The future role of heat pumps in the domestic sector

Tina Fawcett
Environmental Change Institute
University of Oxford
South Parks Road
Oxford OX1 3QY
UK

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Abstract
Heat pumps for domestic heating and hot water supply are currently a niche technology in many EU countries, but they are increasingly expected to form an important role in a low carbon future. This is largely because a future of rapidly decarbonised electricity supply is imagined, in which using electricity via heat pumps is one of the lowest carbon heating options. However, heat pumps are not necessarily a low carbon option at present. In the UK, with fairly carbon-intensive electricity and where natural gas is available for heating, heat pumps do not make significant carbon savings for most householders.

For heat pumps to become a credible low carbon solution in the UK, three transitions unrelated to heat pumps have to occur: (1) transition to low carbon electricity supply; (2) transition to well-insulated housing stock via retrofit; (3) transition to low temperature household heat distribution systems. The most difficult condition for the success of a transition to heat pumps might be entirely unrelated to the technology itself. The risks of heat pumps not delivering expected carbon savings, therefore, are much greater than the risks inherent in this technology. The future role of heat pumps links demand and supply side issues. The benefits of heat pumps vary between countries, regions, individual households and also over time. This makes a policy promoting heat pumps different, and more complex, than policy supporting energy efficiency, which offers universal benefits.

This paper explores the technological, economic, social and energy supply factors which determine the benefits heat pumps could deliver in the UK and other EU countries. It looks at potential mechanisms for moving heat pumps from a niche product to the mainstream. It focuses on the wider issues around the parallel transitions required and debates how, and whether, energy and carbon policy can deal with the complexities involved.

Introduction
Heat pumps, which take low temperature heat from the environment and turn it into higher temperature heat by using electrical energy, currently occupy a small niche within the European residential heating market. They have been more widely adopted in some countries than others, adoption rates being influenced by a wide variety of economic, social, energy-related and technological factors. However, European policy is poised to encourage the wider uptake of heat pumps by including them in a list of renewable energy technologies which can be used to meet national obligations to increase the percentage of heat generated from renewable sources. The UK and many other EU countries have adopted very ambitious long term carbon reduction targets. In order to reach these targets, many future projections of carbon emissions from the housing stock, rely on using low- or zero-carbon electricity for heating. For example, in most scenarios explored by Skea, Ekins et al. (2011) heat pumps become the dominant technology supplying UK residential heating and hot water from 2030-2035 onwards. Heat pumps are widely seen as a key technology for efficiently delivering low-carbon heating (Spiers, Gross et al. 2010).

The significant future for heat pumps which is envisaged stands in sharp contrast to their current position in the UK, where they are installed in low numbers, generally in new

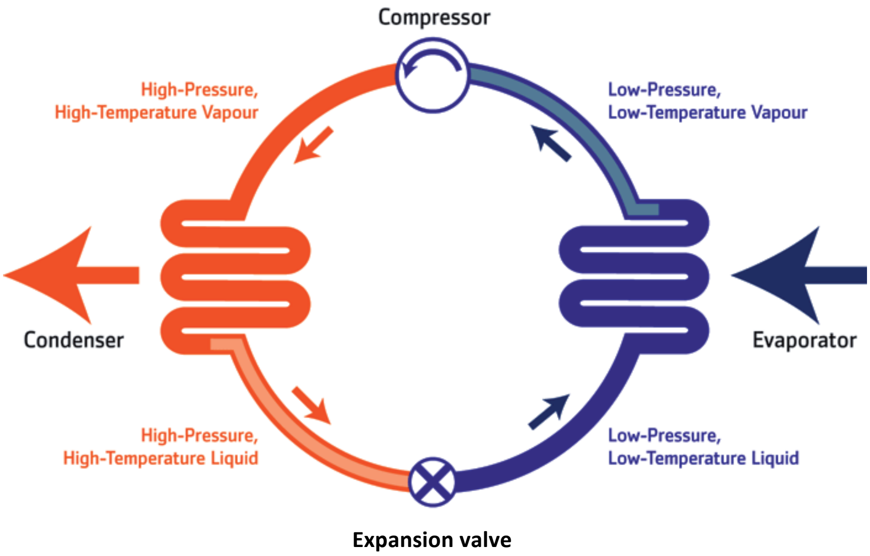

Figure 1: Representation of a heat pump. (Source: www.building.co.uk)

build housing which is remote from the natural gas network. Only in homes off the gas network, might the capital and running costs of heat pumps be competitive with alternatives: they cannot compete on costs with natural gas systems. In addition, an efficient gas condensing boiler will generally produce lower carbon emissions than electrically-powered heat pumps, given the current UK electricity mix. Heat pump installation in existing homes faces two important additional challenges. Firstly, to work at their most efficient, heat pumps require the use of a low temperature heat distribution system, e.g. using underfloor heating or larger radiators, which differs from the traditional UK high temperature water-based radiator systems. Secondly, much existing UK housing is simply too inefficient for low temperature heat to keep it warm, so additional insulation would be required. Given these multiple and complex 'barriers' to the adoption of heat pumps, amongst others, there is absolutely no reason to expect that heat pumps will break out from their niche and become a mainstream heating option. Yet, that is just what low carbon future scenarios seem to demand. Can such a difficult transition be achieved, and if so, how?

In order to explore this question, and the future of heat pumps in the UK and European residential sectors, firstly the technology behind heat pumps is briefly explained. The characteristics of the technology determine how it can be best used. Then the market for heat pumps in Europe and the UK is examined, with a discussion about the factors influencing the very different national preferences for heat pumps. The following section looks at the benefits of heat pumps in the UK at present, with reference to recent field trials and calculation of carbon savings compared with alternative heat sources. Then the future carbon emissions of heat pumps under low carbon electricity scenarios are examined. Current EU and UK policy is summarised and its likely future effects are debated. The routes for heat pumps to emerge from their current small niche are illustrated. Finally, the evidence presented in this paper is discussed and conclusions are drawn.

Heat pump technology and performance

HOW HEAT PUMPS WORK

Electric compression heat pumps take low temperature heat energy from the environment and turn it into higher temperature heat by using electrical energy. Heat pumps make use of the fact that when liquids evaporate they absorb a large amount of energy, their specific latent heat of vaporisation, and this energy is released when the vapour condenses back to a liquid. By using this property, large amounts of energy can be absorbed by and released from the heat pump.

Figure 1 shows how heat pumps work in more detail. Low temperature heat is absorbed from the environment by the working fluid in the evaporator. This energy turns the low temperature, low pressure liquid into a vapour. This vapour reaches the compressor, which increases the pressure of the vapour, thereby increasing its temperature. In the condenser energy moves from this high temperature, high pressure vapour to the (lower-temperature) environment, and the vapour condenses to a liquid. When this high temperature, high pressure liquid passes through the expansion valve, it is transformed into a low pressure, and therefore low temperature liquid. The cycle starts again.

The maximum theoretical coefficient of performance (COP) of a heat pump in terms of the Kelvin temperatures[1] of the warm condenser (T_1) and the cool evaporator (T_2) is

$$COP_{max} = T_1/(T_1-T_2)$$

The COP is the efficiency of the heat pump – it indicates how many units of heat can be delivered per unit of energy (usually electricity) input. The theoretical maximum COP which can be achieved to provide heat at 35 °C when the outside temperature is 2 °C is 9.3. However, in real life, such high efficiencies are not achieved. The COP equation shows that a heat pump operates most efficiently when the temperature gap between the heat source and the heat demand is minimised. In practice, this

1. To change temperatures in degrees C to degrees Kelvin add 273 (273 K = 0 °C)

means that heat pumps work better where lower rather than higher temperature heat is required. The equation also shows that the higher T_2, the input heat temperature, the higher COP can be achieved. For an example of how these factors affect the performance of real heat pumps, see Table 1, which shows how COP varies with input and output temperatures for two Worcester Bosch air source heat pumps.

As output temperature strongly influences COP, this makes new build properties which can be designed with low temperature heat distribution systems more suited to heat pumps than properties with existing high temperature systems. An underfloor heating system in a new home would typically use heat at 30–35 °C, compared with traditional UK radiator systems which use heat at 60–75 °C. 'Oversized' radiators can use water at moderate temperatures, say, 40–55 °C. Hot water in stored systems is typically heated to 55–60 °C. HP system design needs to balance the heat requirements of users, the COP which can be achieved at different heat delivery temperatures (and therefore running costs), and capital costs. It is common for HP installations to include supplementary direct electric heating, for use in extremely cold weather and/or to top up the temperature of hot water. This reduces the capital cost of HP systems. In theory another heating system, such as a gas boiler, could be used for topping-up HP, creating a 'bivalent' system, but this is not an option used in the UK.

In addition to COP, it is important to look at the system efficiency of a heat pump installation. The system efficiency is the amount of heat the heat pump produces compared to the amount of electricity needed to run the entire heating system (including domestic hot water, supplementary heating and pumps). For a given installation the system efficiency will be lower than the COP. For many purposes, including estimating householder costs and benefits, system efficiency figures are more relevant than COPs.

Heat pumps are a long-established technology. While there are expectations that the technology will continue to gradually improve, and higher COP figures can be achieved (IEA 2010) and that better system design and installation can improve performance (EST 2010), there is no expectation of a dramatic improvement to heat pump performance.

TYPES OF HEAT PUMP

There are various types of heat pump available. The most common are air source heat pumps (ASHP), which absorb energy from the air, and ground source heat pumps (GSHP), which absorb energy from the ground. Heat pumps can supply energy for space heating, for space and water heating or for water heating alone. Presently, those which provide both space and water heating are most popular in the UK housing sector (Roy, Caird et al. 2008). Heat pumps can be reversible, so that they provide cooling in summer, and these are popular in warmer EU countries (Eurobserver 2009).

Ground source and air source heat pumps each have some advantages and disadvantages compared with the other technology, which are summarised in Table 2.

Table 1: Variation of COP with inlet and delivery temperatures for two ASHPs.

Temperature		Heat pump COP	
Inlet	Delivery	7kW	9.5kW
-7°C	35°C	2.3	2.5
2°C	35°C	3.0	3.3
7°C	35°C	3.4	3.8
7°C	45°C	2.8	3.0

Source: www.worcester-bosch.co.uk

OTHER HEAT PUMP CHARACTERISTICS

Heat pumps differ from other heating systems in a number of ways. Heat pumps are more complex than traditional gas or oil boilers – and therefore need greater and different skills to achieve a high-quality installation, skills which are currently in short supply (Spicer 2010). Heat pumps use electricity, often at peak times on the supply network, so there are many challenging supply issues around connecting large numbers of heat pumps to the electricity network (Spiers, Gross et al. 2010). This challenge could be managed if and when smart grids are put in place. In addition, in houses with a high heat load, given the UK single-phase electricity supply, a heat pump might not be able to draw enough power to heat the home. More generally, the high start-up current demands of standard heat pumps are harder to meet with single-phase electricity, compared with three-phase available in other countries (Singh, Muetze et al. 2010). These issues are not going to be considered in detail in the remainder of this paper, but it is important to recognise them.

Heat pump installations & market

EU OVERVIEW

Within Europe a significant market for residential heat pumps exists only in Sweden, Switzerland and parts of Austria. In other countries the market share of heat pumps remains small, and the heat pump is not considered a first choice when installing or replacing heating and hot water equipment (IEA 2010). In

Table 2: Comparison of ground source and air source heat pumps, UK.

Ground source heat pumps	Air source heat pumps
Can achieve higher COP than ASHP, because the source of heat is better, 10ºC ground temperatures year-round. (Centre for Alternative Technology 2010a)	Lower COP, as heat pumps have to deliver most energy at the lowest temperature part of the year. Therefore higher running costs.
Require access to land for either a borehole or trenches for heat collection network. Using trenches requires a large garden, or other access to land. Boreholes require favourable geology.	Suitable for a wider range of properties, as no specific land requirement.
Higher installation and capital costs (see later for details).	Lower installation and capital costs.

Switzerland in 2006, 75 % of all new single-family dwellings were equipped with heat pumps. With the exception of Sweden, up till 2006 the heat pump market in Europe has mainly concentrated on new buildings.

Data on heat pump sales in 2007 and expected sales for 2008 is available across a number of EU countries (Eurobserver 2009). The information is chiefly based on statistics from national industry associations, because most official statistical bodies in the EU do not regularly publish data on the number and capacity of HPs. The data mostly reflect the domestic market as the high capacity GSHP market geared to heating collective housing or other buildings is hardly monitored at all. The Eurobserver data indicates that 102,400 GSHP were sold in the major EU markets in 2007 (this encompasses 14 countries) and sales are expected to increase to 112,200 in 2008. In 2007, sales were highest in Germany (26,887), Sweden (27,938) and France (18,600), and between them these countries accounted for 72 % of total sales.

Data from EHPA (reported in Eurobserver, 2009) which covers eight European countries (Austria, Finland, France, Germany, Italy, Sweden, Norway and Switzerland), recorded GSHP sales of 107,022 in 2008 compared with ASHP sales of 469,370. So, ASHP sales are four and a half times those of GSHP in these countries. Of the ASHP sales, 48 % were reversible – so also capable of cooling, mostly of the air-to-air type. These may be single room heater/coolers, rather than whole house systems, but the figures don't give this level of detail.

UK

The market for heat pumps in the UK is currently very small. GSHP are installed in greater numbers than ASHP and this pattern is expected to continue into the near future. There were around 1000 installations GSHP in 2005/06, most of which used a horizontal trench for the ground loop (79 %) with only 13 % using the more expensive boreholes (Roy, Caird et al. 2008). Most provided heating and hot water and over half were connected to underfloor heating systems. Few provided cooling as well as heating, but indications are this may be changing. Systems had a maximum output 8-14 kW, similar to a gas boiler. The market seems to be growing rapidly as sales in the UK are reported as 3,000 units in 2007, with an expected rise to 5,000 in 2008 (Eurobserver 2009). A different report gave a central estimate for 2009 GSHP installations of around 8,000 (NERA and AEA 2009). Sales of ASHPs are very low, and were not recorded in the Eurobserver (2009) data. From published reports and expert discussions it has been estimated that the total number of ASHPs sold in the UK by 2010 could be 1,750 (NERA and AEA 2009).

DISCUSSION

The market for HP varies hugely between different countries, from a very high uptake in Sweden and Switzerland (in new-build properties), to very low in the UK. There are a number of factors which can be used to explain this variation: climate, government policy on energy and environmental issues, energy prices, availability of competing energy sources, electricity supply and generation characteristics, housing characteristics, history, geography and geology. Different authors highlight different factors to explain the relative success or failure of heat pumps in a particular location (e.g. IEA (2010), Lund, Sanner et al. (2004), Le Feuvre (2007)). The consensus is that a wide range of issues influence the uptake of heat pumps, and there are few quick and easy routes to increasing their adoption.

There are non-European countries where heat pumps have been rapidly increasing in popularity (e.g. China, Japan (BSRIA 2008)). However looking at these growth patterns in more detail shows they may be of limited relevance for most European countries. Spicer's (2010) study of New Zealand illustrates this. New Zealand has experienced rapid growth in heat pump installation with approximately 21 % of houses thought to have an air source heat pump, with annual sales more than tripling between 2003-04 and 2008-09. This growth is expected to continue. The rising installation rate of ASHPs in New Zealand has taken place against a background very different from that in the UK and most EU countries. Most importantly, New Zealanders tend to heat mainly their living rooms rather than having whole-house heating systems. Thus sales of ASHPs have been of equipment which does air-to-air heating within one room of the house. Approximately 60 % are also being used for summer cooling – a completely new electricity load. Competitor fuels are largely solid fuel (including coal) and electricity. ASHPs are being encouraged in some areas as a means of reducing local air pollution from burning solid fuels. Given the very different economic, technical, energy-related and social contexts in New Zealand, the high growth rate is not really indicative of what could happen in the EU. While learning from experience in other countries can be valuable, national context remains hugely important.

Probably the most important reason heat pumps are not more popular in the UK is their cost relative to the most common alternatives (Pither and Doyle, undated). The UK's Energy Saving Trust has published capital cost figures for various heating systems, and the running cost savings from averagely efficient ASHP and GSHP in comparison with gas, oil and electric systems (Table 3). Capital costs include installation, but not any changes required to heat distribution systems. The running cost savings are based on comparison with averagely efficient gas and oil systems, not with new, more efficient systems.

While all the figures in Table 3 are averages, and costs for individual homes can vary widely, it does show that both ASHP and GSHP have considerably higher capital costs than the most common alternatives, and in some cases running costs are also higher. Given the high capital costs for HP, there is an argument that they make better economic sense in homes with high heating and hot water demand where greater running cost savings are available. However, the focus in the UK debate, and in industry literature, is on using this technology in homes which are already energy efficient, and therefore have lower energy demands. As mentioned earlier, there are technical reasons why HP may not be suitable for inefficient properties. This focus may also relate to the fact that HP is being sold as an environmentally-beneficial solution, rather than primarily a cost-effective one (a claim which has more validity in other countries, such as Sweden, with different energy price structures).

Heat pump costs may change over time. Future capital costs could reduce with greater numbers being sold and installed in the UK market. However, current projections on consumer energy prices suggest that electricity is likely to become more expensive relative to gas by 2020 (Ofgem, 2009). The ratio of average electricity to gas price per kWh was 3.4:1 in 2010 (derived

Table 3: Average capital costs for heating systems, UK, 2011.

Heating and hot water system	Typical capital cost (£/Euros)	Annual running cost savings compared with gas (£)	Annual running cost savings compared with oil (£)	Annual running cost savings compared with electricity (£)
Gas boiler	£2,500 / 2,900	-	-	-
Oil boiler	£3,000 / 3,500	-	-	-
GSHP	£9,000 -17,000 / 10,500 – 19,800	-£40	£50	£420
ASHP	£6,000-10,000 7,000 – 11,600	-£130	-£40	£300

Source: www.energysavingtrust.org.uk, accessed 2011

from data in DECC, 2010). The Ofgem study looked at four different scenarios to 2020. All scenarios showed consumer prices rising, and in each scenario electricity costs rose more than gas, with an average 41 % electricity price increase between 2010 and 2020, compared with 26 % for gas. If these projections are correct, the economic case for heat pumps in the UK, compared with gas, could become less rather than more favourable. However, as detailed later, policy is being developed which will offer price support to HP and therefore reduce the cost to the householder of choosing HP.

What benefits do heat pumps deliver in the UK?

RESULTS OF UK HEAT PUMP TRIAL

Until recently, there had been almost no publicly available data on the performance of heat pumps in the UK. In a comprehensive literature review, Singh, Muetze et al. (2010) found only two studies reporting data. They concluded that very few installations have been subjected to monitoring to establish their effectiveness and running costs. Fortunately, in 2010 the Energy Saving Trust published results on the first phase of the most comprehensive field trial of the technologies ever undertaken in the UK, which studied heat pumps at 83 sites (54 ground source and 29 air source.) The trial began in early 2009 and monitored both technical performance and customers' experiences for a full 12 month period. Data on customers' experiences has not yet been published in detail. The trial will continue for another year to enable further investigation into the factors that influence heat pump performance on an installation-by-installation basis.

Monitored system efficiency data was presented for 47 GSHP and 22 ASHP, with estimated data presented for 6 ASHP (Figure 2). The estimated data is not included in the following analysis. The average system efficiency of GSHP was 2.3, and the average for ASHP was 1.9. At the most efficient end of the distribution, there were 9 GSHP with system efficiencies of 3.0 and 3.2, and one ASHP with a system efficiency of 3.0. At the least efficient end, there were 9 GSHP and 10 ASHP with system efficiencies of less than 2.0.

These results are considerably less good than experience in other European countries. The Fraunhofer Institute for Sustainable Energy (ISE) has published a survey of heat pumps in Germany. They found that ASHPs in new buildings achieved an average COP of 3.0, while those added to existing buildings had an average COP of 2.6 (very few of the existing homes had underfloor heating) (Centre for Alternative Technology 2010b).

EST presented the results in a positive light, e.g. "results show that a number of heat pump installations performed very well, achieving an overall system efficiency rating of three and above", but also noted that "some installations performed as well as heat pumps studied in European field trials, but many failed to meet these levels" (EST 2010). EST has used the findings to give detailed advice to customers and installers on how to ensure they get a high quality heat pump installation. There was some negative press coverage about the results of the trial, with one headline being 'UK heat pumps fail as green devices, finds study' (Vaughan 2010), but most reporting followed the more positive EST line about improvements of various sorts being required (e.g. BBC News 2010). However, it seems clear the findings are very far from an endorsement of the UK heat pump industry, with many systems performing poorly.

Earlier research had also shown some householders experiencing problems with their GSHP installations. Roy et al (2008) carried out a survey of GSHP adopters. Their results showed that nearly 90 % of adopters of GSHP were very happy with their system, the system has raised the energy awareness of 70 %, but only 40 % reported the cost savings they expected. Key problems centred around the complex controls designed to make the most efficient use of electricity and achieve comfortable room temperatures. Only 40 % found the controls easy to use and 20 % had great difficulty. A quarter of users complained about the slow response times of the system and/or its inability to heat rooms to the required temperature.

Until the second year of the EST study has been completed, it won't be clear exactly why UK heat pump performance has been so poor in so many cases. The preliminary results suggest that over-complicated system designs and poor understanding of heating controls by both installers and householders contribute to inadequate performance.

CURRENT CARBON AND ENERGY SAVINGS FROM HEAT PUMPS

Heat pumps are clearly a more efficient way of using electricity for heating, compared to direct electrical heating. In most countries, including the UK, direct electrical heating is only used by a minority (due to its expense) and the relevant comparison is likely to be with another fossil fuel – usually gas or oil. Whether a heat pump generates carbon savings compared with mainstream alternatives also depends critically on the national carbon intensity of electricity. This varies widely throughout the EU, from a low of 0.05 $kgCO_2$/kWh in Sweden up to 0.86 $kgCO_2$/kWh in Greece, with the EU-27 2006 five year rolling average being 0.39 $kgCO_2$/kWh (DEFRA and DECC 2010).

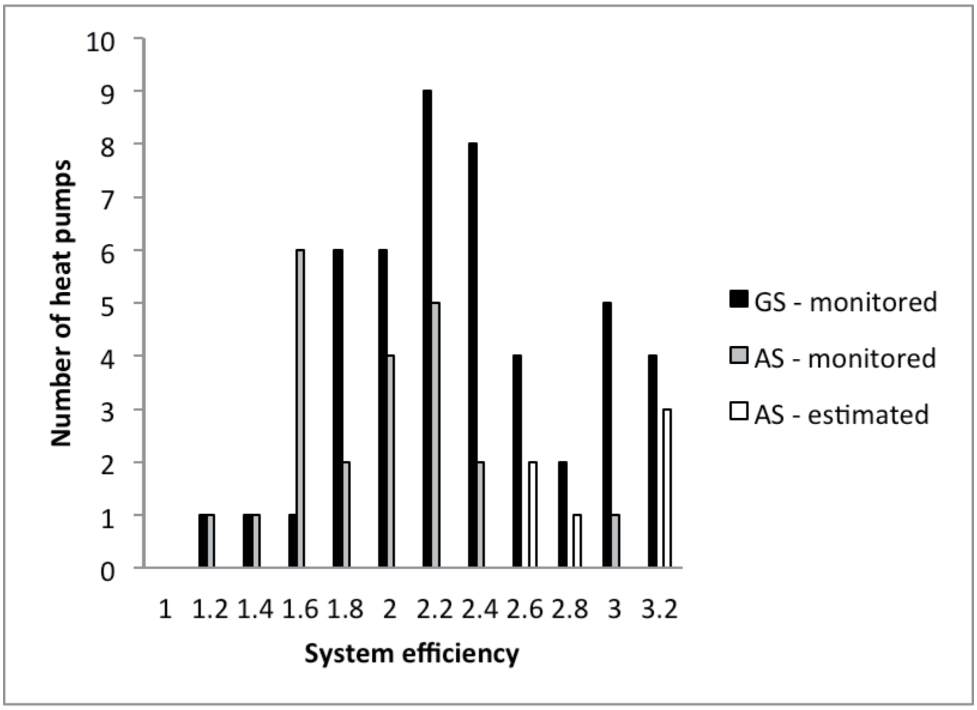

Figure 2: Results of EST heat pump field trial.

In the UK, heat pumps have a higher hurdle to jump than in many other countries to make carbon savings compared with mainstream alternatives. This is because UK has higher than EU average carbon emissions from its electricity (grid five year rolling average figure, 2008, = 0.55 $kgCO_2/kWh$), and the competitor heating fuel used by more than 80 % of the population is natural gas – the least carbon-intensive fossil fuel. The calculations in Figure 3 show that a heat pump would have to achieve a system efficiency of greater than 2.6 in order to result in reduced carbon emissions compared with a new, efficient gas boiler. The calculations are based on delivering 16,000 kWh of heating and hot water energy per year (similar to recommended 'medium' annual gas usage figure, Ofgem, 2010), using current carbon intensity figures for gas and electricity (DEFRA and DECC 2010) and assuming a gas condensing boiler with seasonal energy efficiency of 88 %. If system efficiency of 3.0 was achieved, a heat pump would save 13 % of emissions compared with gas. Using figures from the EST trial, the average UK GSHP emits 14 % more emissions than an efficient gas boiler, and the average UK ASHP, 38 % more. In some ways this is an unfair comparison, as most heat pumps will replace oil, LPG or electric heating systems, which have higher carbon emissions than gas boilers. However, the comparison is relevant to the majority of the UK housing stock which uses gas as the heating fuel.

These figures assume that heat pumps are not used in reversible mode to increase summer cooling. This is clearly a risk, as mentioned earlier, almost half of ASHPs sold in Europe are reversible and so can be used for cooling as well as heating.

Future carbon emissions from heat pumps

Currently UK heat pumps on average perform less well on carbon emissions than using gas as a heating fuel. However, this is not expected to be true into the future. The calculation which underlies Figure 3 are based on current electricity carbon intensity. In order for the UK to meet its low carbon targets, there is universal agreement that reducing carbon emissions per kWh of electricity is crucial. This can be achieved through increasing the percentage of renewables and/or nuclear energy and introducing carbon capture and storage for fossil fuel plants. There is still huge debate about the mix of technologies which should be used on the supply side, as well as the role of demand management. However, as Table 4 shows, future expectations are that the carbon intensity can be reduced by a factor of ten within the next twenty years. The Committee on Climate Change (CCC) – an independent body which advises the government on emissions targets and the progress towards meeting them – note that the decarbonisation goal for 2030 has been accepted by a wide range of stakeholders, including business groups and NGOs (Committee on Climate Change 2010:243). This acceptance, however, does not make the projections any less challenging. A fall of carbon intensity of 45 % is expected from 2008 to 2020. In the previous twelve year period period, between 1996 and 2008, the five year rolling grid average carbon intensity has fallen from 0.62 to a low of 0.53 in 2001, rising to 0.55 $kgCO_2/kWh$ in 2008, a fall of 11 % (DEFRA and DECC 2010). As Spiers, Gross et al (2010:22) note, the transformation of the electricity system and build rates implied by the CCC's scenarios (and other similar scenarios) are dramatic and without precedent.

With the exception of Sweden and France which already have very low carbon electricity supplies, all EU countries will need to follow an electricity de-carbonisation route to meet their long-term carbon reduction goals.

If these figures are achieved in reality in the UK, then carbon emissions from averagely efficient heat pumps should be lower than those from gas-based heating systems before 2020, and very much lower by 2030 and beyond. If such low carbon electricity can be supplied in sufficient quantities, from a carbon

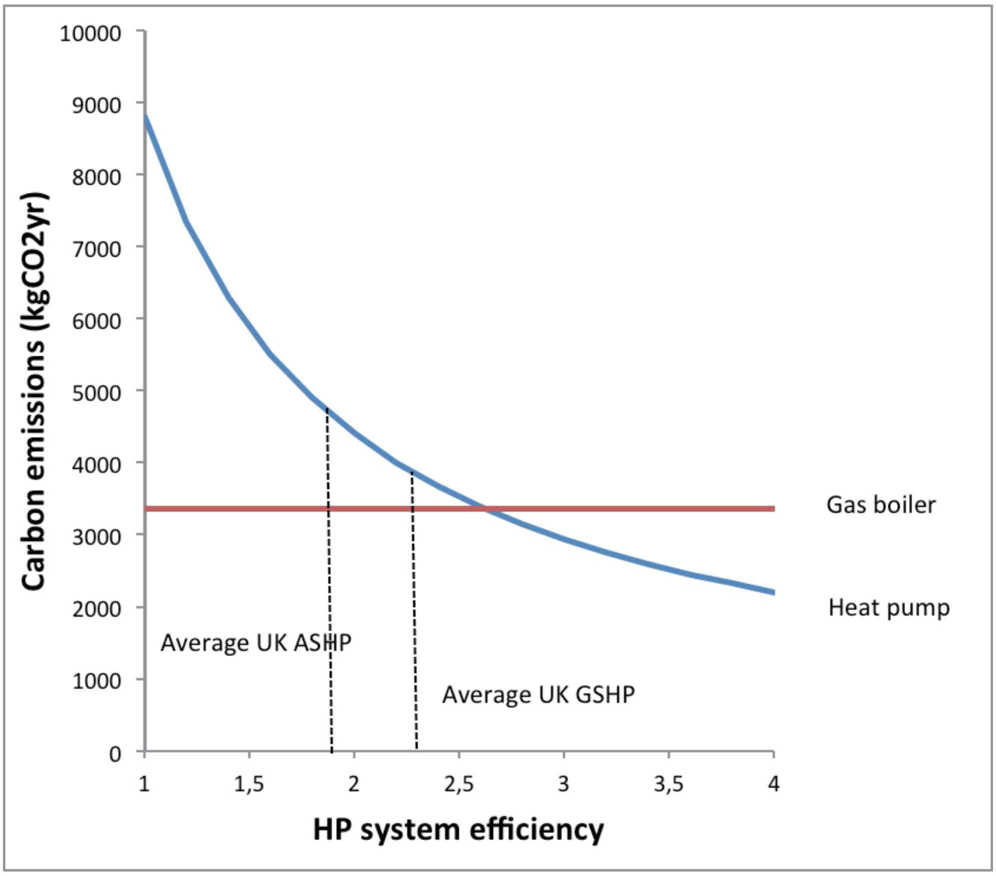

Figure 3: Carbon emissions from gas and heat pump heating systems, UK, 2008.

Table 4: Projections of carbon intensity of electricity, UK, 2020–2050.

Date	Carbon intensity $kgCO_2/kWh$	Source
2008 (five year rolling average)	0.55	Defra and DECC, 2010
2020	0.30	(Committee on Climate Change 2010), to be achieved if current government ambitions on renewable energy and other low carbon sources are met.
2030	0.052	(Committee on Climate Change 2010), medium investment strategy (0.04 – 0.13 kgCO2/kWh with high to low investment range)
2030 – 2050	Falls to around 0.01	Markal modelling on behalf of CCC, (Committee on Climate Change 2010)

perspective heat pumps are an obvious choice for space and hot water heating. However, simply being a lower carbon option, does not guarantee that people will want this form of heating, that there will be an industry in place to install it, that it would be cost competitive with alternatives, or that the changes to housing infrastructure and heat distribution systems which are also necessary would occur.

Policy

Policy on heat pumps has been developed as part of a larger move towards encouraging the use of renewable and more efficient heat sources.

EU

The EU Directive on renewable energy 2009/28/CE (EU 2009) sets ambitious targets for all Member States, such that the EU will reach a 20 % share of energy from renewable sources by 2020 and a 10 % share of renewable energy specifically in the transport sector. The directive includes both ASHP and GSHP within its definition of renewable sources of energy on the condition that they meet minimum performance standards, i.e. provided that the final energy output "significantly exceeds the primary energy input required to drive the heat pumps". Annex VII of the directive determines the accounting method for energy from heat pumps. It stipulates that only heat pumps whose energy gain is at least 15 % over the input primary energy shall be taken into account (calculated as the mean on the European scale), as based on measurement of useful heat delivered and the seasonal performance factor. Because the measurement procedures for useful heat and the seasonal performance factor have not been finalised (they are due to be produced no later than 1 January 2013) it is not clear precisely what COP this will equate to. However, current estimates are that a COP of above 2.875 will be required (Stringer 2010).

UK – HEAT PUMPS

Prior to the adoption of the Directive on renewable energy, the UK had policy in place to increase the take up of microgeneration and renewable technologies by individuals and organisations. The Low Carbon Buildings Programme (LCBP) was launched on 1 April 2006, giving grants to a variety of microgeneration installations in homes, public buildings and businesses. GSHPs were included from the start of the scheme and air source heat pumps were added from 2/6/2008. For homes, grants were conditional upon their having certain energy efficiency measures, including cavity wall and loft insulation (where relevant), heating system controls and low energy light bulbs. From 2006-2008, GSHP were awarded a maximum of £1,200 (1,400 Euros) grant or 30 % of the total cost (whichever was the lower of the two). Installations in the first two years of the LCBP grant scheme (2006-07 and 2007-08) were 213 and 231 GSHP systems respectively (Bergman and Jardine 2009). While not totally insignificant in a market as small as the UK's, this was nevertheless a very small intervention.

Under the renewable energy Directive, the UK has a challenging and legally binding target of generating 15 % of its energy from renewables by 2020. Part of the UK strategy to achieve this target is the introduction of a 'Renewable Heat Incentive', which will offer incentives on a vastly increased scale compared with LCBP. The government's ambition is to move from 1 % to 12 % of all heat generated from a renewable source by 2020. The original intention was that this would represent over £850 m (£1000 m Euros) of investment, however, this has been reduced by 20 % following a government spending review. The money to pay for the scheme will come via central government, rather than from a levy on energy bills as originally planned. As yet, the payments which will be made for particular technologies have not been confirmed. ASHP and GSHP will be included within the scheme.

DISCUSSION

The decision by the EU and national governments to classify heat pumps as 'renewable' is not without its critics. In its response to the RHI proposals, the UK's Sustainable Building Association (known as AECB) stated that "Either heat pumps should be redefined as non-renewable energy, or heat from fossil CHP plant should be redefined as renewable energy" (AECB 2010) on the grounds that CHP plant would result in lower carbon emissions than a typical heat pump. In an article on whether heat pumps should be considered a renewable source of energy, Nowak (2009) suggests that: "The individual stakeholder's position towards heat pumps is … shaped by his or her perception of the use of electricity for heating, by the way electricity is used in the country/region concerned and by the proportion of renewable sources used to produce it". There are no universally true statements about the environmental benefits at a household or national level of heat pumps. The context in which they are used, and the options they can be compared against are critically important. Given the variations in electricity carbon intensity across Europe, and the expected changes over time, a debate on whether heat pumps are a renewable form of energy may be rather sterile. But AECB do make an important point about the differing support given to various more efficient/lower carbon technologies (whether or not they are defined as renewable) and questioning whether governments are promoting some (less good) technologies at the expense of others.

Discussion: A future transition towards heat pumps?

DESCRIBING THE PROBLEM

In Europe and the UK, heat pumps for whole house heating are primarily a technology which is installed in new build properties (IEA 2010). One key reason for this is that to get good performance from a heat pump, a low temperature heat distribution system is required, and it could be both expensive and disruptive to install this in an existing property, particularly if underfloor heating was required. However, for heat pumps to be widely adopted, this will have to occur. The other disadvantage of older properties is that they are less well insulated than new ones. A low temperature heat distribution system will not be sufficient to maintain acceptable internal temperatures in a poorly-insulated property, so many older properties will need much improved building shell insulation as well as new heating system, in order to allow a heat pump to be fitted. This adds considerably to the complexity and cost of a transition to mass adoption of heat pumps. The economics of heat pumps in their current niche are much more favourable than in the mainstream for reasons that are likely to persist. Similarly the technical and social difficulties in installing heat pumps in existing houses are inevitably greater than in new build.

In the UK, the niche is even smaller. Most heat pumps are installed in new build properties which are not connected to the natural gas grid – these make up around 10 % of new homes. Market expansion seems most likely to occur in on-gas grid new homes (around 180,000 built per year), where heat pumps and suitable heating systems can be designed in, with additional costs of heat pumps subsidised through the forthcoming Renewable Heat Initiative. If heat pumps did move into this larger niche it would offer the opportunity for growth in the industry and should lead to reductions in cost via increased competition and economies of scale. However, as EST's results showed, the UK heat pump installation industry is not currently of high standard, and there are concerns that the Renewable Heat Incentive will wrongly encourage growth before quality, training and skills are improved. It could lead to "premature adoption and consumer disenchantment" putting at risk the longer term market for heat pumps (Renewable Energy Forum, 2010:6). Market expansion for heat pumps from new homes into the 25 million existing homes is likely to require further policy measures.

The timetable for a transition to heat pumps implied by current policy and research seems to come in two distinct parts. The EU timetable requires large increases in renewable heat to be delivered by 2020, which would imply a considerable number of good quality heat pumps installed by that date. The UK Renewable Heat Initiative will support this policy with financial incentives, as yet of unknown duration and generosity, from 2011. EST will deliver its second year report on heat pumps in mid- to late-2011, advising in detail on how high quality installations can be achieved. By contrast, UK modelling of low carbon electricity futures suggests heat pumps will be installed in large numbers only from 2030-2035. These timetables suggest a possible surge of interest in heat pumps in new housing – if high quality systems can be delivered – up to 2016-20. Then from 2030-35, heat pumps replace all other central heating systems in existing housing. This scenario, simplistic as it is, does not seem very attractive. What would be more compelling would be a scenario whereby the quality, market share and consumer confidence in heat pump installations increases over time, so that heat pumps are a strong contender to deliver very low carbon heating once sufficient low carbon electricity supplies are available. To achieve this, there would have to be a significant market for heat pumps in existing housing well before 2030.

ROUTES TO THE MAINSTREAM

Then the question is how to encourage heat pump installation in the existing housing stock. Is there a niche within that stock where they would face lower costs and fewer social and technical barriers to installation? Newer existing housing where the heating system has reached the end of its life (say, within housing which is 15-20 years old) is better insulated than older housing, and could probably be heated using low temperature heat without needing comprehensive insulation measures in addition to a low temperature heat distribution system. This would reduce the cost and disruption of switching to a heat pump. Targeting this section of housing which is off the gas network would improve the economics further. Another target group might be this type of housing owned by social landlords rather than private owners, as they may be attracted to the lower running costs of heat pumps (despite high capital costs) in the interests of their tenants. Environmentally-minded home owners might be prepared to face the additional costs and disruption involved in retro-fitting a heat pump, assuming that lower carbon electricity is a reality by that point, and that significant carbon savings can be made. So there are some niches within the mainstream which are less problematic for heat pumps to occupy, but given the need in many cases to change the heat distribution system, it is hard to see heat pumps being cost competitive if anything like today's relative equipment and fuel/electricity costs still apply.

RESEARCH GAPS

There are many gaps in understanding how a transition to a heat pump-dominated future could occur. The following questions are amongst those requiring further research.

- Where are the most promising niches for heat pumps within the existing housing stock? These need to be identified, and policy designed to encourage the uptake of heat pumps within them. Policy may need to be multi-faceted covering low temperature heating systems and insulation/air tightness upgrades as well as the heat pump itself.
- What percentage of the national housing stock would be technically suitable for heat pump installation, now and in the future? NERA &AEA (2009) did preliminary research which split the UK housing stock into a number of types and looked at the technical suitability of each type of heat pumps for each housing type. Much more detail is needed on the number and types of property suitable for GSHP and ASHP. The technical problems, for example, land availability and access to land in the case of GSHP, noise impacts on neighbours for ASHP, need to be explored.
- How can low temperature heating systems be installed in existing homes at least cost and with least disruption? How can this work best be combined with significant upgrades to the building fabric? In the UK, a programme called 'Retrofit for the future' (www.retrofitforthefuture.org) is trying out these options with heat pumps in some existing buildings. Results from this trial should provide useful evidence.
- What is the risk that mass installation of heat pumps would increase the summer cooling demand? How is this risk related to current (and expected future) climate? How can the risk be reduced?
- What are householder experiences of heat pumps, particular when retrofitted into older homes? How could these be improved? The second year of the EST study should give some insights into this.
- How can a small-scale and fragmented heat pump installer industry (Bergman and Jardine, 2009) transform into a sector capable of delivering high quality installations in large numbers?

FINAL THOUGHTS

Moving heat pumps into the mainstream existing housing stock presents a real challenge. It is highly unlikely that renewable heat policies alone could accomplish this. Governments would need to take a more comprehensive approach which involves significant upgrades to the housing stock, and a change in preferred heating systems to the low temperature variety. Existing research suggests possible routes to upgrading the housing stock (e.g. Fawcett and Boardman, 2009), but these are far from easy. There appears to be no consideration as yet around policy on heat distribution systems. In the absence of a future which includes radical and comprehensive low carbon policies, such as increased carbon taxation or personal carbon allowances, it is hard to imagine heat pumps fulfilling their theoretical potential to deliver mass low carbon heating and hot water.

Heat pumps present a dilemma. On one hand they can be described as a proven technology which is suitable for the mass market, can deliver reliable heating and hot water efficiently and which, in combination with low-carbon electricity, can deliver a very low carbon heating and hot water system. However, they can also be described as expensive, disruptive in existing homes, only relevant to a minority of householders if (current) lower running costs or carbon emissions are the desired benefits, a technology which can lead to increased summer cooling demands, requiring on-peak electricity and often lacking a fully professional installation industry. A transition to heat pumps will require the negative aspects of this technology to be overcome and to ensure its positive characteristics deliver what they promise.

Conclusions

Heat pumps are currently a niche technology in the EU and UK. In two European countries, Sweden and Switzerland, heat pumps have a significant share of the heating market in new homes, and of the existing home market too in Sweden. Although improvements in efficiency and reduction in costs would make heat pumps a more attractive option, these are unlikely to be sufficient factors to drive a transition towards heat pumps in the mainstream. Moving out of the new build niche in the UK will be difficult for heat pumps as they require both low temperature heating systems and high levels of building insulation to operate well – neither of which is typical of the existing housing stock. These requirements add to the cost and disruption involved in installing heat pumps. Current European and national government policy will create incentives for the further uptake of heat pumps, but these are unlikely to be sufficient to make them a mainstream heating option.

In the more distant future, after 2030, in theory heat pumps will become a very attractive low carbon option due to the availability of low carbon electricity throughout Europe. However, it is vital that thought is given now to how this longer-term scenario could be facilitated by current measures to increase the market for heat pumps in the shorter term, up to 2020. Support for retrofitting heat pumps into existing housing may require policy in new areas, such as the design of low temperature heating systems, and will certainly require a great deal of coordination across different policy areas. Heat pumps highlight just how interconnected various developments towards a low carbon future are: this technology cannot deliver significant carbon savings unless we also have considerable supplies of low carbon electricity, a very well insulated housing stock and a switch towards low temperature heating systems. Heat pumps cannot lead us towards a lower carbon future. They can only be a following technology when other major energy and housing system changes have already been accomplished.

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