NIBE

Energy Infrastructure of the Future: Ground Source Heat Pumps

July 2020

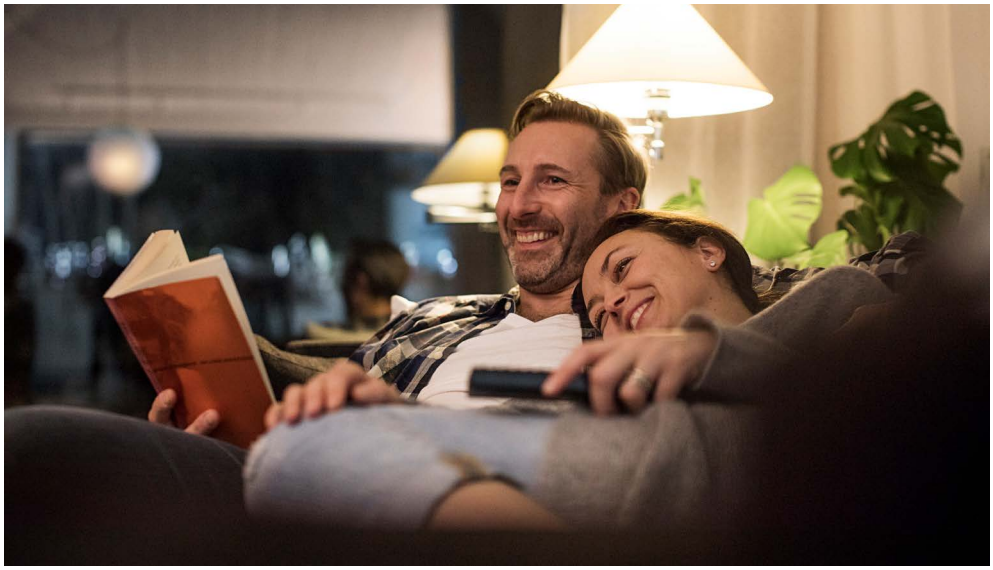
Energy Infrastructure of the Future: GSHPs

Executive Summary

Ground source heat pumps create large carbon savings compared to their fossil fuel counterparts. If the ground works and accompanying installation are carried out at new build stage, they are also just as cheap and easy to put in place. Therefore, with the net-zero carbon emissions for 2050 target set in legislation, and the Future Homes Standard requiring low-carbon heat in new builds from 2025, we need to start building new developments with ground source heat pumps as standard.

This paper puts forward a proposed scheme that would help finance the ground works for ground source heat pumps, making their cost comparable to gas boilers through a standing charge paid regularly by the household. This will pay back the initial capex for the ground works and create warmer, low-carbon new build homes, generating benefits for all parties.

Contents



NIBE Energy Systems Limited

Unit 3C Broom Business Park, Bridge Way, Chesterfield, S41 9QG

Email: marketing@nibe.co.uk Website: http://www.nibe.co.uk/

Introduction

In response to public and political pressure demanding action on climate change, the UK Government recently adopted a net-zero carbon emissions target for 2050, increasing the ambition set out in the Climate Change Act of 2008. The net-zero target is necessary to limit the effects of climate change and is achievable utilising the technologies that are available today, which are low-carbon and can provide warm, comfortable homes that are cheaper to run throughout the year. NIBE Energy Systems therefore supports the net-zero target, and this report seeks to highlight the role that Ground Source Heat Pumps (GSHPs) could play in generating low-carbon heat in buildings across the UK. This is because NIBE has unique expertise in GSHPs and to date ground source technology has not played as much of a role in heat decarbonisation as it could and has not been considered as thoroughly as air source heat pumps. Whilst increased uptake of renewable heat across the board should be encouraged, the benefits of GSHPs should be recognised and deployment supported where appropriate.

To date, the deployment of low-carbon heating across the residential housing stock in the UK has been low, particularly in the case of GSHPs. For example, the total number of GSHPs installed under the domestic Renewable Heat Incentive (RHI) in March 2020 was just 11,000, compared to over 46,000 air source heat pumps and over 12,000 biomass boilers. However, applications for the domestic RHI are at a 4 year high with over 3,400 seen in Quarter 1 2020[1] with the majority (over 85%) for air source heat pumps, demonstrating their increasing popularity.

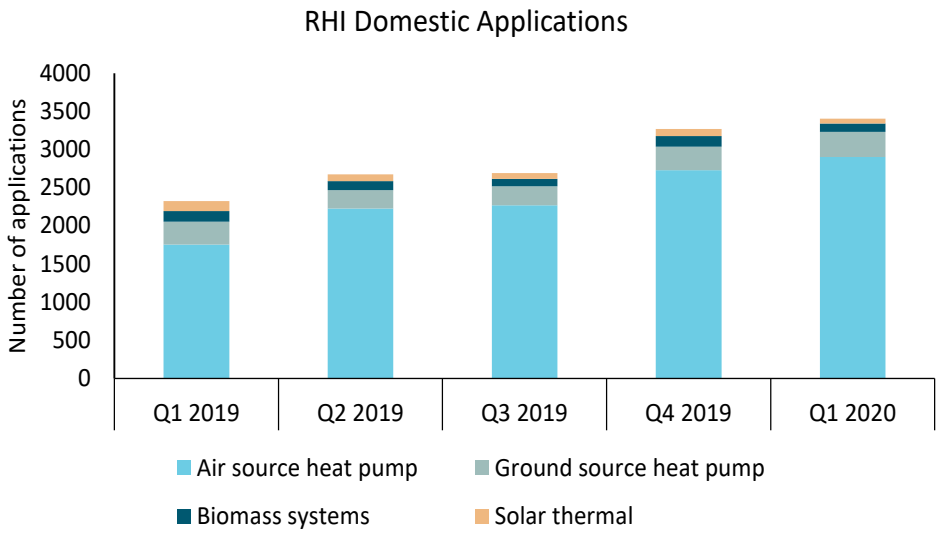


Figure 1 - Domestic Renewable Heat Incentive (RHI) applications by technology (Source: BEIS (2020)[2]

[iii] *In 2017, NIBE Energy Systems surveyed 137 individuals on their views of the heat pump installation market. The survey targeted installers with over 50% of respondents identifying themselves as installers.*

The Committee on Climate Change (CCC) highlighted in their 2019 report[3] that homes across the UK are currently not fit for the future, and more needs to be done to provide low-carbon heating. NIBE suggest that some of the challenges highlighted by the CCC could be met by GSHPs, particularly for new builds where it is cheaper and easier to install heat pumps and for off-gas grid properties that often use fossil fuel heating systems such as oil or LPG.

The Government's commitment to phasing out of oil heating in new build properties is welcomed, but there needs to be an accelerated change from new homes using fossil fuel heating including natural gas to renewable sources to ensure that climate change goals, such as net-zero by 2050, are met and consumers are able to heat their homes cost-effectively. The Department for Business, Energy and Industrial Strategy (BEIS) estimate that around 1% of new homes have oil boilers, however the EPC register indicates that this figure could be higher, and gas boilers represent the majority of heating systems in new homes. The Future Homes Standard will mandate the end of fossil fuel heating systems from 2025 in new homes, as such there is a need to ensure that the infrastructure for renewable heating such as GSHPs is in place to help deliver this aim.

Similarly, for off-grid rural properties, GSHPs can be significantly more cost-effective, less polluting and lower carbon than many of the alternative heating fuels. Research shows that oil and LPG levelised fuel costs are around 6p per kwh[4] compared to electricity's 5p per kWh. Due to the lower efficiency of an oil or LPG boiler in comparison to heat pumps (90% compared to 320%[5]), running costs for oil and LPG are significantly higher and more volatile as they are more affected by geopolitical changes compared to electricity. This means that GSHPs are a logical step forward for off-gas grid rural properties.

The gas and oil boilers mentioned in the new homes and off-gas grid properties above have a lifetime of around 10-15 years however GSHPs have substantially longer lifespans of over 20 years and their boreholes can remain for well over 50 years.[6] In addition, the cost of retrofitting a GSHP at the end of its long lifetime is comparable to other heating systems. This means that once the groundwork costs are covered, there is little long-term financial difference between a GSHP and other technologies.

NIBE believe that the groundworks needed for GSHPs should be seen as a long-term infrastructure investment and policy should be designed to encourage deployment. Incentivising energy infrastructure investments such as boreholes by making them attractive through policy should help to deliver increased uptake of this low-carbon technology.

This report considers the ways in which GSHP groundworks could be supported by policy to increase deployment and reduce the cost to consumers.

New homes today

In their report on UK Housing, the CCC went as far as recommending that from 2025, 'no new homes should be connected to the gas grid' and 'they should instead be heated through low carbon sources and have ultra-high levels of energy efficiency'.[i] GSHPs are a strong option for new build houses, as there is less disruption when groundworks are carried out at the same time as other building work, particularly if the boreholes and ground loops that collect the heat can be shared between numerous properties in a multi-house development.

Ground works are a high cost element of installing a GSHP however, if shared between adjacent homes, the cost of installing a GSHP is much closer to that of an ASHP. To take this principle further, when shared between multiple new build properties the costs of heat pump installation is similar to fossil fuel heating systems, as at this stage the heat emitters can be appropriately sized, and the pipework is designed to this specific system from the outset. Moreover, there is no need to purchase oil or LPG storage tanks or pay the connection fee to the gas grid when GSHPs are installed.

Barriers to deployment

Despite public support for renewables being high at 82%[7], current uptake rates of low-carbon heat in the UK are substantially beneath the levels that they need to be to reach net-zero by 2050. Around 50,000 heat pumps (79% air source, 21% ground source) have been installed into homes under the Renewable Heat Incentive to date[8], which is a disappointing 0.2% of the estimated 27.6 million households in the UK[9]. Whilst there are some installations taking place without government support, these are believed to be low.

There is a variety of reasons for the low uptake of heat pumps across the UK. NIBE installers highlight that barriers to uptake include high upfront costs which could be addressed through the reform of the Renewable Heat Incentive, a lack of knowledge of low-carbon options, and a lack of installers or skills in the heat pump supply chain.

There is evidence that consumers do not always factor in carbon emissions during the decision making process when purchasing a home or new heating system and instead prioritise characteristics like location and proximity to amenities. For consumers that do purchase a heat pump, carbon savings are moderately important as shown below however cost saving is the greatest driver for heating system choice for most consumers, with 20% of installers highlighting that sustainability is often seen as a bonus. This suggests that reducing barriers to uptake and incentivising uptake of renewables is important.

There are also barriers linked to house builders seeing no long-term benefits of installing low-carbon technology like GSHPs. Although GSHPs are cost-effective over their lifetime and deliver ongoing savings for consumers, developers do not see these long-term savings and want to avoid the upfront costs of GSHPs, so deployment is low. This forms a barrier between the developer and the consumer.

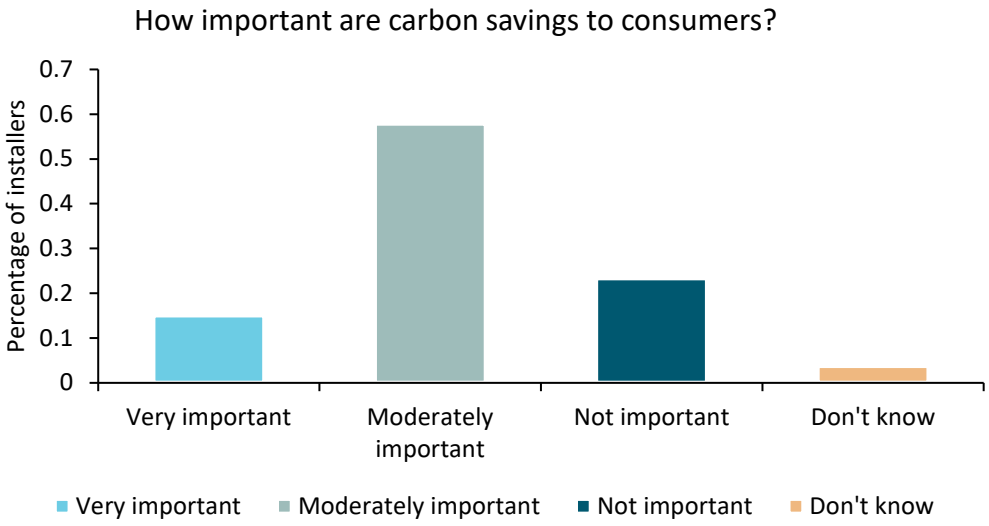


Figure 3 - NIBE Installer Survey- heat pump drivers: carbon emissions (2017)

Our research (see figure 2) shows that cost is the most significant barrier to the installation of heat pumps according to our installers. This could be addressed by reforming the way groundworks for GSHPs are funded through considering it an energy infrastructure investment.

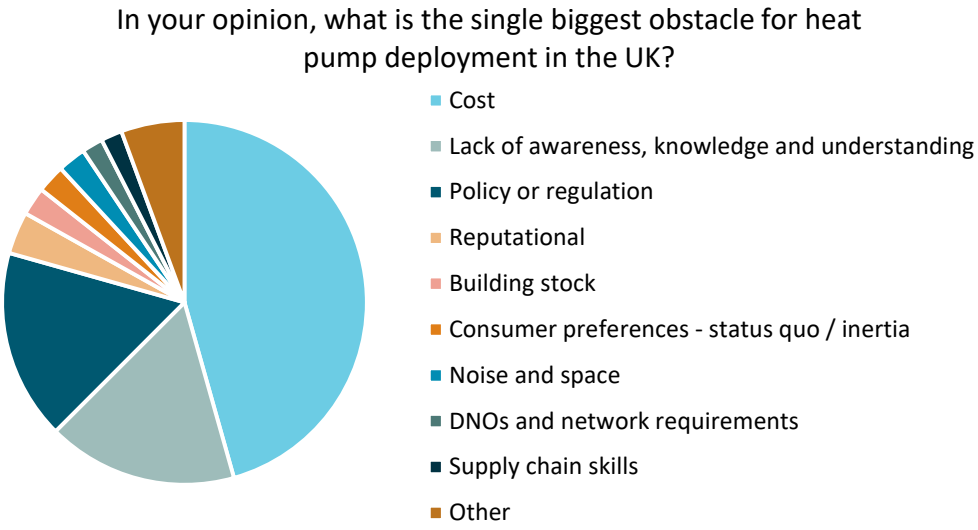


Figure 3 - NIBE Installer Survey: heat pump deployment obstacles (2017)

More homes and higher standards

The Government has committed to building 300,000 each year new homes by the mid-2020s, to tackle the so-called 'housing crisis' and ensure there are enough affordable properties across the UK. This ambitious target is almost double the amount of homes built in 2018[10] (165,090 new homes completed) and implies that significant work must be done to increase the number of new homes built year on year to 2025. In the year to December 2019, 260,000 EPCs for new dwellings were lodged, up 6% on the previous year, however the challenge of building 300,000 annually remains.

From October to December 2019, 82% of new properties were given a B rating and 1% given an A rating[11] . New homes should be fitted with low-carbon heating as standard to help reduce carbon emissions in line with net-zero and the Future Homes Standard.

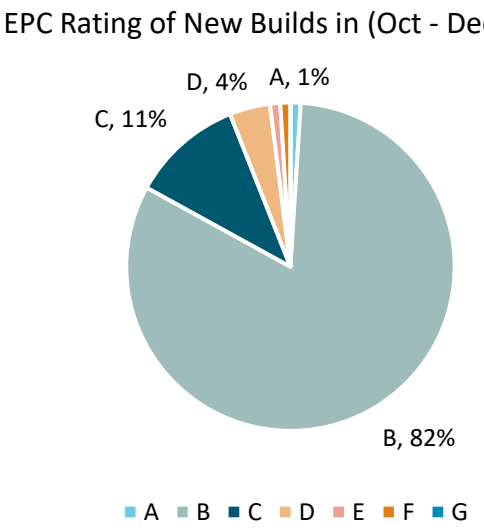


Figure 4 - Energy efficiency ratings (EER): New domestic properties, England October 2019 - December 2019 (Source: MHCLG[12])

Failing to install low carbon heating into new build homes now will have detrimental effects on the carbon targets in the future. Therefore, standards of new build homes should reflect this and be at a such a level that low-carbon heating is the only option that will ensure that these high levels are met. Failing to build low-carbon homes now will mean that they might have to be retrofitted at a higher cost later (the CCC indicate that this could be as much as £21,500 more) and whilst emitting higher volumes of CO2 into the environment.[13]

The homes that we build today must be fit for the future and one way to do this is to futureproof the energy infrastructure surrounding them. New homes should have the infrastructure to become net-zero in the future, even if they do not reach this level now and this involves putting the groundworks in place for GSHPs when it is easiest and most cost-effective – when the homes are being built.

The Future Homes Standard was announced in the Spring Statement 2019 and expressed the Government's ambition to mandate the end of fossil fuel heating systems in new builds and ensure 'world-leading' levels of energy efficiency. Whilst the details of the policy are currently still being developed, the mandated end of fossil fuel systems will help to meet net-zero in the residential sector and for this GSHPs should be considered.

With the electricity grid seeing substantial decarbonisation over recent years and the proposed emissions factors for SAP10 putting electricity at lower levels than natural gas, heat pumps are becoming an increasingly viable option. However, the upfront cost compared to alternatives can be a barrier to deployment in new homes given the prioritisation of cost during the construction of a property.

Part of the solution: GSHPs

Overview of technology

GSHPs work by extracting warmth from the ground that surrounds large pipes buried in a property's garden, via boreholes that can reach several kilometres. The heat from the ground is absorbed into fluid (usually a mixture of water and antifreeze) that is circulated around a ground loop pipe and passed through a heat exchanger into the heat pump. As the ground stays at a constant temperature under the surface throughout the year, the heat pump is just as effective in summer as it is in winter and represents a stable method of heating the home all year round.

Ground loops can vary in length depending on the property's size and heat demand. Logic dictates that a larger property with a larger heat demand will require a longer ground loop pipe as more heat will need to be extracted from the ground. Conducting the ground works necessary for GSHPs is very cost-effective when servicing multiple homes at once. This is because the machinery that is used to drill the boreholes, known as rigs, can simply be moved between properties in the same development at a very low cost, making it more effective to build the ground works for a number of properties at the same time than individual buildings. If homes are serviced on an individual bases, the cost associated with the borehole drilling can be a substantial proportion of the overall cost due to the need to hire the rig for a single purpose.

Boreholes should be installed approximately one metre from the foundations of the home and once the boreholes are drilled and pipes are in place, a heating engineer can simply connect the heat pump system to provide a cost-effective and reliable source of heat. This means that once the groundworks are completed no specialist technology or skills and training is necessary for the installation of a GSHP and this makes it comparable in terms of cost to fossil fuel systems. Installing numerous boreholes on a new build development site at the same time minimises costs, disruption and makes logical sense. The costs associated with drilling one borehole are comparable to the costs of drilling several and the need to only hire one rig which can be used on multiple boreholes.

GSHPs have a longer lifetime than many renewable and fossil fuel heating system alternatives, are more efficient, more constant throughout the year, and are not as affected by the design of a system which can vary depending on the installer. Therefore, it makes sense to treat large scale ground works in a similar manner to other energy infrastructure such as heat networks and gas and electricity infrastructure. As such, the Government should recognise the significant role that GSHPs can play in heat decarbonisation and treat the infrastructure needed for them to work effectively in the same way that gas and electricity infrastructure are considered a priority.

A quiet, space-saving solution in large developments

GSHPs are virtually silent compared to oil boilers or gas boilers and have smaller space requirements compared to other low-carbon heat technologies like ASHP and bioenergy boilers as much of the mechanical workings of the system are buried seamlessly underground and there is no need for feedstock storage. Their location under the ground also means that they provide a constant heat source and static temperature. With space at a premium on new build sites, the ability to install a renewable heating system without the requirement for additional space is an attraction for developers. Due to GSHPs having a small above ground footprint and being located within the home with minimal aesthetic and very low noise impacts, GSHPs offer an ideal solution for large developments.

GSHPs also have wider consumer benefits compared to other heating methods including the ability to provide both active heating in winter and passive cooling in the summer, which is free to the occupant and removes the need for separate air conditioning or cooling systems. This is particularly important given the predicted summertime overheating risks and the findings of a BEIS recent study highlighting that some properties which overheat significantly will require extensive mitigation measures[14]. Overheating can have direct effects on health, safety, comfort and productivity and the Committee on Climate Change warn of high heat related fatalities linked to increasing temperatures[15]. For homes heated by ASHPs, the system must be reversed to achieve the cooling mechanism, and this is associated with a cost to the consumer.

Carbon and end-of-life retrofit savings

A GSHP is 5 times more efficient than a gas boiler. This combined with the low carbon intensity of the grid, mean that installing a GSHP instead of a gas boiler, will reduce emissions by 87%. Opting for a GSHP instead of an oil boiler could lower carbon emissions from a home by 91%.[16]

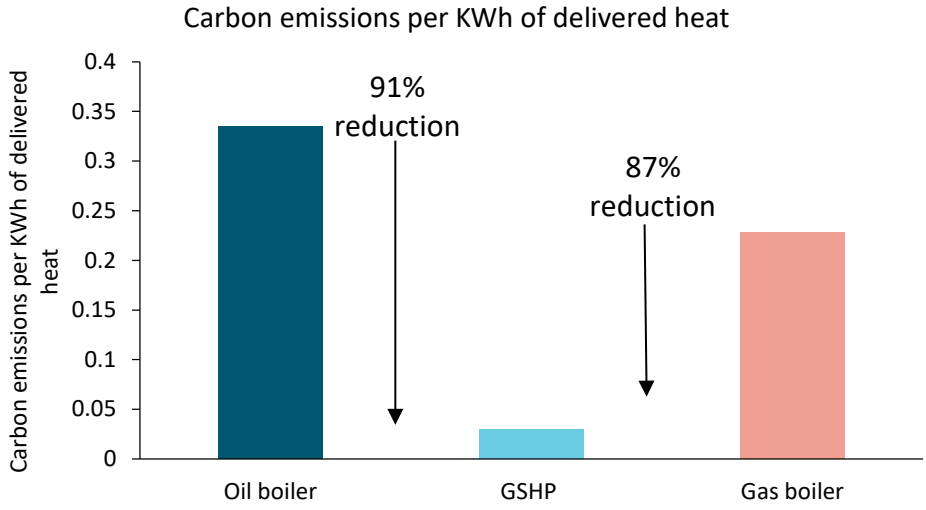


Figure 5 - Carbon emissions from different heating sources, showing that GSHPs have the lowest emissions compared to oil or gas boilers.

The electricity grid in the UK rapidly decarbonising, achieving a 10% reduction in the carbon intensity of the UK's electricity grid from 2011 to 2016[17] with further reductions expected (see Figure 5). The proposed SAP10 emissions factors recognise the substantial grid decarbonisation seen over recent years with the carbon intensity of electricity being revised to 0.14 compared to gas at 0.21, making GSHPs one of the most effective means of reducing carbon emissions from new homes.

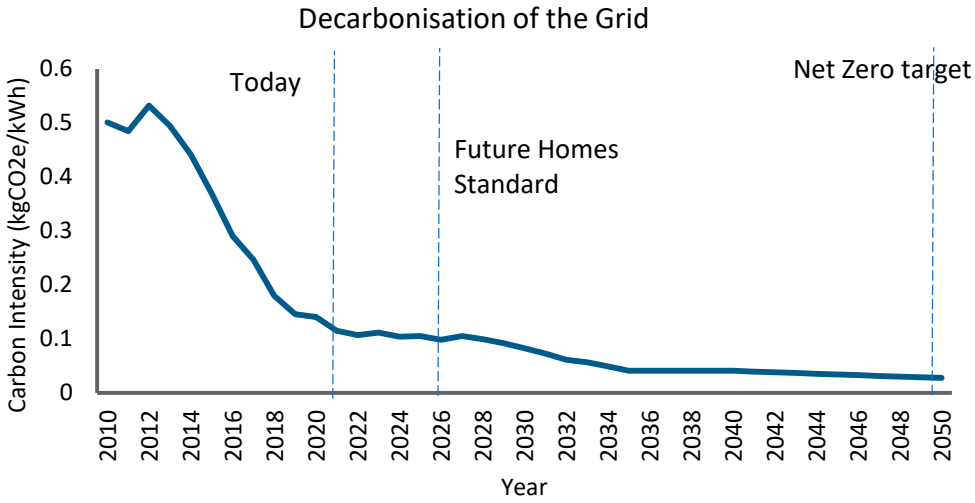


Figure 6 - The carbon emission intensity of electricity is predicted to fall over the next few decades as the grid decarbonises.[18]

When replacing a GSHP at the end of its life, the cost is comparable to the installation of an ASHP as groundworks have already been undertaken and heat emitters are all appropriately sized. The below figure demonstrates the difference in cost at the end of heating system life if a home already has the infrastructure required to install a GSHP versus a home which needs groundworks prior to installation. Additionally, GSHPs tend to be more efficient than ASHPs and therefore create more operating savings.

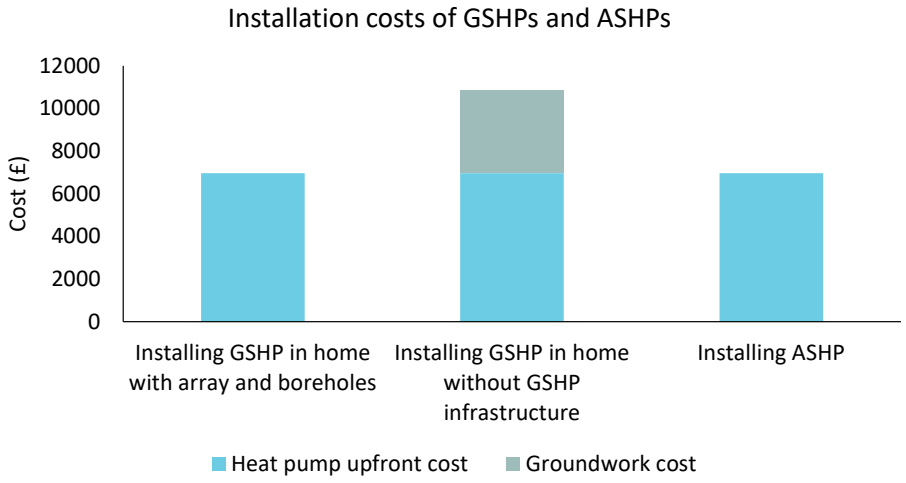


Figure 7 - Estimated installation cost for GSHPs and ASHPs in home with and without groundwork infrastructure installed

Policy is needed to support new infrastructure

With the new net-zero target, there is a need to support the technologies that can help achieve the low-carbon transition in heating. The infrastructure of a GSHP is cheaper and easier to address for multiple homes at once and the Government should consider this when allocating resource for new energy infrastructure. In a similar way that standing charges are placed on heat network or gas bills to cover the costs of infrastructure, the costs of installing the groundworks for GSHPs could eventually be recuperated by including a small, regular payment on the bills of homes that benefit from the technology.

On homes connected to the gas grid, there is a standing charge of 10p – 80p per day which remunerates the cost of supplying the home with gas[19]. This payment contributes towards some of the infrastructure associated with the gas supply and a similar approach could be taken with the boreholes and groundworks needed for GSHPs. On average households pay around £13.50 in standing charges per month. For homes without a gas connection, an electricity standing charge exists ranging from 5p - 60p per day. In addition, homes connected to the gas grid pay a one-off gas connection fee of around £988 (assuming a development of 10 properties)[20].

New homes can charge a ground rent figure to final property occupants to recuperate more of the costs associated with upkeeping the land on which the property sits. To incentivise the installation of GSHPs developers could alter the ground rent fee, or include a heat infrastructure fee, covering the costs of the ground works. Below we outline two potential financial mechanisms to enable the cost of groundworks to be incorporated into monthly repayment packages.

NIBE estimate that it costs around £30 per meter to drill the boreholes needed for one property. At 70-80m per borehole, the total costs of a borehole for one property is £2,100 - £2.400. The cost of all the groundworks equates to around £3870 per heat pump for an individual property.

Box 1: Financial model for GHSP infrastructure investment – developer scheme

With ground source heat pump infrastructure having a lifetime of at least 50 years, charging a standing fee / ground rent of £77.40 a year (just £6.45 per month) consumers would pay £3,870 to those installing the infrastructure to recuperate the cost associated with the groundworks over the period.

The consumer would benefit from substantial running cost savings and lower carbon emissions, whilst also paying less a month in standing charges / ground rent. Currently households pay around £13.50 in standing charges per month for their gas supply as well as an initial connection fee of around £988. An economic proposal that illustrates the financial benefits of the proposed approach is below:

Gas standing fee = £13.50/month

GSHP standing fee = £6.45/month

Difference = £7.05/month

Initial gas connection fee = £988

Consumer savings across infrastructure lifetime:

= £7.05 x 50 years + £988

= £5,218

Option 1 – Developer Scheme	Gas boiler	GSHP	Difference
Standing fee (monthly)	£ 13.50	£ 6.45	£ 7.05
Connection fee (one-off payment)	£ 988	£ 0	£ 988
Lifetime (50 years) savings			£ 5,218

The costs for deploying a drilling rig and the associated staff are in the region of £2,500, although this reduces when addressing multiple boreholes for multiple properties at the same time. Estimating that one deployment of a drilling rig could address 5 properties, the cost per property is £500 and under economies of scale could be even less. This street-based approach is logical and increases the efficiency of the drilling process, therefore should be encouraged by those undertaking the infrastructure work.

Coupled with extremely low maintenance requirements consisting of only an annual circulation of antifreeze through the ground loops, over multiple properties the costs of installing GSHP infrastructure can be considered very economical. For similar reasons, the use of GSHPs and the associated infrastructure funding method described in this paper for commercial properties should also be considered. Linking up commercial and residential properties in the same groundwork infrastructure would bring mutual benefits to those using the heat as well as those providing it. NIBE intend to produce a proposal on commercial properties in due course.

There have also been successful partnerships between Dandelion (further discussed in box 2 below) and funding given in the USA for research, development and testing of their products. This has provided evidence that the costs and time taken to install ground source infrastructure can, and is likely to, fall as the technology becomes more commonplace. For example, Dandelion have received assistance with research, development and testing of a new drilling technology which claims to reduce the time taken to install infrastructure from up to one week to just one day from the New York State Energy Research and Development Authority's challenge. Understandably this comes with cost reductions, with the company reaching a 25% reduction in homeowner costs (aiming for a 50% reduction level) and expansion to 25% more locations.[21]

Similar help to that offered to Dandelion with the research, development and testing of GSHPs and the infrastructure model proposed in this paper in the UK could help to create viable projects in this country which will all help to decarbonise heating in line with climate change goals.

Box 2: Financial model for GHSP infrastructure investment – Heat as a service

The recent research and development into alternative heating models in the UK, such as the Heat as a Service study carried out by the Energy Systems Catapult, indicates that there may be scope to develop innovative business models for heating domestic and non-domestic properties across the UK. GSHPs could play an important role in developing these new business models, for example the ground loop infrastructure could be bought and maintained by an energy supplier or an ESCO to provide heat as a service to the final consumer.

Dandelion, a Google start-up company in America, has linked the installation of a ground source heat pump with a monthly payment plan that customers report is much cheaper than their previous heating system; the average consumer saves over $2,200 (£1,700) per year on their heating and cooling bills. Prices for this service start at $135 (approx. £105) per month, and Dandelion reports the equity of the home is improved as a result of installing the system. A similar model in the UK could soon come into fruition but will involve the recognition of the value of a heat pump heating system in homes and an appropriate pricing plan, such as heat as a service, comparable to that in Dandelion's approach.

Futureproofing new homes when they are being built, by ensuring that groundworks are appropriate for low-carbon solutions such as GSHPs, will make it much easier for them to be connected to a source of low-carbon heat in the future. Even if not connected to a GSHP unit today, new build homes represent the most logical time to undergo the significant ground works needed for them to be fitted in the future. There is much less hassle, cost and time associated with installing GSHP infrastructure in new developments at the same time as the foundations for the property and other structural groundwork is carried out. This should be recognised by industry as well as by government who should encourage this sort of best practice approach, ultimately to help achieve government goals in the decarbonisation of heat, reaching net-zero emissions by 2050 and creating homes that are fit for the future.

Treating groundworks as an energy infrastructure investment and funding them centrally will mean that the costs associated with groundworks shared and thus making GSHPs more appealing for consumers and developers alike.

Conclusions and recommendations

To meet ambitious carbon emission reduction targets, the UK Government must set out a clear policy supporting GSHPs by providing investment into their infrastructure. This would allow consumers to install GSHPs knowing that they would pay back the costs of the groundworks as a small and regular standing charge, similar to those on existing energy bills. The proposed funding method in this paper brings about economically viable projects for infrastructure developers and substantial lifetime bill savings for consumers. This is in addition to the social and environmental benefits of installing a low-carbon heating system across many different properties, which will help to achieve the net-zero by 2050 target and contribute enormously to the decarbonisation of heat.

The Government should implement the Future Homes Standard as soon as possible to mandate the end of fossil fuel heating in new builds. This would help deliver on carbon emission reduction targets as well as provide cheaper and cleaner energy for households across the UK. It would also be helpful for industry and government to research alternative business models for heating, including heat as a service and conduct widescale trials that prove how successful funding GSHP infrastructure can be, giving confidence to consumers and the wider market.

References

[1] BEIS (2020) RHI monthly deployment statistics https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-march-2020-quarterly-edition

[2] BEIS (2020) RHI monthly deployment statistics https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-march-2020-quarterly-edition

[3] Committee on Climate Change (2019). UK Homes: Fit for the Future?. Retrieved on 07/08/19 from https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

[4] Domestic fuel prices as per June 2019. https://www.confusedaboutenergy.co.uk/index.php/domestic-fuels/fuel-prices

[5] Central Heating Quotes. https://www.centralheating-quotes.com/boiler/oil-boilers/ and BRE (2011). Default values of Seasonal Performance Factor for heat pumps. https://www.bre.co.uk/filelibrary/SAP/2012/STP11-HP-01_Heat_Pumps.pdf

[6] CCC (2019). Net-Zero Technical Report. Retrieved on 31/10/19 from https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf

[7] BEIS (2019) Public attitudes tracker https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817872/BEIS_Public_Attitudes_Tracker_Wave_30_key_findings.pdf

[8] BEIS (2019). RHI monthly deployment data: June 2019. Retrieved on 07/08/19 from https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-june-2019

[9] Office of National Statistics (2019). Families and households: 2018. Retrieved on 07/08/19 from https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2018

[10] MHCLG (2019). House building; new build dwellings, England: December Quarter 2018. Retrieved on 07/08/19 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/790069/House_Building_Release_Dec_2018.pdf

[11] MHCLG (2020) Energy Performance of Buildings Certificates Statistical Release: Q4 2019: England and Wales https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/861840/EPB_Cert_Statistics_Release_Q4_2019.pdf

[12] MHCLG (2020) Energy Performance of Buildings Certificates Statistical Release: Q4 2019: England and Wales https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/861840/EPB_Cert_Statistics_Release_Q4_2019.pdf

[13] Committee on Climate Change (2019) Housing Fit for the Future https://www.theccc.org.uk/publication/uk-housing-fit-for-the-future/

[14] BEIS (2019) Research into overheating in new homes https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835240/Research_into_overheating_in_new_homes_-_phase_1.pdf

[15] Committee on Climate Change (2019) Heat and Preventable Deaths in the Health and Social care

[16] System https://www.theccc.org.uk/wp-content/uploads/2019/07/Outcomes-Heat-preventable-deaths-case-study.pdf

[17] NIBE (2019). Analysis undertaken using NIBE product data and BEIS emissions data.

[18] BEIS (2019). Updated energy and emissions projections: 2018. https://www.gov.uk/government/collections/energy-and-emissions-projections

[19] BEIS (2019) Data tables Electricity emissions factors to 2100 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/793632/data-tables-1-19.xlsx

[20] Peter Earl (2019) Guide to standing charges https://www.comparethemarket.com/energy/information/what-is-energy-standing-charge/

[21] Currie and Brown (2019) The Costs and Benefits of Tighter for New Buildings. https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/

[22] Priyanka Shrestha (2019). New York backs tech that cuts installation time for ground-source heat pumps. https://www.energylivenews.com/2019/11/26/new-york-backs-tech-that-cuts-installation-time-for-ground-source-heat-pumps/