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Residential Heat Pumps

Heat pumps capture ambient heat from the air or the ground and transfer it inside a building. They provide an efficient alternative to conventional methods of heating, such as boilers. This POSTnote summarises the use of heat pump technology for residential buildings and the constraints to their uptake in the UK.

Overview

- Heat pumps have the potential to reduce CO_2 emissions significantly from residential heating systems if widely adopted.
- Quality assurance of heat pump installation is critical for effective performance that delivers CO_2 emission reductions as well as user acceptance, along with cost influences.
- A widespread adoption of heat pumps would have implications for the wider energy system, as extra generation and electricity network capacity would be required.
- Large scale district level heat pump systems may be the most suitable form of the technology in urban areas, but have not been adopted in the UK.

Background

Half the energy sold to UK consumers is used for heating, most of which is in the form of space and water heating in residential buildings (Figure 1).[1] There are two ways to reduce the carbon dioxide (CO_2) emissions and increase the contribution from renewable energy in line with UK and EU legislative targets:[2]

- improved insulation to reduce the heat demand of buildings
- reduced carbon intensity of heating by a switch to low-carbon heating systems, such as heat pumps.[3]

Residential heat pumps use electricity to capture heat from sources such as the air or the ground and increase its temperature, so that it can be used to heat space and water (Boxes 1 and 2). Most residential heat pumps distribute the captured heat via a system of heat emitters that include radiators or underfloor heating. Since heat pumps run on electricity, their CO_2 emissions will be further reduced if electricity supplies are successfully decarbonised (POSTnote 383), the main aim of the government's Energy Bill 2012-13. Heat pump installation is being incentivised through public policy in the UK and other countries.

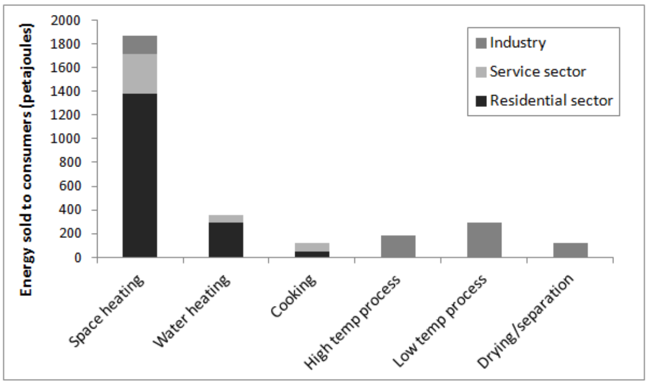
UK Policy Context

Several government policies affect the uptake of heat pumps, particularly financial incentives but also planning policy and building regulations.

Financial Support

Low-carbon heating technologies such as heat pumps can be financially attractive in certain circumstances, but are more expensive than conventional options such as gas-fired boilers. The government's main policy for low-carbon heating is currently a financial incentive, the Renewable Heat Incentive (RHI). This provides a payment for each unit of heat produced, with tariff levels varying depending on the type of heat pump and its size.

Figure 1. Energy used for heating in the UK in 2010[1]



Of the energy sold to consumers for heating, 71% comes from natural gas, 13% from electricity, 9% from oil, 3% from solid fuel, 2% heat from district heating networks, and 2% is bioenergy and waste. Overall, this energy use represents one third of the UK's territorial greenhouse gas emissions (POSTnote 428).

The RHI is similar to the Feed In Tariff scheme, which is available for small electricity-generating technologies. Following delays and changes of policy detail, the RHI is being introduced in two phases.[4] Phase 1 began in November 2011 and provides tariffs for installations in non-residential buildings, which can include houses that are on a district heating system. Phase 2 will extend RHI tariffs to the residential sector in summer 2013. In the interim, one-off grants known as "Renewable Heat Premium Payments" are available for residential properties.[5] Eligibility requirements stipulate that the properties must be off the gas grid. There are 4 million such homes across Britain, amounting to 8% of the housing stock.[6] The heat pump installation must be accredited by the Microgeneration Certification Scheme (MCS) to receive RHI payments, which also provides quality assurance for consumers. Although it will still be legal to install heat pumps without following MCS procedures, it may increase running costs and reduce performance for consumers who choose to do this.

Planning System

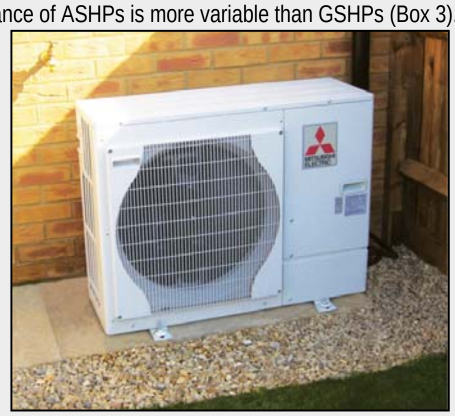
In addition to financial support, the Government has made it easier to install heat pumps through changes to the planning system. Permitted development rights were introduced for residential and some commercial heat pumps in England in accordance with the Green Energy (Definition and Promotion) Act 2009, introduced as a private member's bill with cross party support. They have since been extended to Wales, whilst Scotland already allows air source heat pumps (ASHP, Box 1) as long as they are 100 m apart. These rights give national planning permission, subject to qualifying conditions, to development that would otherwise need permission from a local authority. A particular qualifying condition for ASHP is the level of noise they are allowed to emit, since the main unit is installed outside a home. The government will reconsider the noise standard as part of the review of national planning permission in 2013.

Building Regulations

The market for heat pumps will be supported by future changes to building regulations. These are devolved to Scotland, Northern Ireland and Wales. In England, they specify a minimum energy performance standard for new buildings and for building work on existing properties. Since the adoption of the EU Directive on the Energy Performance of Buildings in 2006, this standard has been specified in terms of CO_2 emissions. The standard is due to tighten towards 'zero carbon' for new homes by 2016, which will require higher levels of insulation and probably the adoption of low-carbon technologies such as heat pumps.

Box 1. Air Source Heat Pumps (ASHPs)

ASHPs are based on components similar to those found in air-conditioning units, but provide heating instead of cooling. A fan draws air into the unit, where heat is absorbed, increased to a higher temperature, and transferred into the home. Air temperatures vary more than ground temperatures throughout the year, so the performance of ASHPs is more variable than GSHPs (Box 3).



Example Air Source Heat Pump (Source: Mitsubishi Electric)

Heat Pump Performance

Heat pumps operate on the same principles as refrigerators and air conditioners. All these devices capture heat from a cool location (e.g. inside a fridge) and transfer it to a warmer location (e.g. the kitchen), thus allowing temperature control. They do this by evaporating and then condensing a refrigerant fluid in a closed cycle; as the fluid evaporates it absorbs heat, and as it is condensed it releases heat. In this way, heat pumps capture heat from an external source and provide it to the inside of a building. [7] If installed and operated effectively (Box 3), heat pumps can provide efficient space and water heating.[7] The operating efficiency of a heat pump must be above a certain threshold if it is to offer energy and carbon savings compared to conventional heating systems. Field trials in Germany and Switzerland demonstrated good operating efficiencies for ground source heat pumps (GSHP, Box 2) and ASHP. A UK trial, however, gave mixed results, concluding that performance is sensitive to the suitability and quality of the installation.

The UK trial demonstrated that appropriate installation is crucial – particularly the size of the heat pump and the selection of heat emitters (e.g. the radiators).Optimal types of heat emitters for heat pumps (Box 3) are common in Germany, with a market share of 50% for underfloor heating in detached and semi-detached new build houses.[8]

Box 2. Ground Source Heat Pumps (GSHPs)

GSHPs capture heat by passing a cool liquid through a system of pipes installed under the ground. These pipes can be oriented horizontally, as shown in the picture below, or vertically, in a borehole. Heat from solar radiation is naturally stored under the ground at 10-15°C all year round, and is absorbed by the cool liquid as it flows around the piping. A GSHP unit increases this heat to a higher temperature and transfers it into the home. An example GSHP unit is pictured on the front page of this POSTnote (Source: Kensa Engineering). Black piping can be seen that brings the circulating liquid from the ground loop to the heat pump, which connects to the house through the wall.

Installing horizontal ground loops (Source: Kensa Engineering)

The better performance of heat pumps in Germany and Switzerland is partly because the technology is more established in those countries, meaning there is greater experience among installers of the technology, although it is also partly because those trials defined performance differently (Box 2).

The UK trial was carried out before the MCS was updated in March 2012. This update introduced sizing guidelines for heat pumps and for heat emitters (such as radiators), which MCS installation companies must use. Future installations should therefore see improved performance compared to the field trial results. Any heat pump receiving a Renewable Heat Premium Payment (RHPP) may be chosen for a metering package, so that data can be collected by the Department of Energy and Climate Change (DECC), to allow further learning about field performance of heat pumps. Several heat pump manufacturers are investigating the possibility of remote monitoring of their heat pumps and better diagnostics of faults.

Heat Pump Installation in the UK

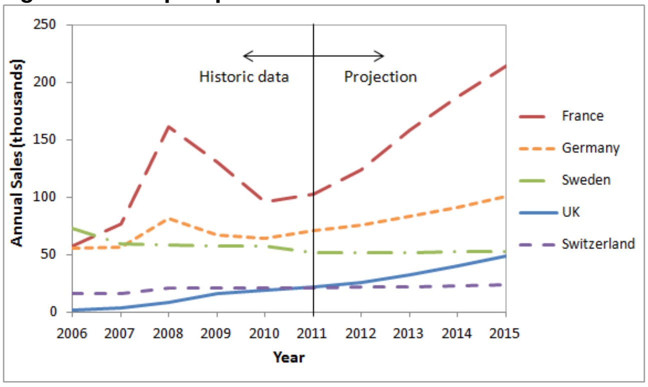
Most heat pumps in the UK are currently installed off the gas grid to replace conventional electrical heaters, oil-fired boilers and Liquid Petroleum Gas (LPG) boilers. Electrical heaters, oil-fired and LPG boilers are more expensive to run and also produce higher carbon emissions than gas boilers.[9] A key market is social housing, which is required by Government to be assessed against the Code for Sustainable Homes, which includes energy efficiency standards. Heat pumps are a mature technology with established markets in other European countries. Figure 2 shows annual sales in a selection of European countries including the UK. Although UK numbers are small, they have been increasing: installations across both residential and commercial buildings increased from 2,000 to 21,000 per year over the period 2006-11.[10] The market research organisation BSRIA expect annual installations to reach 49,000 per year by 2015, though this will be sensitive to policies such as the RHI.

Expanding the Market for Heat Pumps

Cost of Heat Pumps

For a mass market for heat pumps to develop in the UK, costs will need to be brought down to compete with gas central heating boilers, the dominant heating technology. This is one of the aims of the RHI, which aims to provide certainty to investors in the heat pump industry. Although heat pumps use established components found in a range

Figure 2. Heat pump markets in selected countries[10]



Box 3. Carbon Intensity and Seasonal Performance Factors

The overall carbon saving from providing heating to a building with a heat pump depends on two things:

- the carbon intensity of electricity that is generated and distributed to households (the "upstream" electricity system), and;
- the efficiency with which the heat pump uses this electricity to provide heating (the seasonal performance factor, SPF).

The carbon intensity of the electricity system is a function of the type of power stations used to generate electricity. For example, a coal plant emits nearly twice as much carbon as a gas plant per unit of energy generated. The carbon intensity of electricity will be reduced as electricity is decarbonised, and as a consequence the emissions from electrical heating technologies will also reduce. At present, an ordinary electric heater provides less than one unit of heat from one unit of electricity. On average, a heat pump produces more than one unit of heat from one unit of electricity (the SPF) and so its effective carbon emissions will be less.

The operating efficiency of a heat pump primarily depends upon the temperature difference between the heating distribution system and the heat source. The smaller the difference, the more efficiently the heat pump operates, as the heat pump expends less energy increasing the temperature of the heat captured from outside the building. This means that large radiators or under-floor heating, which can operate at 35ºC, systems improve performance, as the temperature difference is much less. In trials in Germany and Switzerland, GSHPs were found to provide an overall average seasonal performance factor (SPF) of above 2.6. For very energy efficient buildings, SPFs of 5.0 were measured. For ASHPs, the trials gave an SPF of 2.2-3.4.[11] In UK trials, the SPF of GSHPs was 1.6-3.4, while ASHPs were 1.2-2.2 (though one manufacturer's heat pumps, reported separately, achieved a figure of 3).[12] The UK field trial figures are not directly comparable to those from Germany and Switzerland because of slight differences in the way performance is defined, but these differences do not completely account for the reduced performance of UK installations.[13] The SPF does not give the complete picture of energy efficiency compared to alternatives such as gas boilers, as the efficiency of generating distributing electricity would need to be considered along with the efficiency of extracting and transporting gas. At around a SPF 2.5,[7] a heat pump's carbon efficiency is approximately equivalent to a gas boiler, but with decarbonisation of the electricity system, this 'breakeven' SPF will decrease, with heat pumps having the potential to be the lowest carbon intensity option for space heating.

of technologies (such as air conditioning), a recent study for the Low Carbon Innovation Co-ordination Group[14] has suggested innovations in design and installation could deliver significant cost savings.[15] The capital cost of installing a heat pump, including pipe work, water storage tanks and radiator replacements, is approximately £6,000 to 10,000 for an ASHP and £9,000 to 17,000 for GSHP.[16] The running cost of heat pumps depends on their operational efficiency and on the price of electricity.[12] Heat pumps work most efficiently when the temperature difference between the outside heat source and the inside plumbing system is small. They are usually designed for the limit of an outside temperature of -3ºC and 21ºC inside, but the lower the temperature outside the more electricity is used per unit of heat produced (Box 2). ASHP's perform least well on the coldest days, and may need to run as direct electric heaters if they freeze up, resulting in higher costs, CO_2 emissions and extra load for the electricity network.

Consumer Confidence and Understanding

For heat pump sales to increase in the UK, installers and consumers need to understand where they are suitable and have confidence in the technology. Suitability depends on how well insulated a building is, whether there is sufficient space available (particularly for GSHPs), the proximity of other dwellings for ASHP's (because of noise issues) and acceptance by the user of the operating characteristics of the heat pump.

Continuous Low-Temperature Heat

The dominant technology for domestic space heating, central heating boilers, offers users the convenience of high power heating that rapidly alters room temperatures, which suits the lifestyles of many users. By contrast, heat pumps operate best by providing continuous, low-temperature heating (Box 2). For example, by providing heat to radiators at between 35ºC-50ºC, instead of the 60-70ºC supplied by a gas boiler. Users need to understand and accept this different operating approach. Heat storage could help maximise heat pump performance, by allowing a heat pump to operate continuously even when the user demand is intermittent (for example, when occupants are away at work or over a weekend). However, daily heat storage in water requires space for a large (up to a 1,000 litre) tank, limiting its feasibility to larger properties.[15]

Suitability of Properties

For continuous low power heat to work effectively for space heating, buildings need to be well insulated. The most suitable buildings will be new build properties or existing properties that can be retrofitted with high levels of insulation. There also needs to be space to install the heat pump. ASHP systems are more suitable for retrofitting in medium to low density housing such as semi-detached or detached houses. An alternative for higher density housing is large-scale district heating systems that could use large network heat pumps to exploit sea, rivers, sewage systems, geothermal heat or industrial waste heat as the heat source (Box 4). There may be disruption associated with installation of local heat distribution networks, such as road works, but widespread adoption of reinforcing residential heat pumps could also result in disruptive changes in electricity distribution (see below).

Water Heating

Heat pumps can be used to heat domestic hot water tanks. However, as the pump operates at a lower temperature (less than 55ºC) compared to 70ºC for a gas boiler it may be necessary to use an immersion heater to top up the heat for frequent hot water use. This will reduce the system's overall energy efficiency (seasonal performance factor, Box 3). By contrast, unused hot water will waste heat that would otherwise have been used for space heating, reducing overall effectiveness of the heating system.[12] Water should also be heated to at least 60ºC once a week to minimise risks from Legionnaire's disease.

Adaptation of Infrastructure

There is a limit to the amount of power that can be distributed through electrical wires. If heat pumps are fitted to replace oil and gas boilers, as envisaged by the Committee on Climate Change's scenarios, then the UK's electricity generation and distribution networks would need to be reinforced to accommodate the power needed to meet the needs of a large number of heat pumps. Ofgem has a group working looking into this issue, particularly for rural areas towards the extremities of the existing grid. However, if heat pumps are fitted to replace electric heating systems (approximately 6% of residential space and water heating), the demand on the generation and networks would be reduced. In addition to the network issues, more (low carbon) generation capacity would be required.

> Box 4. 'Neatpump' District Heating Scheme[17]
> Glasgow-based Star Refrigeration, and its Norwegian Partner Norsk Kulde, sold the world's largest district-wide heat pump to the city of Drammen. It provides up to 15 megawatts of heat for the community of Drammen Fjord, the system supplying hot water pumped through a network of underground pipes to heat more than 6,000 homes and businesses in the city. Star's 'Neatpump' is a heat pump system that can extract heat from seawater, air or any industrial waste stream, such as air conditioning or large scale cooling processes. The system can provide water at up to 90°C for heating buildings on a district scale. Electricity for the Drammen System is provided by hydropower, a low carbon energy generation technology.

Policy Certainty

Cost and consumer confidence in installers is critical for establishing a market, as well as for delivering reductions in emission and running costs for heating properties. In addition to quality assurance and consumer confidence, stability of government support has been shown to be criticial.[11] For example, in France policies supporting heat pumps resulted in rapid take up (Figure 2), followed by a slump when policies withdrew financial support, although consumer confidence was also a factor. Sweden and Switzerland went through similar phases in the late 1980s and early 1990s. There has been policy uncertainty in the UK, with delays and changes in the implementation of RHI and currently a consultation to lower the tariff paid (from the proposed cap of 17.3p/kWh).[18] At present, it is not possible to get both a Green Deal loan (POSTnote 409) and the RHI for a heat pump installation, limiting the option of installing a heat pump to those consumers with sufficient funds to cover the upfront capital cost, but DECC are considering a linkage.

Endnotes

1 DECC, 2011, *Energy Consumption in the UK: Table 1.14, Overall Data Table*
2 The Climate Change Act (2008) requires a 50% reduction in the UK greenhouse gas emissions by the mid-2020s and an 80% reduction by 2050, all from 1990 levels. The EU's Renewable Energy Directive, which requires 15% of energy consumed to come from renewable sources by 2020, up from 3% in 2009.
3 See, for example, UKERC, 2009, *Energy 2050*
4 House of Commons Library, 2012, *Renewable Heat Incentive (SN06328)*
5 http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/premium_pay/premium_pay.aspx
6 Consumer Focus, Sep 2011, *Off-gas consumers*
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9 DECC, Jan 2012, *Emissions from Heat: Statistical Summary*
10 BSRIA Worldwide Market Intelligence
11 Delta-ee, 2011, *Heat Pumps in the UK: How Hot Can They Get?*
12 EST and DECC, Mar 2012, *Detailed Analysis from the First Phase of the Energy Saving Trust's Heat Pump Field Trial*
13 Laughton C, 26 June 2012, *Heat Pump Field Trials and Implications for Design*, available from http://www.gshp.org.uk/GSHPAconference2012.html
14 A group encompassing the major public sector backed funding and delivery bodies that are supporting low carbon innovation in the UK
15 LCICG, 2012,*Technology Innovation Needs Assessment Heat Summary Report*, http://www.lowcarboninnovation.co.uk/document.php?o=10
16 http://www.energysavingtrust.org.uk/
17 Star Refrigeration, 2010, *Case Study 64: Neatpump*, http://www.icsenergy.dk/PDF/Neatpump/Case%20Study%20No%2064%20-%20Neatpump-drammen.pdf
18 http://www.endsreport.com/index.cfm?go=36166

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