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Heat pumps

Overview

- Heat pumps are a key technology for achieving net zero emissions from domestic heating. The UK Government has a target of 600,000 installations per year by 2028 and 72,000 were installed in 2022.
- Heat pumps are technically suitable for most UK homes if installed appropriately. The supply chain has significant growth potential but stakeholders indicate it is currently constrained by a lack of consumer demand and government policy uncertainty.
- Heat pump installation costs are higher than gas boilers, in part due to the need for additional retrofitting. Large cost reductions are unlikely. New finance options and government support could make them more affordable.
- Heat pumps currently have similar running costs to gas boilers. Reducing the price of electricity relative to gas would make heat pumps more competitive. Additional savings are possible with flexible electricity tariffs.
- The public's interest in and understanding of heat pumps is low. A lack of qualified heat pump installers is a further potential barrier to rollout, as are constraints imposed by planning rules and the need for electricity infrastructure upgrades.
- The UK Government's Boiler Upgrade Scheme provides grants to assist with installation costs. Support is also available for installers and manufacturers to expand supply chains. Other measures are being considered as part of the Energy Bill.

Background

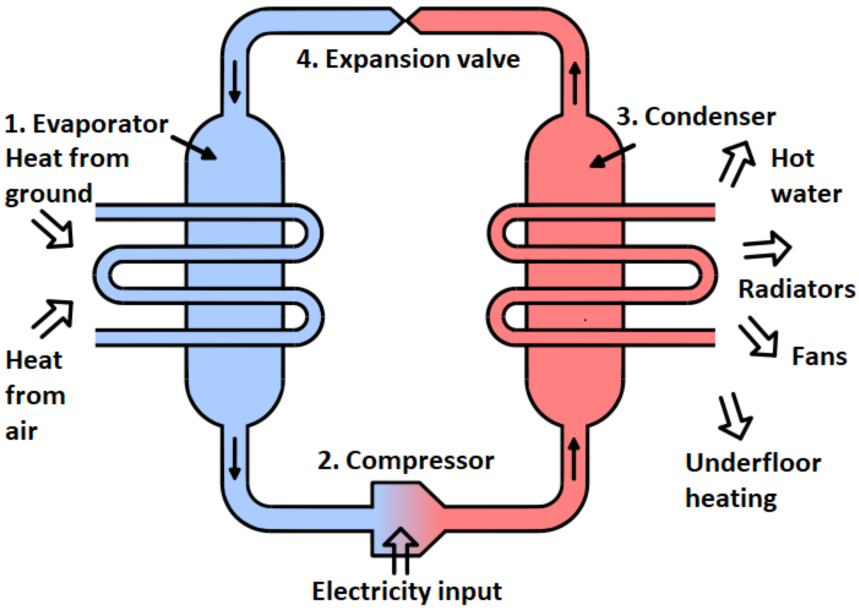
A third of UK energy consumption is used for heating, mostly in the domestic sector.[1] Three quarters of energy used for heating is from burning fossil fuels, primarily natural gas. The Climate Change Committee* projects that, to reach net zero, domestic heat pumps will be needed in at least half, but likely closer to 80%, of homes by 2050.[2] Heat pumps are widely used in some European countries, such as Norway (60% of homes) and Sweden (43%),† but account for 1% of UK homes.[3,4]

This POSTnote updates a note from 2013 (PN 426) with new developments in the domestic heat pump sector.

Heat pump technology

Heat pumps transfer heat from the external environment into buildings, to provide space heating and hot water.[5] They use the same principle as refrigeration and air conditioning but in reverse (Figure 1). Heat pumps run on electricity and can replace fossil fuel boilers. When combined with decarbonisation of the electricity supply, this reduces CO_2 emissions from heating. Heat pumps do not emit any air pollutants.

Figure 1: How do heat pumps work?



Note: The heat pump refrigeration cycle. The refrigerant absorbs heat from the outside environment and evaporates (1). Electricity is used to compress the refrigerant and raise its temperature (2). The hot refrigerant transfers heat into hot water, which supplies the home (3). The refrigerant expands and cools down (4), and returns to the evaporator to absorb more heat (1).

* The Climate Change Committee is an independent statutory body established to advise the UK and devolved governments on reducing greenhouse gas emissions and the impacts of climate change.

† Percentage of households with a heat pump in selected countries:[3] Norway (60%), Sweden (43%), Finland (41%), United States (12%), China (11%), France (11%). Germany (4%).

The most common heat sources are the air and ground, but water or waste heat[‡] are also used. Air source heat pumps (ASHPs) use a fan to pass air across the evaporator, from which heat is extracted. Ground source heat pumps (GSHPs) extract heat using underground pipes. Heat is transferred either to water (air/ground-to-water), heating the building via radiators or underfloor heating, or to air (air-to-air), which can directly heat the building.

Heat pumps output heat more slowly than boilers so using heat pumps to supply domestic hot water requires hot water storage. The maximum temperature recommended for hot water in taps is 50°C,[6] which is easily achievable by modern heat pumps.

Some heat pumps can provide cooling (PN 642), either passively if the source temperature is below the building temperature, or actively by reversing the refrigeration cycle.[7–9] ASHPs are more suitable for active cooling, while GSHPs can provide passive cooling since the ground is colder than the air in summer.[10] The latter is more energy efficient. Cooling with radiators and underfloor heating can create condensation on radiators and pipework. Fan-assisted radiators or smart control systems can avoid this.[11]

Box 1: Measuring heat pump efficiency

Heat pump efficiency is measured by the coefficient of performance (COP), which is the ratio of heat produced to electricity consumed. More heat energy is produced than electrical energy is consumed (COP > 1), because heat is also extracted from the environment. A smaller temperature difference between the heat source and heat emitter increases performance. Since source temperature varies across seasons, COPs are typically averaged over the year (seasonal performance factor, SPF).

GSHPs have higher SPFs than ASHPs because ground temperature is higher than air in winter, when most heating is used.

Recent technological advances in heat pump design

Heat pump technology is not new and there have been few major technological breakthroughs in the last 10 years. However, incremental design improvements have increased performance and flexibility of deployment.

Technological innovations in heat pump components[12,13] and smarter control systems,[14] have increased seasonal performance factors (SPFs), and reduced the SPF difference between ASHPs and GSHPs (Box 1).[15] Heat pumps have also become smaller and quieter. There can be a trade-off between these factors, since larger

‡ Many activities produce heat as a by-product, which could be harnessed by heat pumps. Examples include data centres, many industrial processes, water treatment plants and refrigeration.

units have more space for noise insulation, but additional innovations have also reduced noise.[16]

UK and EU restrictions on fluorinated gases[17–19] have promoted new refrigerants that have less impact on global warming.[20] Some of these refrigerants can operate at higher temperatures, leading to domestic heat pumps that can output water at up to 80°C,[21–23] similar to a gas boiler.

Integrating heat storage technologies offers potential for shifting energy demand to off-peak times. These technologies are yet to reach commercial deployment.[24–26] Smart controls also offer potential for flexible integration with the wider energy system.[14,27,28]

How do heat pumps perform in the real world?

Maximising performance requires minimising the temperature difference between the heat source and heat emitter (radiators, underfloor heating or fans). Larger emitters transfer more heat and require a lower flow temperature (the temperature of water leaving the heat pump) to maintain the same room temperature, improving performance. Pipes need to be large enough to deliver sufficient low temperature heat to the emitters.[29] Evidence shows that existing UK central heating systems are often poorly optimised.[30]

For efficient operation, heat pumps and emitters should be sized to match the heating demand of the building. Undersized heat pumps will not achieve the desired building temperatures. Oversized heat pumps will operate at partial load, which reduces efficiency, although improved compressor technology has reduced this effect.[31] Continuous low temperature operation is generally the most energy efficient way to use a heat pump.[32] Most people use gas boilers on demand, so user education is required to switch heating patterns.[33–35]

Insulation reduces the heating demand of a building, which reduces heating costs, and the size of heat pump required. However, the energy efficiency of UK buildings is among the worst in Europe.[36,37] Reducing heating demand allows lower flow temperatures for a given size of emitter, increasing performance.[38,39] If insulation is considered it should ideally be installed before a heat pump so that the heat pump is correctly sized.

Four trials have measured heat pump performance in retrofitted UK homes (Table 1). Early trials reported poor average performance due to bad installation, such as incorrect heat pump sizing.[40] The Electrification of Heat Demonstration Project has delivered improved performance due to technological improvements and better installation.[41] European trials have achieved even higher performance, showing that further improvement is possible. It is not fully understood why UK installations have performed worse, but a combination of the factors discussed above is likely.[40,41]

Table 1: Heat pump retrofit field trials

Trial	ASHP efficiency (average SPF)	GSHP efficiency (average SPF)
UK trials		
Energy Saving Trust phase 1 (2009-2010)[42,43]	1.9	2.5
Energy Saving Trust phase 2 (2011-2012)[44]	2.45	2.82
Renewable Heat Premium Payment (2013-2015)[45]	2.44	2.71
Electrification of Heat Demonstration Project (2020-2023)[41]	2.80	Data not yet available
Selected European trials		
Superhomes (Ireland, 2017-2019)[31]	3.35	No data
Fraunhofer (Germany, 2018-2019)[46,47]	3.1	4.1

Note: Seasonal performance factor (SPF) is a measure of heat pump energy efficiency (Box 1). Higher numbers represent greater efficiency. Direct electric heating has an efficiency of 0.99, and gas boilers between 0.75-0.85.[48,49]

Are heat pumps suitable for all types of buildings?

The Electrification of Heat trial showed that heat pumps can be successfully retrofitted into a wide range of buildings.[41,50,51]

Most UK housing will need radiator upgrades to achieve good performance.[30,50] High temperature heat pumps could operate with existing radiators, but are currently more expensive to purchase, and high temperature operation reduces performance.[23] Other retrofit requirements are highly variable between properties. Therefore, suitability is dependent on balancing increased retrofit costs against decreased running costs. Government research showed that heat pumps are the cheapest electric heating solution over 15 years for most homes, but energy efficiency measures can be expensive to install and might deliver only small running cost savings.[52] However, there are large system benefits from reducing heating demand with efficiency, and there is significant potential for increased energy efficiency in UK homes.[53] Even poorly insulated buildings can achieve high performance as long as the heat pump and emitters are appropriately sized.[54,55] Such properties are expensive to heat, regardless of the heating source.

Small properties, such as flats and terraced houses, can pose practical problems. Many properties with combination boilers now lack hot water tanks, and this space has been repurposed.[50,56] New heat storage technologies can provide more space-efficient options.[57] External ASHPs are impractical to install and service in flats above ground level. Networked GSHPs could be an alternative for these properties (PB 46)[56,58,59] with multiple properties connected to a shared network of boreholes and individual GSHPs installed within each property. Heat networks (PN632), which can be powered by heat pumps, are another alternative for high density housing.

Air-to-air heat pumps could be more suitable for buildings where heat loss is extremely high (for example park homes or large, poorly insulated buildings) and it is more cost effective to heat individual rooms on demand.[60] Direct electric heating would also work in this situation, but is less efficient than heat pumps.

UK Policy Context

The UK Government's Heat and Buildings Strategy (2021)[61] sets a target of 600,000 heat pump installations per year by 2028 (2.5% of homes per year). 72,000 were installed in 2022.[62] In comparison, Finland converted 34% of homes to heat pumps from 2000-2018, and the current conversion rate is 3% per year.[63]

Industry stakeholders and academic reviews point to the experience of European countries with greater deployment as showing that stable, long-term policy is key to expanding heat pump markets. They highlight three areas as being important:[64–66]

- making heat pumps the most economically viable heating option
- financial support for those who cannot afford to transition
- regulation to ensure installation quality and to phase out fossil fuel systems.

Stakeholders have raised concerns about the lack of long-term strategic policy direction on the role of heat pumps in decarbonising domestic heating.[62,67–73]

Financial support

The Boiler Upgrade Scheme (BUS) provides grants of £5,000 for ASHPs and £6,000 for GSHPs to homeowners in England and Wales.[74] Several schemes additionally support low income households.[75–81] Home Energy Scotland, and Warmer Homes Scotland provide grants up to £9,000 and additional zero interest loans for heat pumps and energy efficiency, alongside personalised advice.[82,83] Some grants are available in Northern Ireland but there is no dedicated funding for heat pumps.[84]

The BUS was criticised in February 2023 by the House of Lords Environment and Climate Change Committee[68] for its low uptake rate, but industry stakeholders have suggested that uptake is accelerating rapidly.[85] In addition, there is widespread agreement that the amount and duration of funding is insufficient.[67,69–71,86–88] The Government responded to the Committee, outlining its measures to increase uptake, alongside wider support to expand heat pump supply chains.[89]

The Home Energy Scotland Programme has been better received by industry and policy stakeholders due to its greater financial support and provision of customer advice.[67,69,90,91] Scotland also provides larger grants for rural homes that typically have higher heating demands.

Planning system

Permitted development rights (PDRs) allow for the installation of GSHPs and ASHPs in homes without a planning application, subject to certain conditions.[92–96] Units cannot be sited within 1m of the property boundary in England (3m in Wales, 1m from the property in Scotland, and 1m from another property in Northern Ireland). This is a major barrier to siting ASHPs in rear gardens of many urban homes. This restriction was introduced due to noise concerns, but industry stakeholders suggest that the rule is redundant as technological advances have reduced noise from ASHPs and there are additional noise requirements in ASHP PDRs.[97] The size of the unit is restricted in England and Wales, but not in Scotland or Northern Ireland. This may be counterproductive, since larger units are typically more efficient, and have more noise insulation. PDRs are currently being reviewed in England and Scotland.[98,99]

Widespread rollout of networked GSHPs will require infrastructure works under public highways. Currently this requires planning permission, adding significant time and cost. Installers have called for the regulations covering existing utilities[100] to be extended to heat pump installations involving works on a public highway.[59,101]

Building regulations

2021 amendments to building regulations in England require all new heating systems, or full system replacements, to be designed for flow temperatures of less than 55°C,[102] which would be compatible with heat pumps. Some industry stakeholders and academics called for this to be extended to cover like-for-like boiler replacements so that homes are upgraded to be heat pump ready,[87,103] but this would increase replacement costs for customers.

The UK Government's Future Homes Standard, due in 2025, proposes to effectively ban fossil fuel heating in new builds.[104] This will provide a market of 150,000-200,000 homes per year[105] where the dominant heating technology is likely to be heat pumps.[103,104] Phase out dates for fossil fuel heating in existing homes have not been set, but consultations on off-gas grid homes are awaiting a formal government response.[106]

Energy Performance Certificates

Energy Performance Certificates (EPCs) inform homeowners and tenants of the likely heating costs and carbon emissions of their property. Industry stakeholders point out that EPC assessment is based on historical price and carbon factors for electricity and does not adequately recognise the energy efficiency of heat pumps and their decarbonisation potential. Replacing a gas boiler with a heat pump can result in a worse EPC score.[107,108] EPC reform is being considered in England and Scotland.[109,110]

Consumer barriers to uptake and possible solutions

Heat pump installation rates have historically been higher in rural, off-grid areas, where heat pumps can offer significant running cost savings over oil or LPG.[111] This is reflected in applications to government support schemes.[112,113] There is some evidence that the BUS is increasing demand outside of these areas.[113]

Installation and retrofitting costs

Gas boiler replacements typically cost £2,000-4,500.[114] Heat pump retrofit costs vary widely, depending on the amount of retrofitting required, but costs can often exceed £10,000.[50,115,116] Retrofit is a one-time cost, so future heat pump replacement costs would be more comparable to boiler replacements. Large companies such as Octopus Energy and British Gas are offering ASHP installations from £3,000 (including £5,000 BUS grant) in England, or £500 (including £7,500 grant) in Scotland, in properties with minimal retrofitting requirements.[117,118] More complex installations are typically delivered by SME installers.

What contributes to heat pump installation costs?

Installation cost reductions are expected as the market expands. Recent reviews suggest that 15-25% reductions by 2030 could be realistic,[115,116] which is lower than the UK Government's ambitions of 25-50% by 2025 and parity with gas boilers by 2030.[61] Heat pumps themselves are unlikely to significantly reduce in cost, since they are a mature technology. Cost reductions are expected from streamlined installation practices and supply chains. However, a shortage of installers, particularly BUS-registered installers, is currently contributing to high labour costs and long waiting times.

High quality retrofitting requires pre-installation surveys and system design beyond that typical for boiler installations. The installation takes longer than a boiler replacement, increasing labour costs, but the skills required are similar.[119]

GSHPs are more expensive to install due to the ground works required. Networked GSHPs offer potential cost savings. Third party financing and ownership of ground infrastructure could make networked GSHPs cheaper to install than ASHPs for individual properties. Properties would then pay an ongoing connection charge to the infrastructure owner.[120,121]

Policy support to address installation costs

The BUS reduces the cost to homeowners but has been criticised by industry and consumer groups for not providing grants to cover additional retrofitting requirements.[69,71,87,90] Home Energy Scotland does provide funding for this.

Even with a grant, most homeowners will buy heat pumps on finance in the future. Government can support private finance through guarantees for lenders to support mortgages, unsecured loans, or new products such as property-linked finance.[122–124] Low or zero interest government-backed loans have significant public interest,[125] and have been successfully deployed in Scotland, France and Germany.[83,126,127]

The social housing sector has made significant progress in heat decarbonisation through government grants.[128] The private rental sector lags behind on heat pumps and energy efficiency.[129] There is little incentive for landlords to invest in measures that reduce tenants' energy bills. Improved minimum energy efficiency standards for private rentals can incentivise progress, alongside affordable finance for landlords.[123,130]

Heat pump running costs

Under the current energy price cap (from 1 July 2023)[131], heat pumps with an SPF around 3, which has been shown to be achievable with good design and installation, have comparable running costs to gas boilers.[132] Prior to 2021 the price of electricity was higher relative to gas,[133] and heat pumps were relatively more expensive to run.[134] At that time, oil boilers were more expensive to run than heat pumps,[34] but are now similar because oil prices have risen less than electricity prices.[135] Heat pumps are significantly cheaper to run than direct electric heating due to their higher efficiency.[56]

Improving real world SPFs would make heat pumps cheaper to run. Permanently reducing the price of electricity compared to gas would also incentivise heat pumps.[136,137] Removing policy costs[§] from electricity bills has been suggested as a means of partially achieving this.[139–142] The UK Government is exploring reforms of the wholesale electricity market that could also have an impact (PN 694).

Time-of-use tariffs offer cheaper electricity to customers when electricity demand is low. These are used for electric storage heaters and electric vehicle charging, and are starting to be offered for heat pumps.[143] Their introduction in Jersey significantly increased demand for heat pumps.[144,145] Well insulated buildings can run their heat pump during off-peak times, and retain heat when the heat pump is switched off during peak evening demand. Heat storage increases the potential for flexibility.[146]

Public attitudes towards heat pumps

Currently, polls show that a third of homeowners are interested in installing a heat pump.[147,148] Installation cost, followed by technology suitability and disruptive installation, are cited as the most common concerns. Customer satisfaction amongst those who have installed a heat pump is high, and similar to gas boilers.[149] Polling, and interviews with industry and academic stakeholders, cite a lack of public information as a major barrier.[4,150]

[§] 12% of the price of electricity bills comes from environmental and social levies, compared to 3.4% for gas bills.[138] These levies fund policies that support decarbonisation of buildings and energy supplies, and address social issues such as fuel poverty.

There is evidence that knowledge sharing within communities can result in large increases in uptake of energy efficiency measures[112] and heat pumps.[151] Industry and academic stakeholders suggest that a media focus on negative experiences also contributes to low public confidence in heat pump technology.[152–154] Negative experiences often relate to poor installation, leading to lower performance and higher running costs than expected.[34,155,156] Measuring and sharing real world performance and experiences of early adopters could improve public confidence.[157,158] Consumers have expressed a desire for property-specific advice, covering their retrofit options, the likely costs and benefits, financing options, and how to find an installer.[125,147,159,160] This is provided by Home Energy Scotland but availability across the rest of the UK is variable.

The additional time required to retrofit a heat pump, compared to replacing a boiler, is seen as a barrier, in particular because half of boilers are replaced near or at the end of their life.[161,162] Incentivising people to install heat pumps at other trigger points in their life (such as moving house) is seen by some stakeholders as a way to address this.[147]

Wider energy system implications of heat pump rollout

Replacement of fossil fuel boilers with heat pumps reduces total domestic energy consumption but total electricity consumption would increase significantly. Some estimates suggest that annual electricity demand could increase by 25-50%, and peak demand by 50-100%, in a scenario where 80-90% of households install heat pumps.[163,164] This would require significant investment in electricity infrastructure to deliver more power to households, particularly during peak times.[165,166] Improving building energy efficiency would significantly reduce heating demand.[163,164,167–169]

Heat pumps offer scope for flexible demand through time-of-use tariffs. The customer response to this is untested on a large scale, and small trials have had mixed results.[27,28,170] Heat storage on 12-24 hour time scales, using smart hot water tanks or heat batteries, could provide significant demand flexibility.[171,172]

Meeting demand during prolonged cold spells with low windspeeds is particularly challenging, since heating demand will be high, and electricity production will be low.[**,173] Demand flexibility could help but flexibility from heating and electric vehicles during prolonged cold weather may be limited.[166] Long duration energy storage (PN688) is necessary to meet demand during these periods.

[**] Wind power will make up a significant proportion of the UK's future electricity generation, and so prolonged periods of low windspeeds will require other means of electricity generation to be available.[2]

Supply chain constraints

Manufacturing and sourcing

Two thirds of heat pumps installed in the UK are manufactured abroad, whereas over half of boilers are manufactured in the UK.[174] There are potential job losses in boiler manufacturing if the switch to heat pumps is not accompanied by increased UK heat pump manufacturing.[175] The Heat Pump Investment Accelerator Competition is offering £30m to support domestic heat pump manufacturing.[176]

The UK Government is proposing, as part of the Energy Bill, to require a minimum percentage of boiler manufacturers' annual sales to be heat pumps (Low-Carbon Heat Scheme).[177,178] This may encourage innovation to reduce heat pump unit costs[179], but obligations on manufacturers have not been widely tested in other countries.[64]

Availability of heat pump installers

There are 4,000-5,000 Microgeneration Certification Scheme[††] (MCS)-certified heat pump installers in the UK.[89,119,180] The number of uncertified installers is harder to estimate, but a 2023 survey suggested that 20% of heating installers had installed a heat pump in the last two years.[181] The UK Government's target is 50,200 installers by 2030.[61] There are over 130,000 certified gas engineers,[182] who have many of the skills required to install heat pumps. Surveys suggest that over half of installers are willing to upskill to install heat pumps if there are sufficient incentives, but demand for heat pumps is low compared to gas boilers so there is little incentive to retrain for heat pumps.[181,183–185]

The heating industry is currently dominated by sole traders and SMEs, and the average age is over 50. According to an industry survey, older installers are much less interested in retraining.[185] The need to recruit young people is widely recognised but there are few avenues for new entrants,[67] and little promotion of heating engineering as a career for young people.[119] SMEs are unlikely to take on apprentices unless there is very high consumer demand, due to the cost and time commitment.[119] There is significant capacity for training amongst larger companies but demand from installers is low.[186] The UK Government is launching a Low Carbon Heating apprenticeship in September 2023.[187]

The cost of training and loss of earnings whilst training may total several thousand pounds.[185,188] The UK Government offers grants up to £500 for training.[189] Policy uncertainty around phase out dates for gas boilers, and the possible role of hydrogen in domestic heating, has been cited by installers as a reason not to retrain. France saw a 264% increase in installer training from 2018-2019 following the Government's decision to phase out oil boilers within 10 years and provide scrappage grants.[190]

Some industry stakeholders called for low temperature heating training to be mandated for Gas Safe certification, but this is not universally supported. Certification

[††] The Microgeneration Certification Scheme was established by the UK Government to create and maintain industry standards for small-scale renewable energy systems, including heat pumps. It is now an independent charitable foundation.

of installers is currently covered by Competent Persons Schemes (CPS),[191] and MCS.[192] MCS accreditation is required to access most government funding. Standards are widely agreed to be important to build consumer confidence, but many stakeholders view MCS as overly bureaucratic and costly, and CPS as not thorough enough.[181] Some industry and policy stakeholders expressed concerns that standards are not enforced with real world performance evaluation.[193] MCS is currently consulting on streamlining the accreditation process, and improving field-based compliance checks on installation quality.[194]

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