elementenergy
an ERM Group company

Low Carbon Heat Study

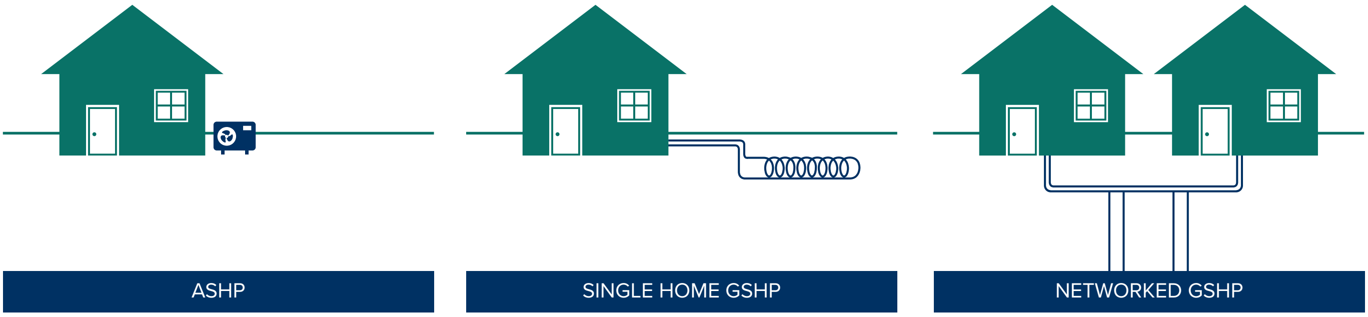
An assessment of the impact of ground and air source heat pump deployment and heating demand flexibility on the GB electricity system and households

May 2023

Executive summary

Heat pumps and networked heat pumps

Heat pumps absorb heat from outside and use electricity to upgrade it and transfer it inside a building. Because they make use of existing heat stored in the ground, or that is present in the air, and use electricity to absorb and transfer it rather than generate heat directly, they can achieve much higher efficiencies than boilers or direct forms of electric heat. Due to their high efficiencies and their ability to operate on low-carbon electricity, heat pumps are central to the government's plans of decarbonising heating in buildings, with a target of 600,000 installed per year from 2028[1].



Some heat pumps absorb heat from the outside air, known as air-source heat pumps (ASHPs). Other heat pumps absorb heat from pipework installed beneath the ground, known as ground source heat pumps (GSHPs). Although installing these groundworks for GSHPs is effort-intensive, there can be significant benefits from installing GSHPs over and above those provided by ASHPs, including even higher efficiencies.

Single home GSHPs have an independent ground loop array for each individual home with a GSHP. **Networked GSHPs** use a shared ground loop array in which the heat-absorbing pipework is installed for a number of properties at once, with each home having a separate GSHP to utilise the heat from these shared pipes. A networked approach to GSHPs significantly expands the range of building types that could benefit from the technology, from new builds, to terraced homes and high-rise tower blocks. Using this shared ground loop array allows for the cost of the groundworks to be spread across a large number of houses, resulting in cost savings for each individual home. This approach can also enable a 'utility' funding model whereby individual homes do not own or pay upfront for the shared ground loop array network, but instead pay a connection or network fee, just like the current model for gas or electricity. Households connected to a heat pump network retain control of the heating for their home and their choice of energy provider. There is no metering or charging for heat, just a standing charge for access to the shared ground array.

Kensa has commissioned Element Energy to conduct expert independent research into the comparative benefits of ASHPs to networked GSHPs. Element Energy's Low Carbon Heat Study investigates this, with findings published across two reports:

Low Carbon Heat Study Phase 1, which compares the comparative cost and performance of installing ASHPs and GSHPs in individual households (both single home GSHPs and networked GSHPs).

Low Carbon Heat Study Phase 2, which investigates the performance and cost impacts of installing ASHPs and GSHPs on Great Britain's national electricity system.

This executive summary presents the key findings from these two studies, with more detail provided in the Phase 1 and Phase 2 reports which are published alongside this executive summary.

The Low Carbon Heat Study investigates the impacts of installing networked GSHPs in homes across Great Britain

In the Low Carbon Heat Study Element Energy has conducted detailed modelling to assess the cost and performance of ASHPs and GSHPs, both for individual houses and across the entire housing stock in Great Britain.

Phase 1 considers ASHPs and GSHPs (both networked GSHPs and single home GSHPs) in two building types – a Victorian 3-bed terraced house and a new-build 3-bed semi-detached house – and compares the upfront cost and running cost of each technology. In Phase 2 this analysis is expanded to include archetypes representing the entire housing stock in Great Britain in 2050. Phase 2 examines the impact varying degrees of ASHP and GSHP heat pump deployment has in 2050 on peak electricity demand for Great Britain, total electricity consumption, and system costs, as well as the ability to match electricity demand with variable renewable generation in a highly electrified low-carbon energy system.

Modelling of heat pump performance and demand flexibility

The hourly efficiency of ASHPs and GSHPs is modelled in the Low Carbon Heat Study, considering the impact of weather, defrost cycles of ASHPs, and heat extraction by ground loop arrays of GSHPs.

Demand flexibility involves shifting electricity consumption from one period of time to another. This can include avoiding use of electricity at times of high demand, or to match electricity demand to times with high renewable supply to avoid curtailment of renewable generation. Demand flexibility can result in cost savings for the whole electricity system by minimising dispatchable capacity (GW) and generation (TWh) and by minimising the cost of upgrading the electricity grid to cope with higher peak demands following electrification. These system cost benefits of demand flexibility can be translated into consumer cost savings through lower wholesale and network costs and access to variable electricity prices, which can incentivise consumers to shift their electricity consumption.

Heat demand flexibility is investigated in Phase 1 and Phase 2 through pre-heating and through the use of heat batteries. **Pre-heating** involves providing additional heating to a home ahead of need and using the thermal mass of the home to allow the temperature to vary within a fixed temperature range deemed to maintain occupant comfort. Heat demand flexibility through the use of a heat battery involves storing heat when electricity prices are lower and releasing it when needed and typically when electricity is more costly and carbon intensive. Both of these methods – pre-heating and use of a heat battery – are modelled in the Low Carbon Heat Study across a range of scenarios.

British electricity system modelling and heat pump scenarios

Both Phase 1 and Phase 2 use Element Energy's proprietary Integrated System Dispatch Model (ISDM) to model the British electricity system in a net-zero emission future scenario in 2050. The ISDM models generation of electricity across Great Britain, integrating renewable electricity generation (from onshore wind, offshore wind and solar) with nuclear power, biomass generation, hydro power, and dispatchable generation at times of low renewable availability.

The ISDM also includes the impact of demand flexibility in electricity consumption; including for heat demand flexibility (as described above) and for flexible charging of electric vehicles. The electricity demand modelling includes domestic electricity demand for ASHPs, GSHPs, other electrified heating (direct electric and district heating), appliances, and other sectors including electric vehicle charging, industrial electricity demand and non-domestic heating and appliance consumption.

Phase 2 of the study uses Element Energy's ISDM to model demand flexibility and renewable electricity generation in a decarbonised electricity system in 2050, with ambitious energy efficiency improvements and a British population highly engaged in decarbonisation. Six scenarios were modelled to explore the impact on the national electricity system of demand flexibility and of varying the proportion of ASHPs and GSHPs, as below. All scenarios assume the same total number of heat pumps in domestic buildings in Great Britain in 2050 (23.3 million)[2]; but with differing proportions of this total made up of ASHPs or GSHPs.

Table 1: Heat Pump and Flexibility 2050 Scenarios

Scenario	Heat pump proportions	Demand flexibility modelling	Use of heat batteries
15% GSHP	15% GSHPs; 85% ASHPs	All sectors	No
38% GSHP	38% GSHPs; 62% ASHPs	All sectors	No
100% GSHP	100% GSHPs; 0% ASHPs	All sectors	No
Only flexible heating	38% GSHPs; 62% ASHPs	Pre-heating only; other sectors inflexible	No
38% GSHP & heat batteries	38% GSHPs; 62% ASHPs	All sectors	Yes
100% GSHP & heat batteries	100% GSHPs; 0% ASHPs	All sectors	Yes

In all scenarios the domestic housing stock is fully decarbonised. There are 23.3 million homes with heat pumps installed in each scenario, with the split of these heat pumps between ASHPs and GSHPs varying between scenarios. This is in addition to 1.7 million homes using direct electric heating, and 6.2 million homes connected to district heating networks.

The scenarios with 100% deployment of GSHPs are not intended to represent likely scenarios, as ASHPs are likely to play a significant role in the electrification of heat in the future. These 100% GSHP scenarios were included to explore the potential benefits to the British energy system of increasing GSHP deployment alongside demand flexibility. Current market deployment of GSHPs in the UK is estimated at 15%, whilst a 38% deployment level for GSHP is equivalent to that modelled by National Grid's 'Consumer Transformation' scenario in 2050 within its Future Energy Scenario report[3]. It should be noted that recent policy changes, including the replacement of the Renewable Heat Incentive with the Boiler Upgrade Scheme, have reduced the relative deployment levels of GSHP compared to ASHP. As such, a 15% GSHP deployment level should not be taken for granted and policy changes will likely be required to deliver the benefits outlined in this study[4].

Widespread electrification of road transport, industry and heating in buildings is necessary for the decarbonisation of the UK[5], which will lead to a significant increase in annual and peak electricity consumption. This Low Carbon Heat Study investigates how this peak demand can be reduced through the use of GSHPs and electricity demand flexibility.

Study findings

This executive summary presents the key findings from Phase 1 and Phase 2 of the Low Carbon Heat Study, regarding peak demand of the electricity system, annual electricity demand for heating, impacts on national heating and electricity system costs, and on benefits to individual householders. For more detail and further findings please see the Phase 1 and Phase 2 reports of the Low Carbon Heat Study.

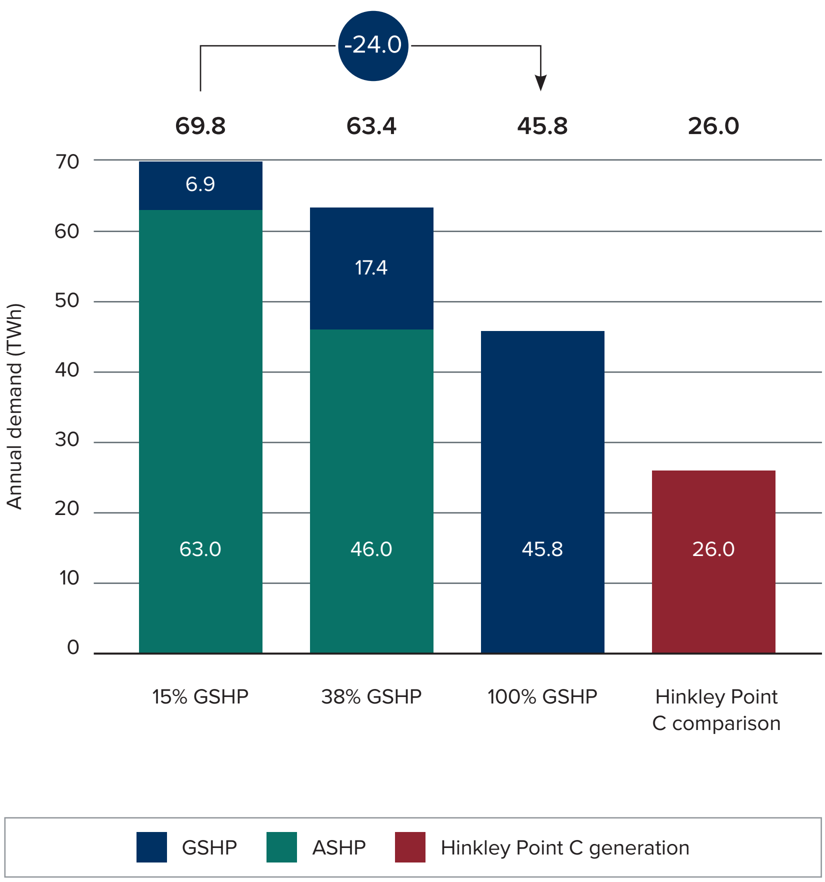
The higher efficiency of GSHPs relative to ASHPs, particularly in weather conditions where the need to defrost the external unit reduces the efficiency of an ASHP, can result in significant electricity savings if GSHPs are installed widely across the British housing stock. The hourly performance of ASHPs and GSHPs in real weather and use conditions is modelled in detail in the Phase 1 report.

Reduced electricity consumption

Increasing the proportion of GSHPs in domestic homes with heat pumps could save up to 24 TWh per year of electricity in 2050.

- Installing GSHPs in 38% of British homes with a heat pump, rather than in 15% of such homes, would save 6.5 TWh per year in 2050. This is roughly equal to the current electricity consumption of 2.2 million homes.
- Installing GSHPs in every British home with a heat pump, rather than in 15% of such homes, would result in savings of 24 TWh per year in 2050. This is roughly equal to the expected annual generation of Hinkley Point C[6].

Figure 1: Annual electricity demand from 23.3 million heat pumps



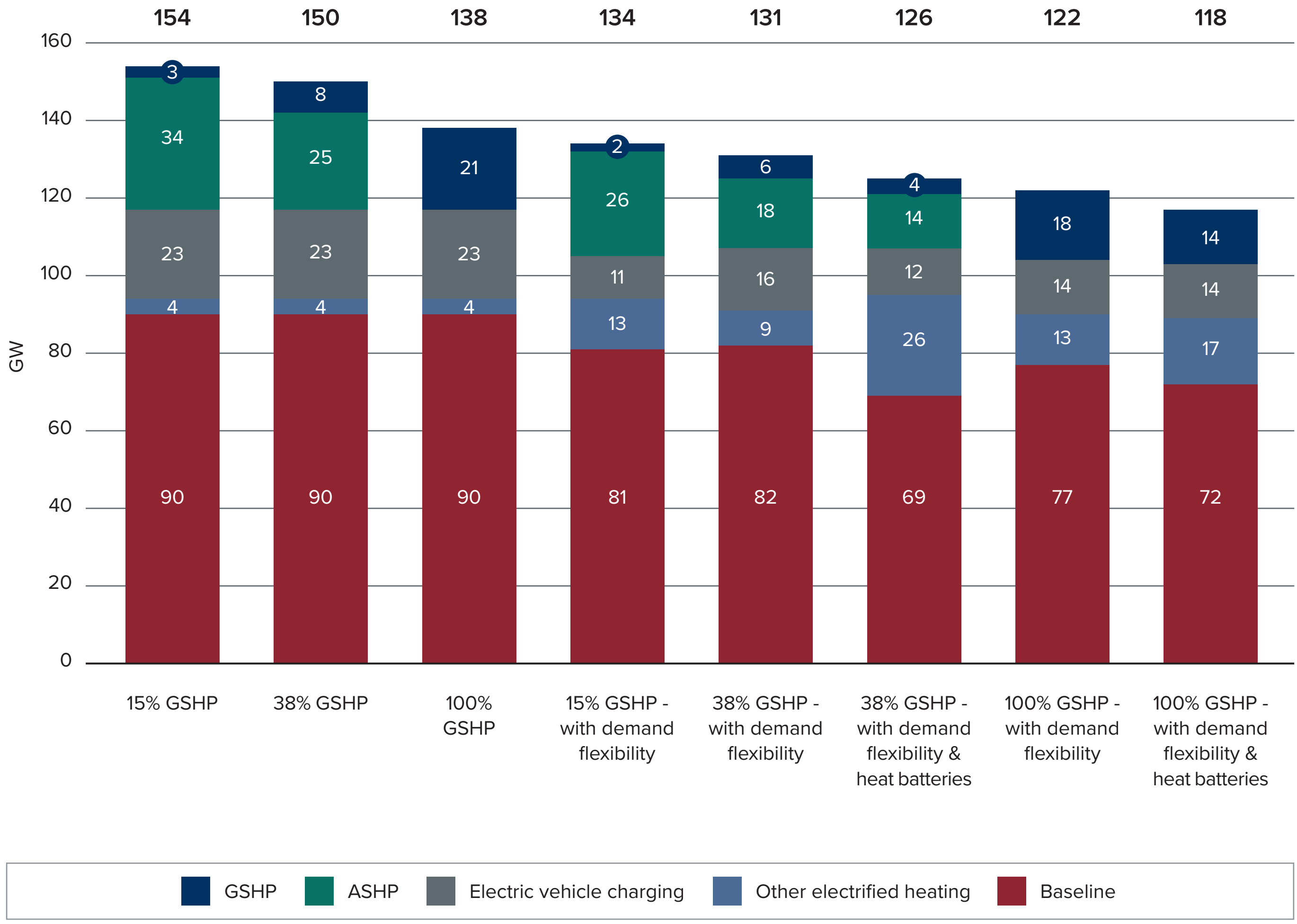
Peak demand reduction

A 24% reduction in annual peak electricity demand can be achieved through increasing the share of GSHPs, and using demand flexibility

The annual peak electricity demand was modelled for the six scenarios using Element Energy's ISDM before and after demand flexibility, with key results shown in Figure 2.

- Increasing the proportion of GSHPs in domestic homes in 2050 from 15% to 100% of heat pumps leads to a 16.8 GW reduction in peak electricity demand even without any demand flexibility, due to the higher efficiency of GSHPs.
- Pre-heating alongside demand flexibility in electric vehicle charging and other sectors leads to 20.8 GW peak electricity savings with 15% proportion of GSHPs; this increases to 32.5 GW when demand flexibility is used alongside 100% GSHP deployment.
- Installing heat batteries in 50% of homes with heat pumps alongside 100% GSHP deployment leads to the largest savings of the scenarios studied, with 36.6 GW saved compared to 15% GSHPs and no demand flexibility. This represents a 24% reduction in peak demand compared to this initial case.
- In the scenarios below, "baseline" represents all other uses of electricity other than domestic heating and electric vehicle charging. Baseline electricity consumption in the peak hour changes as a result of a number of factors including movement in the timing of the peak demand hour in various scenarios.

Figure 2: Modelled peak electricity demand in 2050



Reduced system costs

Up to £13.5 billion per year could be saved by maximising the deployment of GSHP

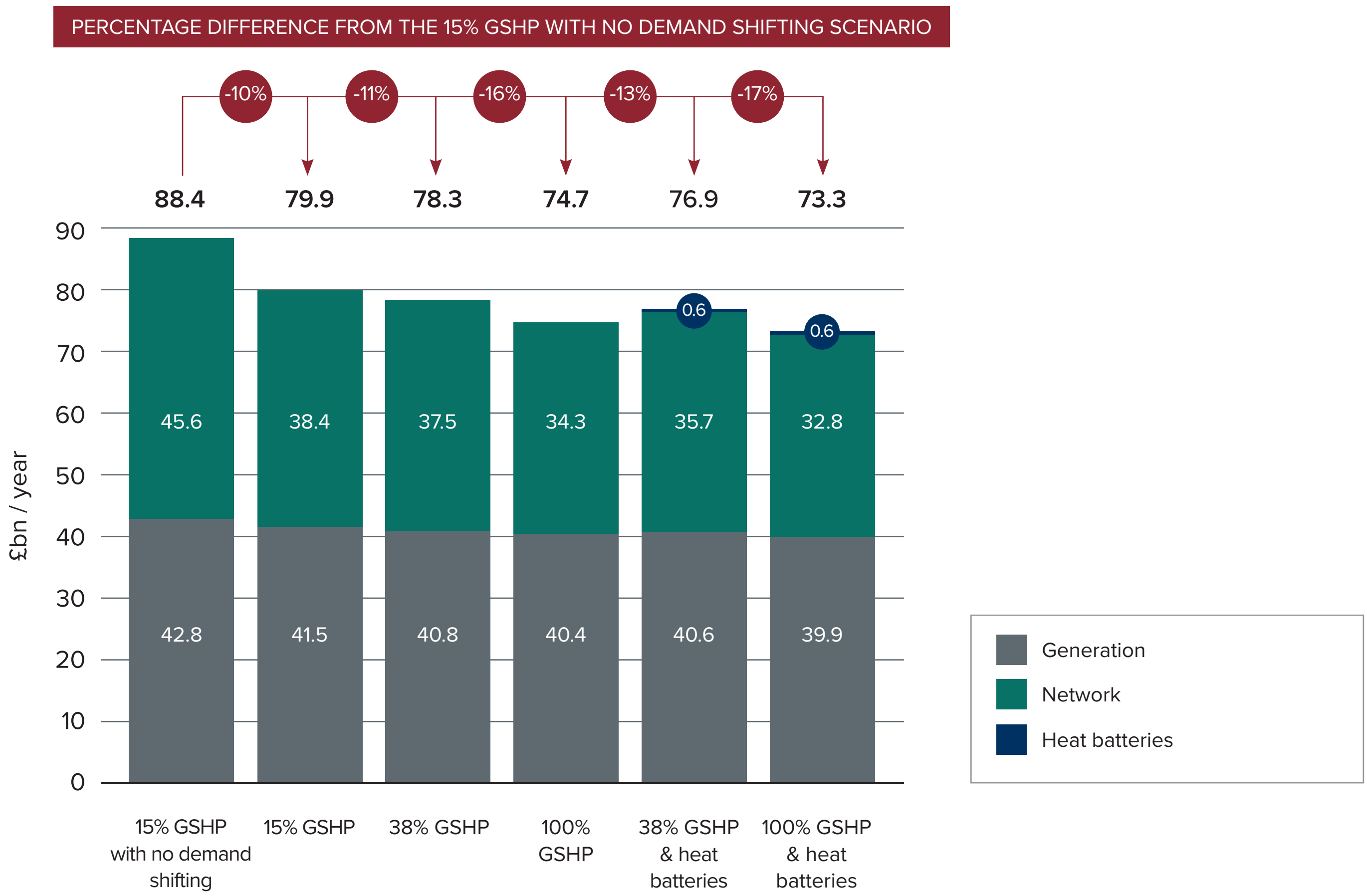
Element Energy's ISDM has modelled Great Britain's national electricity system at an hourly resolution, and analyses how engaged residents can flexibly use their heat pumps and electric vehicles to maximise the use of renewable electricity and to avoid peak hours of electricity demand. Increasing the use of renewable electricity reduces electricity system costs due to lower need for dispatchable generation (i.e. low-carbon hydrogen in turbines). Shifting electricity demand away from peak hours results in further cost savings due to reducing the need to upgrade the electricity network in Great Britain following electrification.

The graph below shows the annualised cost of electricity production (generation) and transmission and distribution (network); in the heat battery scenarios on the right the additional annualised cost of installing a heat battery in 50% of homes with heat pumps is included.

- Demand shifting with heat pumps and electric vehicles reduces electricity system costs in all scenarios, by £8.6 billion per year where GSHPs make up 15% of all heat pumps, and £13.8 billion per year where GSHPs make up 100% of all heat pumps.
- The benefit from the additional flexibility provided by heat batteries in 50% of British homes with heat pumps offsets the cost of installing the heat batteries themselves.
- Up to £15.1 billion per year could be saved in the scenario with the highest deployment of GSHPs and heat batteries.

The electricity system cost savings from increased deployment of GSHPs and use of demand flexibility could be passed onto consumers, so that decarbonisation of the national electricity supply and of heating provides benefits to consumers, including through consumer fuel bills.

Figure 3: Annualised electricity system costs in each scenario



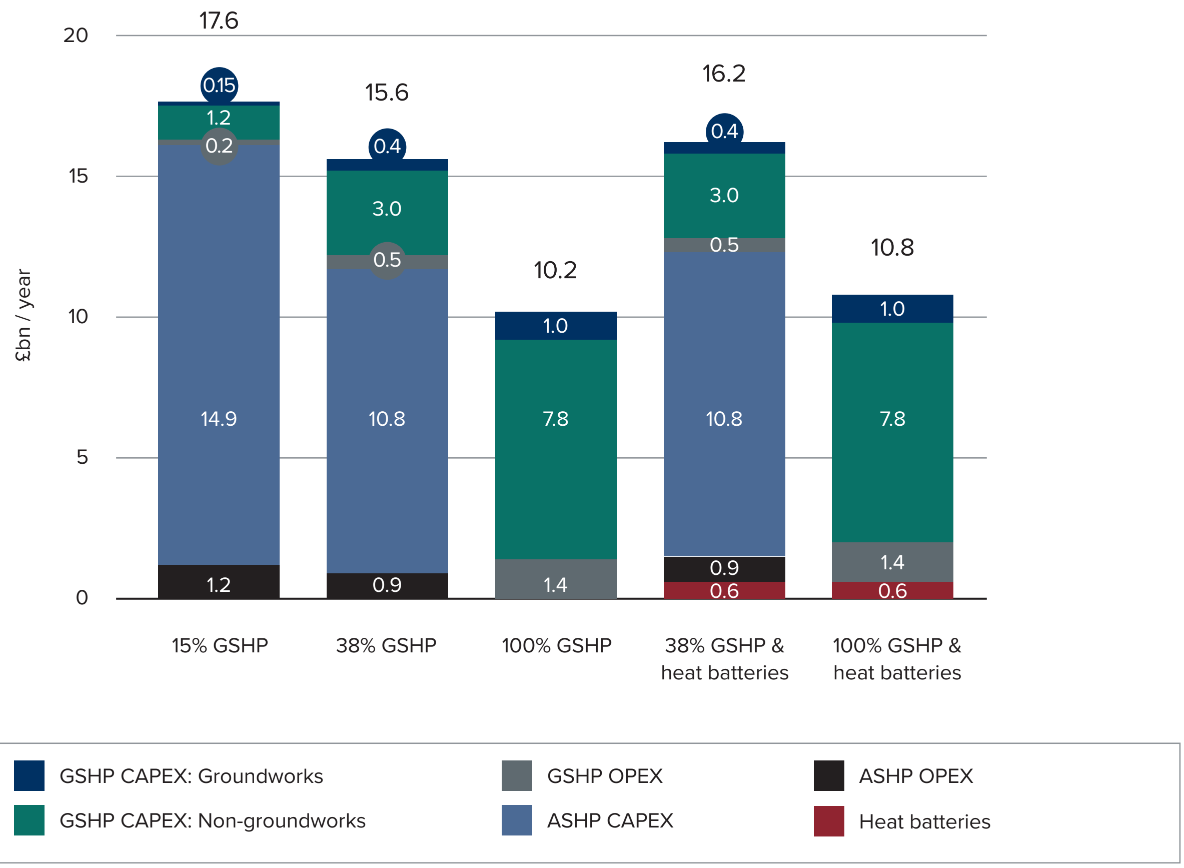
Heating system costs

Total annual heating system costs could be reduced by up to £7.4 billion a year through increased deployment of GSHPs

Phase 2 of the study also examines the total annualised heating system costs to Britain under different scenarios of heat pump deployment and flexibility.

- Total annualised heating system costs were highest under a low GSHP deployment scenario. With GSHP heat pumps making up just 15% of all heat pumps, total annualised costs were £17.6 billion.
- Increasing the level of GSHP to 38% of the total resulted in a £2 billion a year saving. In a hypothetical 100% GSHP scenario, total heating system costs were reduced by £7.4 billion a year, down to £10.2 billion.
- Costs for heat batteries assume 50% of all houses with heat pumps in 2050 have a heat battery installed.
- Annualised heating costs presented below represent total capital costs of 23.3 million heat pumps installed through to 2050, with costs annualised over assumed lifetimes of 15 years for ASHPs, 25 years for GSHPs, and 100 years for GSHP groundworks.

Figure 4: Annualised capital and maintenance costs for GSHPs and ASHPs

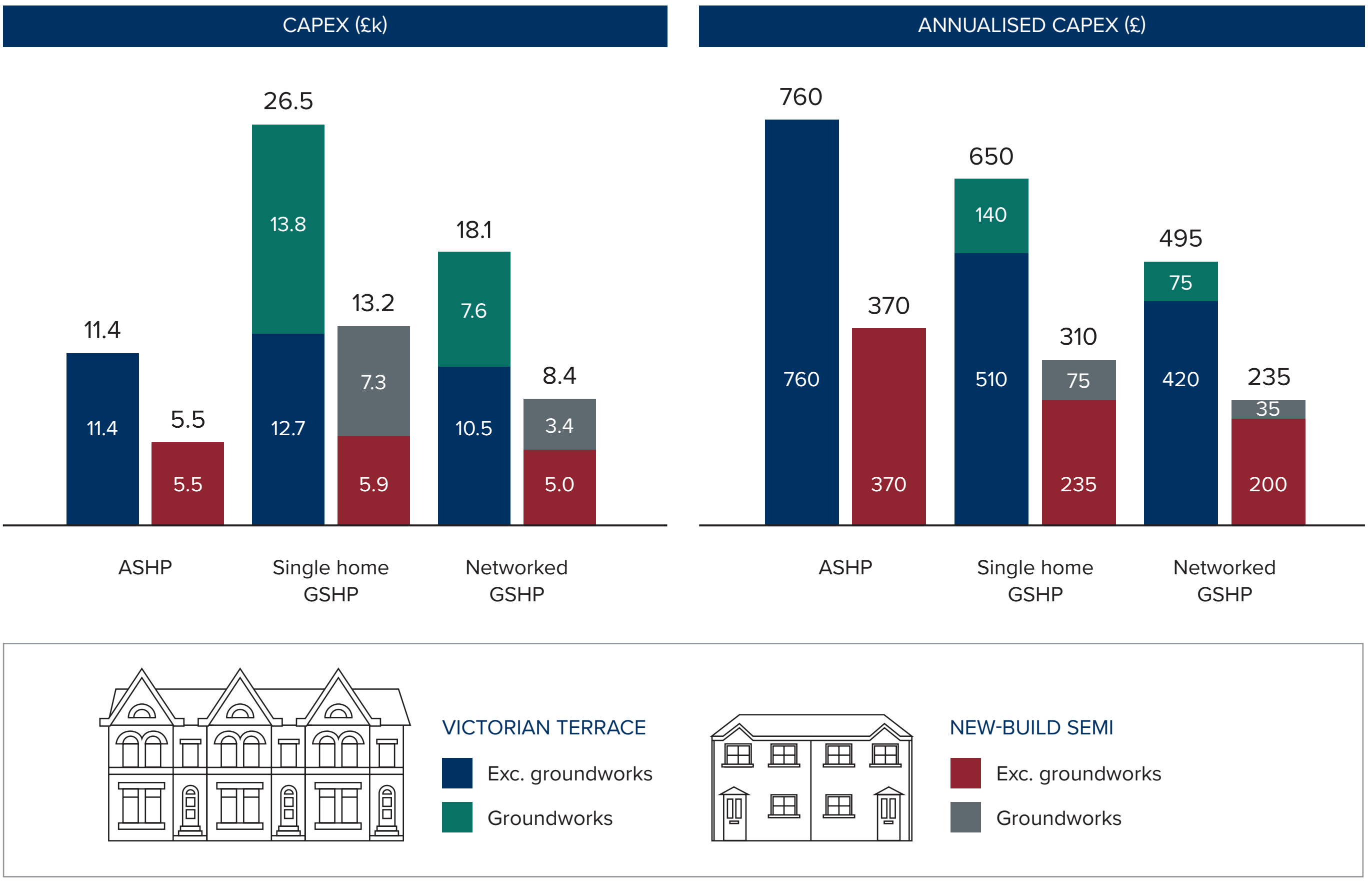


Householder costs

Total annualised costs for networked GSHP systems can be 16 to 18% lower than for ASHPs.

Phase 1 of the Low Carbon Heat Study investigates the total costs of ASHPs and GSHPs in two types of homes; a pre-1919 3-bed Victorian terrace and a 3-bed new-build semi-detached house. The GSHP costs were modelled for single home GSHPs and for networked GSHPs. The upfront costs included all costs related to the purchase and installation of heat pumps, with ASHP cost data taken from a range of public sources and GSHP cost data provided by Kensa. For more information, please see the Phase 1 report.

Figure 5: A comparison of upfront capex (left) and annualised capex (right) for ASHPs, single home GSHPs and for networked GSHPs



- The upfront cost of the GSHP is several thousand pounds higher than the ASHP for both single home and networked GSHPs and in both building types, largely due to the upfront costs of the groundworks.
- However, when the upfront cost of the systems are annualised, the GSHP cost is £60-265 per year lower than for ASHPs; this is due to longer assumed GSHP lifetimes (25 years, vs 15 years for ASHPs) and much longer lifetimes of the ground loop systems (100 year technical lifetime). The utility funding model enabled by networked ground source heat pumps also means capital costs can be financed upfront and paid annually by householders through a connection/network fee.

Figure 6: A comparison of total annualised costs for ASHPs and networked GSHPs

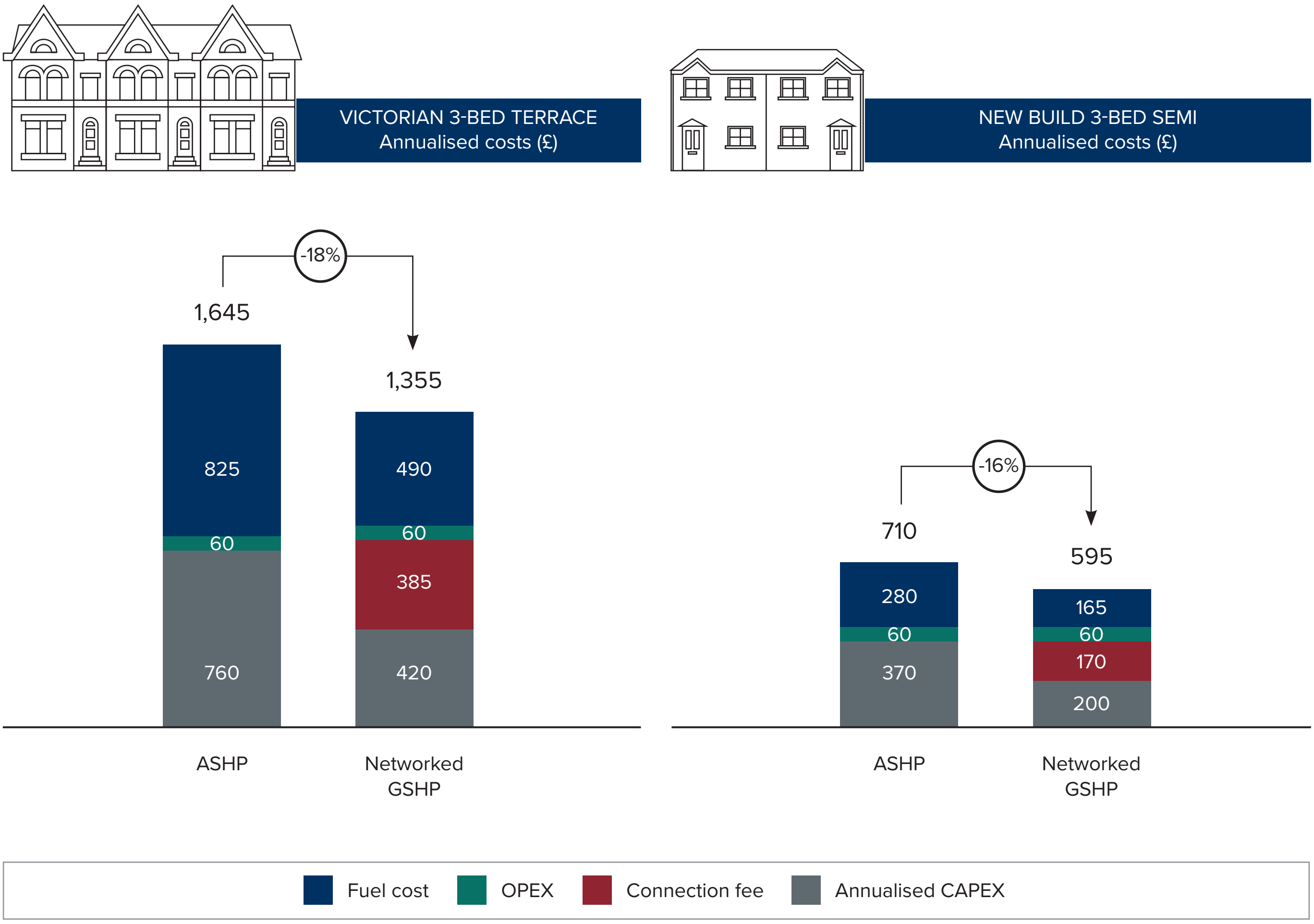


Figure 6 shows that installing networked GSHPs instead of ASHPs leads to annualised cost savings of £115 per year in a 3-bed semi-detached house, and annualised cost savings of £290 per year in a 3-bed terraced house.

- As shown in Figure 6, the lower annualised upfront cost of the networked GSHP system, coupled with higher operational efficiency of GSHPs, results in an 18% lower total annualised cost in the Victorian 3-bed terrace and 16% lower in the new build 3-bed semi-detached home, compared to the ASHP system. The fuel costs in Figure 6 include the savings from higher modelled efficiencies of GSHPs, but do not include any fuel cost savings from demand flexibility.
- Figure 6 annualises the total cost of heat pump installations (capex, opex, connection fee, and fuel costs). In contrast to Figure 5, which annualises the cost of ground works over an assumed 100 year lifetime, Figure 6 assumes these costs are paid over a 40 year period via a connection fee. Assumed 15 and 25 year lifetimes for ASHP and GSHP, respectively, remain the same.

Conclusions

Networked GSHPs and heat demand flexibility have the potential to deliver significant benefits to householders, national energy security, climate goals and the electricity system, but incentives will be required to encourage the flexible use of heat pumps, electric vehicle charging, alongside those provided for the roll-out of heat pumps and energy efficiency.

Despite the lower annualised CAPEX of GSHPs, and the wider system benefits they can provide to Britain, the complexity and upfront costs of installing shared ground loop arrays is likely to be a major barrier to higher levels of deployment of the technology through to 2050. Additional policy specifically targeting rollout of networked GSHPs will likely be required to unlock the long-term and system wide benefits this approach can offer.

References

1 HM Government (2020) The Ten Point Plan for a Green Industrial Revolution

2 This 23.3 million is aligned to the total number of heat pumps installed in Great Britain in 2050 in National Grid's Future Energy Scenarios Consumer Transformation scenario.

3 National Grid (2022) Future Energy Scenarios

4 Ofgem (February 2023) Boiler Upgrade Scheme Quarterly Report - Issue 3. GSHP made up 2.4% of the total heat pump installations funded via the scheme.

5 Climate Change Committee (2020) The Sixth Carbon Budget, Balanced Net Zero Pathway

6 Blackridge Research & Consulting (2022), Hinkley Point C Nuclear Power Station Set To Become UK's Largest Nuclear Power Project

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