windows.

Flexibility propositions focused around providing services to DSOs using heating assets on the LV network are still at an embryonic stage (beyond some existing services provided by some storage heaters), and price signals / markets are not yet developed enough to make these propositions viable. To ensure that domestic heat flexibility is being used to mitigate rather than exacerbate peak demand impacts for the DSO, DSOs will need to clearly communicate their local needs – likely via a mix of distribution charges, new flexibility tenders, bilateral contracts, overriding opposing signals if needed and, after half-hourly settlement is introduced, by establishing or working with a local energy market using price signals.

1. Introduction

This report aims to provide a 'landscape' of technologies and mechanisms that could be deployed by 2030 to help deliver low carbon electric heating.

1.1. Project scope

This is the second work package (WP) in the Peak Heat project. Peak Heat is helping WPD understand the impacts of electric heating loads and domestic thermal storage on the electricity network, and the role that flexibility could take in helping to mitigate network impacts. The project fits within WPD's innovation strategy to understand the demands and usage of heat pumps and other technologies particularly in the following areas:

- Usage patterns and profiles of Heat Pumps - understanding the impact of significant Heat Pump integration on the network;
- Flexibility of heat demand - how and when can heat load be shifted through flexibility to manage network loading whilst providing the required service for customers.

This WP characterises the range of domestic electric heating and thermal storage technologies that could be or will likely be deployed, as well outlines the ways in which these technologies may be used flexibly. In this way, this WP feeds into subsequent work packages and helps to support the broader aims of the Peak Heat project, which are to help WPD understand the impacts of electric heating loads and the role that flexibility (including thermal storage) could take in helping to mitigate network impacts. Specifically, the work undertaken in the other WPs and interaction with the work completed in WP2 is summarised as follows:

- WP1 – Identifies the study areas of WPD's network for the project and characterises the housing stock into representative house archetypes, to be used in the modelling (WP3&4) as representative house types that typify the broader domestic building stock. WP2 feeds into this WP by providing data on which areas of WPD's network are likely to see high electrification.
- WP3 – Simulates house archetypes to identify their heat demand profiles and heat loss factors during average winter and '1-in-20'[2] peak winter conditions. Both daytime occupancy and non-daytime occupancy profiles will be explored, allowing the most suitable of these profiles to be applied in each of the study areas. The heat demand will then be used to determine the electricity demand profiles for the different archetypes by taking into account the efficiency of the different technologies as well as the impacts of thermal storage. The efficiencies and performance assumptions of different technologies under varying conditions as identified in this report will be used to inform those used in WP3, as will the types of control strategies, potential for using certain

[2] A peak weather event that statistically is predicated to occur one in every 20 winters.

technologies flexibly and likely operation profiles of technologies when used with more dynamic tariffs or business models.

- WP4 – Takes representative mixes of house archetypes and combines them with information on network typologies and heat pump (and thermal storage) uptake rates (as provided by WP2) to allow their aggregate impact on network infrastructure to be identified under different temperature and flexibility scenarios.

The report therefore provides some key metrics for these technologies which will inform the flexibility potential associated with them:

- Technical / performance characteristics
- Applicability / suitability to different house types & sizing
- Potential uptake
- Technical potential to be used flexibly.

It also looks at the emerging approaches / mechanisms being used with these technologies to provide more flexibility, and how these may impact their operation.

1.2. Technologies covered in this report

In line with WPD's innovation strategy, the focus will be on heat pumps as the key technology/heat source within this project, with domestic thermal storage also being key as this offers significant potential for flexibility.

Technologies covered in this report include:

Electric heating:

- Air source heat pump (ASHP) - high & low temperature
- Ground source HP
- Hybrid HPs – described at a higher level as their impact on the network will likely not be as great as other technologies since during cold periods of peak heating demand, the boiler element will be the main source of heating.
- Direct electric – described at a higher level as they offer limited opportunities to be used flexibly.
- Storage Heaters – described at a higher level as these are not the core focus for other parts of the project.
- Other novel solutions – e.g. Tepeo, Caldera (covered at a higher level, as their uptake is unlikely to be significant or applicable to the domestic sector before 2030)

Thermal storage:

- Domestic hot water (DHW) tanks / cylinders
- Smart hot water tanks
- Buffer tanks
- Phase Change material storage
- Building thermal inertia
- Underground energy storage

Flexibility approaches:

- Control requirements for flexibility for above technologies
- Static and dynamic time of use tariffs
- Novel business models or propositions that may incorporate very different control strategies for above technologies

1.3. Structure of this report

The report is structured as follows:

Chapter 2 gives an overview of the likely pathways for decarbonising heat, highlighting key trends in the UK heating market, typical heating system arrangements in UK homes, and the opportunities / ‘threats’ to the development of the low carbon electric heating market.

Chapter 3 looks at the heat pump landscape, outlining key technical characteristics of different heat pump types, their applicability / suitability to different house types and summarises their potential uptake.

Chapter 4 follows a similar structure to chapter 3 but focuses on the different types of domestic thermal storage – their applicability/suitability and sizing in different house types and potential uptake.

Chapter 5 looks at a higher level at other competing (and more novel) electric heating technologies and summarises their potential uptake, technical characteristics and ways in which they are / could be used for flexibility.

Chapter 6 outlines key flexibility approaches used with domestic electric heating and thermal storage, summarise their potential uptake, and look at ways in which these approaches impact the operation of these heating technologies.

2. The potential for decarbonising heat

This section looks at existing heating systems in the UK today and the potential options for decarbonising heat. In some scenarios, indicators point towards a future with high levels of electrification and heat pump uptake, increasing demand on electricity networks.

2.1. Domestic heating in the UK

Energy efficiency, heat pumps, heat networks, hydrogen and biomethane could all play a vital role in the decarbonisation of heat, with different solutions applying to those on and off gas grid. The route taken to decarbonise heat will influence, and be influenced by, the development of electricity and gas networks. For example, increased heat pump uptake will likely require reinforcement of electric networks; while hydrogen uptake for heating will mean the gas grid must be adapted to transport hydrogen.

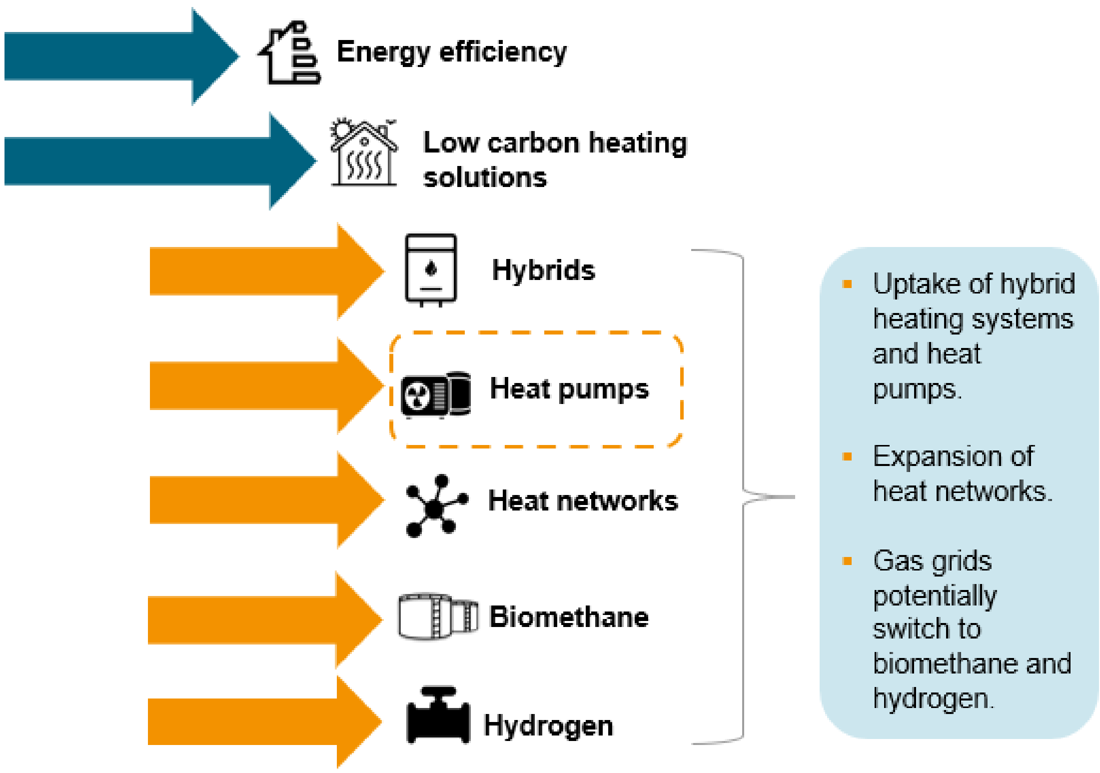


Figure 3. Range of heat decarbonisation options

There is still a high level of uncertainty around what role different solutions will play, and there are many different potential pathways for long-term decarbonisation. These vary around:

- 'Electrification' – most gas boilers switch to heat pumps.
- 'Green gases' – hydrogen or biomethane replace natural gas.
- A 'balanced' approach where both play a role.

Through shutting down coal power generation and growing wind capacity, the UK grid has decarbonised fairly quickly. Currently natural gas accounts for the majority of power generation, supplemented by nuclear, renewables and imports.

Renewables account for around 25% of electricity generation, the majority coming from centralised biomass. Interconnectors with neighbouring countries currently total around 5GW (France, Netherlands, Belgium and Ireland), and are planned to more than double in the next 5 years.

Construction of a major new nuclear site by EDF Energy has begun; but it would be very ambitious to expect it to be commissioned until the latter half of the 2020s. A ban on onshore wind has led to a stalling of growth from new renewables – and the lifetime of the current nuclear fleet being extended.

Biomethane will have a small role, as ambitions for biogas in the UK are lower than in e.g. France – where there is a clearly defined target to grow its use in the gas grid by 2030. Nevertheless, it is accepted that this will have a small part to play in the UK (albeit with no specific target).

It is currently unclear whether hydrogen will be deployed, when exactly that might happen, whether its use will extend to domestic heating or be limited to transport / industrial applications, and if it will be used at a national level or limited to certain regions. Nevertheless, hydrogen could form the basis of a decarbonised gas grid in the UK. It is seen as a credible option to decarbonise significant parts of the gas grid, with the UK and Scottish Governments and the Welsh Assembly all keen to support a growing evidence base on to what degree hydrogen should feature.

UK Gas Distribution Network companies (GDNs) are driving interest in hydrogen for heat as it allows decarbonisation of heat while protecting their business and avoiding stranded pipeline assets. In addition, hydrogen boilers are viewed by the traditional heating industry as possibly the least disruptive method of decarbonising heat from a customer perspective.

BEIS is currently funnelling £100m into hydrogen for heating through schemes like Hy4Heat to fund hydrogen appliance development, prove the safety case and understand infrastructure requirements. However, it is believed that BEIS will have to make a decision before 2025 whether to greatly increase funding for hydrogen for heating in order to meet its net zero targets for the heating sector.

2.2. Typical heating system arrangements in UK homes today

The UK gas network is one of the most extensive in Europe, developed from the 1960s following the discovery of North Sea oil and gas reserves.

Over 80% of UK homes (~24 million) are heated by gas boilers running on natural gas and 6 - 7% of these (more than 1.5 million) are replaced each year. A growing share of gas heating systems use "combi" boilers, where domestic hot water is generated by the boiler instantaneously when required. Combi gas boilers gained popularity (also coinciding with the ban on non-condensing gas boilers in the mid-2000s), mainly due to less space constraints and availability of more efficient models on the market. Older gas heating systems are more likely to have “system” boilers, where hot water generated by the boiler is stored in a tank/cylinder until it is needed. The hot water cylinder might also be equipped with an electric immersion heater which prevents the water temperature from falling too low.

There are also over a million UK homes with oil (system) boilers supplied by oil stored in a tank outside the home. Because these homes are not connected to the gas grid, electrification is the preferred decarbonisation option. It has been estimated that over 90% of off-gas homes are technically suitable for electric heating without improved insulation (Delta-EE, 2018).

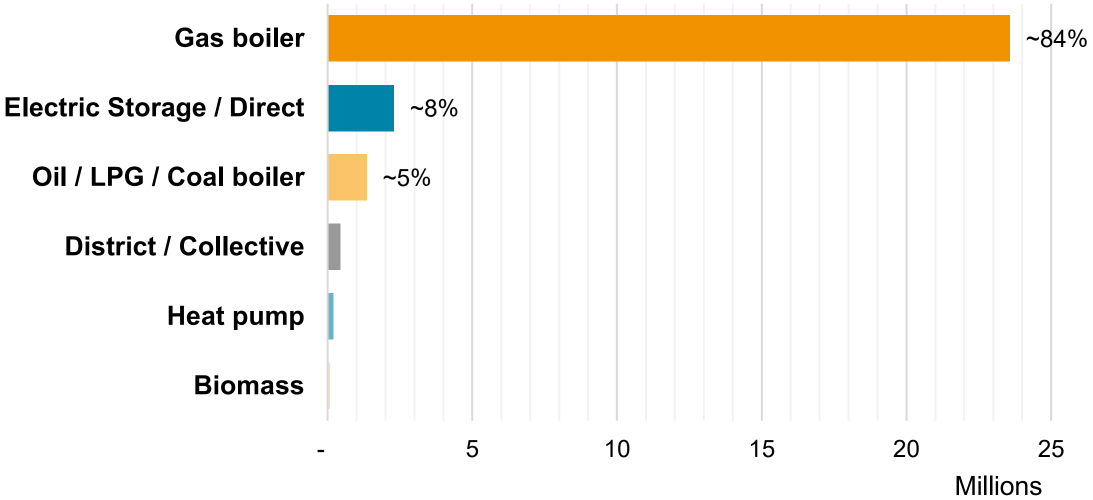
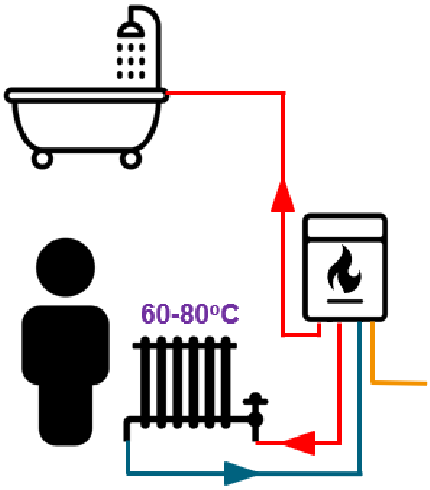


Figure 4. Heating systems in UK homes, 2017, (Sources: English, Scottish and Welsh Housing Surveys, ADE, EHPA, Delta-EE)

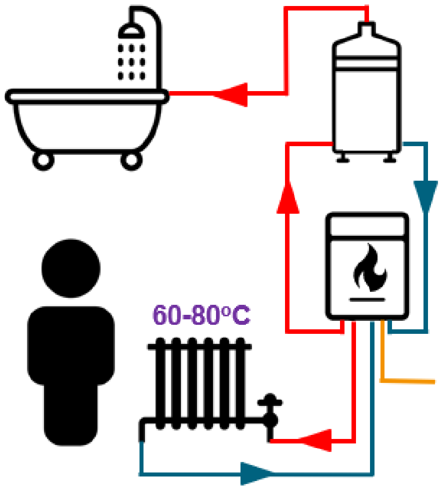
Gas "combi" boiler:
~12 million homes & rising



- small, wall-hung boiler
- small, hot radiators
- hot water made on demand

60%-90% efficient

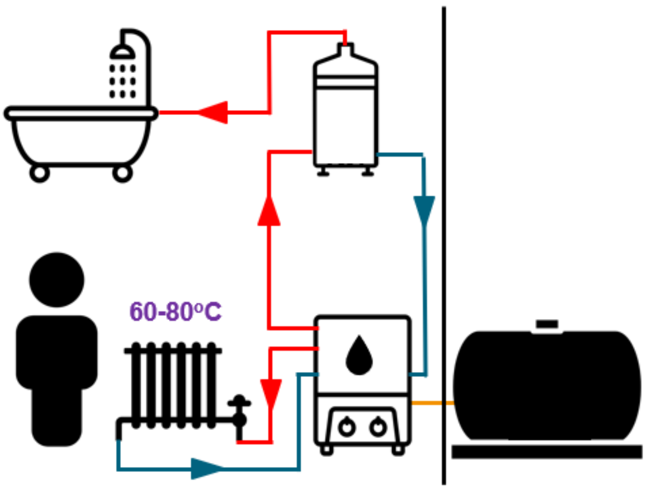
Gas system boiler:
~12 million homes, slowly decreasing



- small, wall-hung boiler
- small, hot radiators
- hot water stored (need space for a tank)

60%-90% efficient

Oil system boiler & oil tank:
~1.4 million homes (remaining ~steady)



- larger, floor-standing boiler
- small, hot radiators
- hot water stored (need space for a tank)
- oil tank outside the house

60%-90% efficient

Figure 5. Typical heating system arrangements in UK homes today (Source: Delta-EE)

2.3. Electric Heating Systems currently installed in the UK

Heat pumps account for only ~1% of household heating systems, with just over 200,000 heat pumps installed in the UK today (see Figure 4). The new build sector is key for hydronic heat pumps. A hydronic (or wet) heating system utilizes heated water to distribute thermal energy throughout a building. All ground source (GSHP) and the majority of air source (ASHP) heat pumps are hydronic systems (see Figure 6 below). For more detail on heat pump types and how they operate, see Chapter 3.

Registered social landlords account for over a third of hydronic heat pump sales annually (across both retrofit and new build). About 97% of electric hydronic heat pumps are installed in off-gas homes, mainly replacing oil or LPG boilers while 60% of hybrid heat pumps are installed in off-gas homes, and 40% in on-gas homes.

High-end new build housing is the main application for air/air heat pumps, to counteract potential overheating. Air/air heat pumps (another type of ASHP but with a warm air output) are typically cooling-led, but all units installed in the UK can also provide heating. A small number of single-split air/air systems are being retrofitted into homes, usually to provide cooling for specific rooms/areas (e.g. bedrooms and conservatories).

About ~1.4 million homes across GB have storage heaters (English and Scottish House Condition Survey (2018)). Retrofitting like-for-like replacements accounts for over 95% of annual storage heater sales. The majority of these units are installed into off-gas grid areas, especially in social housing.

Replacement of older direct electric systems still accounts for the majority of electrically-driven heating sales. Some are also installed as supplementary heating. Direct electric heating is increasingly being installed in small new build multi-family homes (MFHs) (despite higher running costs), due to the lower thermal demand in new build homes, low capital cost and ease of installation and use.

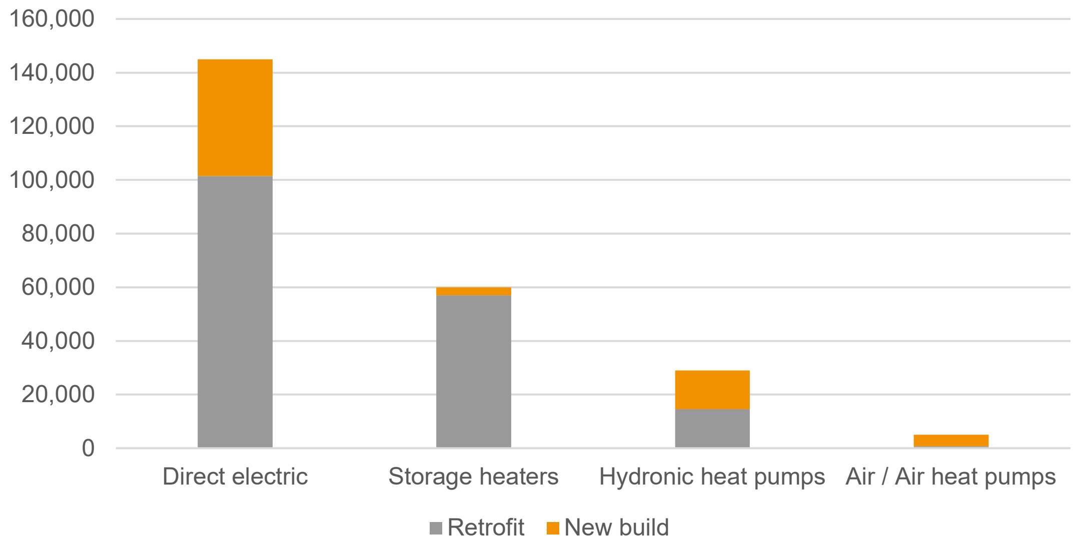


Figure 6. UK electric heating annual sales in 2019 by technology and end-user segment. Source: (Delta-EE, 2021)

2.4. Key future trends in the UK heating market

As shown in Figure 6, there were around 29,000 heat pumps installed in the UK in 2019 (roughly equally split between new build and retrofit). Future growth will be largely driven by building regulations and government subsidies.

Two important policy indications towards increasing electrification of heat in the UK are the Future Homes Standard and the recently announced 10 Point Plan:

2.4.1. The Future Homes Standard

The 'Future Homes Standard' will be introduced in England in 2025 – effectively driving out individual fossil fuel heating from new build.

- In January 2021, the UK government confirmed that the much discussed 'Future Homes Standard' (FHS) will be introduced from 2025. The new standard will require a reduction in annual CO_2 emissions of 75-80% compared to homes built today and means the vast majority of new homes built in England after 2025 will be built without individual fossil fuel heating.
- Electrically driven heat pumps will probably become the most used source of primary space heating in new homes after 2025 – although other low carbon solutions, including district heating (and possibly even some direct electric heating) will probably also be eligible. Biomethane – and 'green hydrogen' – could also potentially qualify, depending on their assumed carbon intensities (and availability).

Current new build regulations for England (Part L) are also being strengthened in 2021, as an interim step towards the FHS.

- The Government has chosen to implement the higher of their two proposed options, i.e. a 31% reduction in CO_2 over current levels, which will be introduced later in 2021. This is likely to boost sales of electric heat pumps – and hybrid heat pumps – in the coming years, as some builders find them more cost effective than the alternative options (condensing gas boiler + solar PV + other measures) to meet regulations.
- The Government has decided to retain the fabric energy efficiency standard (FEES), meaning minimum levels of insulation similar to today will still need to be included in new homes.
- The "transitional arrangements" on new build are being tightened, to speed up the rate at which house builders must comply with the new rules.
- Local planning authorities will still be able to set higher standards than national building regulations if they wish. (the consultation on the FHS had suggested withdrawing this ability).

At the same time, the Government has launched a new consultation which proposes changes to existing homes to make them "low carbon ready".

- In the new 'Future Buildings Standard' (FBS) consultation, there is a proposal to mandate that when replacing parts of a "heating system" (i.e. the heating appliance plus part of the distribution system – the radiators and/or pipework) in an existing home, the new system must be designed to operate at 55°C flow temperatures.
- This change in designed flow temperature will mean a) condensing boilers will operate more efficiently and b) the distribution system is suitable for use with a low carbon heat

source, e.g. a heat pump or a district heating connection in the future - essentially making the home "renewables ready".

2.4.2. UK's '10 Point Plan'

The UK government's '10 Point Plan for a Green Industrial Revolution' was announced in 2020.

Key elements of the plan:

- Increased implementation of heat pumps to decarbonise buildings, with an ambition for 600,000 HPs to be installed per year by 2028. This represents a 20x increase from current sales of around 30,000 / year.
- The 10 Point Plan also aims for:
  - Increased use of hydrogen for heating, with an aim for a town 'equivalent to tens of thousands of homes' to be heated entirely by hydrogen by 2030 (see Section 2.7.1.).
  - Additional funding and support to make buildings 'more energy efficient'
  - The Heat and Buildings Strategy - which will likely have further information on government proposals for tackling emissions from existing homes, especially those 'off-gas' - will be published in 2021.

The Future Homes Standard (and changes to Part L in England building regulations) will be an important contributor towards the UK achieving its stated aim of 600,000 heat pump installs per year by 2028 – as announced in the "10 Point Plan" published in autumn 2020. But even if all new homes switched to heat pumps (which would not account for other solutions such as district heating), significant inroads need to be made in retrofit if the aim is to prove achievable.

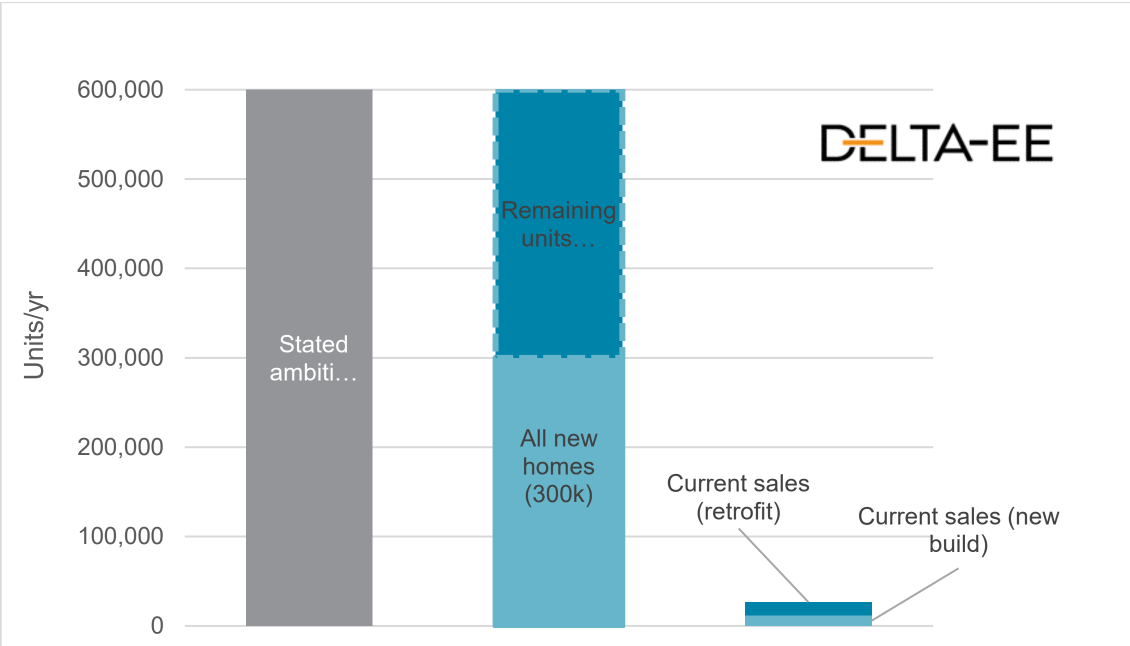


Figure 7. Where might 600,000 heat pumps be installed in the UK in 2028? (Current sales relate to 2020 data) Source: (Delta-EE, 2021).

Delta-EE's view (making up the 'Central Scenario') is that UK sales could exceed 120,000 heat pump installations per year by 2025 – largely in new build (~90,000). This is based on current support and market conditions for heat pumps in the UK and known likely policy developments. By 2028, this could be 200,000-250,000 per year – short of the 600,000 per year aim, but an almost 10-fold increase on current levels. This ~250,000 by 2028 would be split more evenly between new build and retrofit (~140,000 and ~110,000 respectively). Achieving these levels of growth will require significant investment in upskilling installers, from government and industry.

Key drivers making up this projection include:

New build:

- Part L introduced from late 2021 boosts installations
- Future Home Standard introduced in 2025, with full effect seen in in 2027, leading to <1% of new homes in 2027 getting a gas connection and a large share of new homes having HPs installed (although a portion are also assumed to receive district heating or direct/storage electric heating).

Retrofit:

- Some heat pumps which would have been installed in the owner-occupier segment in 2021 and 2022 under (the now scrapped) Green Homes Grant instead are installed under the Local Authority Delivery (LAD) scheme, but overall numbers are lower.
- Sales dip a little in 2022 due to the end of LAD and moving from Domestic Renewable Heat Incentive (to 2022) to Clean Heat Grant (CHG), which helps to grow the market in 2023 and 2024.
- The government have talked of introducing a 'market mechanism' in 2024 but little other information on this. However, we have assumed it stimulates some faster growth from 2024.
- From 2027, the rate of growth rises again as social housing providers begin installing more HPs to help meet the government's goal of all social homes to be EPC band C by 2030.
- From 2028, an introduction of a ban on new oil boiler sales (currently ~100,000/year) leads to an extra ~65,000 annual sales of HPs. The remainder of these oil boiler sales are substituted by repairs or biomass boiler installs. This will likely impact old rural dwellings running on oil fired heating first.
- The Future Buildings Standard (FBS) proposal to mandate when replacing parts of a 'heating system' (i.e. the heating appliance plus part of the distribution system – the radiators and/or pipework) in an existing home, the new system must be designed to operate at 55 deg C flow temperatures. This change in designed flow temperature will mean a) condensing boilers will operate more efficiently and b) the distribution system is suitable for use with a low carbon heat source, e.g. a heat pump or a district heating connection in the future, essentially making the home "renewables ready". We assume this has the effect of, long term, slightly boosting HP sales.

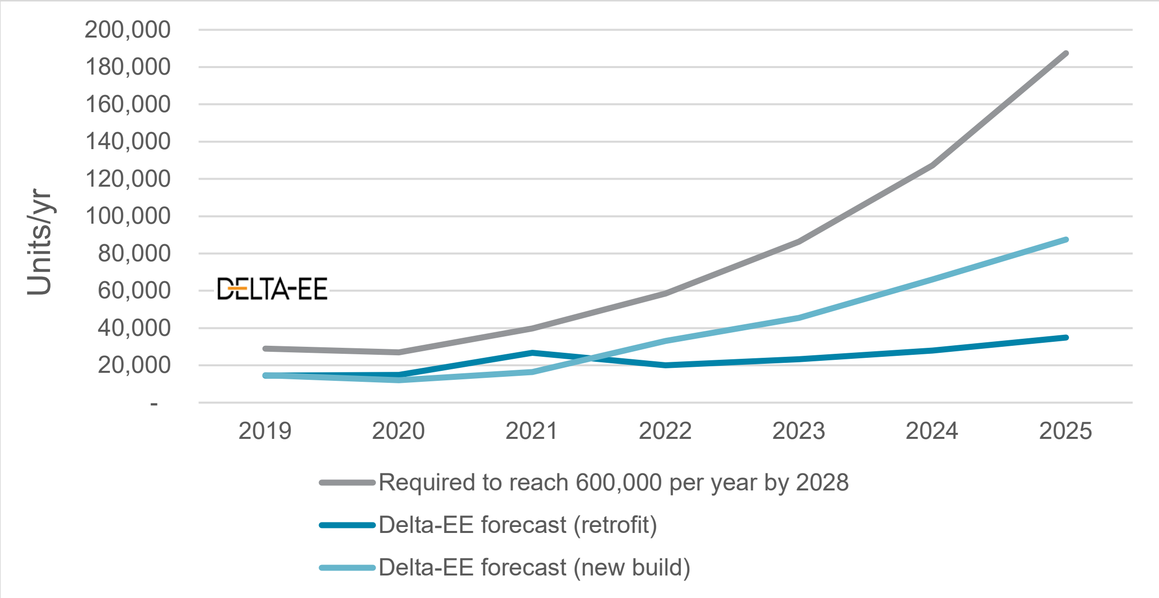


Figure 8. UK heat pump forecasts (new build & retrofit) showing effect of introduction of new Part L in 2021, and ramp-up in activity towards Future Homes Standard in 2025. Grey line applies additional drivers to meet government stated ambitions.

Forecast numbers could be higher than assumed here, if:

- Awareness and appeal of HPs among owner occupiers somehow rises.
- CAPEX of HPs is significantly reduced.
- More upfront financial support is provided (e.g. CHG value is raised above current proposals of a flat £4,000 per install)
- HP OPEX vs alternatives is reduced (e.g. if retail energy prices were adjusted so OPEX of electric HPs is lower than gas boilers; or if flexible dynamic tariffs plus HPs as a proposition is widely taken up).
- The government 'market mechanism' proves more effective in stimulating HP uptake than assumed.
- More action is taken in fuel poor homes (via a new scheme) and/or social homes.
- More innovative propositions or financing mechanisms emerge.
- A big (and successful) market push by market player(s), with an attractive proposition.
- In new build, if more housing providers start installing HPs between 2022 and 2025 in preparation for Future Homes Standard.

2.5. Cumulative uptake (installed base) of HPs to 2030

Taking the assumptions outlined above on the potential and likely ramp up of heat pump installations, and accounting for key drivers in the sector, the installed base (cumulative installs) in both new build and retrofit could reach over 1.6 million units across the UK in 2030. As shown in Figure 9 below, the majority of these will continue to be air source (air to water – a/w) heat pumps.

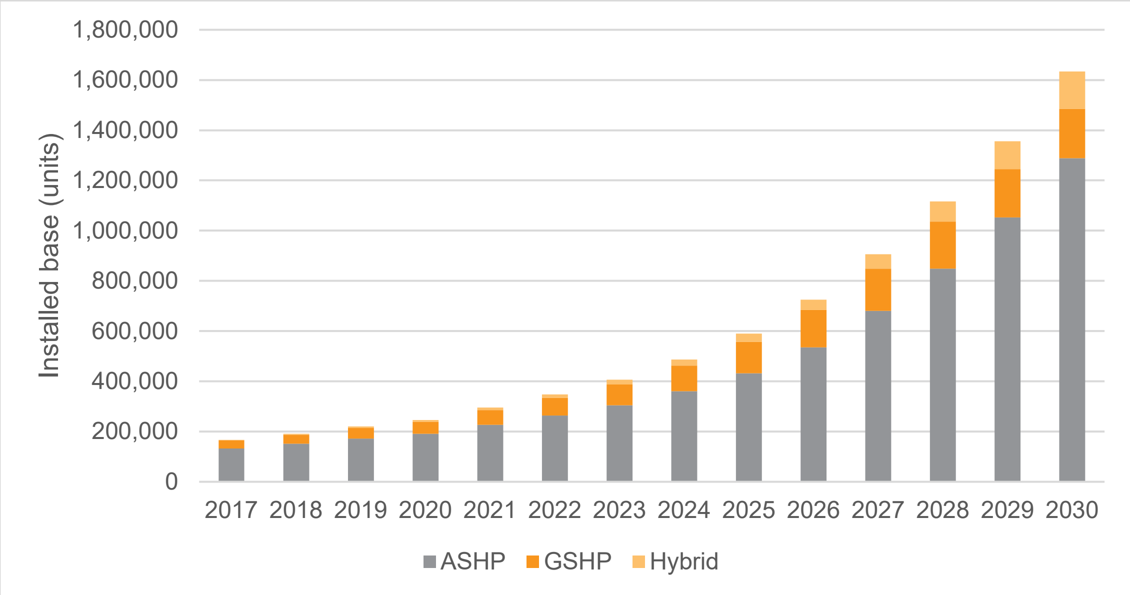


Figure 9. UK heat pump installed base 'Central' forecast (source: Delta-EE, 2021)

Delta-EE's projection for HP uptake on WPD's network is lower than the expected HP uptake by 2030 compared to some of the more ambitious 2020 Future Energy Scenarios (FES) from Regen, with Western Power Distribution's (WPD's) most ambitious Distribution Future Energy Scenario (DFES) estimating ~1.6 million units installed on WPD's network alone (see Figure 10). The reasons for the differences between these projections is as follows:

- Delta-EE's 'Central' scenario is based on considerations around the existing and future housing stock and assessing the likely future impact of announced policies (not including government 'ambitions') on both new build and retrofit properties as outlined in section 2.4.2. This outlook is also based on current levels of awareness and appeal of heat pumps, CAPEX not significantly reducing and OPEX not significantly reducing vs other alternatives.

- We have also included a scenario in Figure 10 that includes many of the same drivers but with these adjusted so that the government's ambition of 600,000 heat pump installs per year is by 2028 is achieved, and what this would likely look like on WPD's network.

- The two highest uptake scenarios (Consumer Transformation (CT) and Leading the Way (LTW)) assume very rapid customer adoption of new technologies, with consumers highly engaged in acting to shift to electric heat pumps (i.e. much higher consumer awareness and appeal). Both scenarios also assume earlier decarbonisation of off-gas grid properties (2026).

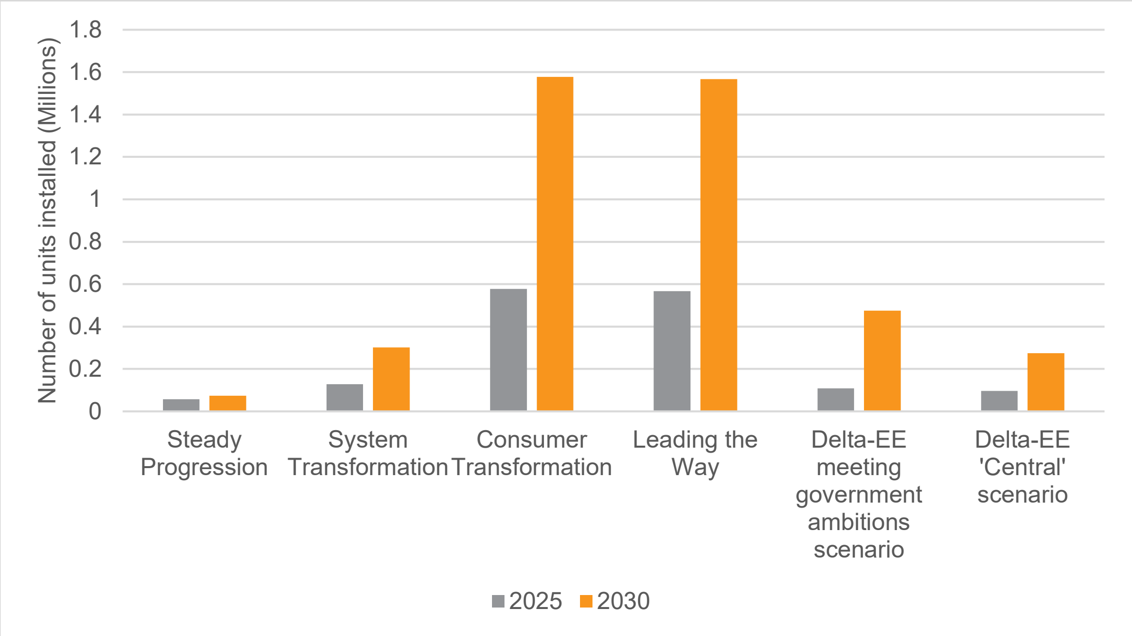


Figure 10. WPD DFES and Delta-EE scenarios for heat pump uptake on WPD's network (Regen for WPD, 2020)

The wider Peak Heat project will look to identify the potential for domestic flexibility (with a focus on heat pumps) on WPD's network. We want to give a range of possible values, including what might be the impact of flexibility under a scenario for highest potential heat pump uptake (a 'worst case' scenario), as well as the potential for demand reduction for a lower heat pump uptake (one could argue more realistic) scenario. For these reasons, the two scenarios that will be taken forward and form the basis of heat pump uptake in subsequent modelling will be the Consumer Transformation (CT) and System Transformation (ST) DFES.

As can be seen from Figure 10, CT to 2030 has very similar uptake to that of Leading the Way (LTW), however CT sees a larger impact from domestic heat pumps on the distribution network (both in terms of peak demand and annual energy demand), due to differing assumptions between scenarios (e.g., LTW assumes higher and faster energy efficiency and insulation improvements to homes). CT therefore provides a good 'worse case' uptake scenario for WPD. ST is also chosen as a lower uptake scenario as, as can be seen from Figure 10, it is most similar to Delta-EE's expectation of reality (Delta-EE's 'Central' scenario). The advantage of using ST over the Delta-EE Central is that the DFES ST scenario is already broken down to the primary substation level on WPD's network, and so can be more easily linked up with and used alongside other data.

2.6. Segmenting the UK building stock by opportunity for electric heat

Key target segments for ASHP are new build homes and large off-gas grid houses (often replacing oil/LPG). Registered social landlords (RSLs) account for over a third of hydronic heat pump sales, across both retrofit and new build. Sales have been rising in recent years in these key end-user segments but are constrained by a number of factors including a lack of awareness and understanding among end-users, and their high capital costs.

- **Hybrid heat pumps** sales are growing in both new build and retrofit markets. Sales are shifting from the majority as add-on retrofit in off-gas homes, to packaged products in on-gas new build, especially in Scotland. However, the economics are currently not yet attractive enough for many customers due to the high spark spread (difference in wholesale cost between gas and electricity).

- **Ground source heat pumps (GSHPs)** are most often found in off-gas, rural homes, where they bring most financial benefit, and they continue to be installed particularly in new build single family homes (SFHs) in these areas**.** GSHPs with a shared loop system are also used for multiple properties and are well-suited to social housing. The costs for GSHPs are being driven by the costs for the development of the ground-source system, with horizontal collector systems at the lower and vertical boreholes at the higher end of the range. Typically, GSHPs are a lot higher in cost compared to ASHPs in domestic installs. This, plus the outdoor space required accounts for lower uptake.

The figure below segments the UK housing stock by primary heating fuel (mains gas, electricity and oil/LPG) and type of home:

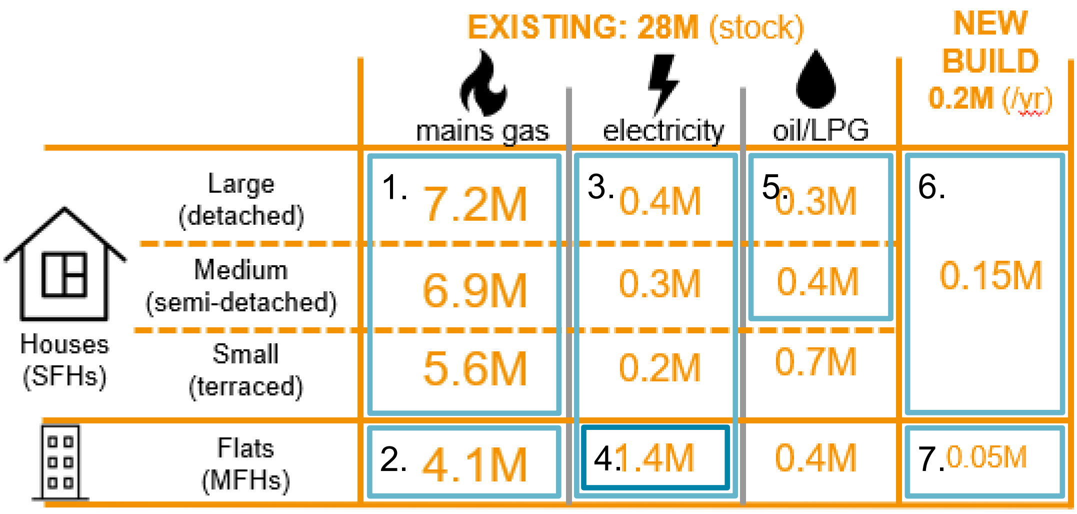


Figure 11. Segmenting the UK building stock

The table below indicates for the housing segments in the above figure, what are the most appropriate low carbon heating technologies for each house type (the house type ‘key markets’), and the current market size (replacements / new installs per year) and growth potential for these technologies in each of these housing segments:

Table 1. Segmenting the existing UK building stock by opportunity for electric heat

Home type (number in stock)	Key market for:	Current market size (systems/yr)	Growth potential (CAGR 2018 – 2025)	Additional info
1. Existing homes (SFHs) on mains gas (19.7m)	Gas hybrid heat pumps	1,000 – 10,000	20 – 30%	Marginal opportunity, replacing gas-only boilers
2. Existing gas-heated flats (4.1m)	Direct and storage electric heaters, shared ground-loop GSHP	10,000 – 50,000	0 – 5%	Small opportunity displacing gas boilers, especially in privately rented and RSL* properties (1.7m)
3. Existing electric-heated homes (2.3m)	Direct and electric storage heaters	>100,000	0 – 5%	Large replacement market, especially among RSL properties (0.4m)
4. Electrically heated flats (1.4m)	Air/air HPs	<1,000	>30%	Small opportunity, displacing direct/storage electric
5. Existing larger oil/LPG-heated homes (0.7m)	Hydronic HPs	1,000 – 10,000	0 – 5%	Good opportunity for replacing oil/LPG boilers
6. New build homes (~0.15m/yr)	Hydronic heat pumps, direct electric and storage electric heating	10,000 – 50,000	>30%	Huge opportunity post 2025
7. New build flats (0.05m/yr)	Air/air HPs, direct and storage electric	10,000 – 50,000	5 – 10%	Large opportunity post 2025

*Registered Social Landlords

2.7. Key 'threats' to electrification of heat

2.7.1. Hydrogen

Hydrogen deployment in the UK is unlikely to have a large impact on WPDs network planning in the short term with the impact on electric heating uptake being relatively small. However, if H_2 become a major heating solution with mass market deployment of H_2 boilers connected to a repurposed gas network, then it could be a serious threat to deployment of electric heating in the longer term, and have a large impact on future electricity network demand forecasting. For the purposes of this research, whilst government is explicitly aiming for mass market pure H_2 heating by 2030, this will likely still be at very low levels or restricted to small, localised areas.

Figure 12. UK government milestones as set out in the Ten Point Plan for a Green Industrial Revolution (Department for Business, Energy & Industrial Strategy, 2020)

The soonest the first homes will have household appliances fuelled entirely by hydrogen will be 2023 and, as the above figure shows, the scaling up of this to the village then potentially to a town level (tens of thousands of homes) will not occur until later this decade. These first homes are set to be built in Low Thornley, Gateshead (well outside WPD's licence area), and it is likely that the scaling up will also occur in the local area.

Even within scenarios for very high uptake of hydrogen for heating homes, such as National Grid's 'Steady Transformation' (the most 'hydrogen heavy' scenario – with over 17 million hydrogen boilers installed in homes by 2050), significant uptake is not expected to be seen until post-2030, as shown in fig. 13. below:

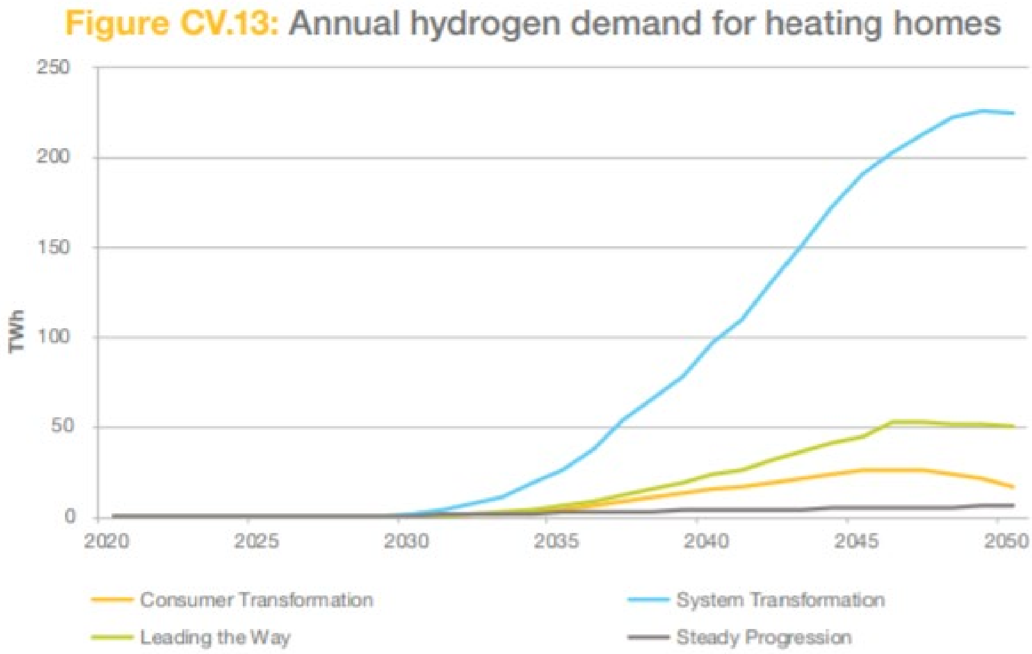


Figure 13. Annual hydrogen demand for heating homes under the 2020 FES (National Grid ESO, 2020)

Specific areas within the gas distribution system will need to be isolated and moved over to hydrogen in coordinated actions. This area-by-area rollout of hydrogen was considered in detail by the H21 projects and would involve the conversion of 3.7 million domestic metering points over 7 years between 2028-2035. This conversion would happen sequentially, with high pressure parts of the network being converted first.

Although it is too early to say whether hydrogen will become the preferred solution for decarbonising heat beyond 2030, electricity network operators need to consider the implications this would have for investing in network upgrades in the short term. Strategies for this interim period will have to ensure that sufficient capacity is available to meet increasing demand from the electrification of heat, while avoiding expenditure on what could become stranded assets if the widespread use of hydrogen halts the uptake of heat pumps.

2.7.2. District heating

Only a fraction of UK homes are heated by district/communal heating systems today, though these may be preferred over individual heating systems for new builds/retrofits in densely populated urban areas. District/collective heating systems are most commonly fuelled by gas, but there is potential for more of this heat demand to be met by heat pumps in future. This could have localised effects on the need for network reinforcement. There is also the possibility that these systems could provide flexibility to electricity networks at a larger scale.

The Committee on Climate Change estimated in 2015 that with government support, heat networks could provide 18% of heat demand by 2050 in a least-cost pathway to meeting carbon targets. Government initiatives in this respect have included the Heat Networks Delivery Unit (HNDU) and the Heat Networks Investment Project (HNIP) which have provided financial support and guidance to the developers of networks. BEIS also launched the February 2020 consultation 'Heat Networks: Building a Market Framework', which set out options for regulating the market in order to enhance consumer protections, whilst supporting market growth. In the

March 2020 Budget, the Chancellor of the Exchequer announced £270 million of new funding for a Green Heat Network Scheme to enable new and existing heat networks to adopt low-carbon heat sources. This is set to launch in January 2022.

2.8. Summary of the opportunities and threats for electric heating uptake in the UK

The opportunities and threats discussed for electric heating uptake in the UK are summarised the table below. Changes to Part L of the new build regulations for England will be the key driver of increased heat pump uptake in the short term. The longer term outlook for heat pumps depends mainly on whether hydrogen proves to be a more viable solution for decarbonising the UK's large on-gas sector of the residential building stock.

Table 2. Summary of key future heating trends in the UK market, implications for electric heating and potential timescales

Key trend	Implication for electrically-driven heating	Likelihood (out of 5)	Scale* (+ve / -ve)	Short term (next 2-3 yrs)	Longer term (>3yrs)
(Effective) ban on fossil fuel boilers in new build homes from 2025	Could make electric heating the standard technology in all new builds from 2025	4	++++	New build regs strengthened	Implemented from 2025 (see section 2.3)
Growing need for flexibility in the UK electricity system	An emerging opportunity for electric – and hybrid – heating technologies to provide residential demand response	2	++	Trials, early commercial offerings	Commercial offerings becoming mainstream, mid 2020's onwards
Rise of service-based offerings e.g. Heat as a service (HaaS)	Could open up a wider share of the market to high-cost technologies (e.g. heat pumps), and generate ongoing revenue for providers	2	++	Trials, early commercial offerings	True HaaS offerings likely to emerge post-2025
Growing desire for cooling	Increases the desirability of air/air HPs	4	+	High end new build houses & retrofitting single splits	Becoming more mainstream, e.g. VRF in MFH**
Hydrogen as an option to decarbonise on-gas homes	If widely adopted, could reduce future opportunities to electrify the on-gas sector	2	- - - -	Trials and evidence-gathering	Policy action (see 2.7.1)

- * Scale = number of homes likely to be affected, ** MFH = multi-family homes (flats).

2.9. Impact of findings, relevance, and recommendations for WPD

The direction of heat decarbonisation to 2030 is likely to be one of high heat pump uptake. The government's 10-point plan, with the ambition for 600,000 heat pumps to be installed in the UK per year by 2028, will be one of the key drivers behind this rapid increase. Delta-EE's view is that a more realistic projection (based on current support and market conditions) could see 200,000 – 250,000 heat pumps installed per year in the UK by the end of the decade (although this will still require significant investment and upskilling within the industry).

Scaled down to WPD's network, Delta-EE's projection of cumulatively installed HPs ('Central' scenario) is low (~270,000) vs some WPD DFES scenarios (such as Consumer Transformation – which sees ~1.6 million installed). Unconstrained (and without assuming reductions in co-incident peak demand), an uptake of the magnitude outlined in the Consumer Transformation scenario could result in around an additional 4.8GW demand at peak. In subsequent modelling in the wider Peak Heat project, we will look to use both of these scenarios as 'upper and lower bounds' of heat pump uptake to ascertain a range of potential demand reduction levels when flexibility measures are applied. As the System Transformation DFES scenario has similar outcomes to Delta-EE's expectation of reality (Delta-EE's 'Central' scenario), but also has advantages over Delta-EE's Central scenario as it is already broken down to the primary substation level on WPD's network, System Transformation DFES will be taken forward as the lower bound scenario.

It is essential that WPD's network can, where appropriate, accommodate this predicted increase in heat demand (no matter the scale of HP uptake) to ensure that the network does not pose a barrier to adoption of low carbon heat. However, it is also not yet clear the extent to which this impact can be mitigated through using these heat pumps more flexibly. This is a key question other parts of the Peak Heat project will look to address.

These findings will be carried forward to other parts of the project in a number of ways:

- The uptake of heat pumps and other electric heating technologies across the different outlooks will inform the scenarios that are tested in the network modelling for work package 4. These uptake scenarios will form the 'baseline' or the potential for maximum demand on WPD's network, and flexibility approaches will be applied to these demands to ascertain the potential reduction at peak.
- The types of homes suitable for electric heating technologies, and the likely split of heat pump uptake between different parts of the UK building stock, will help inform how and where this electric heating is modelled in other work packages.

3. Heat pump technical characteristics

The section outlines key technical characteristics of different heat pump types, their applicability and suitability to different house types, and summarises the ways in which they could be used for flexibility.

3.1. Heat pump introduction

This chapter brings together the key information for heat pumps that can be used to inform the wider study on what the potential for flexibility may be with heat pumps.

Several key factors will be important to consider when looking to understand the potential flexibility available from homes heated with a heat pump. These are:

- The efficiency of the heat pump and its performance under certain conditions – this is covered in section 3.4.
- The type of home the heat pump is installed in and how the heat pump has been sized for that home – this is covered in section 3.5.
- The technical potential for heat pumps to be used for flexibility – this is covered in section 3.6.
- The kinds of control strategies used with heat pumps (driven by different business models / pricing propositions) – is looked at in more detail in Chapter 6.

There are various factors that can influence the efficiency and the flexibility of a heat pump installation, mostly by affecting the flow temperature that the system requires at a given temperature, but also through an increased need for cycling (switching the HP on and off). These can be grouped into three overarching categories:

3.1.1. Heat pump basics

Heat pumps use electrical energy to extract heat from the surrounding environment (air, ground or water) to provide space heating and hot water.

Temperature lift, or delta T (ΔT), is the difference between the outdoor temperature and the flow temperature in the heat distribution system required to achieve the desired indoor temperature.

The Coefficient of Performance (COP) is the ratio between heat output to energy input. A COP of three for example means that for each unit of electricity which the HP consumes it provides 3 units of heat to the building, by “pumping” two units of energy from the lower to the higher temperature level.

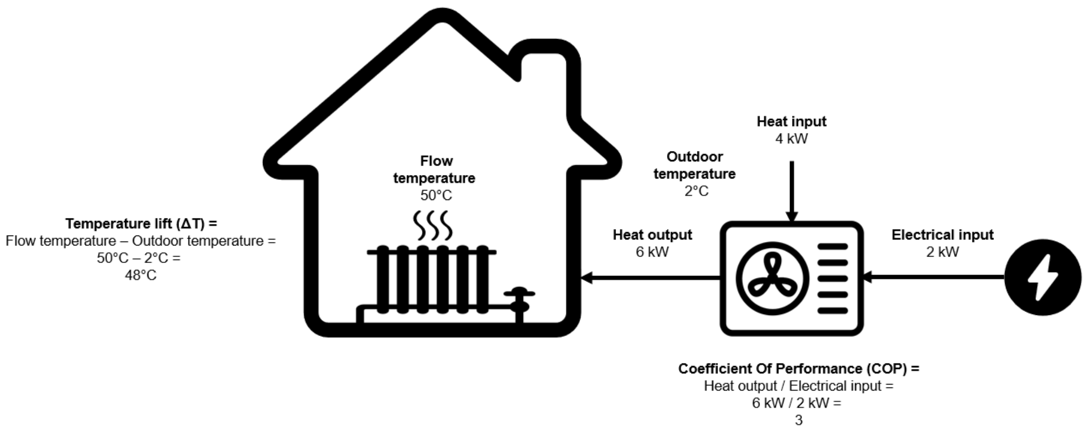


Figure 14. Heat pump coefficient of performance and temperature lift

3.1.2. Technical efficiency and control strategy

As with all products, there are more and less performant heat pumps. Based on a comparison of the current top runner product with the averaged performance values over a range of products, an increase in technical efficiency of at least 15-20% seems technically feasible, but currently only at the expense of higher product costs. The control strategy can help to reduce the temperature lift, by foreseeing weather compensation, as well as through reducing the need for cycling the heat pump.

3.1.3. Building suitability

The suitability of a building for a heat pump installation is probably the single most important factor influencing the temperature lift and therefore the performance of the heat pump on the coldest day of the year.

The thermal performance of a building is a measure of how effectively it retains heat, and hence how much heat must be supplied to the building to maintain a desired temperature level. Thermal performance is generally correlated with building age, with older properties being less well insulated and losing heat more quickly.

Hydronic heating systems distribute heat by circulating heated water through pipes to heat emitters (e.g. radiators or underfloor coils). Hydronic heating systems can be classified as either high temperature systems or low temperature systems. The flow temperature through the heat distribution system affects the size of the heat emitters needed to deliver the required heat output. High temperature systems operate at flow temperatures of up to 80°C and can therefore work with heat emitters of a relatively small surface area. Low temperature systems operate at temperatures of up to 55°C and need larger radiators (or underfloor heating) to transfer the same amount of heat.

At a given heat emitter surface area, more insulation also allows for lower flow temperatures, as less heat needs to be transferred into the building at peak times.

Heat pumps operate more efficiently at lower flow temperatures. Heat pumps therefore perform and "fit" best in well-insulated buildings with hydronic underfloor heating and oversized radiators (with low flow temperatures) and are poorest in non-insulated buildings with smaller size radiators (with high flow temperatures).

3.1.4. Sizing and design

The sizing of the heat pump and the design of the installation can have an important influence on the overall performance of the system. Heat pumps which are designed too small for their building will need to run on higher temperatures to meet the building's heat demand, and they will rely more on the direct-electric back-up heater in order to heat the building. Air source heat pumps (ASHP) and ground source heat pumps (GSHP) with lower flow temperatures will need larger radiators to sufficiently heat a space. Installation of these units may therefor require changes to the distribution system (radiators and pipework).

3.1.5. Commissioning

The proper commissioning of the heat pump is another very important factor for the heat pump's efficiency. Optimising the heating curve, domestic hot water temperature and legionella prevention cycles for the needs of the building and user can be crucial for the performance of the system.

The Energy Saving Trust (EST) carried out a field study to monitor the performance of residential heat pumps between 2008 and 2013. The study took place in two phases to determine the actual performance of heat pumps installed in UK homes. It found that design and installation quality have a very significant impact on how efficiently a heat pump performs (Energy Saving Trust, 2013) with some poorly performing units having COPs approaching 1 in some conditions (i.e. no more efficient than direct electric heating).

3.1.6. Temperature settings and domestic hot water use:

The user behaviour can influence the heat pump performance. Higher room temperatures require higher flow temperatures to reach them.

3.2. Summary of the heat pump types covered in this report

There are several different types of heat pumps. The types covered in this report are:

- Air source heat pumps (ASHP);
  - Low temperature air source heat pumps;
  - High temperature air source heat pumps;
  - Hybrid air source heat pumps;
- Ground source heat pumps (GSHP); and
- Heat pump water heaters.

3.2.1. Low temperature air source heat pumps

An air-source heat pump uses electricity and energy from the outside air in order to supply heat to a building. They can be either 'split' set-ups, or 'monobloc' set-ups (see section 3.3. on typical heating system arrangements with heat pumps).

The seasonal conversion efficiency of electricity to useful heat is around 250-300% in the UK, as the heat pump extracts 1.5 - 2 units of energy from the outside air for every unit of electricity it consumes.

This is subject to seasonal changes, as the outside temperature affects the heat pump's ability to extract energy. The higher the outside temperature, the more energy the heat pump can extract per unit of electricity it consumes. Daily efficiencies will therefore vary.

A low temperature heat pump, as defined in this project, reaches flow temperatures of up to 55°C (this is the temperature of the water leaving the heat pump, which feeds the space heating & hot water circuits). The key factor for the heat pump's efficiency is the difference between the heat source (in this case the outside air) and the flow temperature it has to achieve. Buildings requiring lower flow temperatures (e.g. well insulated buildings and new builds) will therefore achieve higher seasonal conversion efficiencies.

3.2.2. High temperature air source heat pumps

High temperature air source heat pumps have the same key functionalities as low temperature versions (and like low temperature, can either be 'split' or 'monobloc' set-ups – see section 3.3).

The main difference to a low temperature air source heat pump is that high temperature heat pumps can achieve higher flow temperatures of up to 80°C and are optimised to do so.

Their seasonal efficiencies (if required to run at these high temperatures) will nevertheless be lower than those of low temperature systems.

The current market for high temperature HPs is niche (2 – 5% of total air source heat pump sales). High temperature heat pumps may be more suitable for retrofit to existing homes as they can be used with existing high temperature distribution systems (e.g. existing radiators).

3.2.3. Hybrid air source heat pumps

A hybrid air source heat pump is the combination of a low temperature air source heat pump and a fossil fuel boiler (gas or oil), which is controlled by a single, intelligent controller.

The main advantage of hybrid heat pumps is that the controller allows the heating system to switch between fuel sources (i.e. to use the boiler, or the heat pump, or both parts) based on the efficiency of the system under current circumstances (e.g. outdoor temperature, flow temperature, etc.). This can be combined with other information, such as energy prices or carbon emissions, to optimise the operation of the system as a whole.

In general, this will mean that the boiler will take over from the heat pump during very cold periods (when the efficiency of the heat pump part falls).

Hybrid heat pump systems offer the potential to reduce and even remove the electric heating load on '1 in 20' peak days (a peak weather event that statistically is predicated to occur one in every 20 winters – this is an established measure used throughout the gas industry for forecasting peak gas demands) through switching to 'boiler only' mode (using gas for heating, rather than electricity). This however requires controls in hybrids to be configured to enable this, and price signals to be provided to drive this mode of operation. The conventional operation regime using a switch-over temperature will promote this operation, but alternative optimisation methods may allow operation of the HP at lower temperatures if viable (such as under very low electricity price conditions).

3.2.4. Ground source heat pumps

Similar to air source heat pumps, ground source heat pumps use electricity to make renewable energy, in this case from the ground, using either vertical boreholes or a horizontal collector.

From a depth of 10-15 meters the temperature of the ground is stable at around 10°C throughout the year. Due to this higher and more stable source temperature, ground source heat pumps are more efficient than air source heat pumps.

Ground source heat pumps are more expensive than air source heat pumps to install due to the high costs linked to developing the ground source boreholes or surface collectors. However, because the temperature difference between the ground and the indoor set point is smaller, the seasonal efficiencies are higher and therefore they have lower running costs.

3.2.5. Heat pump water heaters

These are air source heat pumps, but do not provide space heating, only DHW.

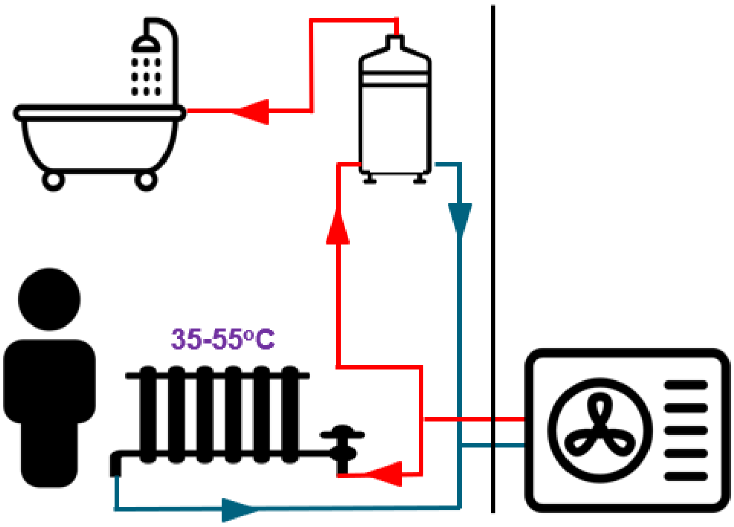
A heat pump water heater is more efficient than an electric water heater because it absorbs heat from the outside air and then uses electricity to circulate that heat, ultimately transferring that heat into the water.

These are suitable to replace less efficient electric storage water heaters in existing buildings, though only a small proportion of buildings in the UK have this type of system.

3.3. Typical heating system arrangements with a heat pump

For ASHPs, the terms ‘monobloc’ and ‘split’ refer to how the system is required to be set up in a home. A monobloc is similar to a combi boiler and is a single block system where the heat pump has all of its components (aside from the hot water cylinder) located inside a heat pump unit installed outside the house. This set up is shown diagrammatically in Figure 15. A monobloc system tends to be easier to install.

Air/water heat pump - monobloc



- larger, cooler radiators (vs. gas boiler system)
- hot water stored
- outside heat pump unit (medium-large)
- hot & cold water travelling through wall

250% - 350% efficient

Figure 15. Typical heating system arrangements with a heat pump – monobloc (source: Delta-EE)

As shown in Figure 16, a split heat pump unit has both an internal unit (usually incorporating the hot water cylinder and installed in a boiler/utility room) and an outside unit (which has a heat exchanger and refrigerant). A second heat exchanger (condenser) allows the refrigerant coming back into the house to release the heat into the heating system for the house (air blower, floor heating or radiators). Split systems are generally more complex to install but can give more installation flexibility as the outdoor unit can be installed up to 30m away from the home. Monobloc systems do not require someone with F Gas qualifications to get involved in the use of refrigerants, installation of a split system requires a refrigerant technician to connect the copper line sets and ensure correct working. However, as there is no water in the outdoor components of a split system, it is generally resistant to freezing and thus more suited to very cold climates. In the UK, in general monobloc heat pumps are cheaper than splits.

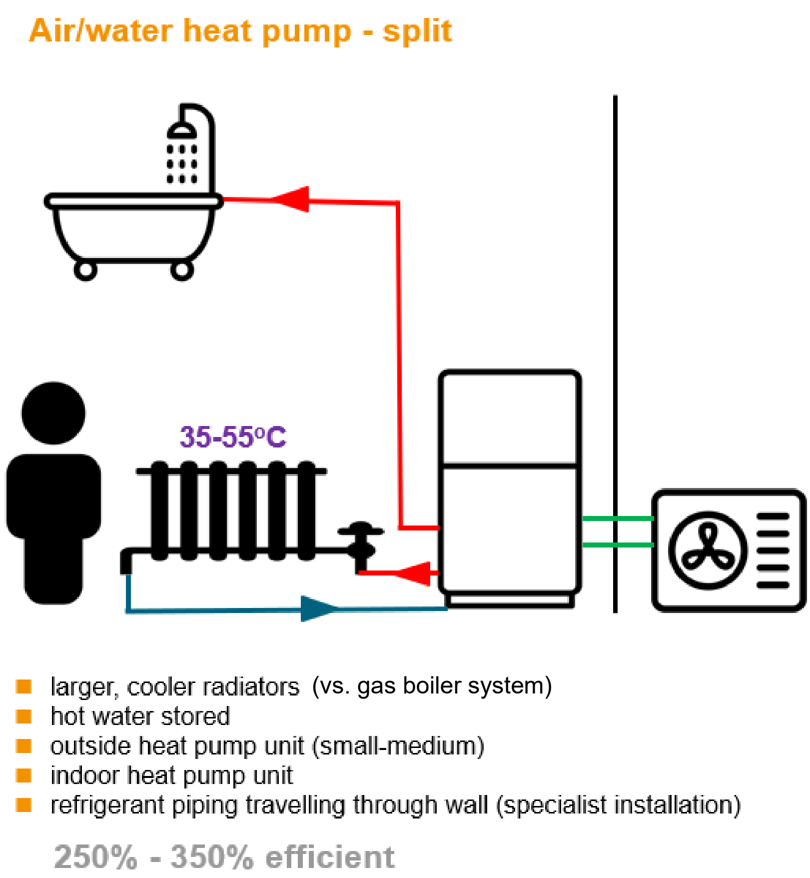


Figure 16. Typical heating system arrangements with a heat pump – split (source: Delta-EE)

Figure 17. shows the typical system set-up of a ground source heat pump – showing the necessary outdoor space required for the groundloop (restricting this type of system to larger homes with outdoor space).

Figure 18. compares the two kinds of set ups you can find with a hybrid heat pump installation – both with combi and system boiler configerations. As this shows, these systems can be used with exisiting small-medium warm-hot radiators and therefore could have more appeal to less well insulated retrofit homes.

Ground source heat pump

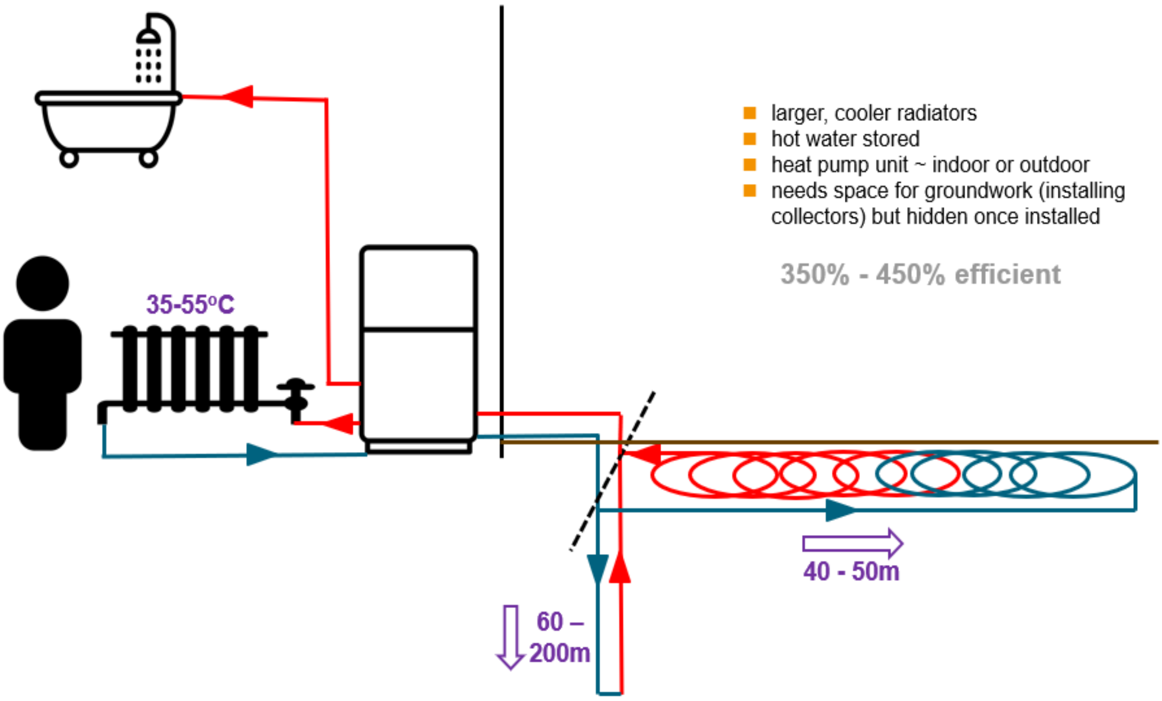
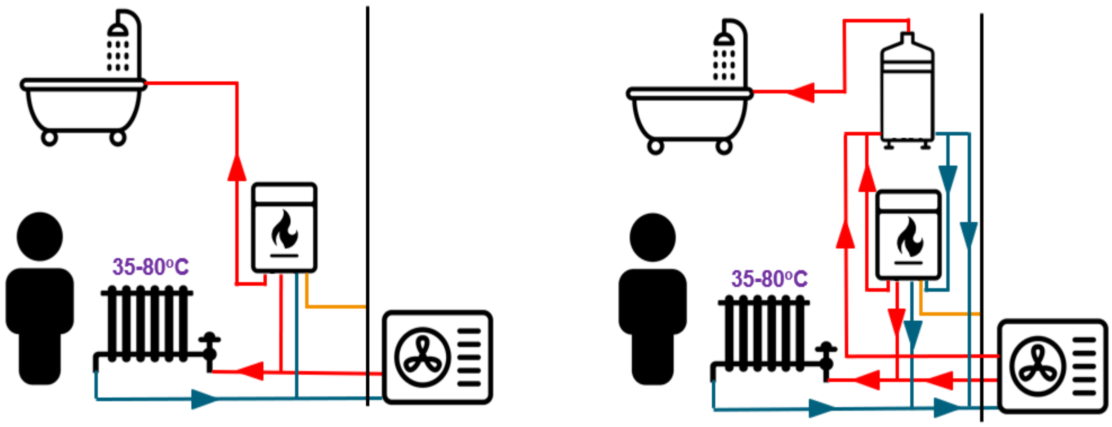


Figure 17. Typical heating system arrangements with a heat pump - ground source (source: Delta-EE)

Hybrid heat pump (with combi boiler)

Hybrid heat pump (with system boiler)



Hybrid heat pump (with combi boiler):

- small, wall-hung boiler
- small-medium, warm-hot radiators
- hot water made on demand
- small-medium heat pump unit outdoors (and maybe indoors, too)

~300% efficient

Hybrid heat pump (with system boiler):

- small, wall-hung boiler
- small-medium, warm-hot radiators
- hot water stored (need space for a tank)
- small-medium heat pump unit outdoors (and maybe indoors, too)

~300% efficient

Figure 18. Typical heating system arrangements with a heat pump - hybrid systems (source: Delta-EE)

3.4. Heat pump key operational characteristics summary

3.4.1. Coefficients Of Performance (COP)

Coefficients Of Performance (COP) are measured steady state efficiency values. To obtain them HPs are tested in accredited test laboratories against the requirements of a measurement standard. As the tests only provide rated efficiencies of a product at a set of pre-defined, steady state temperature levels, only the technical efficiency of different HPs can be compared. Other factors, e.g. the control strategy, are not taken into account by these measurements.

SCOP: The Seasonal COP is a calculated seasonal efficiency of a HP. It is obtained by using the COPs obtained in the laboratory tests to calculate the seasonal efficiency of a HP in different climate zones. As both the calculation and the test methodologies are standardised, these values can be used to compare the technical efficiency of different heat pumps.

The below graph gives average lab test performance COPs from a range of prominent heat pump models. It shows a strong correlation between outdoor temperature and HP COP. This means that as outside temperature decreases, the efficiency of heating decreases. The flow temperatures examined here represent the likely range of temperatures seen across different systems. As UCL analysis identified via taking data from 700 heat pump installations, ~45°C was the mean design flow temperature, 34% of those sampled had those of ~35°C, and 17% had design flow temperatures of 50-60ºC. (UCL Energy Institute, 2017)

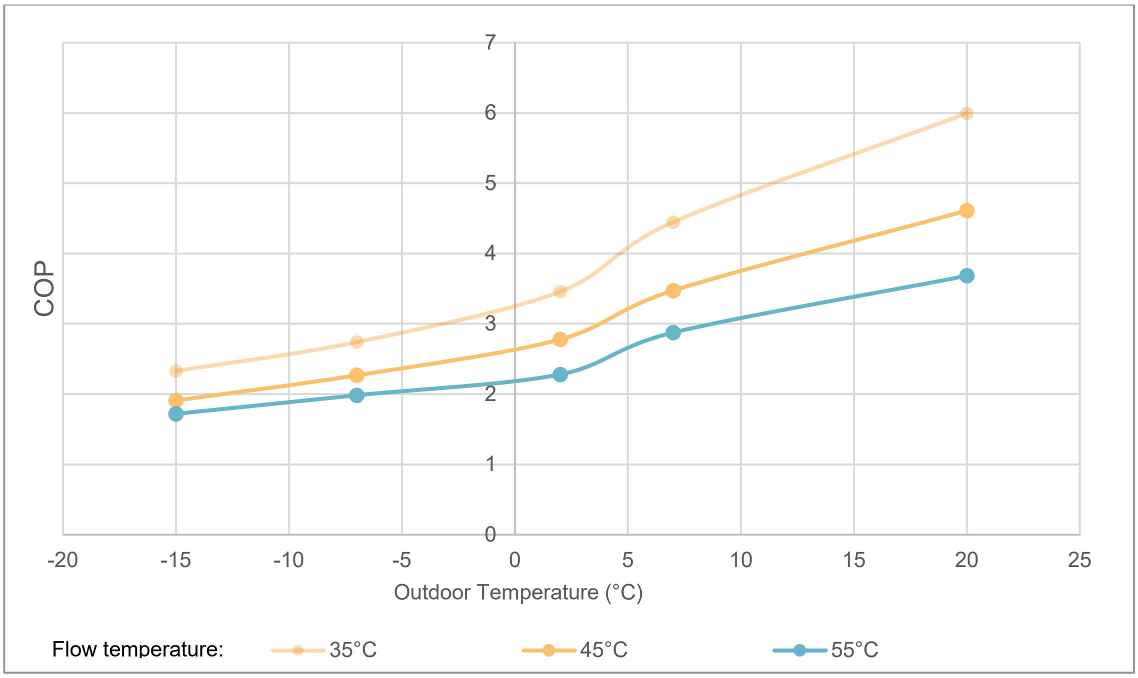


Figure 19: Average Coefficients Of Performance (COP) for ASHPs in the range of 6-10kW at various flow temperatures

As the above graph indicates, the main variable that affects the efficiency of an air source HP is the difference between the outdoor temperature and the heating system flow temperature level (ΔT, or temperature lift). The higher the temperature lift, the lower the efficiency of the HP.

The temperature lift is dependent on the variation in outdoor temperature through the year, and on the variation in flow temperature that is required to heat a building. As the outdoor temperature cannot be influenced, the flow temperature is therefore the main vector to improve a HP's performance.

Many industry experts agree that the in-situ performance of heat pumps is often below the manufacturer reported data, with measures under ideal steady-state laboratory conditions being practically difficult to achieve (Toronto Atmospheric Fund, 2015) (Staffel, 2012). The COPs reported in the table below give a conservative assessment of the maximum electric demand of heat pumps in very cold weather and could be used to assess the highest possible power demand of a heat pump. These 'worst case' COPs were calculated by taking the maximum operational current rating of various heat pumps and converting this to a kilowatt rating (by multiplying by 230 volts; e.g. 13A x 230V = 3kW). The COP was then calculated as the maximum heat pump output divided by the equivalent maximum power draw e.g. for a heat pump with a maximum thermal output of 6kW the COP calculation is 6kW thermal / 3kW max current draw = 2.0 COP. The maximum draw is excluding any immersion or booster heaters, as the heat pump is assumed to have been correctly sized without the need for supplementary direct electric heating.

These worst case COPs (as well as the above range of COPs expected under different temperatures) will be used in subsequent modelling to check that modelled HP COPs under very cold conditions are within a reasonable range of these (and thus operating as would be expected under real conditions).

Table 3. 'Worst case' COPs calculated based on maximum thermal output and maximum current draw (Delta-EE, 2018)

Heat pump type	'Worst case' COP
Low-Temperature ASHP	1.65
High-Temperature ASHP	1.45
Low-Temperature GSHP	2.33
High-Temperature GSHP	1.70

3.5. Heat pump applicability / suitability

3.5.1. Building suitability factors / physical fit

The suitability of a building for a heat pump installation is probably the single most important factor influencing the temperature lift and therefore the performance of the heat pump on the coldest day of the year. Houses heated with radiators require higher flow temperatures than houses heated through underfloor heating, as the surface area of the heat emitters is smaller. At a given heat emitter surface area, more insulation also allows for lower flow temperatures, as less heat needs to be transferred into the building at peak times. Heat Pumps therefore perform and "fit" best in well-insulated buildings with underfloor heating (very low flow temperatures) and are poorest in non-insulated buildings with radiators (very high flow temperatures).

Depending on the type of heat pump system considered, not all homes will be suitable for installation. For example, air source heat pumps will require suitable outside space for an outdoor unit, while ground source heat pumps will require outside space for drilling a hole for vertical ground loop or a large space for laying a horizontal ground loop. In most cases, space for a hot water storage tank will be required internally.

Other factors considered that influence the suitability of different types of heat pumps for different house types are:

- Available space inside the dwelling for hot water tanks & internal units.
- Available space outside the dwelling for external units or for ground loops.
- Availability of gas connection – a gas connection is required for hybrid heat pumps with a gas boiler to be deployed.
- The density of housing. Rural vs urban locations can be used as a proxy for the density of housing.
- Choice of high temperature (HT) versus low temperature (LT) ASHP depends on the age of the dwelling and the type of distribution system installed.

Table 4. Summary of suitable heat pump options for different home types:

Home type	Example home(s)	Suitable HP options	Commentary / rationale
Less efficient, high temperature homes with (smaller) radiators	1950s semi-detached 	ASHP HT	Houses with radiators require higher flow temperatures
More efficient, low temperature homes with underfloor heating and/or large radiators	New build semi-detached 	ASHP LT	Well-insulated with underfloor heating require lower flow temperatures
Large, detached homes with plenty of space, plus well-insulated	New build detached. 	GSHP / ASHP LT	Space available for laying coils / digging borehole
Old, less efficient, high temperature homes with limited space and existing gas connection	1900s mid-terrace 1930s and 1950s semi detached 	Hybrid HP (with large capacity HP needed for detached homes) (possibly ASHP HT)	Can replace existing boilers without amendments to the heat distribution system
Homes with space outside	Detached/semi-detached properties	HP water heater	Needs space for drawing in exhaust air which is rare in UK properties

3.5.2. Sizing

The sizing of the heat pump and the design of the installation can be an important influence on the overall performance of the system. Heat pumps which are designed too small for their building will either need to run at higher temperatures to meet the building's heat demand, and/or they will need to rely more on the direct-electric back-up heater in order to heat the building.

Heat pumps have a comparatively lower kW output than conventional options (boilers), so it is necessary to ensure that the heat pump is sized correctly against the property heat loss. Property heat loss is calculated by measuring all of the building fabric and ventilation heat losses for the coldest day of the year based on geographical location. Property data used to calculate this include areas of the walls, floors, roof, windows and doors and their associated thermal efficiencies or U values (U-value is the rate of transfer of heat through a structure - which can be a single material or a composite - per 1 Kelvin, units $W/m^2.K$). A heat pump will be 'fit' for a property based on its kW rating compared to this calculated kW heat loss of the building, ensuring the kW rating of the heat pump is higher than the heat loss capability of the building to ensure comfort.

Other factors going into this calculation include:

- Type/size of property
- Level of insulation/heat loss
- Size of radiators/underfloor heating
- Desired indoor temperature
- Seasonal outdoor temperatures in the respective area

Below we give some 'rule of thumb' estimates for heat pump sizing based on the size and type of property. One must keep in mind however that there is no fixed size guide, and for proper sizing full room-by-room heat loss calculations are necessary.

Table 5. General 'rule of thumb' estimates for sizing different heat pump types (source: Delta-EE research / industry views)

Technology	'Rule of thumb' sizing methodology / physical fit factors
ASHP LT/HT	■ 2 bedroom house/flat: 5kW ■ Poorly insulated 3 bedroom house: 9kW ■ Well insulated 4 bedroom house: 9kW ■ Poorly insulated 4 bedroom house: 16kW ■ Well insulated 5 bedroom house: 16kW
GSHP	■ For 1kW of heat output a ground area of approximately 50 m^2 is needed. An 8kW heat pump will need $400m^2$. ■ A $200m^2$ four-bedroom house is likely to need an 8kW heat pump. ■ In general, a HP sized to meet 60% of the design heating load (how much heating you need when the indoor and outdoor

Technology	'Rule of thumb' sizing methodology / physical fit factors
	temperatures are at the winter design levels) is likely to meet 85 – 95% of the annual heating energy requirement.
Hybrid HP	■ For hybrid heat pumps, the heat pump element needs to be sized to cover the usual winter scenario, whereas in the case of '1 in 20' scenario the gas boiler will take over the operation. ■ The capacity of the HP typically varies from 3kW to 15kW in hybrids currently on the market designed for domestic use. The capacity required depends on both the heat demand of the house, & the proportion of that demand the HP should meet. The majority of hybrids are designed for the hot water demand to be met completely – or mostly – by the boiler.
HP water heater	■ The water heater's first hour rating is used to select the most suitable size. The first hour rating is the number of gallons of hot water the heater can supply per hour (starting with a tank full of hot water). This depends on the tank capacity, source of heat and the size of the heating element.

3.6. Heat pump flexibility potential

Heat pump operation can be '*flexible'* if its operation can be interrupted (i.e. switched off) for periods of time during the day, or if the timing of its operation can be moved to other times of the day.

The three main factors enabling heat pump flexibility are the building's insulation, its thermal mass and the capacity of any existing buffer tanks:

Insulation: The insulation level of a building determines its rate of energy loss. The higher the insulation level of a building, the longer it will take for its indoor temperature to reduce. A HP in a highly insulated building can therefore provide reduced heat output or be switched off for a longer time than a HP in a less-well insulated building, without the inhabitants' comfort being adversely affected.

Thermal Mass: The thermal mass of a building determines how much heat can be stored in its wall, floors and ceilings by heating them up. A building with a high thermal mass will be able to retain heat and keep its temperature for longer. A high thermal mass combined with a high level of insulation is therefore ideal for enabling flexibility, as it reduces losses to the outside of the building and maintains a more stable level of comfort.

Buffer Tank capacity: The use of buffer tanks is another way to increase the flexibility a HP can provide. By heating up water in a buffer tank when it is not needed in the house, this energy can be used in the building at a later time and can avoid using the HP at peak demand times. **A buffer tank is different from a hot water tank** (used with existing gas boiler systems) **in that its purpose is designed purely to help reduce the cycling of a heat pump**. It holds a circuit of heated water, but this is 'black water' which runs only through the heating systems such as radiators and underfloor heating. This is different to a hot water tank which is designed to hold usable hot water and deliver it to taps, shower and bath when needed. See page 53 for more information on buffer tanks.

Another important factor influencing the flexibility of a heat pump is **the intelligence of its control system**. The more the control system knows and learns about the expected flexibility requirements in the near term (a few hours to one day ahead), the requirements of the occupants and the reaction of the building to specific demand response interventions, the better it will be able to optimise the use of its flexibility potential, provided it has the ability to remotely control the heat pump based on external drivers. The kind of control requirements and information needed for smart/flexible operation of the heat pump in this way are:

- The flexibility available – Heat pumps typically have some thermal storage ability which allows operation to be interrupted. However, in general there is less switching flexibility than direct electric heating.
- Most domestic HPs have integrated control systems (often OEM) for space, DHW heat demand and internal HP management. There is limited scope for external controls to replace heat demand controls – instead, the focus is on smart grid 'requests' from external controllers.
- Standard data points for flexible control - Flow or return temperature (or both) from unit to building heating circuit (including emitters). The system may use external temperature data to predict the charge requirements for later in the day. These data points should also include:
    - Outside air temperature
    - Temperature in the condenser unit
    - Compressor speed
    - Pump speed
    - Fan speed
    - Inside vs outside unit monitoring (where split)
- Technical limits - Heat pump manufacturers advise against hard turn off/on and frequent turn off/on as this is bad for the compressor.

3.7. Impact of findings, relevance, and recommendations for WPD

To minimise the cost of supporting an additional ~1.5m heat pumps on its network, WPD needs to understand:

- Where on the network heat pumps will be located;
- How much more efficiently those heat pumps can be operated to minimise demand on the network, particularly during peak periods; and
- How much flexibility there potentially is to shift when the heat pumps operate in order to limit peak demand on the network.

Location of heat pumps on the network will depend mostly on the suitability of the buildings. Since heat pumps are best suited to well-insulated properties with sufficient outdoor space, initial uptake is likely to be concentrated in new-build single-family housing developments. In contrast, heat pump uptake will probably be limited in densely populated areas with less outdoor space and poorly insulated older properties, as heat pumps work at lower temperatures, so if a home is not sufficiently insulated, this will need to be improved before installation. Heat loss through walls, roof and floors must be minimised to enable efficient operation.

Heat pump efficiency, and hence electricity demand, depends on a wide range of factors. Some of these factors cannot be controlled, such as outdoor temperature. Other factors could potentially be influenced, such as improving insulation levels to reduce flow temperature requirements, ensuring the design and commissioning are done optimally, or modifying the control strategy to avoid short cycling.

Flexibility to shift the time of demand depends on the thermal storage capacity of the system. This can be increased by adding insulation to reduce building heat loss rates, or adding some kind of heat store that can be charged during off-peak periods. Demand can also be reduced by switching to a different heating fuel, which is possible with hybrid heat pump systems. For WPD, the questions are how to incentivise the uptake of such measures, and what kind of control algorithms are needed to optimise the use of thermal storage and hybrid heating systems across the network.

4. Thermal storage

The section outlines key technical characteristics of different types of thermal storage, their applicability/suitability for different house types, summarises their potential uptake, and looks at ways in which they are/could be used for flexibility.

4.1. Domestic hot water tanks / cylinders

Domestic hot water (DHW) tanks are a mature technology used commonly with gas boilers and heat pump systems (around 9 million installed in the UK currently) to store hot water. They have an immersion electric heating element which can be used to top-up the hot water available.

4.1.1. Key DHW cylinder types

- **Direct/indirect**: With a direct cylinder, it is the cylinder itself (without an external heat generator such as a boiler or heat pump) which heats up the water using an electric immersion heater. An indirect cylinder has an immersion heater as a backup source, with the primary heat source being an external type (boiler, heat pump or even solar thermal).
- **Vented/unvented cylinders:** The traditional **vented cylinder** stores and heats up water fed directly from a tank in the loft. Gravity therefore provides a natural force in the system to transfer hot water throughout the property. The benefits of this system are that the cylinder can provide hot water to numerous rooms at a consistent level of pressure, little maintenance is required, and it is simpler to install. As these systems are the most common within UK properties, 'like for like' replacement is often the simplest/most hassle-free option for customers. One of the drawbacks is that the characteristics of this water tank can place a restriction on where the cylinder is installed within the home. Also, its dependency on the gravitational pull from the tank can have a negative impact on the pressure flow of water – resulting in different flow rates between rooms.

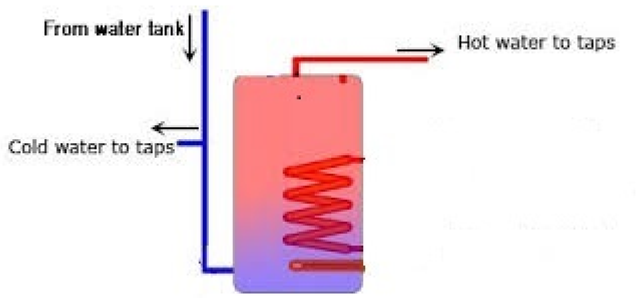


Figure 20. Vented hot water cylinder (Installers Hub, 2021)

Unvented cylinders differ in that they provide mains pressure hot water directly from the cold mains as opposed to tank pressure water provided with a vented cylinder. As the mains pressure hot water provided by an unvented system is fed directly from the cold mains, it provides a better pressure performance and flow rates than a vented cylinder. However, because an unvented cylinder is a 'sealed' system it requires an expansion vessel to hold the excess volume of heated water when it expands within the cylinder. This means a specialist installer is required to install the cylinder and it must undergo regular maintenance to meet safety regulations. This can result in a more expensive product. One of the biggest benefits to an unvented cylinder is the fact that it does not require a cistern tank, providing flexibility when there are space constraints in the property. At the more expensive end, slim line and even horizontal products are available to fit into specific areas. The traditional vented cylinder is gradually being replaced where possible by unvented units **(Heating & Plumbing Monthly, 2019)**.

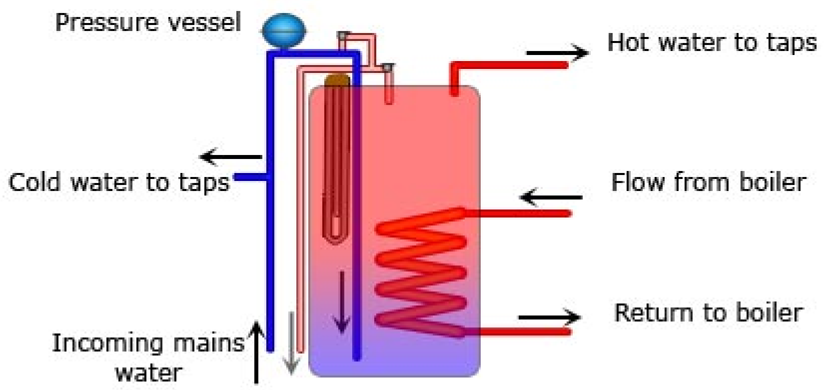


Figure 21. Unvented hot water cylinder (Installers Hub, 2021)

- There are several differences between a standard hot water cylinder (heated by a boiler) and a **heat pump cylinder**, including the location of the immersion heater. A heat pump immersion heater is typically located above the heat exchanger so that it will allow the top part of the cylinder to be periodically heated to 60°C to satisfy legionella guidelines, whilst not deteriorating the efficiency of the heat pump if it is left switched on. A heat pump cylinder will have a larger heat exchanger and will likely require a different interface (thermostat) to communicate with the hot water cylinder.

4.1.2. Performance of Domestic Hot Water cylinders

The overall system efficiency of a central heating system is influenced by the loss of heat from domestic hot water (DHW) cylinders. For heat pumps, this is particularly important, as they are less efficient when operating at the flow temperatures required to produce domestic hot water.

Key technical information for a range of different modern direct and indirect hot water cylinders is shown in the tables below:

Table 6. Key technical specifications for a range of modern indirect (vented) hot water cylinders (source: Kingspan, Dimplex, Heatrae Sadia)

Nominal cap. (l)	Heat up time (min)	Indirect coil (kW rating)	Heat loss (kW/24h)	Number of 3kW immersion heaters	Storage capacity @ 65ºC (ΔT55k) (kWh)
120	24	18.49	1.19	1	7.1
150	27	19.72	1.62	1	8.8
180	33	20.17	1.66	1	
210	35	21.35	1.76	1	12.7
250	41	22.4	2.19	2	15.3
300	52	21.43	2.09	2	18.4
400	48	27.7	2.45	2	

Table 7. Key technical specifications for a modern direct (unvented) hot water cylinder (source: Gledhill)

Nominal cap. (l)	Heat up time (min)	Heating element rating (kW)	Heat loss (kW/24h)	Recovery time after 70% draw off (mins)*
120	24	6	1	90
150	27	6	1.2	121
180	33	6	1.4	157
210	35	6	1.6	192
250	41	9	1.75	224
300	52	9	1.93	263

* There are two reheat times: (1) from cold, i.e. a tank filled with water at 15°C; (2) when 70% of the water has been drawn off, which means a cylinder temperature of 28.5°C, (15°C cold, 60°C hot). Most cylinder thermostats will turn the boiler on when the water temperature has dropped by 10°C, which is when about 20% of the hot water has been used.

Key technical information for the most popular (Superwarm, 2015) unvented cylinder in the UK market (Megaflo) is outlined below:

Table 8. Key technical information for Megaflo Eco (by Heatrae Sadia) Indirect Unvented Cylinder

Nominal cap. (l)	Heat up time* (mins)	Recovery time after 70% draw off (mins)	Indirect coil (kW rating) (15L/min)	Heat loss (kW/24h)	Number of 3kW immersion heaters	Dimensions (Height x depth x width) (mm)
70	17	10	19.8	0.91	1	802x600x579
125	23	15	19.5	1.05	1	1102x600x579
145	24	17	20.9	1.18	1	1229x600x579
170	22	16	19.4	1.2	1	1384x600x579
210	28	19	19.4	1.42	1	1486x600x579
250	34	23	19.5	1.61	1	1738x600x579
300	39	27	20.5	1.69	1	2053x600x579

*15L/min, 80ºC primary flow, from 15ºC to 60ºC

The larger the cylinder the greater the heat loss. The Central Heating System Specification CHeSS require minimum insulation levels for cylinders, as shown in the figure below. For comparison, published heat loss figures from one manufacturer are also shown on the graph – highlighting the ability of modern hot water cylinders to retain the energy stored in the hot water.

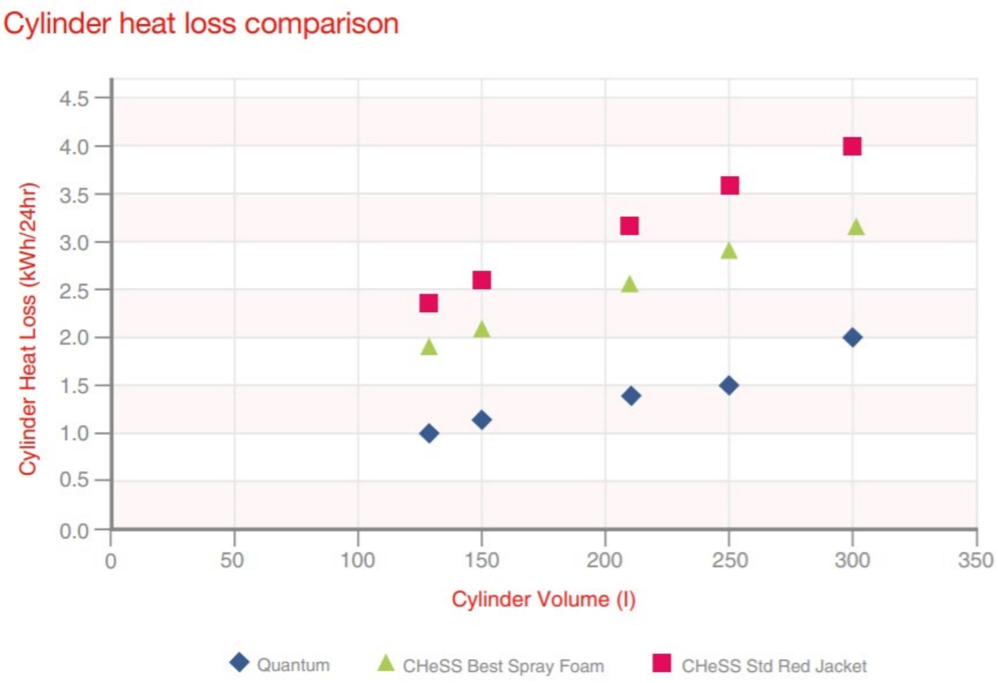


Figure 22 Cylinder heat loss comparison - CHeSS 'High performance' & 'Basic' ratings vs Modern, highly efficient cylinder (Dimplex, 2019)

This relationship is echoed when using DHW cylinders with heat pumps, as shown in the table below and gives specifications for three DHW cylinders of different sizes used as part of their test rig, heated by a direct electric water heater (limited to 4.8kW to be typical of air source heat pumps). Ambient temperature was kept constant at 20°C.

Table 9. Specifications for DHW cylinders with heat pumps (Kiwa, 2013)

Size (litres)	Heat up time	Recovery time after 70% draw off (mins)	Heat pump coil surface (m^2)	Heat loss (kWh/24h)
150	19m12s	15m40s	2	1.38
180	23m19s	17m06s	3	1.63
250	34m16s	34m16s	3	2.21

4.2. Buffer Tanks

A buffer tank is often fitted with a HP to help limit the cycling of a heat pump. It is a type of thermal store that can distribute stored energy to a room in the home. A buffer tank will have at least two copper coils of pipes. The upper coil will be connected to the mains water supply which is heated by the hot water in the thermal store and delivered to taps, showers, etc. The bottom of the thermal store has a second coil, connected to the radiators or underfloor heating (UFH). The thermal store will have controls that ensure water is always delivered at the required temperature – 55°C+ to radiators, 48°C to taps, etc. and 35°C to 44°C to UFH – while allowing the heat source to operate at its maximum efficiency.

A buffer tank is different from a hot water tank (used with existing gas boiler systems) **in that its purpose is designed purely to help reduce the cycling of a heat pump**. It holds a circuit of heated water, but this is 'black water' which runs only through the heating systems such as radiators and underfloor heating. This is different to a hot water tank which is designed to hold usable hot water and deliver it to taps, shower and bath when needed.

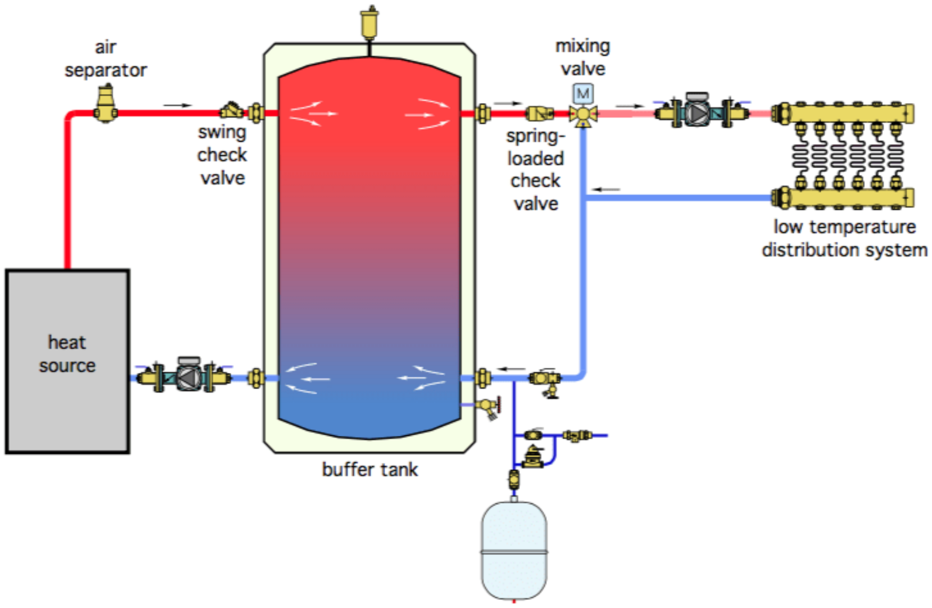


Figure 23 Buffer tank set up with heat pump (Arctic Heat Pumps, 2021)

Buffer tanks store water at a certain temperature, saving energy by eliminating the need to repeatedly heat water from cold and provides instant hot water at source. The most popular heat source of buffer tanks are biomass boilers, which are connected to one side of the tank, with radiators or other hot water output systems connected to the other side. The boiler will heat the water and the buffer tank keeps the water hot until it is needed because it is lined with thermal insulation which reduces heat loss and maintains a constant temperature.

A buffer tank will need to hold approximately 15 litres per 1kW of heat pump capacity. If a 3 bed home requires an output of 10kW this would require a buffer tank sized around 150 litres. The average cost of a buffer tank for a residential property is £450 - £900.

4.3. Phase change material (PCM)

Phase change material heat batteries (PCM)s store energy in the form of heat in the material's change of phase e.g. solid to liquid. A phase change material (PCM) is a substance which absorbs and releases energy at phase transition to provide useful heat or cooling. Generally, the transition is from one of the first two fundamental states of matter (liquid and solid) to the other.

This is an emerging technology (around 1,000 domestic systems installed in the UK currently mainly in trials and models for commercial applications are being developed). PCM is suitable for domestic (and light commercial) applications and has the advantage of being more compact than hot water tanks but the upfront cost is more expensive.

PCM could have a strong uptake in the future in the UK, due to its characteristics (relatively fast demand side flexibility capability), size (is able to displace a larger hot water tank) and availability in the UK via a domestic producer. For these reasons, we regard PCM as a viable domestic thermal storage technology option in the future.

Currently the leading player in the UK is Sunamp – a small technology developer based in Scotland. The first commercialised product (Sunamp PV) stores excess power from solar PV system as heat, which is used to produce instant domestic hot water. Sunamp thermal batteries contain inorganic, non-toxic, salt-based Phase Change Materials (PCM), which absorb and release thermal energy during the process of melting and freezing. When a PCM freezes, it releases a huge amount of energy in the form of latent heat at a constant temperature.

PCM stores can increase self-consumption of PV power and simultaneously reduce the use / increase the efficiency of water heating appliances. The core advantage with a PCM store is that the system is much smaller than an equivalent tank-based system, due to the high energy density. The high efficiency and responsiveness of PCM allows multiple heat sources and tariff structures to be efficiently deployed and can result in lower carbon emissions and running costs for the consumer.

PCM products can operate as direct / indirect water heaters, as well as working in conjunction with heat pumps. These can be used as demand side flexibility assets and could receive signals to provide peak load shifting / shaving.

Larger PCM based heat batteries (up to 250 kWh, currently in development) will be designed to respond to the needs of community and commercial scale heat storage; they may help tackle grid constraints and ensure continuous generation.

4.3.1. PCM heat batteries – technical characteristics

PCM heat batteries provide domestic hot water and can be combined with an off-peak tariff. This is suitable for replacement of outdated direct hot water cylinders. The tables below outline the technical characteristics for available sizes of Sunamp heat batteries.

Table 10. Technical specifications of PCM heat batteries designed to work with high temperature heat pumps

Heat Storage Capacity	Equivalent Hot Water Cylinder size (litres)	Volume of Hot Water Available at 40°C (L)	Standby Heat Loss Rate (kWh/24h [W])	Height (mm)	Width x Depth (mm)
3.5 kWh	71	85	0.45 [19]/ 0.48 [20]	387/455	365 x 575
7 kWh	142	185	0.65 [27]/ 0.68 [28]	588/650	365 x 575
10.5 kWh	212	300	0.74 [31]/ 0.77 [32]	814/860	365 x 575
14 kWh	284	370	0.81 [34] 0.84 [35]	999/1070	365 x 575

Table 11. Technical specifications of PCM heat batteries designed to work with low temperature heat pumps to provide domestic hot water:

Heat Storage Capacity	Equivalent Hot Water Cylinder size (litres)	Volume of Hot Water Available at 40°C (L)	Standby Heat Loss Rate (kWh/24h [W])	Height (mm)	Width x Depth (mm)
3.2 kWh	65	78	0.48 [20]	455	365 x 575
6.3 kWh	128	167	0.68 [28]	650	365 x 575
9.5 kWh	192	271	0.77 [32]	860	365 x 575
12.6 kWh	256	333	0.84 [35]	1070	365 x 575

4.4. Underground Energy Storage

Underground Energy Storage solutions are covered only at a high level in this report, as their cost and space needs are very niche technologies and are not likely to become a significant residential thermal storage solution by 2030 in the UK.

Underground Energy Storage includes the following solutions:

- **Borehole thermal energy storage (BTES)** - drilled holes in ground containing heat exchangers to transfer heat to and from the ground.
- **Aquifer thermal energy storage (ATES)** - natural underground water storage.

BTES can be used in domestic settings but are more likely to be used for large scale projects and are usually installed with solar thermal. ATES is only used for larger applications e.g. blocks of flats. There is potential for use for this technology where large buildings also have cooling requirements.

4.5. Thermal inertia of a building

Thermal inertia is defined as the degree of slowness with which the temperature of a body approaches that of its surroundings and which is dependent upon its absorptivity, its specific heat, its thermal conductivity, its dimensions, and other factors.

A building with a great amount of thermal mass can flatten out heat flow fluctuations; this is referred to as the thermal inertia of a building.

4.5.1. Thermal mass and thermal inertia

The combined mass of construction elements in the building envelope is referred to as thermal mass. Buildings with large thermal mass are generally built with 'heavy' materials, such as concrete, bricks and stone providing a large heat capacity. Thermal mass is often related to the thermal inertia of a building, therefore buildings built with lightweight materials, such as wood, have lower thermal inertia (Verbeke & Audenaert, 2017).

A simplified definition of thermal inertia is the rate at which a building releases heat. If there is a sudden drop in temperature, e.g. because the sun goes down at night, the building envelope will continue to release its stored heat. The slower the heat release the higher the thermal inertia of the building. The rate of heat flow from the materials will depend on the material's heat capacity, thermal conductivity and density. As an example, concrete is one of the materials with highest thermal inertia. Within 12 hours of a temperature drop the temperature decrease will have reached 130 mm into the concrete material (Granström, 2010), meaning that if the wall is thicker than 130 mm the temperature drop would barely be felt within 12 hours.

The level of insulation of a building will not impact the thermal inertia of the building material. However, it will improve the thermal performance of a building. If the insulation is placed on the external side of the wall, it will minimise heat transfer between the heat stored in the wall and the outside air and keep the warmed-up air indoors.

4.5.2. Thermal inertia and comfort

High thermal inertia of a building can contribute to comfortable indoor climate both in warm and cold climates. The thermal inertia of the building materials leads to a more stable indoor climate as heat will be absorbed and stored in the material and then released when the indoor temperature drops, for example at night.

In the summer, a building with high thermal inertia will absorb heat from the outside air but since the rate of the heat transfer is slow it will take longer to reach the inside air, keeping internal temperatures comfortably low.

But high thermal inertia can also have the contrary effect, as it will take more time to heat up or cool down the building. This is especially evident in case of intermittent heating or cooling use, as the slow reaction of the building´s thermal mass can lead to decreased comfort. For heavy constructions it is therefore more suitable to have a smaller, constant heat demand.

4.5.3. Thermal inertia and different types of buildings

As previously mentioned, buildings constructed with heavy materials such as brick, concrete and even heavy timber have a high thermal inertia and will keep a comfortable indoor climate longer despite outside stressors. Well insulated buildings will achieve similar results as the insulation minimises heat transfer from the construction material.

Multi-family homes have higher thermal inertia than single-family homes because they have a smaller ratio of outdoor walls to heated area and usually are usually built with heavy materials.

Table 12. Approximate time for indoor temperature to drop from 20°C to 5°C depending on outside temperature (assuming no space heating) (Energimyndigheten, 2007).

Outside temperature	Brick single family home built in 1970s with 95 mm insulation	Multi family home built in 1960s with concrete as primary material
0 °C	3 days	15 days
-5 °C	>2 days	10 days
-10 °C	1 day	7 days

The table above shows values for homes in Sweden. Since UK homes generally have more poorly insulated homes, we can assume that the indoor temperature will cool down faster in an average UK dwelling.

4.6. Thermal storage applicability / suitability

4.6.1. Building suitability factors / Physical fit

As part of the Integrated Electric Heat project (National Energy Foundation, 2018), the National Energy Foundation (NEF) looked at the kinds of energy storage volumes needed in domestic properties for different heat storage types. This was based on average daily energy demand estimates for hot water of 11kWh and 10kWh (190 l/day at 50°C), for current (non-retrofitted) and retrofitted energy-efficient homes, respectively. The volumes outlined below represent the theoretical minimum volume required to meet one full day's DHW and space heating demand for an average UK home (with four occupants):

Table 13. Theoretical minimum volume of different domestic thermal storage technologies required to meet a full day's heat demand for average UK home, current levels of energy efficiency vs retrofit (National Energy Foundation, 2018)

Storage technology	Capacity (kWh/m^3)	**Volume required storage tank only**		**Volume required storage tank + 200mm insulation**	
		Current stock	Retrofit stock	Current stock	Retrofit stock
Hot water tanks	56	$2.17m^3$	$0.74m^3$	$4.14m^3$	$1.55m^3$
Phase change material	139	$1.09m^3$	$0.3m^3$	$2.06m^3$	$0.87m^3$

Thermal storage faces a number of technical barriers to installation in various property types, often dictating the type of thermal storage that can be deployed, these include:

- space constraints
- relatively low energy density
- weight (when full)
- de-stratification (especially in larger tanks)
- system integration for large tanks
- retrofitting of tank-based system (both small, but especially applicable to large systems) if original building design did not consider installation.

The impact of these issues and how they might apply to different house types, is summarised below, alongside the potential suitable thermal storage options for that house type.

Table 14. Summary of suitable thermal storage options for different house types:

Home type	**Example home(s)**	**Suitable thermal storage options**	**Rationale**
Less efficient, high temperature homes with (smaller) radiators	1950s semi-detached	Vented/unvented indirect cylinder	Cylinder connected to gas boiler

Home type	Example home(s)	Suitable thermal storage options	Rationale
			
More efficient, low temperature homes with underfloor heating and/or large radiators	New build semi-detached 	Heat pump with hot water storage tank	Not enough space for buffer tanks
Large, detached homes with plenty of space, plus well-insulated	New build detached 	Heat pump with buffer tank / unvented indirect hot water tank	Provided there is enough space for buffer tank
Old, less efficient, high temperature homes with limited space and existing gas connection	1900s mid-terrace 1930s and 1950s semi detached 	Vented/unvented indirect cylinder	Cylinder connected to gas boiler
Flats		Heat pump with hot water storage tank; Unvented direct electric hot water tank	Trend towards electric solutions

4.7. Sizing of thermal storage

Correct sizing of a hot water cylinder (so that a household will not run out of hot water) will depend on the size of the house, number of occupants and household habits. The UK Hot Water Association suggests the following values as a general rule (hot water requirements per person per day) (Hot Water Association, 2021):

- Low consumption – 20 to 30 litres
- Average consumption – 30 to 50 litres
- High consumption – 50 to 70 litres

On this basis a typical four-person household would often use around 200 litres of hot water per day, however this does not mean that a 200 litre cylinder is required as it depends on when the hot water is required and whether the cylinder may be partially reheated during the day.

In Table 15 a sample of a range of recommended size specifications are listed for different sized properties, as reported by some of the top indirect cylinder manufacturers (e.g. Joule, Kingspan):

Table 15. Approximate cylinder sizes for properties with different levels of hot water demand

Hot water demand	Property size	Indirect cylinder capacity (litres)
1 standard bath or shower	1 bed	~120
	2 bed	120 - 150
	3 bed	~150
2 standard baths	3 bed	~180
	4 bed	180 - 210
	5 bed+	210+
3 bathrooms	3 – 4 bed	250
	5 bed+	300+

Table 16 gives a set of 'rules of thumb' for sizing different domestic thermal storage technologies, based on discussions with industry professionals.

Table 16. Rule of thumb sizing for a range of domestic thermal storage technologies

Technology	'Rule of thumb' sizing methodology / physical fit factors
Domestic hot water cylinders	• Typical size 150 - 210 litres
Phase Change Material	• Direct hot water production PCM heat battery: 3.5kWh corresponds to 71 litre hot water tank • 7kWh corresponds to 142 litre hot water tank • 9kWh corresponds to 212 litre hot water tank • 12kWh corresponds to 284 litre hot water tank • A consideration when sizing is how long the installer wants the system to stay off for on the coldest day (which is also dependent on the house type). This could be a minimum of 4 hours (which corresponds with the Octopus Agile peak period between 13:30 and 19:30).
Buffer tanks	• Likely to be in general too expensive and too large for UK homes

When using an old hot water cylinder with a heat pump system, it will have a lower differential (the temperature difference between the flow and return), meaning that less heat will pass through the heat exchanger coils. This will mean that the heat pump is not able to deliver enough heat to heat up the water in the cylinder to the desired level. The solution to this is to replace the current cylinder with one designed to be used with a heat pump.

The main difference with a heat pump-specific cylinder is that they have a much larger coil capacity, so there is an increased surface area for the heat to transfer through the coils and warm the water. The cylinder for a heat pump therefore needs to be bigger than a standard indirect cylinder heated by a boiler. For example, single phase heat pumps have a maximum power output of less than 15kW and longer recovery rates, meaning that 200-250 litres is a common selection for a typical four-bedroom house (HPV, 2020).

This means that there may be a trend for tanks to get larger, and this may limit uptake in some properties where there is insufficient space.

The heat exchanger in the hot water cylinder also needs to be matched to the output of the heat pump. Boilers operating at 70-80°C will get a much higher kW output through a coil than a heat pump operating at 55°C.

4.8. Smart Thermal Energy Storage Tanks

Smart thermal energy storage tanks are hot water tanks with electrical immersion heating elements; they either have built-in connectivity capability or have an add-on controller unit installed on them as retrofit.

Adding connectivity to an electric hot water tank allows it to be controlled remotely from an external device (e.g. smart phone), program the temperature at specific times, turn it on/off when needed adding comfort to the user and savings to the energy bill. This feature also allows the smart hot water tank to act as a flexibility asset and to be controlled for network / market / balancing optimisation purposes.

Control of smart hot water tanks can be achieved in the following manner:

- Control via the electric switchboard. Some companies are offering a connected switchboard allowing them to control different loads at home. Controlling loads directly from the switchboard allows multiple controls at the same time and more advanced services such as reacting to price signals to support the network and/or benefit the customer financially.
- Add-on controls for the hot water tank. This type of product involves retrofitting existing tanks by adding a connected controller. Typically, these controls are combined with sensors either inside or outside the tank to measure temperature, flows and usage, providing the customer with insights, control and, occasionally, accessing flexibility values.
- Hot water tank with embedded connectivity: HVAC manufacturers offer tanks with embedded connectivity, typically to extend their connected product catalogue, in their premium products. Other service providers offer these tanks targeting new sales and exploring the access to value streams supporting the network.

We have identified five characteristic that determine the ‘smartness’ of the hot water tank:

- Ability to maximise self-consumption of householders’ generation from PV or other sources
- Ability to use electric hot water heating flexibility for the benefit of the wider electricity system
- Ability to concentrate the heat in a certain proportion of the tank
- Have a ‘tank fullness’ indicator and controls to ensure availability of sufficient hot water when needed
- Ability to heat only as much hot water as is required.

4.8.1. Examples of innovative offerings

The following companies are currently offering smart hot water tank solutions:

- ENECO retrofits over 10,000 direct electric hot water tanks, selling into flexibility markets
- Climote offers a retrofit Smart Immersion Controller which can work with their smart thermostat
- Mixergy selling a suite of smart hot water tanks

Table 17. Examples of smart hot water tank solutions

Company	Country active in	New tank or retrofit	Units installed and status	Works with…	Flexibility markets accessed
ENECO	Netherlands	Retrofit	>10,000 Fully commercial	Directly electrically heated hot water tanks	Secondary reserve* (15-minute blocks)
Climote	Ireland	Retrofit	100s in trials Launch in 2020	Any hot water tank with an immersion heater	Secondary reserve* (30-minute blocks)
Mixergy	UK	New tank	~1000, aiming to install 5,000 by end of 2022 Fully commercial	Direct electric, indirectly heated solar thermal and heat pumps	Primary reserve* (second-level response required)

*Primary and secondary reserves are frequency regulation services procured by the transmission network operator

Table 18. Examples of other companies currently active with smart hot water tanks

Established HVAC manufacturers	Aggregators working with a range of assets	Smart Hot Water Tank specialists	HEM and control companies	PV self-consumption specialists
Ihto Daalderop Glen Dimplex	Voltalis Centrica Tiko	Thermovault	Levelise	There are many companies active with switched to maximise PV self-consumption

4.9. UK residential thermal storage uptake potential

Approximately 9 million homes in the UK already have domestic hot water tanks. There are currently a large number of manufacturers and developers of hot water tanks active in the UK (most major cylinder manufacturers also make heat pump cylinders). Market barriers include the growing penetration of combi boilers plus low renewable heating uptake.

The past decade has seen the demise of the hot water tank in many homes as they are replaced by combi boilers – providing efficient instantaneous hot water without the need of an additional storage tank (see EHS survey data, Figure 24. below). However hot water cylinders are still needed in larger homes, and c.450,000 tanks are sold each year. As the market is estimated to move away from combi boilers and the heat pump market grows, responding to government targets, the hot water cylinder market is also likely to grow, as heat pumps require cylinders with heat exchangers to deliver domestic hot water.

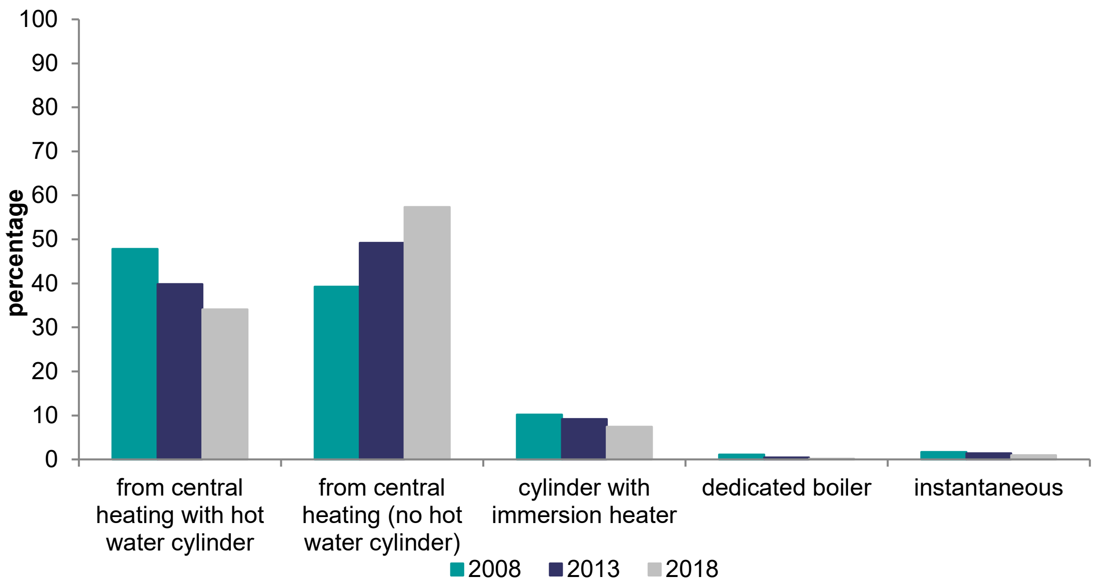


Figure 24. Type of hot water systems, 2008, 2013 and 2018, source: English Housing Survey 2018, dwelling sample

Many houses, following the fitting of a condensing boiler and removal of a hot water tank, are likely to have the required space for installation of a cylinder or a phase change heat store. However, this assumes that the space previously occupied by the tank has not been used for other purposes, which households may be unwilling or unable to give up.

Key drivers for other types of domestic thermal storage include:

- PCM has the potential to go from low 1000s of installs per year (mainly in trials) to 10 – 50,000 by 2030 if the technology can displace tanks. Market barriers include combi-boiler competition, established hot water cylinders, lack of fully commercialised products and supply chain, low renewable heat penetration.
- Buffer tanks are likely too expensive and too large for UK homes and so the residential market for these will remain small/niche
- Smart thermal energy storage tanks (see section 4.8). Could divide into:
  1. Retrofit solutions
  2. New smart tanks

The figure below gives Delta-EE's view as to the likely development pathway of the installed base of hot water tanks, PCM and smart hot water tanks. The downward trend is likely to continue in the near term as tanks continue to be replaced with condensing boilers, but longer term the market for cylinders is likely to pick up again as more are needed to be installed with heat pumps (especially within new build homes). However, this increase is unlikely to match the growth forecasted in the heat pump market, as many larger homes where heat pumps may be retrofit will already have a hot water tank. Although older tanks will need to be replaced to work with the heat pump, this will represent a replacement rather than an increase in the overall base.

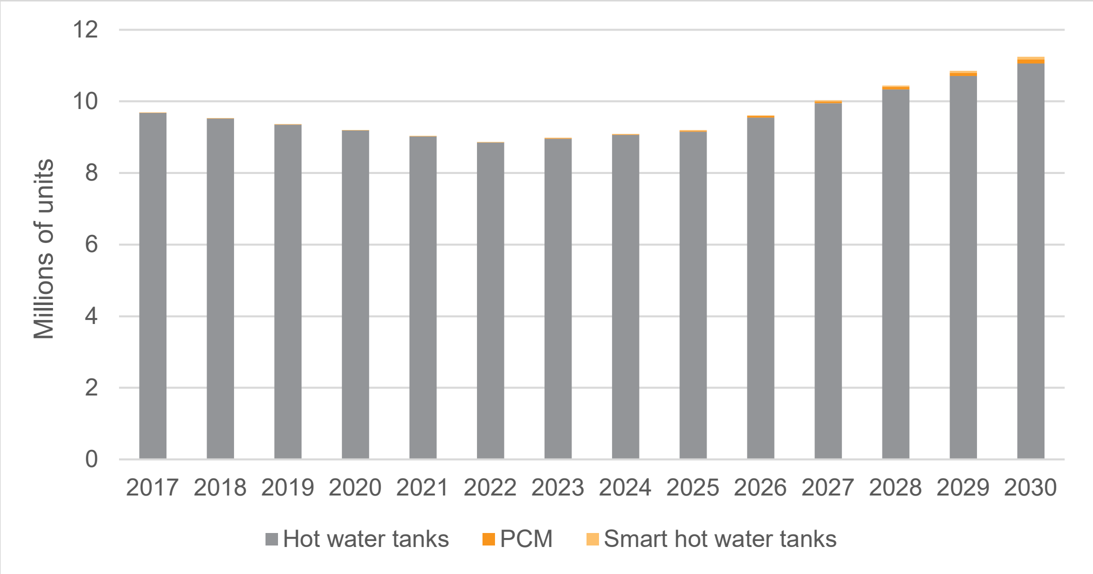


Figure 25. UK domestic thermal storage installed base forecast (source: Delta-EE, 2021)

A replacement rate and decline in numbers seen in the English Housing Survey data has been used to 2023, whereby the market is assumed to pick up in line with heat pump uptake. A growth rate proportional to the heat pump uptake assumed in the Central scenario in 2.5. has been used, however this has been scaled down to accommodate the assumption that a lot of homes will likely already have a hot water tank, and so new sales will continue to be replacements (not adding to the installed base). This will form one of a number of scenarios when taken forward in the modelling in the wider project, and will be used to guide the mapping of thermal storage to the modelled housing stock on WPD's network.

4.10. Impact of findings, relevance, and recommendations for WPD

There is a large existing base of domestic thermal storage (mainly hot water cylinders) in the UK that has the potential to provide flexibility services for DSOs. This is via either:

- (Over) sizing for use with heat pumps (or other heat sources) for load shifting, although this has implications for the number of homes appropriate for such measures.
- Repurposing existing conventional hot water cylinders with connectivity to allow it (via transforming electrical immersion heaters into grid-interactive immersion heaters) to be controlled to turn on/off/modulate in response to market or direct control signals.
- Replacing these cylinders with new, smart cylinders or new technologies such as phase change heating devices that have in-built capability to respond to signals to provide grid services.

With a hot water cylinder in roughly one in three UK homes today, provision of enhanced control and flexibility using these cylinders represents a combined thermal storage capacity, and shiftable load of 100GWh, even before we consider the number of new homes set to be built over the period to 2030 (USER Project, 2020). This is a capacity equivalent to 6 million Tesla Powerwall units, facilitated at potentially a fraction of the cost (USER Project, 2020) when using retrofit add-on devices (with relatively small changes in heating system hardware). Emerging solutions thus offer a promising opportunity for DSOs to mitigate network congestion and constraints.

More modern, highly efficient hot water tanks and storage devices (such as PCM) could also help the local network by reducing overall consumption at times of peak demand. This is reflected in the much higher efficiencies of these devices (compared to older models), which affords customers much lower levels of heat loss, and saving on the number of times these thermal stores need to be 'charged'.

The picture presented in Figure 25 is that of slow increase in the installation of thermal storage technologies (following a period of decline), in line with rising heat pump installations. The vast majority of these installations will continue to be domestic hot water cylinders, with only a small proportion of these (under current trajectories) likely to be 'smart', and able to respond to signals to shift timings of operation. This suggests that if these technologies are to have a significant impact in providing flexibility services to the DSO, they will need additional support to encourage further uptake.

Although, as this chapter highlighted, buffer tanks are unlikely to be a key domestic thermal storage technology going forward due to their size and high cost, it may be that this is an option WPD could consider supporting the roll out to homes where they can fit, as these technologies provide further opportunities around thermal storage and hence larger potential to reduce peak load. For this reason, we will take forward buffer tanks as a potential option to be considered in larger homes within modelling in work package 3.

These findings will be carried forward to other parts of the project in a number of other ways:

- Thermal storage properties and technical characteristics for the technologies and for homes as outlined in this chapter will inform the modelling inputs for work package 3.
- These properties, along with the sizing characteristics of thermal storage technologies will inform the suitability of types of homes for these technologies, and the likely split of uptake of these technologies between different parts of WPD's building stock (work packages 3&4).
- The domestic thermal storage forecast outline above will inform the scenarios that are tested in the network modelling for work package 4.
- Flexibility approaches will be applied to these demands to ascertain the potential reduction at peak under different scenarios.

5. Other electric heating technologies

This section outlines the key technical characteristics of other electric heating technologies, summarise their potential uptake, and look at ways in which they are/could be used for flexibility.

5.1. Summary of other electric heating technology types covered in this report

Electric heating technologies covered in this section include a mix of established and novel solutions. Electric storage heaters and direct electric space heaters are well established technologies in the UK, having been installed for several decades. Despite the fact that electric storage heaters offer possibilities for demand side flexibility (courtesy of new models with better thermal insulation and built-in connectivity, as well as retrofit control solutions for old models), their poor reputation based on the old models' inefficiencies will probably limit their future uptake.

The tenants in social housing do not have the choice, but due to this unfavourable image, many owner occupiers are switching from electric storage heaters to direct electric heaters, or heat pumps. Direct electric heaters work well in properties low thermal demand and are increasingly popular due to their low upfront cost. Nevertheless, due to their nature, these units cannot be used for demand side flexibility purposes, Novel technologies are emerging, but they are still in a trial phase and we are not expecting a significant market uptake by 2030.

Taking into consideration the barriers to deploying the technologies listed in this chapter for demand side flexibility purposes, Delta-EE considers heat pumps and thermal storage solutions profiled in the previous chapters as the most likely technologies with substantial market uptake by 2030, capable of providing flexibility to the DSO.

Electric heating technologies use electricity as a fuel to heat a property. The two most popular technologies in the UK are direct electric (includes a variety of types) and electric storage heaters. Both have relatively large installed base in the UK (1.4 million electric storage heaters and 900,000 direct electric heaters), but are installed mainly in retrofit situations. In the long-term, uptake will be competing with heat pumps.

5.1.1. Storage heaters

Electric storage heaters are one of the very early solutions developed to help with the flexibility to the electricity networks (helping with forward planning of network loads, which were predominantly using coal and/or nuclear power plants).

Electric storage heaters were designed to utilise cheaper, night-time, off peak electricity via Economy 7 or Economy 10 tariffs and to release the stored heat during the day (preferably towards the end of the day, when it is needed by the occupiers). Nevertheless, a substantially higher electricity day rate on many of these tariffs meant that when heat was lost during the day through inefficient thermal insulation of the units, the price paid for any daytime 'top-up' negated the benefits of the cheaper night-time tariff.

The inefficiency of older units created a poor reputation for electric storage heaters, with consumers rather opting for direct electric heaters and, increasingly, heat pumps. Storage heaters are purchased mainly as replacements and most commonly in off-gas areas and social housing.

5.1.2. Direct Electric Heaters

Panel heaters consist of a resistive element that can be switched on and off as required. They are the most expensive form of heating, but they respond fast and have no heat losses. Each kWh of electricity used produces 1 kWh of heat.

These are largely used in retrofit applications. Due to low installation costs, they are popular where thermal demand is low e.g. flats and new build homes.

5.2. Market Outlook

Electric storage heaters are usually installed as replacements for older storage heater units. They can have lower running costs than direct electric heaters if usage is planned in advance (as they can make use of time-of-use tariffs), but have a poor reputation among end-users, due to the inefficient units installed in homes in the past. New models (e.g. Glen Dimplex's Quantum range) offer improved insulation and built-in connectivity for flexibility, mainly targeting replacement of old storage heaters.

In 2020 there were around 49,000 electric storage heaters sold in the UK and this segment is expected to decrease to c. 41,000 units sold per annum by 2025.

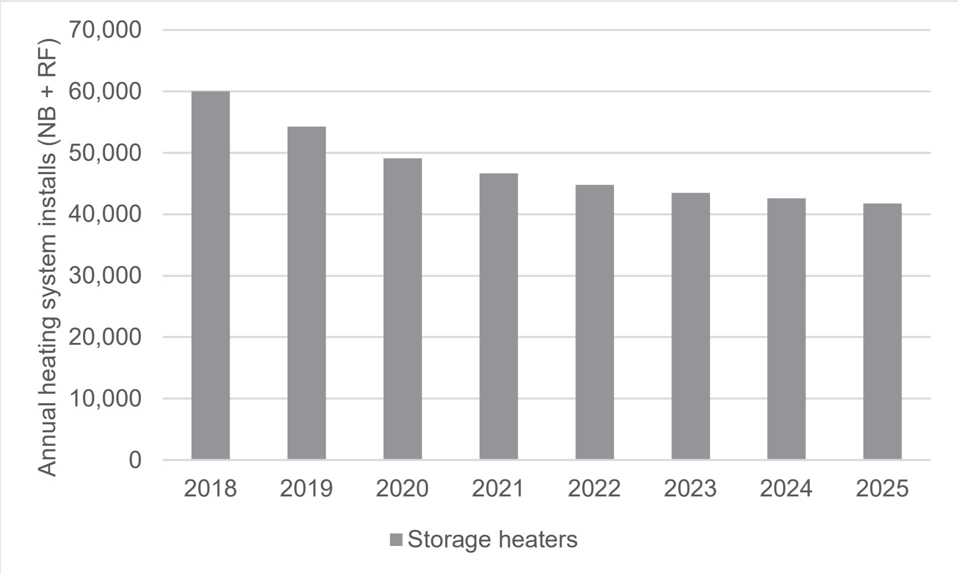


Figure 26. UK electric storage heaters sales forecast (source: Delta-EE, 2021)

Direct electric heaters are popular as the main heating source in homes with low thermal demand (often new build flats with good thermal insulation), due to their low upfront cost. Some are also installed as supplementary heating in homes with other forms of heating.

Demand from new build is a major factor in sales growing from 158,000 units in 2020 to over 210,000 units sold in 2025.

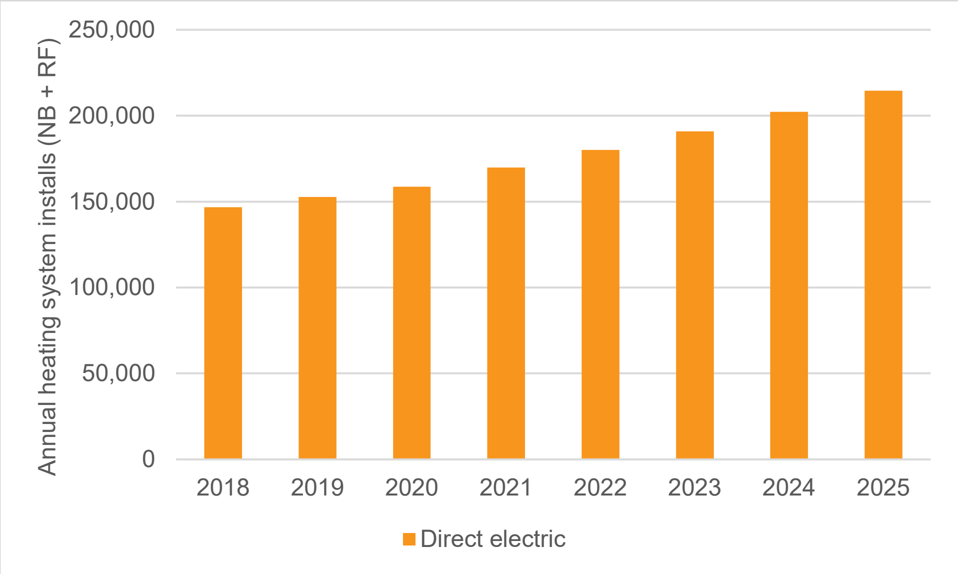


Figure 27. UK direct electric heaters sales forecast (source: Delta-EE, 2021)

5.3. Flexibility approaches used with electric storage heaters– examples & case studies of emerging solutions

5.3.1. New storage heaters with built-in connectivity

Glen Dimplex offers its Quantum range (electric storage heater and water heater) as Smart Electric Thermal Storage System (SETS) with built-in connectivity which enables flexibility.

Despite improved thermal efficiency and ability to control their operation, only an estimated 5% of these electric storage heaters are sold to new build, the rest are for retrofit purposes, replacing old, inefficient units without connectivity.

5.3.2. Retrofitting controls on existing electric storage heaters

Due to the substantial installed base of electric storage space heaters, there is a large potential for retrofit solutions, which can enable old units to be used as flexibility assets via connectivity. Companies such as V-Charge and Connected Response have developed such solutions.

V-Charge offered a flexibility service by upgrading a home's storage heaters and fitting a 'Dynamo' control device, plus a room thermostat. These wirelessly communicated data back to V-Charge on the internal temperature and the charge state of the heat bricks.

Combining this with weather data, V-Charge could remotely operate the control of electric storage heaters to ensure that the temperature of the room is at the temperature agreed with the homeowner, and that there will be enough charge stored when the heater is called upon.

The storage heaters were being used mainly for frequency regulation of the grid and so V-Charge received a payment from the network operator for providing this service. V-Charge was acquired by OVO Energy, but this service has ceased.

Connected Response Ltd.'s retrofit solution focuses on improving the performance of electric storage heaters. It also enables grid connectivity for future demand-response types of services with additional features such as dynamic renewable generation and daily tariff tracking. The cloud-based management system supports external access and the solution enables the storage heater to be used to provide ancillary services and trading/balancing services for the supplier. The way in which this works is set out in the diagram below:

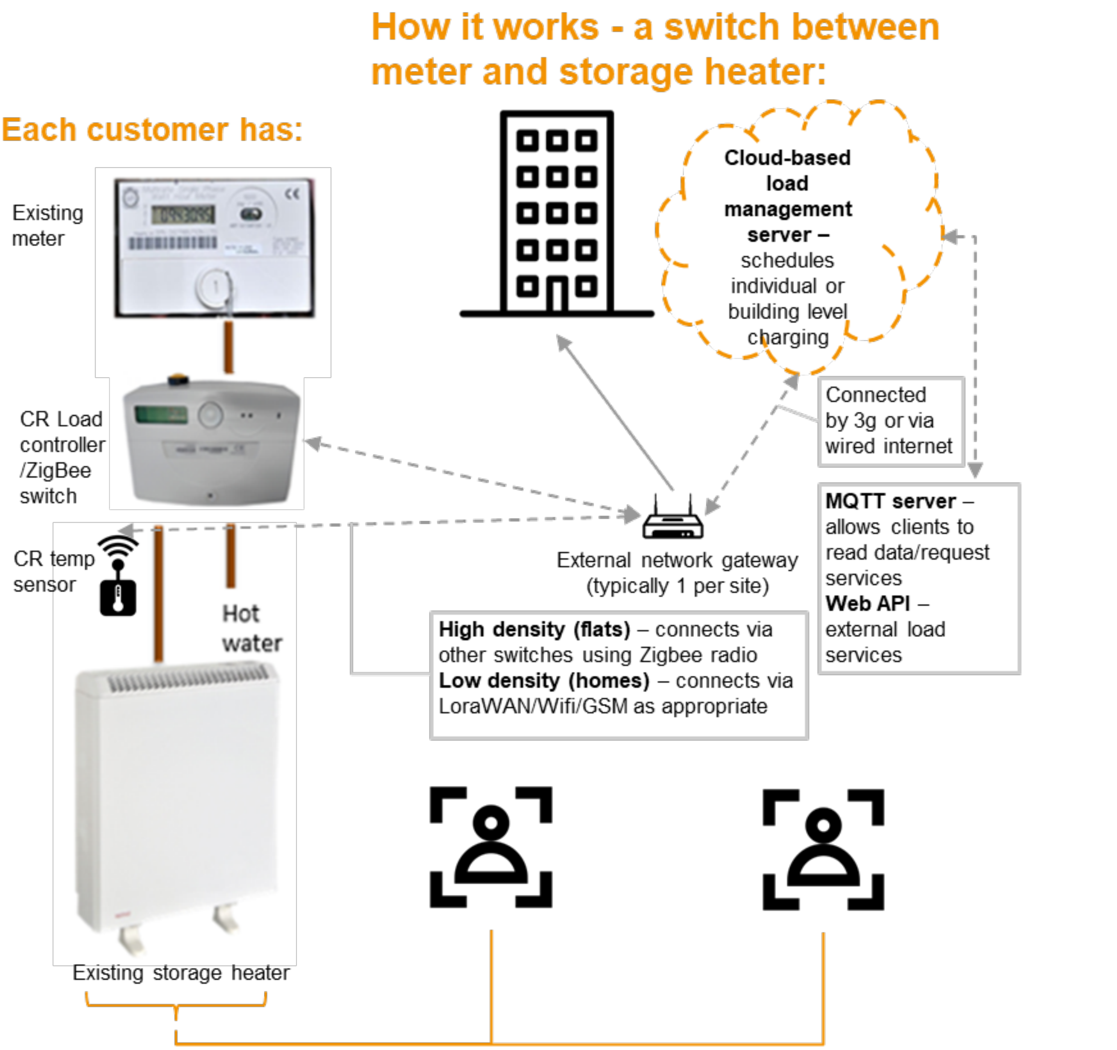


Figure 28. How Connected Response's solution is set up to provide smart operation capabilities to existing storage heaters (source: Delta-EE, Connected Response, 2021). Multiple customers connect to Connected Response's management server.

5.4. Novel Technologies Providing Electric Space Heating

The Tepeo ZEB (Zero Emission Boiler) and Caldera Warmstone Heat Battery are novel technologies still in a trial phase. These are not expected to enjoy significant market uptake by 2030.

Tepeo ZEB (Zero Emission Boiler) uses electricity to charge a heat battery at optimal times of the day and release it to the central heating system and/or hot water system exactly when needed. This 'heat battery' consists of electric resistive heating elements which heat a solid and high-density storage medium (core). When heat is needed, air is circulated around a closed loop system within the ZEB – the air picks up heat from the core and then transfers it to a heat exchanger with the central heating water passing through this, flowing through channels within the core that optimise how heat is transferred through the system (Tepeo, 2020).

Part of the ZEB intelligence is located remotely and is responsible for calculating charging schedules for all active ZEBs. It starts with the predicted hot water and heating demand for the home (using a machine learning algorithm based on the home's historical usage and local weather data). It then looks at the weather forecast for the coming 24 hours and predicts the likely resultant heating requirement. This gives the charging algorithm the target profile of heat output to aim to deliver, with the aim of keeping the charge level as low as possible at any given time.

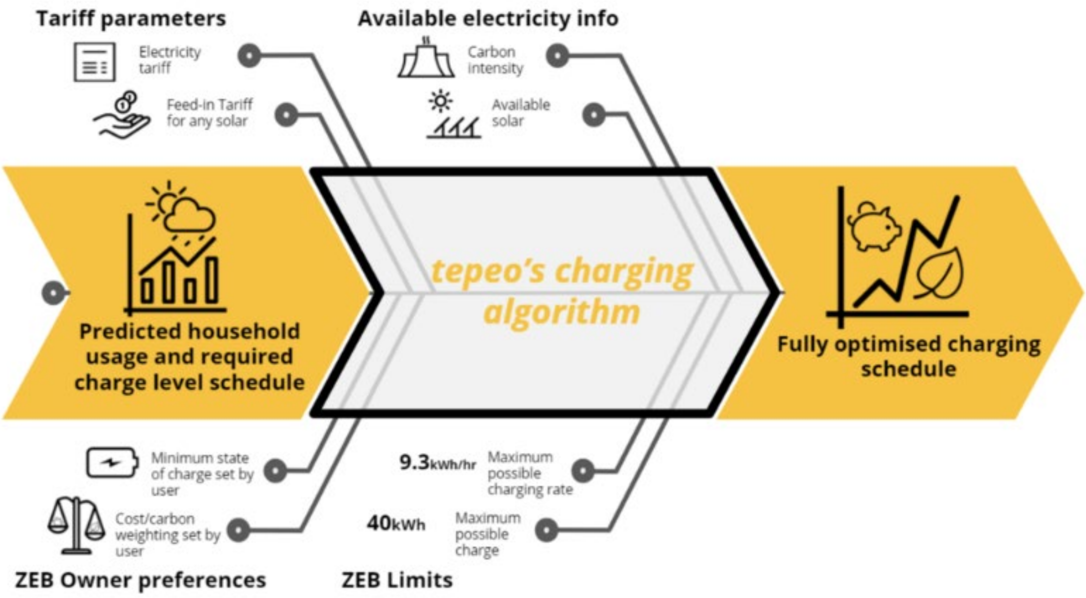


Figure 29. Tepeo charging algorithm process (Tepeo, 2020)

The charging strategy is continuously monitored throughout the ZEB's operation to ensure that the household's heating demands are met. On a typical day, the ZEB might be called upon by National Grid to provide grid balancing services.

The ZEB stores 40kWh of energy which can fully recharge in 4 hours and releases 20kW of thermal energy. The company partners with EDF Energy.

The Caldera Warmstone Heat Battery consists of a block of proprietary material (Warmstone) which is heated by electrical elements (similar to those used in an oven or kettle). Heat is discharged via a heat exchanger (HIU) to produce hot water. Charging is achieved with electric resistance.

A system consists of two elements. The first is a Warmstone Heat Battery located externally to the property. The second is a Heat Interface Unit that replaces the existing boiler.

The heat battery can be charged with low cost electricity from the grid.

The Warmstore Heat Battery weighs 1.5 tonnes and holds enough energy to heat a standard home for 24 hours in winter. Charging is achieved with electric resistance heaters to store the energy as heat.

This technology enables the usage of electricity for charging at optimal times of the day.

5.5. Impact of findings, relevance, and recommendations for WPD

Although unlikely to be as impactful to the distribution network as heat pumps due to their likely low uptake (at least in the near future), these ‘other’ electric heating technologies (such as storage heaters, direct electric and other novel technologies) could impact the DSO as they become smarter and are able to react to market signals and more dynamically shift their operation patterns (and thus demand on the network). Retrofitting large numbers of storage heaters with smart controls for example (paired with new tariffs) could mean WPD sees demand shifting from mainly an overnight load to demand occurring at peak times, or coinciding with other new loads on the network (e.g. electric vehicles) to create new or more peaky demands.

As with heat pumps, to minimise this impact, WPD needs to understand:

- Where on the network these technologies will be located;
- How much more efficiently those technologies can be operated to minimise demand on the network, particularly during peak periods; and
- How much flexibility there potentially is to shift when these technologies operate in order to limit peak demand on the network, and how can WPD influence this flexibility to best meet its requirements.

In other work packages, the findings from this chapter will form a backdrop to the modelling of heat pumps and thermal storage in homes on WPD’s network – ensuring that the sort of take up and usage patterns for other electric heating technologies in the housing stock, outlined above, are reflected.

6. Flexibility approaches

This section will outline key flexibility approaches used with residential electric heating and thermal storage, summarise their potential uptake, and look at how they impact the operation of electric heating technologies, and in turn, impact the distribution network.

6.1. Summary of different flexibility approaches

The different flexibility approaches used with electric heating can be classified into types based on several metrics:

- The values ('value streams') the control mechanism / business model is accessing (i.e. which markets the approach may be looking to derive value from)
- The tariff a customer with electric heating is on (time of use)
- The way these values are 'packaged' to the customer, and how the customer is incentivised to alter their electric heating consumption patterns – i.e. the customer proposition

These are summarised in the following sections.

6.1.1. Value streams

Value streams available to demand response (DR) can be classed broadly into those that are cost avoidance, and those that are revenue generating.

If exposed to the wholesale market price for electricity, assets may be used more flexibly to avoid high costs in the wholesale market which is more volatile than the retail electricity market (and may even generate revenue if prices turn negative).

Network charges typically comprise (1) transmission network charges and (2) distribution network charges.

These charges are used to recover transmission and distribution system costs, respectively, from network users (e.g. end customers).

These charges are typically based on:

- The volume of electricity consumed
- The connection capacity
- When the electricity was consumed (typically during peak periods on the transmission/distribution network).

Larger commercial and industrial customers can shift their consumption to avoid the higher peak costs of transmission and distribution network charges (however this is changing as part of Ofgem's ongoing reviews).

Revenue generating services include ancillary services, the balancing mechanism, capacity market and DSO services.

Ancillary services are one component used by National Grid Electricity System Operator (ESO) to manage the grid. These services help maintain grid frequency and resolve imbalances or congestion.

The balancing mechanism (BM) is a close to real time auction to provide additional balancing capacity to the ESO.

The capacity market is a long-term planning measure to ensure sufficient generation capacity is on the system to meet demand. The market provides payments to encourage investment in new capacity or for existing capacity to remain open. It is normally an auction-based procurement, several years in advance of delivery period.

The DSO services market is one of the more immature markets, emerging due to increased penetration of decentralised generation, electrification of heat and mobility – requiring DSOs to take a more active approach in the management of the distribution network. This is often in the form of DSOs procuring demand response for constraint management (e.g. paying certain customers to reduce their demand when the network would otherwise be overloaded).

Ancillary services, contracted by National Grid ESO via aggregators for residential assets, are the most common value stream accessed by residential demand response and flexible electric heating today. However, the market is not yet well developed, with just a small number of commercial projects tapping into this value stream. The table below gives an overview of value streams potentially accessible to residential demand response in the UK.

Table 19. Value streams potentially accessible by flexible electric heating & typical barriers

Value stream	Description	Accessible to residential demand response?	Typical barrier to residential DR participation
1. Wholesale electricity market	As prices are becoming more volatile, suppliers are starting to use domestic DR to optimise their wholesale market positions and avoid imbalance charges. Aggregators trading domestic DR into the wholesale market is nascent but is of increasing interest to providers.	A number of trial projects are testing market readiness but no commercial examples	▪ Smart metering roll out limited in some markets, restricting business models ▪ Half hourly settlement of residential customers not widespread ▪ Supplier back office functions outdated ▪ Regulation against aggregated assets trading in wholesale markets

Value stream	Description	Accessible to residential demand response?	Typical barrier to residential DR participation
2. Use of network charges	Network charges are typically a fixed and variable part of energy bills.	There are limited trials projects, and no commercial examples, of companies monetising domestic network charges.	■ ToU elements often not passed on to domestic customers, reducing ability to capture value. ■ Settlement calculated based on standard load profiles
3. Ancillary services / balancing	There are pockets of commercial activity using domestic assets to provide ancillary services, but this is not widespread.	Nascent market with isolated examples	■ Minimum bid sizes are too large for the current scale of residential portfolios ■ Metering/testing/communication requirements extensive ■ Contracts not always fit for purpose for domestic providers
4. Capacity Market	There are currently no examples (trial or commercial) of domestic assets being used in Capacity Markets.	No market	■ Market regulations and obligations prevent residential DR participation
5. DSO services	This is not yet a market today. There are some trial projects of DSOs procuring demand response to avoid the costs of network reinforcement.	No market	■ Lack of long term visibility on locational need of flexibility and certainty of the longevity of these value streams

6.1.2. Time of use tariffs

One of the key ways customers can be directly incentivised to change their electric heating consumption patterns is through price signals delivered via time of use (ToU) electricity tariffs, where the price of electricity in a given period (e.g. half-hourly) is dependent on factors such as electricity network constraints and the electricity wholesale price. These come in the form of static and dynamic ToU tariffs.

Static ToU tariffs are relatively common in the UK, used predominantly with the ~1.4 million storage heater homes across GB. Economy 7 (E7) tariffs give a cheaper, off-peak rate that usually runs for ~7 hours overnight when the heaters charge, while the more expensive daytime rate covers the rest of the day. An Economy 7 meter (or smart meter configured to Economy 7 schedule) is needed. Economy 7 tariff off-peak rate time windows vary depending on where the customer lives and which supplier they are with.

Relevant times for WPD are:

- East Midlands – 7 hours between 23:00 and 07:00
- West Midlands – 7 hours between 23:30 and 08:00

- South Wales – 7 hours between 22:00 and 08:30
- South Western England – 7 hours between 22:00 and 08:30

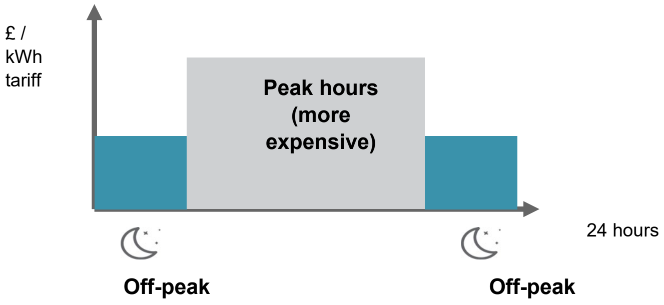


Figure 30. Static time of use tariff operation

These 7-hour periods are primarily determined at the supplier's discretion – depending on the type of E7 tariff the customer is on (which will also depend on the type of meter and control circuit the customer has within their home). In a minority of cases, off-peak timings may also depend on other factors (intrinsic to the tariff) such as forecast temperature.

Economy 10 (E10) tariffs are much less common than Economy 7, and offer ~10 hours of cheaper electricity, usually split across three different periods, to give an extra boost of cheap electricity during the day. An Economy 10 meter (or smart meter configured to an Economy 10 tariff schedule) is needed.

Of the big six suppliers, only EDF, Npower and SSE have customers on specific Economy 10 tariffs.

Like E7, E10 tariff times differ depending on where the customer lives and which supplier they are with, but in general these are likely to be (in England):

- 3 off-peak hours in the afternoon (e.g. 1pm – 4pm)
- 2 in the evening (e.g. 8pm – 10pm)
- 5 overnight (e.g. midnight – 5am).

Figure 31 below shows how an immersion heater (in a hot water tank) may operate when under an E7 tariff during a day in early February. As can be seen, the heater operates overnight and in the early morning during off-peak periods but also 'boosts' the tank temperature in the late afternoon (during peak hours) in order to provide the house with hot water for the evening.

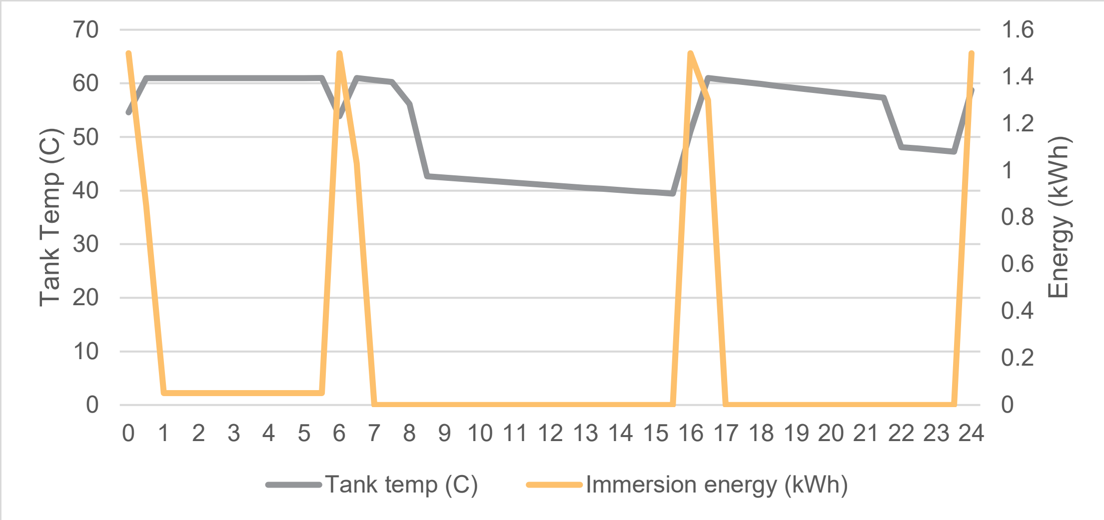


Figure 31. Average February weekday immersion water heater consumption profile on economy 7 tariff (source: Passiv Systems & Delta-EE in (Delta-EE, 2020))

Economy 7 tariffs overall provide a poor customer experience and there are high levels of dissatisfaction around comfort, control, and hidden costs associated with these tariffs (Citizens Advice, 2018).

If signed up to a **dynamic ToU tariff**, customers pay different rates for electricity depending on the time of day and are billed based on their actual consumption during each period using smart meter readings.

Prices are set close to real time (typically one day ahead) for time bands of 1 hour or less and tend to be based on wholesale market prices.

Examples in the UK currently are:

- Octopus – Agile (half hourly pricing) – which exposes the customer (to a significant degree, although also caps prices at 35p / kWh to offer protection form very large price spikes) to the wholesale market price
- Green Energy UK – Tide (4 time periods)
- Vattenfall [SE] – Hourly Electric Mix (hourly pricing)

These dynamic tariffs can have a significant impact on the operation of the electric heating system, as shown by Figure 32 and Figure 33, which highlight the typical behaviour observed from an ASHP run on 2 tariffs; flat (standard) and Dynamic ToU – here an Octopus Agile tariff, under typical winter weekday conditions.

With a flat tariff (e.g. a constant price of 14p at all times), the ASHP maintains a constant room temperature, with the heat pump operating most of the time. The heat pump ramps up in the hours before 7am (the period during which the homeowner is assumed to be active in the home) and a full tank of hot water is required at the beginning of this period, followed by maintaining a 45°C tank temperature (this is the minimum temperature value considered to be useful water for mixing).

For the purposes of this discussion and below figure, the dynamic ToU tariff considered will be based on pricing algorithm as used by Octopus Energy in their Agile tariff (Octopus Energy, 2020). This is a tariff where prices are published day-ahead and consist of wholesale electricity price (multiplied by 2.2) plus DUoS charges (12p added between 4pm and 7pm local time), with the resulting value being capped at 33.33p. Under this tariff, the heat pump avoids consuming at peak rate times when the wholesale electricity price is high and when DUoS charges are high (which in this example is between 8 and 10am and 4 and 7pm), and instead overheats the room overnight to allow reduced power consumption later on at morning peak, 'topping up' heat during cheap morning periods before morning peak, and ramping up just before 4pm to allow reduced power consumption thereafter during evening peak. For a heat pump, it is much more efficient to maintain a steady room temperature rather than allowing the temperature to drop and then ramping up for the high demand period. The heat pump will also take advantage of short periods of very low and negative pricing – spiking to boost temperature during these periods. Both of these factors go towards explaining why in Figure 33, you see spikey heat pump activity during the overnight period.

This mode of operation works out to be about 20% cheaper with the heat pump providing both space heating and hot water. As can be seen from Figure 33, abrupt turn-on and turn-off, smart short-term control is important in taking full advantage of off-peak rate times, and avoiding peak rate times.

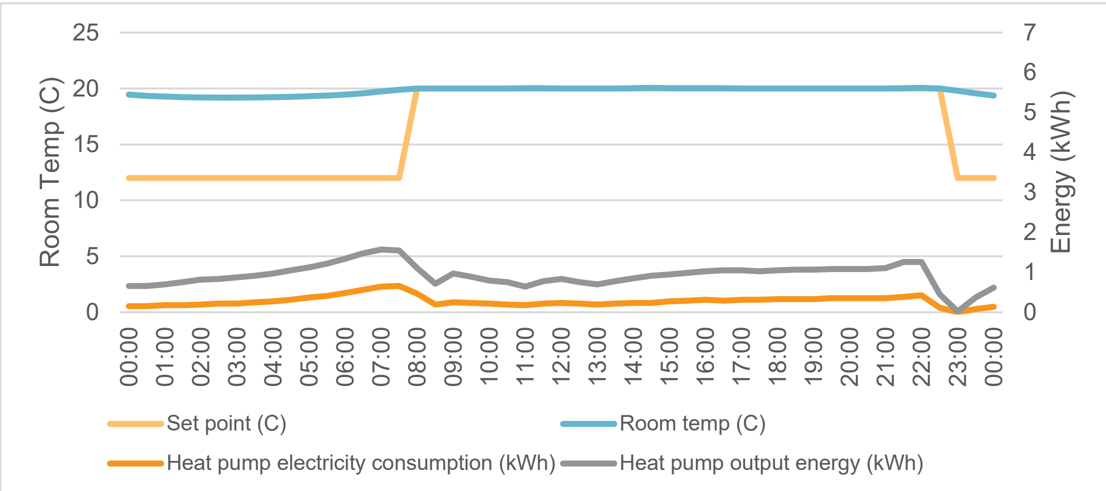


Figure 32. Average February weekday ASHP consumption profile on flat tariff (source: Delta-EE & Passiv Systems in (Delta-EE, 2020))

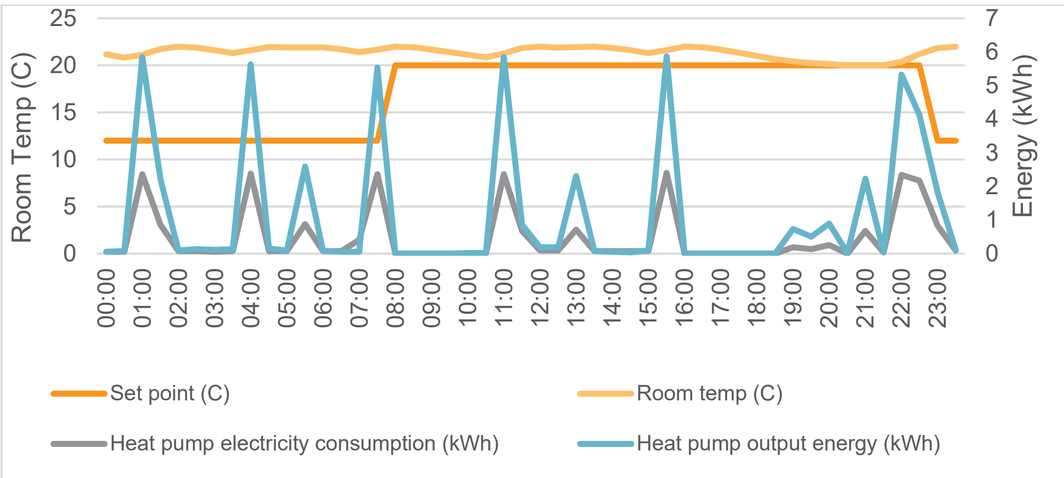


Figure 33. Average February weekday ASHP consumption profile on agile half-hourly tariff (source: Delta-EE & Passiv Systems in (Delta-EE, 2020))

Work done for the 4D Heat project identified that Dynamic ToU tariffs, such as the Octopus Agile tariff, act in some ways as a proxy for driving the consumption of power during times of high (albeit national) wind generation due to the effect of that generation on the wholesale market (called wind curtailment turn-up). Prices are often zero or negative during these ‘wind curtailment’ times. At the same time, significant heating running cost savings are possible from the use of a Dynamic ToU tariff, providing a win-win for the consumer and the national electricity network. It should be noted, however, that a smart control system is required in order to accurately take account of the variable time of use tariff signals and convert to real consumer/network benefits.

For WPD however, if more LV customers are operating their electric heating using such dynamic tariffs and providing national services as described above (via for example consuming power when wholesale prices are low and providing services to national grid during times of high wind generation), this may cause issues for the local network. If, for example, customers are within constrained areas of the network and the ESO or supplier is sending signals to the heat pump to turn up (reacting to weather or system shock events) during the evening peak, this could cause challenges for the DSO. There may be conflict between national needs and DSO needs then when nationally the system is long (more generation that demand – e.g. in instances of high wind) and there is high local demand.

With increasing load on the local network via rising numbers of electric vehicles and heat pumps, these potential conflicts will likely be exacerbated and could cause new problems for the local network. For example, high levels of EVs/HPs reacting to a dynamic tariff such as the one above risks creating new overnight peaks, or peaky demand on either side of current morning/evening peaks. New constraints may also be created if an aggregator wants to dispatch a large amount of load (responding to wholesale or ESO market signals for example) outside of traditional DUoS/E7/E10 tariff windows.

6.1.3. Customer Propositions

In order for these flexibility value streams to be accessed new ways of operating heating assets must be ‘sold’ to the customer. The customer needs to be incentivised to give up some control of their heating assets to their supplier or to a third party, or to change the operation of their heating systems themselves (which may be suitable for some customers, but is unlikely to suit the majority who will not be interested / will not have the time to do this). Here is where the customer proposition is key – providing the right incentives / sharing revenue generated from flexibility value streams in the most enticing way to drive customer uptake and acceptance of flexible control of their heating assets.

There are emerging examples (from the UK and across Europe) of service providers that are optimising customers’ operation of electric heating in response to market signals on behalf of the customer. These models will typically take value from using customer electric heating loads to provide ancillary and balancing services and/or trading this load in wholesale markets and sharing a part of this value with the customer in a number of ways including:

- Providing a revenue share
- Providing a cheaper/flat tariff
- Providing a cost saving on upfront purchase of new electric heating technologies
- Providing improved control (and associated cost reductions for the customer)
- Providing a guaranteed outcome (e.g. a set level of heat or comfort)

The following section details some key examples from the UK and Europe using flexible electric heating to provide innovative propositions to customers, with a focus heat pump technologies.

Optimising operation of heat pumps to wholesale market prices – NIBE: Uplink (Sweden)
NIBE, a traditional heat product manufacturer, launched 'Uplink' in 2014 (NIBE, 2014) as an online monitoring and control program that allows remote access to NIBE's heat pumps.

They have two routes to market:

- Business to customer (B2C): Ethernet cable in all NIBE heat pumps links to the Uplink cloud server, which utilises hourly day-ahead wholesales prices from Nordpool to optimise HP operation. In Sweden all energy suppliers must offer a ToU tariff. However, NIBE chooses to optimize based on NordPool prices to allow them to provide this optimization service to all customers, regardless of who their energy supplier is. Statistics show this 'Smart price adaption (SPA)' saves 5-10% of running costs.
- Business to business to customer (B2B2C): NIBE have co-operated with a small energy supplier and created a 'NIBE energy supply' contract. NIBE help the customers optimise to the ToU tariff and as a result, the supplier benefits from peak shaving and congestion reduction.

NIBE charges an Uplink services fee, but the main value is in keeping customers and making NIBE an attractive partner for utilities, DSR players and installers. Currently around 10,000 customers have installed Uplink, but only in Sweden (as Sweden has the compulsory regulation that all utilities must offer hourly prices to their customers). The following figure explains the NIBE Uplink business model and flows of energy and money between customer and other entities.

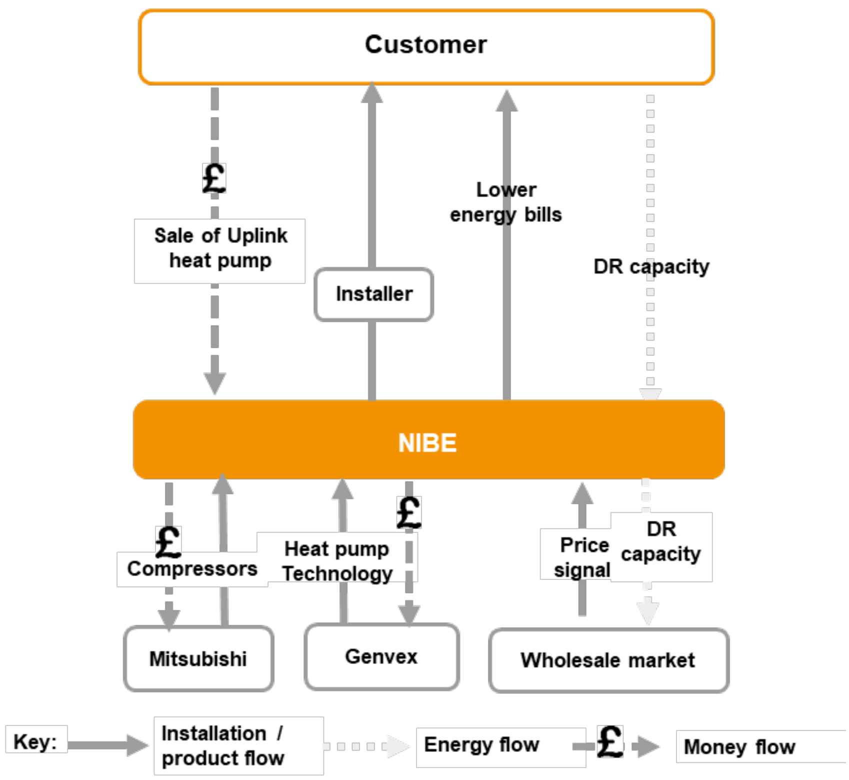


Figure 34. NIBE Uplink business model (Delta-EE, 2020)

- **How might this impact heat pump operation:** Optimising operation in response to wholesale market signals is likely to result in a similar profile to Figure 33.
- **Who is doing this in the UK:** Homely are a new company connecting heat pumps to variable electricity tariffs, such as Octopus Energy's Agile tariff.

Optimising operation of heat pumps with electrical and thermal storage to wholesale market prices – Boxergy
Optimising operation of heat pumps to take advantage of fluctuations in wholesale market prices can be done more effectively if the heat pumps are used in combination with storage technologies. For example, UK start-up Boxergy is trialling combining a heat pump, electrical battery and heat battery (phase change thermal storage unit) in a boxed unit installed outside a customer's home. The system is designed to work with a time based or dynamic tariff, storing both electricity from the grid and heat generated by the heat pump when electricity is cheap. It can provide high temperature heat, making it a retrofit option for the on-gas market. Boxergy are also looking into how they could use their units to provide ancillary services to the grid as an additional source of revenue. The following figure outlines how Boxergy operates the heat pump according to price and carbon factors:

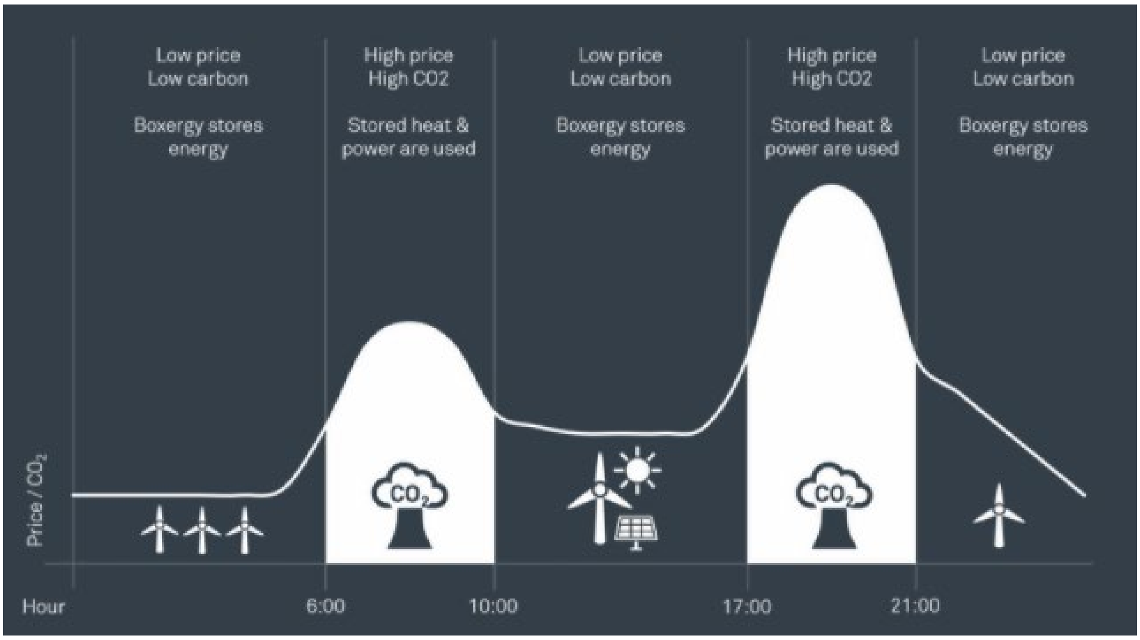


Figure 35. Boxergy operating regime as a function of wholesale electricity price (Source: (Boxergy, 2021))

- **How might this impact heat pump operation:** Optimising operation in response to wholesale market signals is could result in a similar profile to Figure 33, however, heat pump operation could be run more evenly when used in together with the electrical battery.

Providing a cheaper tariff / upfront cost saving – Kaluza (OVO energy subsidiary)
Kaluza is a subsidiary company of OVO Energy, focused on the development and operation of an aggregation platform for residential connected assets, including OVO's own EV charge points and heating appliances, smart thermostats, and home batteries. They have partnerships with several leading manufactures, including Nissan, tado and Dimplex.

Kaluza aim to work behind the scenes managing residential loads on behalf of an energy supplier to reduce procurement costs and generate additional revenue from price arbitrage, grid services and balancing portfolios. Revenue/savings are passed on to participating customers via the energy supplier through a lower tariff – Kaluza has no direct relationship with the customer.

The following figure describes the business model deployed by Kaluza with the customer:

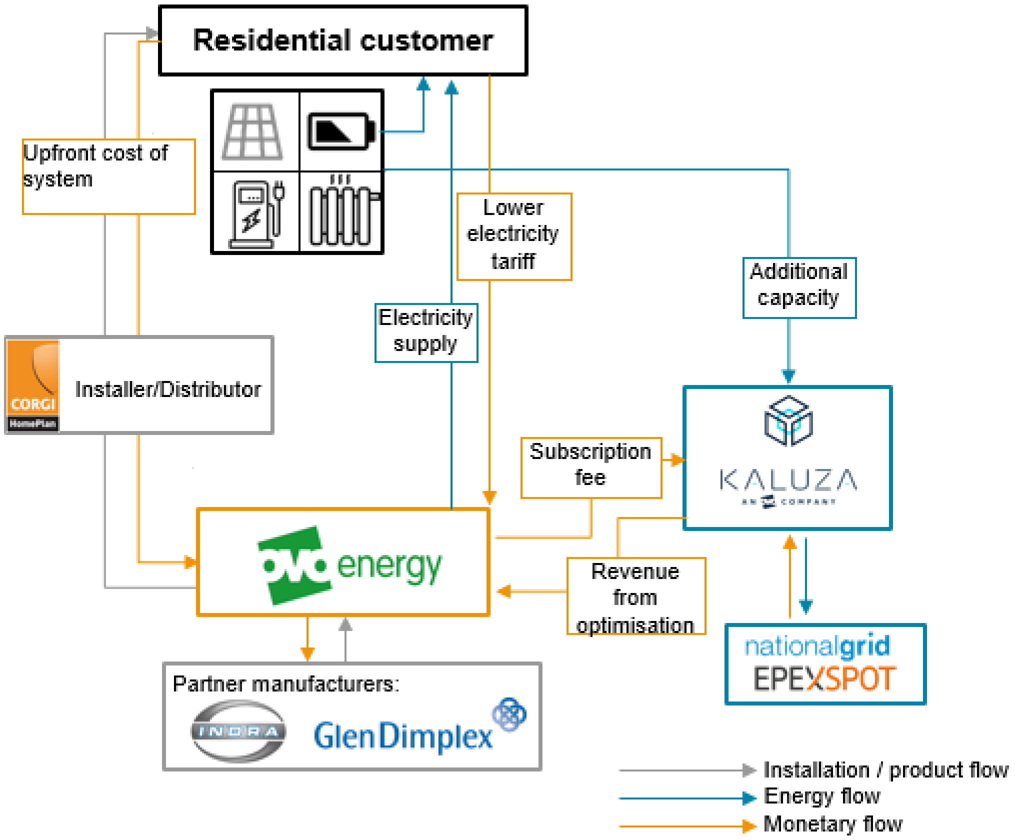


Figure 36. Kaluza business model (Delta-EE, 2020)

- **How might this impact heat pump operation:** Optimising operation to generate additional revenue from price arbitrage, grid services and balancing portfolios is likely to result in a similar profile to Figure 33.

Providing a guaranteed outcome - Eneco: Comfort as a Service (CaaS)

Eneco is the second largest supplier of electricity and gas in the Netherlands. It is trialling selling "comfort as a service" to social housing tenants in newly built properties. In this model, Eneco owns, maintains and operates heat pumps installed in the homes to deliver 20°C during winter and 180 litres (30min worth) of hot water a day. It is currently trialling this in 61 new-build homes in Utrecht owned by housing association Bo-Ex, with whom Eneco has a 15 year contract.

The heat pumps are connected to solar PV panels and the residual electricity for the heat pumps is supplied by Eneco. Eneco meters the electricity used as well as the heat generated. The heat pump is on a separate electricity meter from the rest of the house, so households can still switch electricity supplier for non-heating supply. Eneco's team of data scientists monitors the heat pump performance using both a Modbus adapter (with cellular sim) and NIBE's Uplink API service. Eneco also controls the heating curves, when to fill the hot water tank, and when to run the legionella programme based on real time demand, temperature and cost data. Tenants are still able to set the temperatures in the living areas and bedrooms with a thermostat.

Tenants benefit from having greater certainty over their heating bills, which are often more of a concern with heat pumps. There is also no additional cost for maintenance and repairs of the heat pump. The business model is represented graphically in Figure 37.

This trial began in late 2019. Eneco's immediate priority is to do further trials with other housing association partners to collect more data. Potential next steps include modifying the model for the owner-occupier sector, exploring using the ground-source heat pumps to provide cooling in summer, and eventually opening it up to the retrofit sector (where energy demand is less predictable, and this model is therefore more challenging).

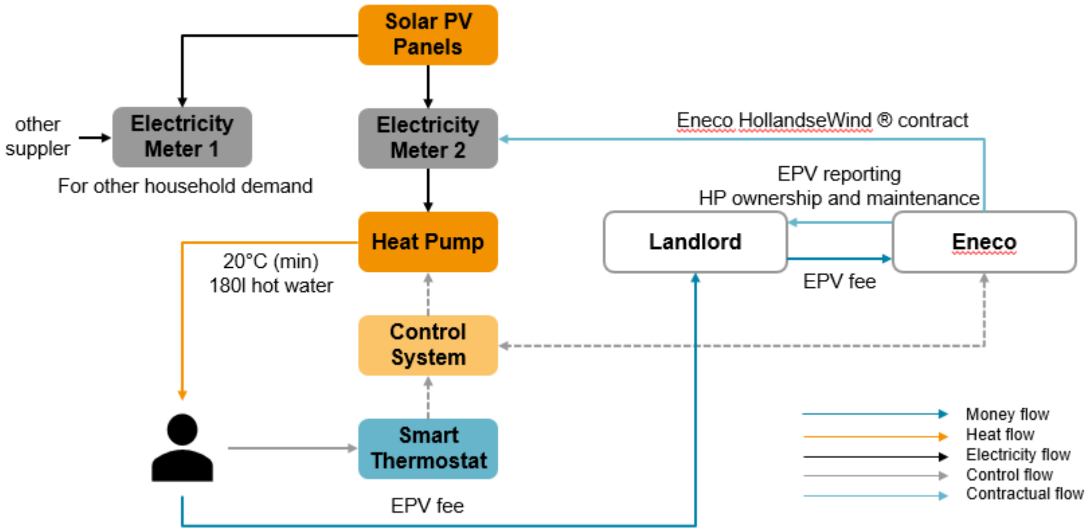


Figure 37. Eneco HP CaaS business model (Delta-EE, 2020)

- **How might this impact heat pump operation:** Eneco has a trading unit that will be able to control its heat pump asset base – this will enable it to incorporate flexibility value streams, improving the business case for its CaaS model. Operating according to these value streams will likely follow a similar profile to that in Figure 33.
- **Prospects for this type of model in the UK:** Models optimising heat pump operation and/or providing warmth outcomes are still very much at trial stage in the UK. But we are likely to see more product/outcome as a service models emerging for heat pumps (in new build or retrofit) if the UK is to meet its target of installing 600,000 a year by 2028.

6.1.4. Customer Propositions using Smart Thermal Energy Storage

Like for heat pumps and other forms of flexible/smart electric space heating, there are also emerging examples of propositions using smart hot water tanks and other forms of thermal storage to capture value from flexibility.

Smart hot water tanks can be heated using the electrical immersion heater during periods of excess supply on the national, district or local electricity system (tapping into values such as FFR, balancing and wholesale markets) and release the heat when required. Services provided by these tanks can generate revenue for the consumer and deliver benefits for the energy system.

Key types of flexibility provided by hot water tanks currently are:

- **PV self-consumption –** Via either an energy management system or PV inverter - Automatic power controllers divert surplus energy generated by a PV system into an element driven device, such as an immersion water heater or storage heater. It also enables monitoring of consumption patterns.
- **Time-of-use tariffs** (see descriptions in section 6.1.2)
- **Ancillary services –** Smart DHW tanks can be aggregated and controlled to provide ancillary services to the TSO. However, to get 1 MW capacity from electric DHW, the Aggregator needs ~500 DSR customers (assuming some diversity in the set points required by different customers, and allowable thermal comfort disruption parameters).

Table 20. Features of the available smart hot water tank suppliers

Feature	Eneco	Climote	Mixergy
Maximising PV self-consumption	No	No	Yes
Using electric heating flexibltiy	Yes	Yes	Yes
Ability to concentrate the heat in a certain proportion of the tank	Not currently Depends on tank design	Partial Make use of an upper and lower immersion elements that are common in tanks in Ireland	Yes
'Tank fullness' indicator and controls	Yes	Yes	Yes
Heating only as much hot water as is required	Yes	Yes	Yes

Early European examples exist of suppliers and aggregators offering 'combined' propositions – combining control of electric heating / heat pumps with control of the water tank in order to provide value for the customer / electricity system. These include:

Viessmann has developed ViShare (a combined proposition) to target the electrically heated new builds in Germany. The package includes PV and storage installations together with a flat electricity rate. Digital Energy Solutions (partly owned by Viessmann) provides DSR services through its home energy management platform. Viessmann's heat pumps and hot water tanks can also be added to this model for further optimisation – see Figure 38.

End-users pay a monthly fee, on top of the system's hardware cost, while in return they get instant monetary savings from PV self-consumption, optimised electric loads and increased comfort and energy independence. ViShare was launched at the end of 2017 and currently has a few hundred connected households.

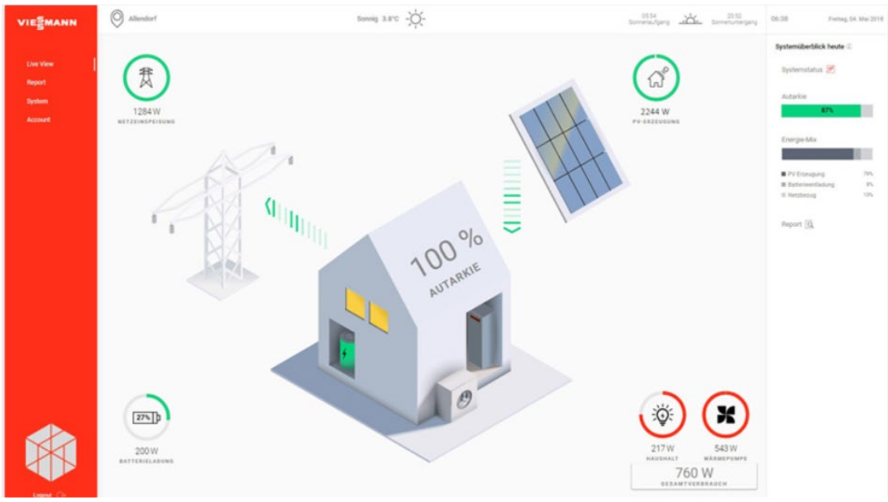


Figure 38. Graphics from Viessmann's ViShare interface

There Corporation – a Finnish start-up specialising in home energy management and DSR – integrates its connected solutions to Kaukora's Jaspi (part of NIBE family) electric hot water tanks.

Connectivity allows the end-user to remotely control and set the preferred water heating patterns. There Corporation can then use the connected hot water tank to provide flexibility to the electricity system with a partnering energy supplier.

End-users need to cover the additional hardware cost for the integrated hot water tanks (€100-€200 more expensive than the traditional one). There Corporation also charges its energy supplier partners a monthly fee for the platform (€5/connected customer per month).

In the UK, several trial / demonstration projects have been launched to utilise the energy storage potential of hot water cylinders installed in UK homes to help balance the system. This includes The USER project (a consortium made up of Levelise, Heatrae Sadia, Ecuity, Energy Systems Catapult and Durham University) (USER Project, 2020), which will optimise a 'virtual community' of 350 homes using AI to allow hot water cylinders to autonomously learn how much each household uses at what time, and to decide which is the best action to take in order to produce lower bills, whilst ensuring energy is not wasted. The project will use Levelise technology and look to retrofit existing hot water cylinders with immersion heaters.

Another example is a project being carried out by Innovate UK and BEIS which is using Mixergy tanks installed in ~700 homes to trial how these tanks can offer frequency response services to the National Grid. This follows a DSR pilot where Mixergy tanks were installed in 78 East Devon District council properties alongside Vaillant ASHPs, PV panels and diverter, allowing the solar panels to charge the hot water tank (CIBSE, 2021).

6.2. UK market status & outlook

As shown in the Figure 40 below, the vast majority of flexible assets in the UK being used for demand response are currently storage heaters (~11MW of capacity), coming predominantly from Ovo (Kaluza) and GlenDimplex Quantum storage heater installations (~8MW) and Connected Response and EDF's smart storage heater retrofit solutions installed in London (~2.5MW). Most of these will operate within Economy 7/10 tariff time windows.

About ~2.7MW of hot water tank capacity is used for demand response, this mostly comes from Mixergy's installed base of smart hot water tanks (providing ancillary (fast frequency response) services).

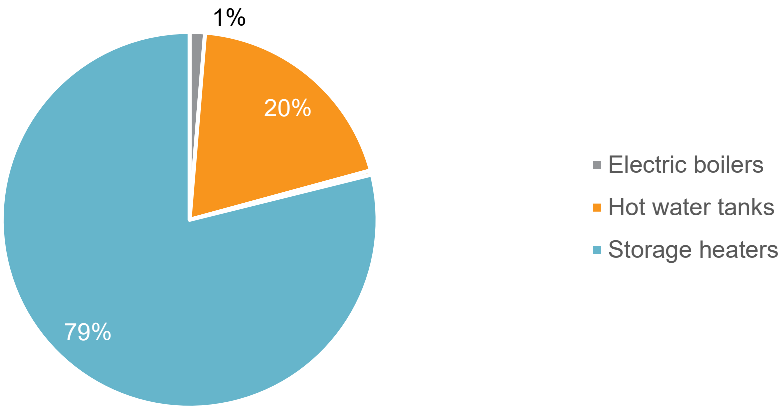


Figure 39. Share of residential flexible electric heating capacity currently used in demand response, by asset type (total capacity 13.7MW)

Key technologies show significant potential for flexibility. For example, if appropriately managed, the 9 million hot water tanks installed in the UK represent a 27 GW demand response opportunity (Levelise, 2018)

Many revenue streams are – in theory – open to being accessed by residential loads in the UK. Ancillary services will likely continue to be key, however profitability is declining as competition increases and the market is gradually shifting towards capturing wholesale market value.

Some barriers still remain (e.g. around metering requirements and minimum load sizes) – however, many of these are around commercial considerations (e.g. the additional cost of settling residential customers on a half-hourly basis) rather than regulatory challenges. Residential electric heating used flexibly is expected to ramp up once half hourly settlement is fully implemented (and energy costs will be more reflective of actual timing of operation vs average load profiles). However, this is not expected for at least another 5 years (possibly towards the end of RIIO-ED2).

Coming changes (e.g. the upcoming review of network charges under the RIIO-2 framework, the smart meter roll-out, currently ~30% penetration) should improve the commercial case for demand response from residential loads from the early-to-mid 2020s onwards.

However, consumer demand for flexible electric heating is key. Appetite for time of use tariffs, for example, could drive increased uptake. However, if enrolment is opt-in, uptake could fall between 1% and 43%. Dynamic tariffs are also much less popular than static time of use rates (Nicolson, Fell, & Huebner, 2018).

In summary, most activity is likely to remain at trial stage until the mid-2020s, but commercial models could grow quickly thereafter.

6.3. Impact of findings, relevance, and recommendations for WPD

Growth in intermittent renewables is driving an increasingly volatile system, with larger benefits to system flexibility, and larger value for those able to provide it. For suppliers this means encouraging their customers to consume energy at different times to lower their risk against increasingly more dynamic needs of the system (reflected in wholesale energy costs and use of system costs). For National Grid ESO this means widening participation in its flexibility services to include distributed portfolios of assets, including from demand side response. Although participation from residential assets in these markets is still in nascent stages, participation is expected to grow.

This increased participation is manifesting in a number of different ways. The way suppliers are encouraging customers to participate or consent to their assets being more dynamically controlled is via offering new (time of use) tariffs (likely through offering additional benefits to the customer vs other tariffs). Suppliers are then able to use flexibility in aggregated loads to create value in trading in wholesale markets and balancing their own portfolios. Aggregators are beginning to offer propositions to customers (such as revenue sharing) to allow them to control and provide ancillary and balancing services to the ESO using aggregated LV load if it can meet the technical and communication requirements of a service at a competitive price.

As this chapter has discussed, more dynamic operation of electric heating (such a heat pump) in response to these market signals will often result in heating profiles similar to those seen when smart electric heating is used with a dynamic time of use tariff such as the Agile tariff offered by Octopus Energy. This is because these types of tariffs will expose the customer to the market signals, costs and risks as outlined above (normally taken on by the supplier) and so the heating operation will be modified to optimise the timing of operation according to these signals. Once half hourly settlement and high smart meter penetration are in place, the drive for customer heating assets to respond in similar ways to market signals will be much stronger. However, this is unlikely to become a key driver of widespread commercial adoption of these tariffs and business model propositions for at least another 5 years (the likely timeframe for Elexon to implement mandatory half hourly settlement).

That said, more dynamic operation of electric heating could increasingly have an impact on the local electricity network operated by the DSO. If, for example, customers are within constrained areas of the network and the ESO or supplier is sending signals to the heat pump to turn up (reacting to weather or system shock events) during the evening peak, this could cause challenges for the DSO. There may be conflict between national needs and DSO needs when for example nationally the system is long (more generation than demand – e.g. in instances of high wind) and there is high local demand. With increasing load on the local network via rising numbers of electric vehicles and heat pumps, these potential conflicts will likely be exacerbated and could cause new problems for the local network. For example, high levels of EVs/HPs reacting to a dynamic tariff such as the one above risks creating new overnight peaks, or peaky demand on either side of current morning/evening peaks. New constraints may also be created if an aggregator wants to dispatch a large amount of load (responding to wholesale or ESO market signals for example) outside of traditional DUoS/E7/E10 tariff windows.

Emerging commercial propositions signal how this consent for increased control of customers' assets may be 'sold' to the customer, however models optimising heat pump operation are still very much at trial stage in the UK. However, we are likely to see more of these sorts of service models emerging for heat pumps (in new build or retrofit) if the UK is to meet its target of installing 600,000 a year by 2028, as these models provide a way to lower the costs associated with these technologies for customers – a key barrier to adoption.

The findings in this chapter will be carried forward to other parts of the project in a number of ways:

- The approaches for using electric heating more flexibly, such with a dynamic time of use tariff, will inform the modelling performed in other work packages. In work package 3, for example an understanding for how use of a heat pump with an Octopus Agile tariff corresponds with customer preferences around comfort, and how much flexibility there may be using these different control strategies within different types of homes can be investigated.
- In work package 4, scenarios for penetration of flexible customer propositions and the likely influence these propositions will have on operation profiles of electric heating (as outlined in this chapter), will be tested and aggregated to the network level to understand aggregated impacts of more flexible use of electric heating.

7. Appendix 1

Appendix 1. WPD DFES 2020 Heat pump uptake

Summary of domestic heat pump uptake totals across WPD 4 licence areas (Regen for WPD, 2020):

Thousands of heat pumps		Baseline	2025	2030	2050
ASHP & GSHP	Steady progression	34	57	74	900
	System Transformation	34	128	301	1,526
	Consumer Transformation	34	568	1,578	5,853
	Leading the Way	34	568	1,567	4,459

South West licence area uptake summary (Regen for WPD, 2020)

Summary of domestic heat pump uptake in the South West licence area:

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
ASHP & GSHP	Steady progression	15	20	24	52	94	182	257
	System Transformation	15	40	89	154	218	317	397
	Consumer Transformation	15	142	347	576	775	958	1143
	Leading the Way	15	142	348	510	682	872	905
Hybrid HP	Steady progression	0	1	10	23	29	45	73

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
	System Transformation	0	14	32	69	88	131	173
	Consumer Transformation	0	7	24	54	84	106	133
	Leading the Way	0	26	85	155	243	341	340

- In line with changes nationwide, there is a dramatic shift to low carbon heating in the South West licence area, in all three of the net zero compliant scenarios. In the more electrified Consumer Transformation scenario, c.73% of homes are primarily heated by a heat pump by 2050.
- The housing stock in this licence area has some differences when compared to national average, with a low level of social housing and smaller numbers of detached homes, along with a high number of hard-to-insulate houses.
- The potential uptake of hybrid systems is lower than the UK average in this licence area because of the high proportion of off-gas homes. In this licence area, 33% of homes are not connected to the gas network, compared to 15% for GB as a whole.

South Wales licence area uptake summary (Regen for WPD, 2020)

Summary of domestic heat pump uptake in the South Wales licence area:

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
ASHP & GSHP	Steady progression	4	7	9	22	43	84	119
	System Transformation	4	15	36	64	96	152	198
	Consumer Transformation	4	72	201	367	517	660	808
	Leading the Way	4	71	200	308	437	587	608
Hybrid HP	Steady progression	0	1	9	20	26	40	64
	System Transformation	0	13	29	61	77	114	148

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
	Consumer Transformation	0	7	21	47	73	91	114
	Leading the Way	0	24	76	137	212	295	293

- In line with changes nationwide, the South Wales licence area sees a dramatic shift to low carbon heating in all three of the net zero compliant scenarios. In the more electrified Consumer Transformation scenario, c.73% of homes are primarily heated by a heat pump by 2050.
- Due to the similarities in the South Wales housing stock to the national average, heat pump uptake in this licence area is projected to fall broadly in line with the GB FES 2020 average over the scenario time frame.
- Hybrid systems are slightly less prevalent in this licence area than GB overall due to a higher rate of off-gas homes which are unsuitable for the technology. The South Wales licence area has 19% of homes off-gas compared to 15% for GB as a whole.

East Midlands licence area uptake summary (Regen for WPD, 2020)

Summary of domestic heat pump uptake in the East Midlands licence area:

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
ASHP & GSHP	Steady progression	7	16	22	56	107	205	291
	System Transformation	7	37	88	155	233	367	478
	Consumer Transformation	7	187	545	985	1,369	1,729	2,090
	Leading the Way	7	183	537	814	1,137	1,506	1,571
Hybrid HP	Steady progression	0	3	24	52	67	103	166
	System Transformation	0	34	73	154	192	279	359
	Consumer Transformation	0	17	54	118	181	224	277

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
	Leading the Way	0	61	193	344	525	722	719

- In line with changes nationwide, there is a dramatic shift in the East Midlands to low carbon heating in all three of the net zero compliant scenarios. In the more electrified Consumer Transformation scenario, c.85% of homes are primarily heated by a heat pump by 2050.
- Due to the East Midland's larger-than-average houses and greater proportion of detached and semi-detached homes, heat pump uptake is projected to exceed the national average over the scenario time frame.
- Due to the slightly lower than average proportion of homes connected to the gas grid in this area – 18% of homes are off-gas, compared to 15% nationally – non-hybrid heat pumps are more prevalent in this region than the projected national average.

West Midlands licence area uptake summary (Regen for WPD, 2020)

Summary of domestic heat pump uptake in the West Midlands licence area:

Thousands of heat pumps		Baseline	2025	2030	2035	2040	2045	2050
ASHP & GSHP	Steady progression	8	14	19	51	99	194	275
	System Transformation	8	36	88	154	227	352	453
	Consumer Transformation	8	176	485	861	1,190	1,499	1,811
	Leading the Way	8	172	482	723	1,004	1,328	1,375
Hybrid HP	Steady progression	0	3	22	47	61	93	150
	System Transformation	0	31	66	139	173	251	324
	Consumer Transformation	0	15	49	107	163	202	250
	Leading the Way	0	56	175	310	474	651	648

- In line with changes nationwide, there is a dramatic shift in the West Midlands licence area to low carbon heating in all three of the net zero compliant scenarios. In the more electrified Consumer Transformation scenario, c.75% of homes are primarily heated by a heat pump by 2050.
- Due to the similarities in the West Midlands housing stock to the national average, heat pump uptake in this licence area is projected to fall broadly in line with the GB FES average over the scenario time frame.
- Hybrid systems are slightly less prevalent in this licence area than GB overall due to a higher rate of off-gas homes which are unsuitable for the technology. West Midlands has 20% of homes off-gas compared to 15% nationally.

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