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Domestic heat pumps in the UK: User behaviour, satisfaction and performance

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Abstract

Consumer adoption of microgeneration technologies is part of the UK strategy to reduce carbon emissions from buildings. Domestic heat pumps are viewed as a potentially important carbon saving technology, given the ongoing decarbonisation of the electricity supply system. To address the lack of independent evaluation of heat pump performance, the Energy Saving Trust undertook the UK's first large-scale heat pump field trial, which monitored 83 systems in real installations. As part of the trial, the Open University studied the consumers' experience of using a domestic heat pump. An in-depth user survey investigated the characteristics, behaviour, and satisfactions of private householders and social housing residents using ground source and air source heat pumps for space and/or water heating, and examined the influence of user-related factors on measured heat pump system efficiency. The surveys found that most users were satisfied with the reliability, heating, hot water, warmth and comfort provided by their system. Analysis of user characteristics showed that higher system efficiencies were associated with greater user understanding of their heat pump system, and more continuous heat pump operation, although larger samples are needed for robust statistical confirmation. The analysis also found that the more efficient systems in the sample were more frequently located in the private dwellings than at the social housing sites and this difference was significant. This is explained by the interaction between differences in the systems, dwellings and users at the private and social housing sites. The implications for heat pump research, practice and policy are discussed.

Keywords: microgeneration heating and hot water systems; domestic heat pumps; consumer surveys, user behaviour; field trial; technical performance.

1 Introduction

To meet the challenges of the 2008 Climate Change Act, the UK government set demanding targets to reduce CO_2 and other greenhouse gas emissions by 34% by 2020 and by 80% by 2050 on 1990 levels (HM Government 2009a). Tackling the heat demand is particularly important because heating accounts for the largest single proportion of the UK's final energy demand at approximately 49%, of which about two fifths is domestic demand (DTI 2007; HM Government 2009b). A number of reports have identified the importance of microgeneration heat technologies – defined as the small-scale production of heat from a low carbon source – to achieve the UK's renewable energy and carbon emission reduction targets (e.g. House of Commons 2007; EST 2007; BERR 2008). The UK's microgeneration strategy suggested that widespread adoption of low carbon and renewable heating technologies, including solar thermal, heat pumps and biomass stoves and boilers, could reduce domestic carbon emissions by up to 6.5% by 2030 and by up to 15% by 2050 (DTI 2006), and therefore make a small, but significant contribution to achieving carbon reduction targets.

However, a major government commissioned study on the potential for microgeneration, estimated that by 2007 there were only 95,000-98,000 installations in UK homes, mostly solar thermal hot water systems (accounting for over 92% of total installations) and less than 2,000 ground source heat pumps (Element Energy 2008), although no data for air source heat pumps were provided. From this very low base the UK heat pump market grew rapidly in 2009 and 2010 with approximately 8000 ground source and 30,000 air source heat pumps installed, almost all in residential buildings (Fritsch 2011). The market for domestic solar PV grew even more rapidly following the provision in the UK of a generous feed-in tariff between April 2010 and December 2011 (and then reduced by 50%) with about 100,000 installations by September 2011 (DECC 2011). The Energy Saving Trust (EST) estimates that up to 10 million microgeneration systems could be installed by 2030, saving up to 10 megatonnes of CO_2 per annum (EST 2010). Nevertheless, these and other studies have identified many barriers to UK household adoption of microgeneration technologies, especially high upfront cost, but also consumer factors including lack of awareness and information, the considerable technical knowledge involved in microgeneration purchase decisions and scepticism regarding the performance of unfamiliar technologies (Watson *et al.* 2006; House of Commons 2007; EST 2007; Element Energy 2008; Roy, Caird and Ableman 2008).

As part of the drive to promote adoption of domestic low-carbon and renewable technologies various government grants and subsidies have been offered such as the Low Carbon Buildings Programme (LCBP, which finished in 2010) and the Scottish Communities & Householders Renewables Initiative (SCHRI now renamed Energy Saving Scotland Home Renewables Grants) and the feed-in tariff. The Renewable Heat Incentive introduced in 2012 aims to promote the rapid uptake of low carbon and renewable heating systems, and especially heat pumps, which are viewed across Europe as an increasingly important technology as the proportion of renewable grid electricity to power them grows.

Though better financial incentives will undoubtedly encourage faster consumer adoption of microgeneration heat technologies, a recent survey by the authors of over 900 adopters and non-adopters of these technologies, including heat pumps, found that improved information and advice was also vital to promote adoption (Caird and Roy 2010). The information and advice most frequently desired (by 71% of survey respondents) was independent information on the performance and payback of different systems, which is often unavailable because of the cost of independent testing. Consumers did not want to rely on manufacturers' claims about heat pump performance and the associated reductions in carbon emissions, which are usually based on laboratory rather than real life conditions.

As the UK's leading provider of energy saving advice, the Energy Saving Trust sought to address the lack of independent evaluation of domestic heat pumps by undertaking the first large-scale field trial in the UK to investigate heat pump performance in real-life installations, and the technical and user factors that influence performance (EST 2010). This built on other EST monitoring studies of the performance of domestic-scale wind power (EST 2009) and solar thermal systems (EST 2011).

2 The heat pump field trial

The field trial was managed by the EST and consisted of two elements: (a) in-situ monitoring of the technical performance of a sample of UK domestic heat pump systems carried out by three energy contractors; (b) surveys plus interviews of the experiences, perceptions and behaviour of users of these systems carried out by the Open University (OU). The project was overseen by an Advisory Group comprising representatives of energy suppliers, manufacturers, installers and government departments. This paper focuses on the findings of the OU user study, plus some essential information on the technical monitoring part of the field trial.

2.1 Technical monitoring and performance

A list of domestic heat pump systems was considered by the EST for inclusion in the field trial, drawn mainly from government grant-funded installations (through LCBP and SCHRI), and from heat pumps in social housing sites that were provided or managed by eight housing associations, local councils or charities. A few additional sites were offered by heat pump suppliers. From this list 91 heat pump sites were initially selected by the EST for the field trial to represent:

- Different types and manufacturers of pumps: air source, ground source (vertical borehole and horizontal ground loop systems), and water source (e.g. ponds);
- Different heat distribution systems: radiators and/or under-floor heating;
- Systems providing domestic hot water (DHW) and/or space heating;
- Different types of dwelling, including private homes and social housing, with varying energy efficiencies;
- Heat pumps installed in new buildings or retrofitted to existing buildings.

After exclusion of some of the original sites due to technical issues, data collection or other problems, and the addition of a number of replacement sites (plus a few sites monitored by one heat pump supplier using the same protocol), the EST field trial produced full technical monitoring data from 54 domestic ground source (GSHP) and 29 air source heat pumps (ASHP) at 83 sites across the UK, with a full year of monitoring completed in March 2010. A map of the location of the field trial sites across the UK may be found in EST (2010). Almost all (88%) of the private housing sites were off the mains gas network (see Appendix Table A1) and the householders typically previously used oil central heating, wood fuel or electric heating. Likewise 90% of the social housing residents were without mains gas, most having previously used electric storage or solid fuel heating. Thus, few systems were installed as a replacement for, or an alternative to mains gas central heating.

Data gathered by the EST's contractors included information on the heat pump systems, and surveys of the sample dwellings to calculate a RdSAP[1] rating of building energy efficiency. Technical data gathered during the trial using equipment installed at the sample sites included the following:

Electrical energy used in the system (by heat pump, buffer tank, hot water storage tank, pump(s)); auxiliary (e.g. boost) heating: (metered and unmetered); temperature measurements (including of the: heat source and distribution system, domestic hot water delivery, external air and internal living and bed rooms).

From this data the following was calculated:

- Heat pump efficiencies: (Pump Coefficient of Performance (COP)[2], System COP[3] and System Efficiency (SEFF)[4]). These efficiencies measure the heat output of either the heat

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[1] Reduced Data Standard Assessment Procedure 2005 (RdSAP) provides a rating of the energy efficiency of a dwelling calculated using site survey data.

[2] Pump COP measures the pump efficiency calculated from amount of heat produced by the heat pump divided by the amount of electricity needed to run the heat pump alone (EST 2010).

pump or the whole heat pump system divided by the electrical energy input to power the pump or system, so the higher the COP or SEFF the higher the performance;

- Carbon emissions of the heat pump relative to conventional heating systems (electric, gas, oil, solid fuel).

The system efficiencies of the monitored heat pumps varied widely: from 1.3 to 3.3 (mid range 2.3 to 2.5 i.e. 230% to 250% efficiency) for the GSHPs; and from 1.2 to 3.2 (mid range 2.2 i.e. 220% efficiency) for the ASHPs (EST 2010). This meant that some UK installations performed as well as average heat pumps in German and Swiss field trials. However, many did not (especially the GSHPs) and a number performed very poorly indeed, and only a few reached the minimum system efficiency (about 2.9 for the UK electricity supply mix) to count as a renewable energy technology under the EU Renewable Energy Directive. This could be explained by several factors, including inadequate design and sizing of the heat pump systems, and the greater knowledge and experience of continental European installers and consumers (Fraunhofer ISE 2011, Delta Energy 2011).

The carbon emissions analysis indicated that for any saving relative to gas central heating, the heat pump would require a system efficiency of over 2.5 with the current UK electricity supply mix. Only a minority of the heat pumps in the EST field trial achieved this minimum efficiency to compete with gas on carbon emissions although, as noted above, mains gas heating was not an option at most of the sites. Most heat pumps managed the minimum efficiency to save carbon relative to oil central heating, and all managed to compete with direct electric and solid fuel heating. However, as the number of heat pumps increases more will be installed at sites with mains gas - the dominant space heating fuel in the UK. Greater efficiencies will therefore be important to compete with condensing gas boiler central heating on carbon emissions.

Factor analysis of the monitoring data was conducted by the EST and one of its contractors (the Energy Monitoring Company) using statistical modeling to examine likely technical factors that could have influenced heat pump performance across the monitored sites. However, apart from finding a relationship between high heat output of the system and greater efficiency, this did not produce conclusive results (EST 2010). Hence the Open University team was asked to examine the effects of user characteristics and behaviour on heat pump performance.

2.2 User experiences, behaviour and satisfaction

A user study to accompany the technical monitoring was considered to be an essential part of the trial. [5] An earlier UK field trial of domestic micro-CHP systems had shown that user behaviour was

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[3] System COP is the pump efficiency taking into account heat losses from heat pump system tanks (buffer and/or domestic hot water) (EST 2010).

[4] System efficiency (SEFF) is the whole system efficiency calculated from total heat output of the heat pump and any associated auxiliary (boost and/or domestic hot water) heaters divided by the total electricity requirement to run the entire system (including any electric domestic hot water and/or auxiliary heaters, pumps, fans, controls, etc.) (EST 2010).

[5] The user evaluation study was conducted during the first year of the field trial and the analysis refers to technical data gathered and processed during this period, initially received in April 2010 and subsequently updated in April 2011.

one of the factors that influenced performance (Carbon Trust 2007). Thus, it was expected that user behaviour in operating another unconventional heating system such as a heat pump could have a significant effect on its performance (e.g. Guy and Shove 2000; Wilhite 2007) and this needed to be investigated further. For example, for maximum efficiency it is normally recommended to operate heat pump systems so as to provide continuous gentle heat. However, it is not known whether this is actually the most efficient heating pattern and continuous operation could involve 'comfort taking' and hence higher total energy use. Consumers familiar with gas or electric heating may be also be reluctant to leave their heating continuously switched on even if it is more efficient. These issues are discussed below (Section 4.4).

Second, apart from a few case studies and small-scale surveys (e.g. ESD 2006; 2007) there was little available information on UK consumers' experiences of using heat pumps. The German and Swiss field trials did not include user studies, although it was recognised that users' behaviour can have an effect on heat pump efficiency, including their knowledge of heat pump operation, their selected room and DHW temperature settings and their ability to control auxiliary boost heaters (Fraunhofer ISE 2011).

The main existing UK evidence came from a pilot study of over 80 social housing and private households off the mains gas grid in Scotland which had an air source or ground source heat pump installed under a government scheme to address fuel poverty (EST 2008). Questionnaire surveys showed that about 90% of the householders were very or fairly satisfied overall with their new heating system and its ease of use and 75% were satisfied with running costs. Householders were pleased with the constant heat throughout their home and several commented that they could now use rooms that were previously unheated. This indicates that some energy efficiency gains of replacing their old oil or electric storage heating by heat pumps were reduced by comfort taking.

The aims of the OU user study part of the field trial were:

- Obtain feedback from heat pump users on their characteristics, behaviour, experiences, and satisfaction with using a heat pump system;
- Identify any differences in user experiences, behaviour and satisfaction between private householders and social housing residents and in using a GSHP or ASHP system;
- Assess any effects of user characteristics and behaviour on system performance as measured in the field trial, using System Efficiency (SEFF) as the preferred measure of performance, or pump COP when SEFF data was unavailable.

The rest of this paper reports on selected findings of the user study, its relationship to the technical monitoring results and the adoption of domestic heat pumps in the UK.

3 User study: method and sample

An initial questionnaire was mailed to the private householders whose systems had been selected for the field trial to obtain their agreement to participate in the user study; very few refused. Householders who agreed to participate were then mailed a series of postal questionnaires covering Autumn, Winter and Spring/Summer seasons. These questionnaires were developed by the OU research team and based on its extensive previous survey work on obtaining user feedback on domestic energy efficiency and renewable energy technologies (e.g.

Caird, Roy and Herring 2008; Caird and Roy 2010) together with advice and feedback from a pilot survey, heat pump manufacturers, the EST and the Project Advisory Group.

In the case of the social housing sites, permission was obtained from the five social housing managers involved in the trial to contact their residents. A focus group with one group of residents was conducted to ensure that all relevant questions were included in the survey. All the social housing residents were then mailed a questionnaire covering all seasons. The social housing managers advised that a single questionnaire would achieve the best response and they provided additional information about their residents, properties and heat pumps during telephone or face-to-face interviews. A modified integrated questionnaire was also mailed to an extra group of private householders who were added to the original sample, as they were included too late to respond to all three seasonal questionnaires.

All the questionnaires offered multiple choice and/or open-ended questions on:

- Demographic information about the respondent's household size and composition, employment, gender and age range;
- The consumer experience of owning or using a heat pump, its benefits and any operational problems, the provision of advice and support, how satisfactorily it provided heating and/or hot water, use of supplementary heating, how it compared to the user's previous heating and hot water systems and satisfaction with running costs;
- User characteristics and behaviour that might affect the heat pump's performance, such as how the system and its controls were understood and operated; patterns of heating and hot water use, any requirements for supplementary heating, choices of room temperatures and ventilation habits.

A total of 78 users (48 private householders and 30 social housing residents representing 50 GSHP and 28 ASHP systems) completed questionnaires, including from six households that were eventually excluded from the final monitored sample. This resulted in an overall response rate of 78/89 = 87.6%. There were high response rates from both the private (48/55 = 87%) and social housing (30/34 = 88%) sub-samples, due to the willingness of most users to provide feedback on their experience plus a small reward that was offered for returning completed questionnaires.

Table 1 presents the types of heat pumps, housing sites and their heat distribution systems in the user sample. This shows that a quarter (25%) of the heat pumps provided only space heating, while three-quarters (75%) provided both domestic hot water (DHW) and space heating: Over half (59%) of systems had radiators, nearly a third (31%) had underfloor heating, and 7% had both radiators and underfloor heating. Very few heat pumps had a cooling function and users with these systems reported they did not use them for cooling during the field trial period.

Table 1 User sample by heat pump, housing tenure and heat distribution type

Heat distribution system	GSHP [a]	ASHP	Private householders	Social Residents	All heat pumps
DHW & Radiators	50% (25)	39% (11)	35% (17)	63% (19)	46% (36)
DHW & Underfloor	28% (14)	11% (3)	29 % (14)	10% (3)	22% (17)
DHW & Radiators & Underfloor	8% (4)	4% (1)	10% (5)	0% (0)	6% (5)
Radiators & Underfloor	0%	4% (1)	2% (1)	0% (0)	1% (1)
Underfloor	10% (5)	7% (2)	15% (7)	0% (0)	9% (7)
Radiators	4% (2)	29% (8)	6% (3)	23% (7)	13% (10)
Warm Air	0%	7% (2)	2%(1)	3% (1)	3% (2)
Base	50	28	48	30	78

[a] The GSHP group includes 1 water source heat pump

The private householders and social housing residents in the user sample typically occupied very different types of properties. Details are given in an Appendix, Table A1. The table shows that the private householder sites comprised mostly detached properties (81%) with three or more bedrooms (77%), and a relatively large floor area (average 175 m^2). The social housing sites, in contrast, comprised mostly semi-detached or terraced properties (90%) with one to two bedrooms (79%) and a relatively small floor area (average 64 m^2). Analysis of the RdSAP energy efficiency ratings showed that (32%) of private housing sites included more energy efficient buildings (with UK Energy Performance Certificate (EPC) bands A, B, C) compared with social housing sites (7%), although more private dwellings (41%) were also energy inefficient (bands E, F, G) compared with social housing sites (30%).

There were also differences in the households that occupied the properties. The private dwellings were mostly occupied by two or more people (96%) who had typically installed the heat pump as part of a new-build project (59%) or major extension to an existing property (16%). This contrasted with the social housing properties where the heat pump was usually a retrofit installation (93%) in dwellings that were usually occupied by one person (70%), frequently of pensionable age (47%) (Appendix Table A1).

A limitation of the surveys was that, as a result of the in-depth nature of the questionnaires, not all respondents answered all the questions. This accounts for some variation in the sample sizes given in the tables below for different questions or sections of the questionnaires.

4 Data Analysis

A Microsoft Access database was developed to store and analyse the user questionnaire data and to relate this data to the site survey and technical monitoring data. Some responses were aggregated for the purposes of analysis due to the relatively small sample size. For example, the categories: 'strongly agree' and 'agree'; 'disagree' and 'strongly disagree' were combined. An analysis was conducted with all the user-related data to investigate differences between private householders and social housing residents, and between ground and air source heat pump users.

Chi-squared non-parametric tests were used to test the statistical significance of differences in user responses for private householders and social residents, and for GSHPs and ASHPs, and between user-related factors and system efficiency (SEFF) data (or pump COP if SEFF data was not available).

4.1 User characteristics: understanding and knowledge

How well the user understands their heat pump system is likely to affect their ability to operate and control it effectively, hence the users were asked how much knowledge and understanding they and/or other household members had about their heat pump system.

Table 2 User knowledge and understanding of their heat pump system

	How much knowledge and understanding do you, and/or other household members, have about your heat pump system?		
	Private householders	Social residents	All respondents
A lot	33% (16)	3% (1)	22% (17)
A fair amount	48% (23)	37% (11)	44% (34)
A little	19% (9)	43% (13)	28% (22)
Very little/None	0%	17% (5)	6% (5)
Base	48	30	78

Table 2 shows that two-thirds (66%) of heat pump users said they had 'a lot' or 'a fair amount of knowledge and understanding' of their heat pump system. Perhaps unsurprisingly, more private householders (81%), most of whom had their own system installed, claimed to have 'a lot' or 'a fair amount' of knowledge and understanding than the social housing residents (40%), who had a system provided for them. Conversely, 60% of social housing residents compared to only 19% of private householders said they had little or no knowledge and understanding of their system. A chi-squared analysis shows that the greater knowledge and understanding claimed by private householders compared with social housing residents was statistically significant ($p=0.001$).

4.2 User satisfaction with the heat pump experience

In order to provide feedback on their satisfaction with their heat pump system, users were asked to indicate on a scale the extent to which they agreed with a number of statements.

Table 3 presents the user satisfaction results, which are presented graphically (using Excel), in Figure 1.

Table 3: User Satisfaction with the heat pump system

How satisfied have you been with your heat pump system?				
	Strongly agree/Agree	**Neither Agree/Disagree**	**Strongly disagree/Disagree**	**Base**
The heat pump system meets my household's requirements for room heating.	54 (73%)	8 (11%)	12 (16%)	74
The heat pump system has made my home warm and comfortable	58 (83%)	4 (6%)	8 (11%)	70
The system performs reliably	53 (77%)	7 (10%)	9 (13%)	69
Heat pump system meets my household's requirements for hot water [b]	42 (86%)	2 (4%)	5 (10%)	49
I/we get pleasure from using low carbon energy for home heating and/or hot water	55 (80%)	10 (14%)	4 (6%)	69
The controls and displays are easy to understand and use	37 (54%)	13 (19%)	18 (27%)	68
I/we are satisfied with the technical support from the heat pump installer/supplier(s)	46 (63%)	11 (15%)	16 (22%)	73
I/we are satisfied with the costs of running and maintaining the system (compared to our previous heating system)	41 (62%)	9 (14%)	16 (24%)	66

[b]Note smaller sample of heat pumps with DHW (See Table1).

FIG 1

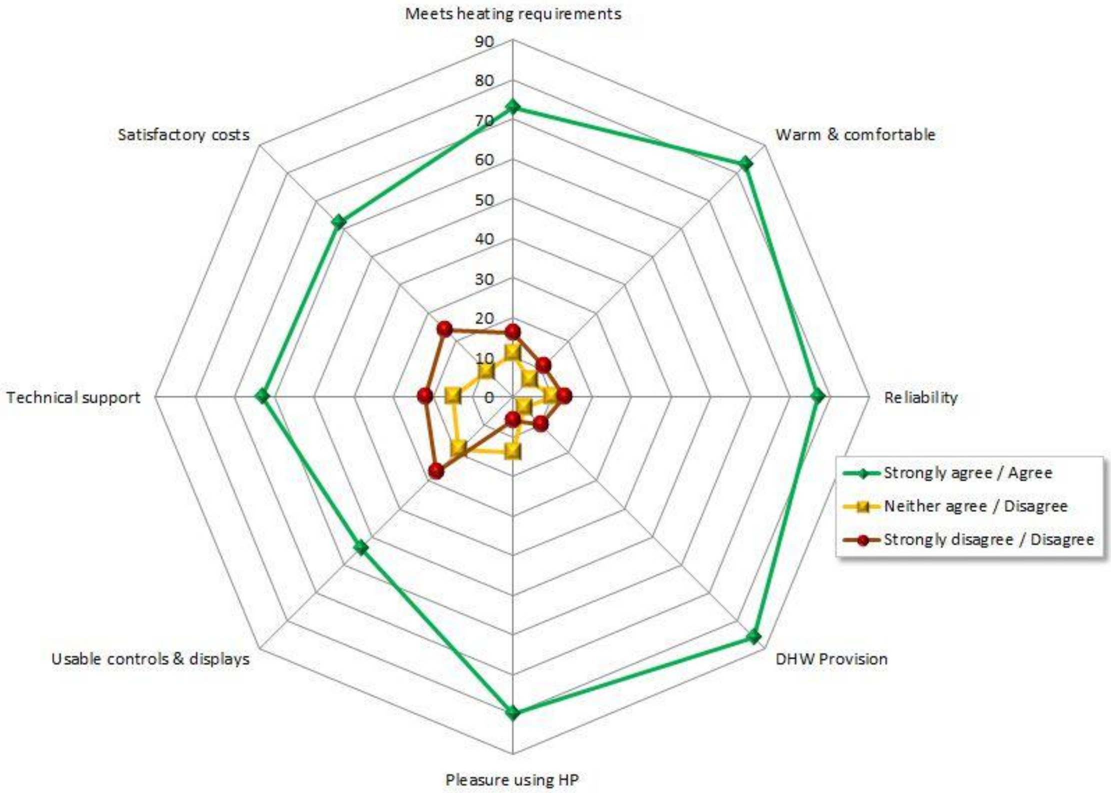

Fig. 1 User satisfaction with the heat pump system

The radial lines present users' responses in percentages. Base n=66 to 74.
n (for the smaller DHW sample) =49

Overall, most users were very satisfied with their ground or air source heat pump systems. For example, nearly three-quarters (73%) of users strongly agreed or agreed that the system meets their household's room heating requirements and even more (83%) strongly agreed or agreed that the system has made their home warm and comfortable, Almost all (86%) of the users of the systems that provided domestic hot water said it met their DHW requirements. Perhaps not surprisingly, the private householders, most of whom had chosen to invest in a heat pump, generally expressed higher levels of satisfaction with their systems than the social housing residents. Moreover, as is detailed later, the private householders owned most of the higher efficiency systems measured in the field trial. Private householders reported greater satisfaction with space heating (79% satisfied) and comfort (91% satisfied) than the social housing residents (67% and 71% satisfied), but there were only small differences between ground and air source systems in user satisfaction with heating and comfort.

Another indication of user satisfaction is how the heat pump system compares with their previous heating system. Table 4 presents the, mainly positive, findings.

Table 4 Comparison of heat pump with previous heating/DHW system

	Overall, how does your heat pump system compare with your previous heating system (in this or a different home)?		
	Private householders	Social Residents	All respondents
Much Better/ Better	85% (35)	58% (15)	75% (50)
Neither Agree/Disagree	7% (3)	15% (4)	10% (7)
Worse/Much Worse	7% (3)	27% (7)	15% (10)
Base	41	26	67

Three quarters (75%) of users rated their heat pump system as much better or better than their previous heating/hot water system which, as most were off the mains gas network, was typically oil central heating or electric heating; with a few solid fuel (coal), mains gas or LPG systems. 15% of users rated their heat pump system as worse or much worse than their previous heating/hot water system and most of these were social housing residents. Table 3 showed that the main sources of dissatisfaction included: understanding and using heat pump controls (27%); the quality of technical support (22%); and running costs (24%). These sources of dissatisfaction are discussed further in Section 4.3 (Problems experienced in use).

4.3 Problems experienced in use

The relatively high satisfaction levels (Table 3 and Figure 1) would suggest that the users experienced few problems using their heat pump system. However, Table 5 shows that a sizeable minority of users experienced one or more problems. These problems are discussed in more detail in the sub-sections below.

Table 5 Main Problems experienced by users

	Have you experienced any problems since you started using your heat pump system?				
Space heating problem(s) experienced	GSHP users	ASHP users	Private householders	Social residents	All heat pump users
Uncertain how best to operate the system and its controls to make most efficient use of fuel or energy	48% (22)	37% (10)	40% (17)	50% (15)	44% (32)
Difficulties understanding instructions on operating and using the system	39% (18)	15% (4)	23% (10)	40% (12)	30% (22)
Unable to heat rooms to required temperature	20% (9)	30% (8)	19% (8)	30% (9)	23% (17)
Slow warm up of heating system	17% (8)	26% (7)	7% (3)	40% (12)	21% (15)
Problems with intrusive noise	15% (7)	26% (7)	9% (4)	33% (10)	19% (14)
Base	46	27	43	30	73

4.3.1 Operation and control

Table 5 shows that the most frequent problems mentioned by users concerned efficient heat pump operation. Nearly half (44%) of users were uncertain how to operate the system and its controls for optimum efficiency. This could be a source of dissatisfaction – as one private GSHP user said '*I would like more information on how to get the best out of the system*'. Although more social housing residents than private householders were uncertain of how best to use controls (50%), the level of difficulty was still relatively high for private householders. Nearly a third (30%) of all users also claimed that they had 'difficulties understanding instructions on operating and using the system'. This is an issue for manufacturers to address, in particular, GSHP users had significantly more problems with understanding instructions than ASHP users (p=0.02). One GSHP user said *'We were left with a manual which to a non-technical person is unintelligible'.*

Problems with operation and controls reinforced the results in Table 3 which showed that just over half (54%) agreed that their heat pump controls and displays were easy to understand and use. More social housing residents (40%) disagreed that the controls were easy to understand and use than private householders (19%). This could be due at least partly to the age of many social residents, nearly half (47%) of whom were pensioners. Open comments from social housing managers and other users indicated that elderly people often had problems operating complex and fiddly controls. For example, one social housing GSHP user said '*It's harder than using a computer; with elderly having them I would expect it being hard for them. My husband has not touched it as he daren't in case it goes wrong, then we will be left for months to suffer*'.

Further analysis showed that two-thirds (65%) of users had tried to adjust the system's controls (base 68). However, most of the adjustments were simply altering the temperature on thermostat(s) and only a few users attempted the more complex task of reprogramming controls on the heat pump unit. One private GSHP user, a builder who had installed heat pumps, said: '*Easy if you stick to the basics. But more know-how is needed if you want to use more of the menus*'.

The remainder may not have tried to make adjustments either because it was unnecessary with automatic control systems, or simply too difficult or impossible. For example, one social housing GSHP user said, *'The heat pump does a marvelous job of keeping the house warm; however being on 24/7 is not my choice. I have no apparent control of it, frustrating'*.

When users were questioned about which improvements to heat pump design and/or technology they would like to be developed, the main improvements desired were controls that provide the user with feedback on fuel and cost savings (68%) and system efficiency (58%) to help them operate their heat pump more efficiently (base 66).

4.3.2 Space heating problems

A problem identified by about a quarter (23%) of heat pump users was that they were sometimes unable to heat rooms to the required temperatures (Table 5). There was also a complaint about the slow warm up of the heating by over a fifth (21%) of users. Slow warm-up was a problem for more social housing residents (40%) than private householders (7%), which chi-squared testing found as statistically significant ($p=0.0004$). This may be explained because more social housing dwellings had a low energy efficiency rating, and there were more pensioners in this group who may require higher levels of warmth. Social residents were also more likely to turn their heating off at night thus making it difficult for the system to warm up sufficiently during the day (see Section 4.4 Space heating behaviour). The relatively slow response of heat pump systems also led to a few complaints (from 14% of users) about rooms being too warm at night or when the house is unoccupied. For example, one private GSHP user said: *'I'm pleased to have reduced carbon impact…but the system is less controllable than hoped and the slow response means we now use more heat in daytime when not needed in order to achieve adequate room temperature in the evenings'*.

4.3.3 System noise

Nearly a fifth (19%) of heat pump users said that intrusive noise was a problem and this was a problem for proportionally more (33%) social residents than private householders (9%) and for more ASHPs (26%) than GSHPs (15%) (Table 5). Most of the problems for social residents were with ASHPs whose fans may be heard if the unit is located near windows or on the outside walls of living or bedrooms, which is more likely given the much smaller average size of the social housing dwellings (Appendix Table A1). Although noise only affected a minority of users, it indicates an area for improvements to heat pump design and installation, especially for social housing.

4.3.4 Technical advice and support

Given the relative complexity of heat pumps compared to conventional heating systems, good technical support and advice for users is especially important. Advice and support on using heat pumps is usually available from manufacturers, installers and, for social housing residents from housing managers who managed the installation of systems.

As private householders purchase their own systems they are particularly sensitive to advice and support for the installation process. This is particularly an issue for the GSHP systems (which are generally more complex than ASHPs) as a number of householders mentioned difficulties with installers who did not take full responsibility for coordinating the full installation process which can involve builders, plumbers, electricians as well as the installer who may be the only one familiar with the technology. One user said *'The main problem was that the installer would not arrange the installation of the field system himself. I had to find a local builder for the digging of trenches and installation of the field pipes'.* In such situations the householder had co-ordinate the installation and found it difficult to apportion responsibility if any problems arose.

While nearly two-thirds (63%) of users were satisfied with the technical support they received from installers and suppliers, 22% were dissatisfied (Table 3). Most of these dissatisfied users were social housing residents who would have liked to have received more advice on how to operate and control their system to meet their requirements for economical and comfortable heating. One social housing resident said *'I think this is a real weak spot. There is a lack of informed view of how best to set, adjust and operate the system'*.

4.3.5 Costs of running and maintaining the system

One of the main factors determining how satisfied users are with their heat pump system is how much it costs to operate in terms of electricity use and any maintenance required. Overall, satisfaction levels were fairly high, although about a quarter (24%) of users disagreed or strongly disagreed that they were satisfied with the running costs when compared with their previous heating system (Table 3). It is notable that two-thirds (66%) of the users who were dissatisfied with running costs were social housing residents, who said they had little understanding of heat pumps and had received little advice on how to operate their system for optimal efficiency. However, some dissatisfaction with costs would be expected as the field trial took place in the context of significant fuel price rises.

Users' comments illustrate the widely differing degree of satisfaction with running costs, often depending on their previous heating system:

'*Cleaner, cheaper, more efficient, more convenient, more effective*' (private GSHP user)

'Definitely more economical and ecologically friendly, but less responsive and requires manual input to meet our needs' (private ASHP user).

'*In use it appears more expensive to run than we thought, but it is still cheaper than oil AND we are warm throughout the house all day/ night'* (private GSHP user)

‘*We were told it would cost a third of price of electric, but there is no difference from people who are using electric storage heaters*’ (social housing GSHP user)

4.4 Space heating behaviour

It is usually recommended that for optimum efficiency, unlike conventional central heating systems, heat pump systems are programmed to provide a constant trickle of low temperature heat. A series of survey questions investigated whether the users normally left their system switched on continuously or programmed to come on and off at set times. The results presented in Table 6 reflect user perceptions of how they operated their heat pump rather than being based on the technical monitoring data (which could not identify if the heat pump had switched off because a set temperature had been reached or because the user had programmed it to switch off).

Table 6 shows that about three-quarters of all heat pump users said they normally operated their system continuously, that is all night (72%), as well as all day (81%) and when the home was unoccupied (76%).

Some significant results emerged associated with the timing of the systems’ space heating provision. Fewer social housing residents than private householders said that their system was switched on all night (p=0.02) and when their home was unoccupied (p=0.01). These statistically significant differences may be due to the types of systems used in the different housing (Table 1). For example, all but three of the under-floor heating systems were in private households, and these are slow to heat up and cool down and usually operate under automatic control, whereas the social housing residents predominantly had radiator-based systems controlled by central heating type programmers. Another possible explanation indicated by open comments was that some social housing residents remained to be convinced that continuous operation was the most efficient and economical way to use a heating system. Some may believe that switching their heating system off at night and when their home was unoccupied was the most cost–effective way to operate their heat pump system.

Table 6. Normal space heating patterns – continuous or non-continuous (intermittent) operation

Now you have a heat pump, how do you normally use energy in your home?							
	Heating pattern	**GSHP users**	**ASHP users**	**Private house-holders**	**Social housing tenants**	**Heat pump users**	**Total Base**
Continuous operation	Usually heat the home constantly/for long periods during the day	85% (33)	74% (17)	85% (35)	71% (15)	81% (50)	62
	Often/usually leave the heating on all night	76% (28)	65% (15)	82% (31)	55% (12)	72% (43)	60
	Often/usually leave the heating on when out of the home	91% (30)	58% (15)	87% (32)	59% (13)	76% (45)	59
Intermittent operation	Usually heat the home for fairly short periods during the day	15% (6)	26% (6)	15% (6)	29% (6)	19% (12)	62
	Rarely/never leave the heating on all night	24% (9)	35% (8)	18% (7)	46% (10)	28% (17)	60
	Rarely/never leave the heating on when out of the home	9% (3)	42% (11)	14% (5)	41% (9)	24% (14)	59
Base	Range The number of responses to different questions varied	33-39	23-26	37-41	21-22	59-62	

This point was mentioned interviews with social housing managers, one who said: '*Some people have had previous systems where they have learned rules such as switch it off if you're out…This is not the most cost-effective route for a ground source heat pump'.*

Heat pump systems operate most efficiently when dwelling heat loss is minimised. This means not opening windows and doors unnecessarily. As one social housing resident said *'I was never shown how to use it or how it works, just told to keep windows and doors shut'.* The results suggest that most users have adopted this advice, as 63% of heat pump users said they 'rarely or never leave windows and/or doors open with the heating on', while only 37% said they 'sometimes or often' do this (base 65). Chi-squared testing suggested that any differences in the ventilation behaviour of GSHP versus ASHP users ($p=0.46$) and in private versus social housing ($p=0.18$) were not significant.

Nearly half (44%) of users used supplementary sources of heating, at least on some occasions during the exceptionally cold UK winter that occurred during the trial (base 72). The technical factor analysis mentioned earlier suggested that heat pump systems that are oversized to meet such unusual peak heat demands do not often work at maximum output, and therefore may be less efficient than systems specified for more normal peak heat demands; hence occasional use of supplementary heating may have been allowed for to meet peak heat demands by some system designers or installers.

Typically the supplementary heating used was wood stoves by the private householders and electric room heaters by the social housing residents. Analysis showed that only 8% who used supplementary heating were actually dissatisfied with their heat pump's heating provision and the use of supplementary heating was often from choice. As one private GSHP user said, '*It meets our needs quite well. We used our wood-burning stoves as well, but could have managed without*'. Another said, 'I *lit the wood stove rather than increase the load on the HP*'. A more likely source of dissatisfaction would be with undersized systems that switch on an auxiliary electric boost heater when unable to meet the heat demand. This can result in inefficient operation and unexpectedly high fuel bills, especially if the user is unaware of or has no control over such direct electric boost heating. One private GSHP user commented, '*the internal booster heater came on and the electricity bill was huge'*. Another social housing resident said, '*I tried to change from winter settings to summer, found it very difficult to work out how to do this. I worried in case it had been using the immersion heater as fuel bills are very high'*.

4.4.1 Comfort taking behaviour

The adoption of a heat pump may affect household energy behaviour, leading to more energy awareness and careful use, or to 'comfort taking' where consumers increase their energy use because providing more constant warmth than a conventional heating system is inherent to a heat pump system and/or because the heat is perceived as cheaper and so can be used more freely. Table 6 showed that about three quarters of users had indeed adopted continuous space heating behaviours. It was important to consider changes in energy behaviour for understanding the contribution of domestic heat pump installations to the reduction of carbon emissions.

When we asked users about their normal space heating behaviour we found that 85% of users heated all the rooms of their home rather than just the occupied rooms (15%) which some did previously with electric, wood or solid fuel heating (base 72). The results also showed that 59% of users estimated that they usually heated their living room to relatively high temperatures (22° C or more) (base 61) [6] Such behaviours provided some evidence of comfort taking as a result of using a heat pump. Some users' open comments illustrate this: *'My family now are spoilt and go about in pyjamas and light clothing; whereas when we moved here we were wearing coats inside in the winter'* (private ASHP user).

'Comparable cost to run but gives us constant hot water and even warmth rather than peaks. We heat the whole house now versus the odd room previously' (private GSHP user).

Further information on potential comfort-taking effects associated with heat pumps came from an analysis of user responses to questions about any changes to their energy use behaviour since the heat pump system installation (Table 7).

Table 7 Changes to user energy behaviour following heat pump system installation.

Since changing to a heat pump system			
	Private householders	**Social residents**	**All respondents**
I/we are more careful in the way I use heating/hot water than before	43% (13)	45% (10)	44% (23)
No Change	50% (15)	14% (3)	35% (18)
I/we are less careful in the way I use heating/hot water than before	7% (2)	41% (9)	21% (11)
Base	30	22	52

Table 7 shows that 44% said they had changed their behaviour to be more careful with their use of heating and/or hot water than before and this included many who had adopted continuous heating patterns. Some 21% of users claimed to be less careful in the way they use heating/hot water than before the heat pump was installed, most of whom were social housing residents using GSHPs. The results showed that almost all of the self-described 'less careful' users heated their homes overnight and when their home was unoccupied. Some perceived this heating pattern as wasteful even though they were following advice provided on the most efficient way to operate heat pumps. As one ASHP user said, '*We would like more control over room temperatures. It is not easy to alter and the slow response means we generally do not alter it. Energy is wasted by heating the house at night*'.

This suggests that users need better guidance on the most efficient way to operate heat pumps so that they can be clear on whether they are actually being more or less careful with energy

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[6] This corresponded with a monitored living room temperature mean of 19 to 20°C, and a range from 16 to 23°C.

usage or whether their perception is a hangover from the habits they had developed when using conventional heating systems.

4.5 User factors and heat pump system performance

A key aim of the user study was to identify possible relationships between user characteristics, behaviour and satisfaction and heat pump performance as measured by its system efficiency (SEFF). The results of the EST technical monitoring (discussed in Section 2 The heat pump field trial) showed that most of the system efficiencies for both ground source and air source heat pump systems ranged between 2.2 and 2.5, although some installations achieved efficiencies greater than 3.0 (i.e. 300%) while others only managed efficiencies well under 2.0 (EST, 2010). The statistical modeling analysis of the heat pump system type and technical monitoring results undertaken for the EST, mentioned earlier, was unable to explain this significant variation in performance across the monitored sites (EST, 2010). The only factor that appeared to be strongly related to system efficiency was the heat load – the closer the system was to attaining its maximum heat output the higher its efficiency. Although it is difficult to disentangle the many factors which may affect heat pump performance, the user study provided indications of additional factors that may prove important.

When the full year's heat pump performance data became available we used system efficiency data to categorise sites into low (SEFF <2.0), medium (SEFF 2.0-2.5); and higher performing (SEFF >2.5) systems. SEFF data was not available in ten cases due to technical monitoring limitations. For these cases we used pump COP data instead (see footnotes 2-4) Table 8 identifies 22 low, 26 medium; and 22 higher performing sites in the user sample.

By inspecting the classified data (e.g. as in Table 8), hypotheses were established regarding how the user characteristics and behaviour might affect system efficiency (e.g. greater user understanding of heat pumps is associated with higher efficiencies). Chi-squared tests were then used to calculate the statistical significance of differences in the data and hence to test the hypotheses. The statistical test results for the user factors plus other variables are shown in Appendix Table A2.

Table 8 User-related factors categorised by heat pump performance [c].

Characteristic	SEFF <2	SEFF 2-2.5	SEFF >2.5	Total
Knowledge and understanding of heat pump system				
A lot	4% (1)	16% (3)	46% (10)	14
A fair amount	57% (13)	47% (9)	36% (8)	30
a little/none	39% (9)	37% (7)	18% (4)	20
Base	23	19	22	64
Space heating behaviour				
Heating usually on all night	59% (10)	74%(14)	100% (18)	42
Heating rarely on all night	41% (7)	26%(5)	0	12
Base	**17**	**19**	**18**	**54**
Heating usually on when out	56% (9)	65% (13)	95% (18)	40
Heating rarely on when out	44% (7)	35%(7)	5% (1)	15
Base	16	20	19	55
Satisfaction with running costs				
Strongly agree/Agree	50% (9)	58% (11)	80% (16)	36
Neither agree nor disagree	6% (1)	16% (3)	20% (4)	8
Disagree/Strongly disagree	44% (8)	26% (5)	0	13
Base	18	19	20	57

[c] measured by system efficiency (SEFF). Pump COP is used for a few cases where SEFF was not available.

The results suggested that greater user knowledge and understanding of the heat pump was related to higher system efficiency because 82% of users of higher performing systems claimed to have either a lot or a fair knowledge of their heat pump system. This contrasted with only one user of a low performing system who described themselves as having a lot of knowledge of their system (Table 8). The chi-squared test established the significance of this difference (p=0.018) (Appendix Table A2).

The results also suggested that more continuous operation of the system was significantly related to higher system efficiency (p=0.012 to 0.02). All the higher performing systems were left switched on at night and 95% when the property was unoccupied. This contrasted with 59% of low efficiency systems that were left on at night and 56% when the property was unoccupied (Table 8).

In addition, the results suggested that higher satisfaction with running costs was related to higher system efficiency (p=0.02). None of the users of higher performing systems were dissatisfied with costs and 80% were satisfied or very satisfied. This contrasted with 44% of users of low efficiency systems who were dissatisfied with running costs. This finding is not surprising given that lower efficiencies will generally mean higher fuel costs.

Although the chi-squared tests indicated that the above findings were significant, when the data was disaggregated for this analysis the sub-sample sizes were too small to produce statistically robust findings. The findings should thus be regarded as indicative with a larger sample needed for confirmation.

As well as the above, several hypotheses for other user factors and system efficiency were also tested. These included differences in living room temperatures, ventilation behaviour, use of supplementary heating, ease of use of controls and satisfaction with technical support. However, none of these were statistically significant (see Appendix Table A2).

4.6 Housing type and system performance

In addition to user factors, the relationships between heat pump type, housing type and system efficiency were tested (Table 9)

Table 9 Characteristics of heat pump trial sites categorised by system efficiency (SEFF)[d]

Characteristic	**SEFF <2**	**SEFF 2-2.5**	**SEFF >2.5**	**Total**
Private Housing	54% (12)	42% (11)	95% (21)	44
Social Housing	46% (10)	58% (15)	5% (1)	26
GSHP	45% (10)	77% (20)	73% (16)	46
ASHP	55% (12)	23% (6)	27% (6)	24
Base	22	26	22	70

[d] SEFF or pump COP data used for the categories are based on final analysed monitoring results as updated in April 2011.

The heat pump type was found to be significantly related to system efficiency (p=0.03). This was explained by the higher percentage of higher performing systems that had a ground source (73%) than an air source (27%). The higher performing systems also employed more underfloor heating (59%) than radiators (27%), whereas the low performing systems had more radiators (59%) than underfloor heating (32%), the remainder being mixed under-floor/radiator systems.

Chi-squared tests showed that the type of housing in the sample – whether privately owned or socially rented – was strongly related to system efficiency (p=0.0001) (Appendix Table 2). Most of the higher performing systems were found in private housing (95%), compared to only one installation (5%) in social housing (Table 9). As housing type was associated with several related factors (e.g. dwelling size and energy efficiency, user characteristics and behaviour, new build or retrofit installations, and heat pump type), the significant association between heat pumps in private housing and higher system efficiencies may be explained by the interaction of these factors.

These factors included the finding that more private householders than social residents lived in higher energy efficiency rated dwellings (Energy Performance Certificate bands A, B, C) (Section 3 User study and Appendix Table A1); Chi-squared testing showed that there was a significant difference in the energy efficiencies of private and social housing (p=0.003). Other factors reported in Section.4.4 (Space heating behaviour) was that social residents had significantly less knowledge and understanding of their system than private householders (p= 0.001) and were more likely to operate their system non-continuously than private householders (p=0.01).

The significantly poorer performance of the heat pumps in the social housing also accounts for the finding that their residents were more dissatisfied with their heat pump systems than private householders, particularly with regard to running costs, technical support and comparison with their previous heating system.

5 Summary and conclusions

The in-depth consumer surveys of participants in the EST heat pump field trial showed that the majority of users were very satisfied with their ground source or air source heat pump systems. For example, nearly three-quarters of users agreed that the system meets their household's room heating requirements and almost 90% of the users of the systems that provided domestic hot water said it met their DHW requirements. Over 80% of users agreed that the system has made their home warm and comfortable; with several commenting that the constant and whole home warmth offered by the heat pump was one of their main advantages over their previous heating system. Three quarters said the heat pump was much better or better than their previous system, although in almost 90% of cases the heat pump was replacing electric, oil wood or solid fuel heating in homes without main gas central heating.

Despite these generally high levels of satisfaction, a sizeable minority of users expressed dissatisfaction and/or experienced various problems in use. The main complaints were over two fifths of users not knowing how to operate their system for optimum efficiency and economy, and nearly a third having difficulties understanding operating instructions. About a quarter said they were dissatisfied with their understanding and use of controls, the comparative costs of operating their system and the technical support and advice received from suppliers and installers. Also, about a quarter reported problems with heating their home to desired temperatures, and over a fifth complained about the slow warm up of their heating and/or heat pump noise (especially from ASHP fans).

Perhaps not surprisingly, the private householders, most of who had chosen to invest in a heat pump and who owned most of the higher efficiency systems measured in the field trial, generally expressed higher levels of satisfaction and had fewer problems with their systems than the social housing residents, who had a system provided for, or in a few cases imposed on, them.

Statistical analysis of the technical monitoring data conducted for the EST was unable to provide a satisfactory explanation for the wide variation in efficiencies of the heat pump systems in the field trial or for the relatively poorer performance of the systems in the UK field trial compared to similar trials conducted in Germany and Switzerland. The Open University therefore examined the possible effects of a wide range of user characteristics and room heating behaviour on heat pump system efficiency. This found statistically significant relationships between higher system efficiencies and both greater user knowledge and understanding of the heat pump and more continuous operation of the system. However, the sub-sample sizes were not large enough for these findings to be statistically robust and these findings would need larger samples for confirmation.

The effect of housing type on heat pump system efficiency was also tested. This found that the system efficiencies of the heat pumps installed at the private housing sites were significantly higher than the efficiencies at the social housing sites (probability of this being due to chance $p = 0.0001$). Almost all of the higher performing systems (with efficiencies above 2.5 or 250%) were found in private housing and only one installation in social housing. Housing type for the field trial sample is associated with many variables; therefore the strong association between the private housing sites and higher system efficiencies and between the social housing sites and lower efficiencies depends on the interaction of these variables. These included the larger average size of the private dwellings; the greater proportion of new-build systems with underfloor heating in the private housing, while the social housing had a greater proportion of retrofit systems with conventional radiators. Other differences included the greater knowledge and understanding of the private householders and the non-continuous heating patterns more frequently adopted by the social housing residents. The heat pump field trial offered limited scope to control these and other variables so as to clearly identify their effect on heat pump efficiency.

Thus, the reasons for the under performance of many of the UK field trial systems is not clearly known, but likely reasons uncovered in the user study include the lack of understanding among UK consumers of heat pumps and their operation, and the use of multiple contractors which had to be co-ordinated by the purchaser, sometimes leading to poor quality installations. In addition the inexperience of many UK heat pump installers probably resulted in inappropriate design and sizing of some systems leading to complaints about under- or over-heating, slow warm up and/or high fuel bills.

These and other issues call for a number of actions, which include:

- Enhanced training of installers to provide better system design and installation. This training should have improved with the launch of the Microgeneration Certification Scheme (MCS) in 2008, which came into effect after the installation of most of the field trial systems;

- More education, advice on, and support for, efficient and economical heat pump operation for heat pump users, especially social housing residents, from manufacturers, installers and social housing providers.

- One-stop installation services to avoid the need for customers to co-ordinate multiple contractors or take responsibility for the quality of the installation.

Heat pump manufacturers could also make changes to improve the acceptability and take-up of heat pump systems, including:

- Designing more user-friendly instructions and control systems. Some manufacturers have already improved the user interface of their controls since the field trial installations;

- Developing controls and displays that provide users with feedback on system operating efficiency, fuel and carbon savings;

- Displays that indicate when any auxiliary boost heater in the system has switched on, with a user override option unless a heat boost is required for viral disinfection;

- Reducing the noise levels of heat pumps, especially of ASHPs intended for installation in small homes, including social housing, where the unit may be sited close to living areas.

As noted above, most systems in the field trial were installed at sites without access to mains gas. This means that, even given the relatively low average efficiencies of the field trial heat pump systems, most should reduce carbon emissions as replacements for oil, solid fuel or electric heating. However, many of the systems would not save either fuel bills or carbon as a replacement for gas central heating, at least with the existing UK grid electricity fuel mix. Also there was evidence of 'comfort taking' as a result of the extended heating regime and warmth normally provided by heat pumps that may reduce their energy and carbon saving relative to conventional heating systems. This means that for heat pumps to count as a renewable energy source and be competitive with mains gas heating in terms of carbon reductions and so be worth adopting much more widely in the UK, their efficiency would have to improve to the levels of systems in the German or Swiss field trials. This applies especially to the ASHPs which can be installed in many more locations than ground source systems. Nevertheless, during the lifetime of heat pumps installed now, as the UK electricity supply decarbonises, heat pumps should become increasingly competitive with gas as well as other heating systems.

Our user study has shown that heat pumps can provide a heating and hot water system which is very attractive to UK consumers, and the field trial has shown that well-designed and installed heat pumps can operate efficiently in UK conditions and save carbon emissions. However, a number of improvements are needed if heat pumps are to become a widely accepted alternative to conventional domestic heating systems in the UK. More research is needed to fully identify the reasons for the widely varying performance of the heat pump systems in the field trial. Hence the EST together with the UK Department of Energy and Climate Change are continuing investigations, focusing on the under performing sites, and at the Open University the authors are conducting site-by-site analyses of the existing technical and user data to provide better answers to this question.

Appendix

Table A1 presents details of the private and social housing sample including their property and household characteristics. Table A2 presents the results of chi-squared tests used to assess the significance of relationships between system efficiency and user-related and other factors.

Table A1 Private and social housing: property and household characteristics

Dwelling/household characteristics	**Private housing**	**Social housing**
Type of Property	**Mostly detached**	**Mostly semi-detached or terraced**
Detached house & Bungalow	81% (33)	3% (1)
Semi-Detached	12% (5)	63% (19)
Terraced	5% (2)	27% (8)
Flat	2% (1)	7% (2)
Base	41	30
Number of bedrooms	**Three quarters have 3 bedrooms or more**	**Mostly 1-2 bedrooms**
1-2	23% (10)	79% (23)
3-6	77% (34)	21% (6)
Base	44	29
Size (floor area)	**Medium/large size**	**Mostly smaller properties**
Average (m^2)	175	64
Base	48	30
Energy Performance Certificate (EPC) bands (measured RdSAP)	**More energy efficient properties**	**Less energy efficient properties**
0-54 (Band E,F,G)	41% (18)	30% (9)
55-68 (Band D)	27% (12)	63% (19)
69+ (Band C,B,A)	32% (14)	7% (2)
Base	44	30

New-build versus retrofit system	**75% are new builds or extended properties**	**Mostly retrofits (93%)**
Newbuild or Converted Property	59% (19)	7% (2)
Major Extension	16% (5)	0%
Retrofit system in existing property with no extension	25% (8)	93% (28)
Base (note smaller sample)	32	30
Property on/off main grid	**Mostly off gas grid**	**Mostly off gas grid**
On main grid	12.5% (6)	10% (3)
Off gas grid	87.5% (42)	90% (27)
Base	48	30
Occupancy	**Mainly two or more person households**	**Mainly one person households**
1 person	4% (2)	70% (21)
2-7 people	96% (43)	30% (9)
Base	45	30
Gender (of respondent)	**Mostly male**	
Male	85% (41)	60% (18)
Female	15% (7)	40% (12)
Base	48	30
Respondent's age		**Nearly half are pensioners**
25-44 years	26% (11)	13% (4)
45-64 years	60% (26)	40% (12)
65 years +	14% (6)	47% (14)
Base	43	30

Table A2 Results of statistical tests of differences between low, medium and high efficiency heat pump systems

Differences between sites classified using heat pump system efficiency data into low (SEFF <2.0), medium (SEFF 2.0-2.5); and high (SEFF >2.5) efficiency groups	**Chi-squared test results** Significant at the .05 level** Significant at the.05 level, but a larger sample required for confirmation *	
System type: Was system type related to system efficiency?		
More higher efficiency were GSHP than ASHP systems	p=0.034	**
More higher efficiency systems had under floor heating than radiator or mixed heat distribution systems	p=0.016	*
Housing type: Was housing type related to system efficiency?		
More higher efficiency systems were in private housing than at social housing sites.	p=0.0001	**
User characteristics: Was the level of knowledge and understanding claimed by users related to system efficiency?		
Users with higher efficiency systems have more knowledge and understanding of their heat pump system than users with low efficiency systems	p=0.018	*
Space heating behaviour: Was space heating behaviour related to system efficiency?		
Higher efficiency systems usually switched on all night rather than rarely/never	p=0.012	*
Higher efficiency systems usually switched on when home is unoccupied rather than rarely/never	p=0.02	*
Higher efficiency systems usually heating all rooms rather than occupied rooms only	p= 0.16	Not significant
Higher efficiency systems usually heating rooms for long periods during the day rather than for short periods	p= 0.19	Not significant
Higher efficiency systems usually heating living rooms to low temperatures (under 18 degrees centigrade) rather than high temperatures (of 22 degrees centigrade or more)	p=0.6	Not significant
Users with higher efficiency systems rarely/never open windows or doors with heating on rather than sometimes/often	p=0.46	Not significant

Users with higher efficiency systems using supplementary heating sources rather than not	p=0.54	Not significant
Satisfaction: Were levels of user satisfaction and dissatisfaction related to system efficiency**?**		
Users with higher efficiency systems more satisfied with the costs of running and maintaining the system (compared to previous heating system)	p=0.02	*
Users with higher efficiency systems more satisfied with the technical support from the heat pump installer & supplier(s)	p=0.25	Not significant
Users with higher efficiency systems more satisfied that controls and displays are easy to understand and use	p=0.1	Not significant

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