energy saving trust

the heat is on: heat pump field trials phase 2

Acknowledgements

Phase 1

Phase I of this project was developed by the Energy Saving Trust and delivered with funding from a wide range of stakeholders including:

Government bodies
The Department of Energy and Climate Change
The Scottish Government
The North West Regional Development Agency

Energy Suppliers
EDF Energy
NPower
British Gas
Scottish Power
Scottish & Southern Energy
E.On UK
NIE Energy

Heat pump manufacturers
Danfoss UK
NIBE
Mitsubishi Electric
Mimer Energy
Worcester Bosch
Baxi Group

Phase 2

Phase 2 of the project was funded by:

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Energy Suppliers
EDF Energy
NPower
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Scottish & Southern Energy
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NIE Energy

Heat pump manufacturers
Danfoss UK
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Mitsubishi Electric

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Foreword

The Energy Saving Trust has a well-established reputation for developing and delivering field trials, which monitor the in situ performance of low-carbon technologies.

Our trials are designed to illustrate how these technologies and products perform in homes across the UK when used by actual householders. The trials also provide useful lessons from householders' day-to-day use and perceptions of the technologies. Customer confidence is essential. This real-life data and feedback allows us to identify areas for improvement and make recommendations to industry and government. We work with manufacturers, installers and government to ensure a robust supply chain, whose day-to-day engagement with technology and consumers will ultimately determine success.

The Energy Saving Trust is the UK's leading organisation helping people save energy and reduce carbon emissions. One of the ways we do this is by providing expert insight and knowledge about energy saving. Our activity includes policy research, technical testing and consumer advice. We have completed and reported on trials for technologies such as LED lighting and solar thermal water heating systems. These trials form part of our extensive market transformation activity in the domestic low-carbon technology sector.

The Energy Saving Trust is independent and impartial, and not tied to any commercial organisation or driven by political or corporate motivations. This enables us to work with a variety of industry stakeholders, who know that our findings will be evidence-based and unbiased.

This field trial study of heat pump performance was developed in 2008. Phase 1 was completed and reported on in 2010. Phase 2 undertook follow-up research and this report outlines its findings.

After Phase 1, the Energy Saving Trust worked with relevant trade bodies, heat pump manufacturers, the Department of Energy and Climate Change (DECC) and the Microgeneration Certification Scheme (MCS) to improve heat pump installation guidelines and training. The Energy Saving Trust will again work with the relevant parties to help improve heat pump installation and product standards within MCS using the findings from Phase 2 of the field trial.

The findings presented in this report have been independently peer-reviewed by leading UK heat pump experts to ensure impartiality of results.

We worked with relevant trade bodies, heat pump manufacturers, the Department of Energy and Climate Change (DECC), and the Microgeneration Certification Scheme (MCS) to improve heat pump installation guidelines and training

Executive summary

The Energy Saving Trust carried out a field study to monitor the performance of residential heat pumps between 2008 and 2013.

The study was undertaken in two phases to determine the in-situ performance of the technology in UK homes. Both air source and ground source heat pumps were studied in households across the UK.

The trial involved investigation of the following three areas:

- comprehensive performance monitoring of the heat pump system
- improvements to system performance through design and control
- user behaviour and perceptions of using a heat pump

Results from Phase 1, which included 83 sites, were published in 2010. The results were studied to identify areas for improvement in the installation, design and control of systems, and ways to help customers to understand how to optimise system performance.

The performance of heat pumps in Phase 1 showed wide variation. As a result of the detailed analysis carried out, the Microgeneration Certification Scheme (MCS) installation guidelines have been updated. The Energy Saving Trust strongly recommends that householders use MCS accredited installers to ensure that their heat pump performs correctly. Both phases of the trial have shown that the best-performing systems were those deemed to be properly designed and installed.

Phase 2, undertaken from 2010–2013, undertook a comprehensive study of 44 heat pumps to investigate the variation in performance shown in Phase 1. Phase 2 included a number of sites that performed poorly in Phase 1. Some well-performing sites were also selected in an effort to create exemplar sites. The following activities were undertaken in Phase 2 to identify a process to achieve improved performance from heat pump installations:

- Every site from Phase 1 was analysed in detail to understand what factors impacted in-situ performance.
- Installer standards were reviewed and improved.
- Manufacturers and installers carried out modifications to a sample of mis-sized or underperforming heat pumps.
- Heat pump users were provided with guidance to improve understanding of the controls and how best to manage heat pumps to optimise performance.
- In-depth monitoring was undertaken for one full year to investigate the impact of interventions.

- The impacts of various interventions on heat pump performance were determined through the analysis of performance data.
- Heat pump users provided their opinions after the final period of monitoring.

None of the heat pumps included in this trial were installed using current MCS installer standards. However, six new sites were installed largely in accordance with the new standards as confirmed by the manufacturers. Thirty-two of the 44 Phase 2 sites had customised interventions undertaken. The interventions were, when possible, undertaken following the MCS installer guidelines at the time. It is expected that heat pumps being installed today, to the current guidelines, would perform even better.

The results from performance monitoring are encouraging: the major and medium interventions, in most cases, led to improved performance. Minor interventions also resulted in small but significant improvements. Customer behaviour was shown to impact performance, but it is less significant than the correct design and installation of a system.

Users' perceptions are also encouraging: heat pump users were more satisfied with their systems after the Phase 2 interventions. A large and significant proportion stated they would recommend a heat pump to a friend.

Many of the trial's users indicated they would like more information about their heat pump at the point of installation. This can be achieved through training of installers and independent advice.

Based upon the results of the study, the Energy Saving Trust is convinced that heat pumps can play a significant part to help the UK reach its targets for reducing carbon emissions. Heat pumps can provide an effective, efficient solution for heating in many homes.

Key findings: user perceptions and behaviour

80% of users interviewed were either satisfied or very satisfied with the space heating supplied by their heat pump...

...while the figure for hot water production was 84%. Levels of satisfaction reported in Phase 2 were higher than those from Phase 1.

77% of the users interviewed stated they would recommend a heat pump to a friend, mainly because of the efficiency and running costs of the systems.

Different control strategies were implemented by the users and the majority were very satisfied with their chosen system. A number of users said they would benefit from greater control and more information from their system, particularly referring to their auxiliary or immersion heater.

Users' understanding of their systems is varied. Data suggests that there is a correlation between knowledge of system design and control and overall performance.

A large and significant proportion of users stated they would recommend a heat pump to a friend

Key findings: technical performance monitoring

Average system performance factors:

2.82
Ground source system

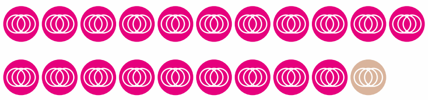
2.45
Air source system[1]

Both averages are deemed to be higher than in Phase 1.

As with Phase 1, design, commissioning and installation quality was shown to impact performance. The heat pumps that experienced major interventions, many in accordance with updated installer standards, achieved improved performance compared with Phase 1. This is an early indicator of the successes of these revisions to achieve consistent, high quality heat pump installations.

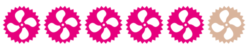
In 36 cases it was possible to calculate the performance of the heat pump using the criterion for being classified as renewable under the EU Renewable Energy Sources Directive (EU RES)[3].

Systems which could be defined as renewable under the directive:



20/21 Ground source systems

9/15 Air source systems



5/6 Newly-installed air source systems

Performance improvements between Phase 1 and Phase 2:

20/32 heat pumps undergoing interventions between Phase 1 and 2 achieved improvements in performance. The remainder achieved similar or slightly lower performance[2]. These improvements of performance were due to a range of technical and behavioural interventions at the sites.

1 These figures represent SPF_{H4}, a method used to calculate the efficiency of the entire heat pump as a heating system. This is discussed in further detail in the section 'System boundaries' on page 20.
2 With the exception of one site, which developed a fault in Phase 2.
3 The EU Renewable Energy Sources Directive requires a heat pump to perform to a minimum SPF_{H2} of 2.5 to be classified as renewable. This is discussed further in the section 'System boundaries' on page 22.

Conclusions

Heat pumps can provide an efficient alternative for householders.

The technical data obtained and the users' feedback indicates that well installed and operated heat pumps can perform to a very high standard in UK homes.

Although standards have improved, heat pumps are sensitive to design and commissioning.

The field trial provides early indications that the reasons for underperformance are understood and have been addressed by the new Microgeneration Certification Scheme (MCS) installer standards[4]. The revised standards have led to improved design and commissioning of heat pumps.

Customers provide positive feedback, but require more information.

The majority of the customers were satisfied with the heating and hot water provided by their systems but there were varying levels of understanding amongst customers of how to best use the various controls in order to achieve the best performance from the equipment.

Different aspects of a heat pump system impact on its performance.

Based upon a number of performance calculations, different aspects of the heat pump system can impact efficiency. Customers may benefit from feedback about which parts of the system impact operating efficiency, particularly auxiliary and immersion heaters.

Various control strategies can be utilised to achieve a high performing heat pump.

The majority of systems were run continuously using weather compensation and internal thermostats to control heating needs. A number of well-performing systems were controlled non-continuously, however, and delivered high levels of customer satisfaction.

4 DECC has run roadshows for installers to inform them of the new standards and a webinar is available on the MCS website at www.microgenerationcertification.org

Definitions

ASHP	Air source heat pump, a technology that takes heat from the air and 'pumps' it to a higher temperature, where it can be used to provide space heating or produce domestic hot water.
GSHP	Ground source heat pump, a technology that takes heat from the ground and 'pumps' it to a higher temperature, where it can be used to provide space heating or produce domestic hot water.
MCS	Microgeneration Certification Scheme, an industry-led and government-supported quality assurance scheme that seeks to ensure consistent and quality installations of microgeneration technology, including heat pumps.
EU RES	EU Renewable Energy Sources directive, a European Union directive, which classifies how renewable energy is calculated.
Intervention	A change that has been made to the heat pump in an effort to improve performance. Interventions are usually technical but can also be behavioural.
System efficiency	The amount of useful heat the heat pump produces compared with the amount of electricity needed to run the system. Useful heat is deemed as heat delivered for space heating and the heat delivered to the taps as domestic hot water.
SPF	System performance factor, another calculation used to define heat pump efficiency. It is the amount of heat produced by the system compared with the amount of electricity consumed. There are four SPF calculations (H_{1-4}), which depend on the system boundary used.
System boundary	A defined area that decides what aspect of the heat pump system is included in the SPF calculation. There are four system boundaries, each of which corresponds to an SPF calculation (H_{1-4}).

The background

The UK Government has committed to reduce greenhouse gas emissions by 34% (from 1990 emission levels) by 2020 to meet legally binding targets. As 27% of UK CO_2 emissions come from the energy used in our homes, we need to find ways to reduce our consumption and increase low-carbon heating and power.

With this in mind, the UK and its devolved governments have introduced a range of initiatives to encourage consumers to invest in low-carbon technologies. Most recently, the Renewable Heat Premium Payment (RHPP) scheme has distributed thousands of grants to British homes for renewable heating products. The Feed-in Tariff has driven the market for technologies producing renewable electricity. The forthcoming Renewable Heat Incentive (RHI), announced by DECC in July 2013 for a spring 2014 launch, is aimed at stimulating growth of domestic renewable heating systems in a similar way.

Accurate performance information is required to ensure that customers choose the correct technology to heat their homes. To better understand in situ performance of heat pumps, the Energy Saving Trust developed a field trial to undertake in-home performance monitoring in 2008. At that time, consumers could rely only on laboratory tests and manufacturers' performance claims.

What is a heat pump?

The heat pumps in this study serve the same purpose as a domestic boiler but, rather than burning a fuel to produce heat, they move heat from a low-temperature heat source and 'pump' it to a higher temperature where it can be used to provide space heating or produce domestic hot water. The source is normally heat in the ground or the outside air.

Measuring performance

Like running a fridge, these processes use electricity and cost money. The running costs of a heat pump depend upon its efficiency.

In very broad terms, the efficiency of a heat pump may be defined as the ratio of heat produced to the electricity used. This ratio is dependent on (amongst other things) the temperature of the source (air or ground), the temperature of the heat produced and the electricity used by the system.

The amount of electricity used to run a heat pump – and hence the efficiency – depends on the heat pump's efficiency and quality of design and installation. Environmental conditions, including the temperature of the heat source – which changes seasonally – and the desired temperature of the heat produced also impact the performance. As a general rule, if less electricity is used by the heat pump system it will have a better system performance.

In the trials, we measured the performance of the heat pumps in terms of system efficiency. This can be calculated by the following equation:

$$\textbf{System Efficiency} = \frac{\text{Heat supplied by heat pump for space heating} + \text{heat delivered to taps}}{\textbf{Electricity to...}\ \text{fans/pumps} + \text{heat pump} + \text{auxiliary} + \text{immersion} + \text{building fans or pumps}}$$

Ground source heat pumps
Ground source heat pumps extract heat from the ground, which can then be used to heat radiators, underfloor or warm air heating systems and hot water. A ground source heat pump circulates a mixture of water and antifreeze around a loop of pipe – called a ground loop – which can be buried in the garden. Heat from the ground is absorbed into the fluid and then passes through a heat exchanger into the heat pump. The ground stays at a fairly constant temperature under the surface, so the heat pump can be used throughout the year – even in the middle of winter. The length of the ground loop depends on the size of the home and the amount of heat needed. Longer loops can draw more heat from the ground, but need more space. If space is limited, one or more vertical boreholes can be drilled instead.

Air source heat pumps
Air source heat pumps absorb heat from the outside air and turn it into heating and hot water. An air source heat pump extracts heat from the outside air in the same way that a fridge extracts heat from its inside. Air source heat pumps are situated outside the property and can produce heat even in cold winters.

Phase 1

What happened?

Phase 1 of the field trial monitored 83 heat pumps for a full year, from spring 2009 to spring 2010. The purpose of the study was to identify how a sample of heat pumps installed in UK homes perform over the course of one year. The study also provided valuable insight into the factors that affect the performance of heat pumps, including:

- System sizing
- Type of heat source/sink
- Building efficiency
- User behaviour
- Heating patterns and average internal temperatures
- Installation practices

The sample comprised 54 ground source heat pumps (GSHP) and 29 air source heat pumps (ASHP) from 14 manufacturers. The sample included both owner-occupiers and social housing tenants.

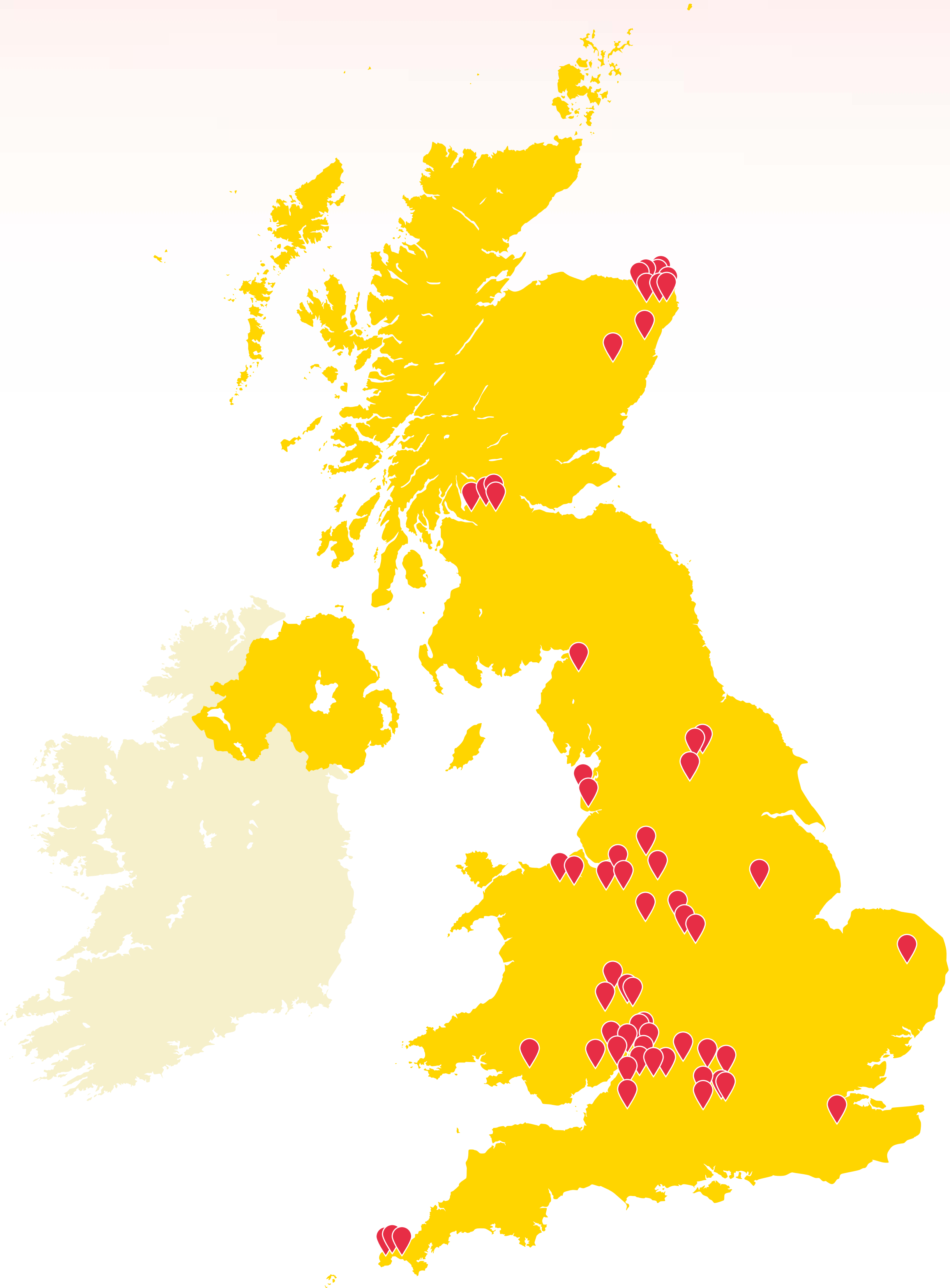
Participating sites were identified via a number of sources, primarily householders who had installed a heat pump using the Low Carbon Building Programme (LCBP) and Scottish Communities and Householder Renewable Incentive (SCHRI) grants. Further sites were identified through housing associations and energy suppliers.

Phase 1 of the field trial started before the Microgeneration Certification Scheme (MCS) was introduced. None of the heat pumps included in the trial had been installed under the scheme; however, they were installed and accredited through the Clear Skies programme, the predecessor to the MCS. Phase 1 of the field trial therefore monitored installations of products that were current as of 2008.

As a result of the Phase 1 findings, the MCS installer standards were subsequently revised. The technology, standards, supply chain, and installer knowledge and practice continue to evolve and improve.

83 heat pumps were monitored in the Energy Saving Trust heat pump field trial, distributed across the UK.

Figure 1



Phase 1 findings

The field trial methodology focused on measuring the system efficiency of the monitored heat pumps.

System efficiency is the amount of useful heat the heat pump produces compared with the amount of electricity needed to run the system. Useful heat is deemed as heat delivered for space heating and the heat delivered to the taps as domestic hot water.

The most recent analysis of the Phase 1 dataset was conducted by the Department of Energy and Climate Change (DECC) in March 2012[5]. This report will refer back to such analysis when discussing the Phase 1 findings. The sample size used in this analysis was revised down to 71 due to data quality issues.

The performance values monitored in Phase 1 varied widely (as shown in Table 1). The best performing systems showed that properly designed and installed heat pumps can operate well in the UK, and that the technology has real potential to help the UK meet its carbon reduction targets. It was also apparent that many systems did not perform as well as expected.

System efficiencies of air and ground source heat pumps in Phase 1 Table 1

System efficiency	ASHP	GSHP
Median	1.83	2.31
Range	1.2-2.2	1.55-3.47
Number	22	49

In Phase 1, ground source heat pumps had higher measured system efficiencies than the air source heat pumps. The highest efficiencies reached over 3, as shown in Figure 2.

The measured efficiencies of the air source heat pumps monitored in Phase 1 were lower than those of the ground source heat pumps (as shown in Figure 3).

After discussion with industry and the field trial's advisory group, it was decided that further research should be undertaken to investigate the reasons behind the varied performance measured in Phase 1.

Phase 2 of the field trial was developed to identify such causes of varying performance at a number of sites.

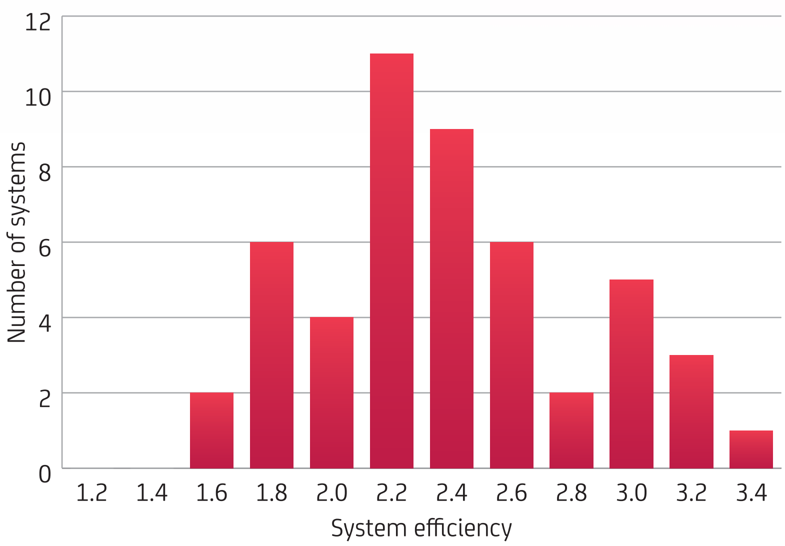
Installer standards improved

The original Phase 1 sites were installed before the Microgeneration Certification Scheme (MCS) was introduced.

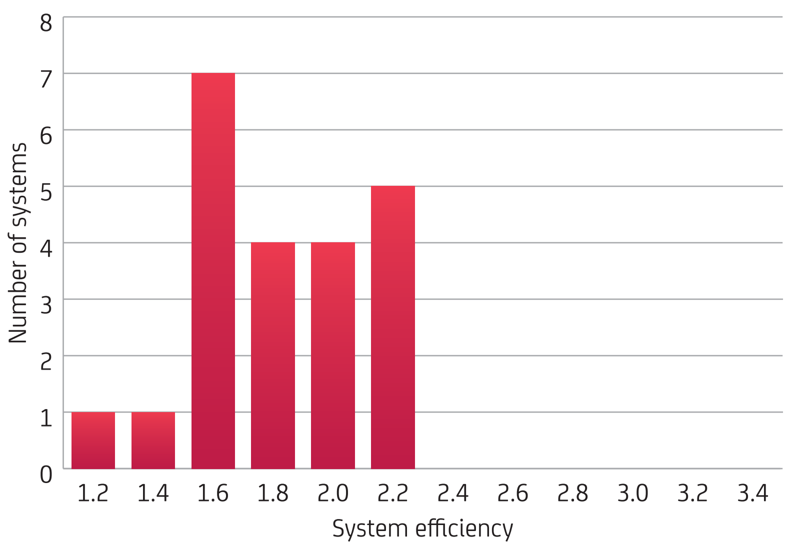
Phase 1 indicated that substandard heat pump design, installation, and commissioning practices can lead to poor performance. Between Phase 1 and Phase 2 MCS standards were revised, through consultation with industry and stakeholders, to improve the quality of future heat pump installations.

5 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48327/5045-heat-pump-field-trials.pdf

Phase 1 system efficiencies of GSHPs Figure 2



Phase 1 system efficiencies of ASHPs Figure 3



The findings from Phase 1 can be summarised as follows:

- Measured system efficiencies were varied for both ground and air source systems.
- Many heat pumps performed very well but a number delivered efficiencies lower than expected.
- Heat pump performance was found to be sensitive to specification, design, installation and commissioning practices. This led to a thorough review of installation and training guidance and the eventual revision of MCS installer standards.
- Householders reported a good level of satisfaction with both the space heating and hot water provided by the heat pumps. There was no significant difference between air source and ground source systems.

Phase 2

The objective of Phase 2 was to build on the lessons learned from Phase 1 and to investigate the reasons that caused the varied measured performances of heat pumps. These reasons included, but were not limited to, system installation and design, control strategies, and customer understanding.

Before the scope of Phase 2 was agreed, the Energy Saving Trust and manufacturers involved discussed the Phase 1 data site by site. The aim was to determine what aspects of the heat pump had influenced each site's performance and how to improve individual systems. A number of interventions that could be undertaken at each site were proposed. Wherever possible, the proposed interventions were designed in accordance with the recent changes to the MCS installer standards. Manufacturers were encouraged to visit their own sites to check on installation quality, confirm the appropriate sizing of the heat pumps and to agree the intervention work.

It was agreed that manufacturers would carry out the interventions at 32 Phase 1 sites, to be followed by a year of monitoring to measure impacts. The majority of sites taken forward from Phase 1 were those that showed the worst measured performance. It was hoped that the interventions undertaken during Phase 2 would enhance operating performance, and that the data collected would show how each site had improved and why. Some well-performing sites were selected for Phase 2 interventions to turn them into 'exemplar case studies'.

The interventions varied in scale and could be classed as major, medium or minor. Six Phase 1 sites that did not receive any intervention were also included in the second phase of monitoring to act as control sites. Six new sites were also included; these were all air source systems.

In broad terms, major interventions required input from a heat pump expert and the specific manufacturer; medium interventions could be carried out by a competent plumber; and minor ones consisted of simple changes or improvements to control regimes overseen by the householder.

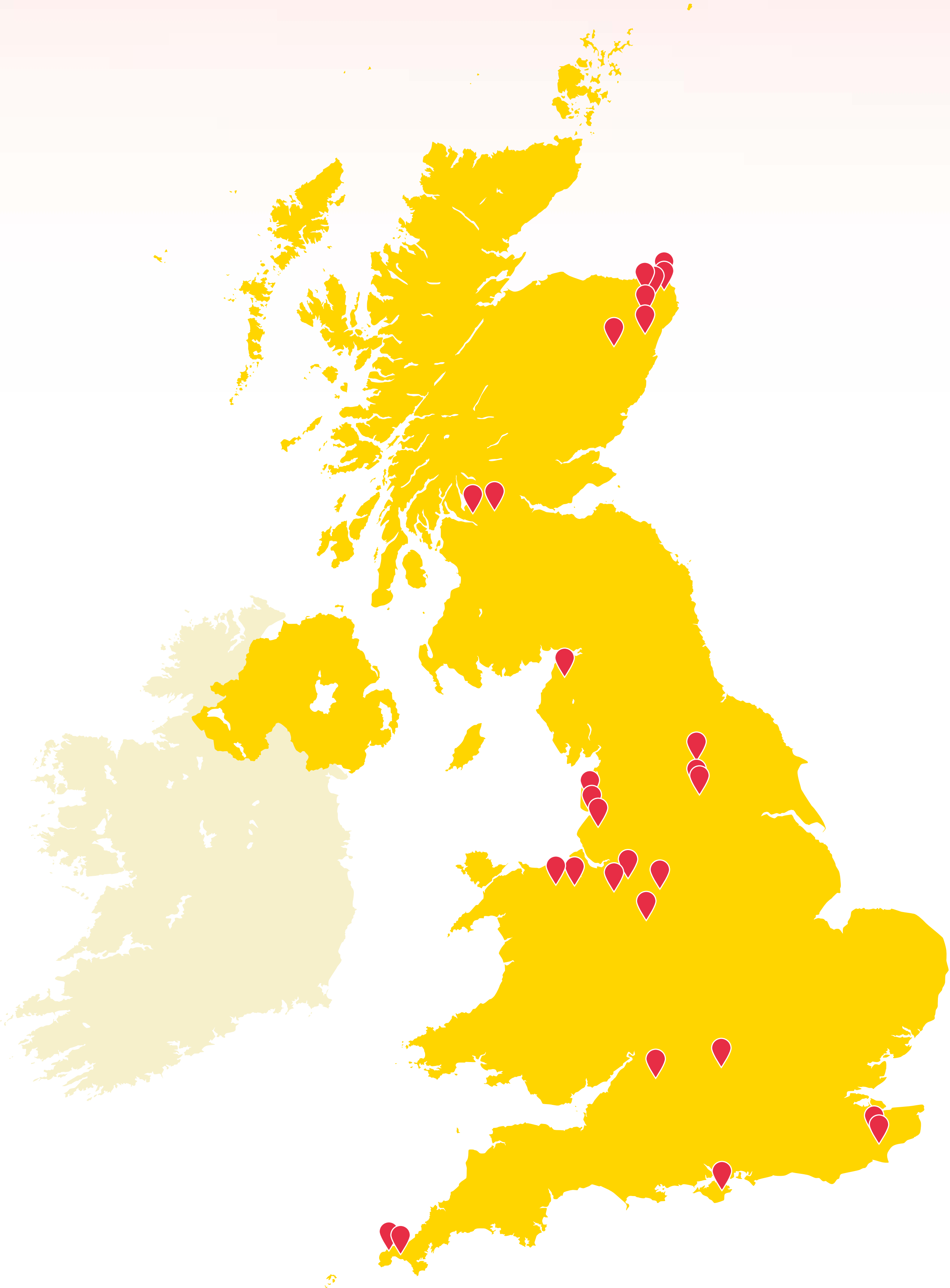
In several cases, the manufacturers, having inspected their own sites, felt that the heat pumps were incorrectly sized for the property. To rectify this, a number of heat pumps were replaced as part of Phase 2 implementing the installation standards at the time. These were classed as major interventions. It was clear that designing and commissioning a heat pump appropriately is key to driving good performance: this was an important area to investigate in Phase 2.

Breakdown of Phase 2 sites Table 2

Classification	Number of sites
Major intervention	12
Medium intervention	9
Minor intervention	11
No change	6
New site	6

44 sites were included in Phase 2 of the field trials

Figure 4



Other interventions and improvements included:

- adding variable speed circulation pumps on the central heating side for better efficiency
- installing low-temperature radiators and heat emitters
- decontaminating ground loops.

These improvements can be made by a competent plumber and not necessarily by a heat pump expert.

A number of small changes were also made, including adding extra insulation to pipes or improving the control strategy. These are generally low-cost improvements and can be performed easily.

When possible, these interventions used the latest MCS installer techniques, although it was not possible to redesign entire systems to the new standard. The performance of heat pumps with interventions undertaken was expected to be higher than the installations from Phase 1. Current heat pumps installed under today's standards are expected to be of an even higher quality.

Further description of the specific interventions undertaken can be found in the key findings section.

Phase 2 monitoring

After the interventions had been completed by the individual manufacturers, the heat pumps were monitored for another year (from spring 2011 to spring 2012).

A number of changes were made to the monitoring systems used to collect the data. The original data collection methodology from Phase 1 was used, but extra sensors were installed at many of the sites to collect more data and allow for a greater number of performance calculations. This enabled the project team to investigate the heat pumps' performance more accurately.

System boundaries

Different components of the heat pump use varying amounts of electricity. Measuring these different uses allows us to calculate heat pump efficiency. There are different methods to calculate efficiency and these depend on what aspects of the heat pump system are included in the 'system boundary'.

A European Commission funded programme, SEPEMO (**SE**asonal **PE**rformance factor and **MO**nitoring for heat pump systems) was undertaken from 2010 to 2012 to define system boundaries and ensure consistent definitions of heat pump performance across Europe. The outcome was four different boundaries and four different calculations of heat pump efficiency. These are referred to as Seasonal Performance Factors (SPF) and they range from SPF_{H1} to SPF_{H4}. The higher the H number the wider the system boundary. This means the boundary includes more of the components that use electricity or produce heat. For the purposes of this report we shall refer to only two of these seasonal performance factors, SPF_{H2} and SPF_{H4}.

Until recently, different programmes in various countries used different definitions of system performance and SPF. In the recent analysis report of the Phase 2 field trial data, the Department of Energy and Climate Change recommends the use of SPF_{H4}. However, other programmes, such as the EU

Renewable Energy Sources (RES) directive that defines energy as 'renewable' in the EU, use the calculation of SPF $_{H2}$[6]. For consistency and clarity this document shall refer to SPF $_{H2}$ and SPF $_{H4}$ when discussing heat pump efficiency.

In Phase 1 it was not possible to calculate these values for the heat pumps monitored because the calculation used to define performance was system efficiency. System efficiency is similar to SPF $_{H4}$ but it only incorporates the heat from the hot water delivered to taps. SPF $_{H4}$ includes the heat produced that is supplied to the hot water tank. If a heat pump provides hot water for the property then the system efficiency will be lower than SPF $_{H4}$ due to heat lost through the hot water tank.

The SEPEMO project began after Phase 1 so it was not possible to use these measurements (SPF $_{H2}$ and SPF $_{H4}$) for the initial field trial, but the calculations were revised for Phase 2 using SEPEMO's recommended definitions.

The Energy Saving Trust believes that using SPF $_{H4}$ is the fairest way to calculate system performance, as it is more consistent with the performance calculations used for other heating products and it does not penalise heat pump installers for customer behaviour. For the purposes of this document, comparisons between Phase 1 and Phase 2 performances will refer to system efficiency, and Phase 2 performances will also be displayed in SPF $_{H2}$ and SPF $_{H4}$. For more information on system boundaries and definitions of performance, please refer to DECC's analysis of the Phase 2 field trial data.

SPF $_{H2}$

In this system boundary, only the electricity used by the heat pump itself and the source fans or pumps is included. The calculation used for SPF $_{H2}$ is:

$$\text{SPF}_{H2} = \frac{\text{Heat delivered for space heating and to domestic hot water tank}}{\textbf{Electricity to...}\ \text{inlet fans/pumps + heat pump}}$$

SPF $_{H4}$

In this system boundary, the electricity supplied to the heat pump, all fans or pumps and electricity delivered to any incorporated auxiliary or immersion heater is included. Auxiliary heaters are used to boost space heating, and immersion heaters are used to provide extra hot water. Electricity used by any other fans or pumps included in the building's heating and hot water system is also included.

The calculation used for SPF $_{H4}$ is the same as for SPF $_{H2}$, but due to the larger system boundary the extra heat produced and electricity used is included.

$$\text{SPF}_{H4} = \frac{\text{Heat supplied by heat pump for space heating and to domestic hot water tank + heat produced by immersion}}{\textbf{Electricity to...}\ \text{inlet fans/pumps + auxiliary + heat pump + immersion + building fans or pumps}}$$

6 Heat pumps need to achieve a SPF $_{H2}$ of at least 2.5 to be deemed renewable under the directive.

Phase 2 findings

The findings of Phase 2 of the Energy Saving Trust's heat pump field trial build upon the conclusions gathered from Phase 1.

The first phase of the trial monitored 83 residential heat pump installations across Great Britain from April 2009 to March 2010. The findings from Phase 2 provide useful insight into the impacts of the interventions undertaken at 32 of the original installations, a control group, and a further six new heat pumps.

The results from the in-situ monitoring illustrate that improvements to operating performance (system efficiency and SPF) were achieved at many sites that had interventions; only a few demonstrated a poorer performance.

The results of interviews show that the majority of customers are highly satisfied with the heat and hot water that their systems provide.

This section provides a discussion of two key areas, including:

- The perceptions of heat pump users
- The technical performance of heat pumps, including:
  - comparison of system efficiency by intervention – Phase 1 and Phase 2
  - Phase 2 performance by SPF_{H2}
  - Phase 2 performance by SPF_{H4}
  - performance of ASHP + GSHPs

The first section illustrates how customers use their heat pumps and discusses the levels of satisfaction achieved amongst participants. The second section illustrates how the interventions, classified by category, affected system performance across the sample. The third and fourth sections present the monitored heat pump performance in terms of two system boundaries: SPF_{H2} and SPF_{H4}.

User perceptions and behaviour

User experiences are important indicators of heat pump performance. As part of Phase 1, the Open University undertook research with the users through a number of online and postal questionnaires to investigate each user's behaviour, perceptions and satisfaction of their heat pump system.

The Energy Saving Trust carried out follow-up interviews with the heat pump users in Phase 2 to understand how the interventions impacted user perception or behaviour. User perceptions were compared with those gathered during Phase 1 of the trial and, in many cases, illustrate improved satisfaction.

The Phase 2 user perceptions were gathered through undertaking in-depth interviews with 35 of the users (80% of Phase 2 sample). The interviews, conducted both face-to-face and by telephone, investigated each user's experience of living with a heat pump, how it had performed and how they controlled their heating and hot water needs.

80% of the Phase 2 users were interviewed about their heat pump, how it performed and how they controlled their heating and hot water needs.

Summary of user perceptions and behaviour

80% of users interviewed were either satisfied or very satisfied with the space heating supplied by their heat pump...

...while the figure for hot water production was 84%. Levels of satisfaction reported in Phase 2 were higher than those from Phase 1.

73% of the users interviewed enjoyed the stable air temperatures their heat pumps produce; those who used secondary heating did so primarily for social reasons.

77% of the users interviewed stated they would recommend a heat pump to a friend, mainly because of the efficiency and running costs of the systems.

All the users of the newly installed air source heat pumps incorporated in Phase 2 reported high satisfaction levels of the heating and hot water produced by their systems.

A number of different control strategies were implemented by the users and the majority were very satisfied with their chosen system. Two-thirds operated their heat pumps continuously, whilst one-third preferred a non-continuous control strategy. Running a system continuously is thought to be the most economical way of controlling a heat pump as it leads to greater overall efficiency.

The results from our interviews indicate that both continuous and non-continuous control strategies can provide good customer satisfaction in comfort and running costs.

Users' knowledge of their systems was varied and the level of knowledge and heat pump performance can be linked. This highlights the need for good upfront research by the user and appropriate handover and support from installers.

A number of users indicated that they would benefit from greater control and more information from their system, particularly referring to their auxiliary heater. Most users understand the impact that auxiliary and immersion use has upon system efficiency, but require greater feedback on when this is occurring.

Technical Performance Monitoring

Investigating the technical performance of a heat pump allows for the efficiency of the system to be calculated.

Overall efficiency determines the running costs and the carbon savings. In this study, technical performance was measured and categorised to allow for comparison of different system types, for example air and ground source heat pumps or by category of intervention.

Heat pump performance by intervention type
The 38 heat pumps involved in both Phase 1 and Phase 2 were classified into the following categories:

- major intervention
- medium intervention
- minor intervention
- no change

Examples of the interventions undertaken at these sites are presented in Table 3, opposite.

Figure 5 illustrates Phase 2 performance (system efficiency) compared with the measured performance in Phase 1 categorised by intervention type. The data have been corrected to account for the different external temperatures during the two phases. Each bar represents one site, indicating its change in performance compared with Phase 1. Each red square above the bar illustrates the achieved Phase 2 system efficiency for the corresponding site. The figure illustrates that a vast majority of such sites improved during Phase 2.

Twelve sites had major interventions and the majority of such sites achieved a significantly higher system efficiency in Phase 2 compared with Phase 1. This result was expected because a majority of these interventions included a replacement of the heat pump. For example, ten sites had heat pumps replaced with new units (five GSHPs and five ASHPs). In five cases, the replacement heat pumps were sized to a smaller kW rating than the originals, two units were replaced with a larger kW model, and three remained the same the size.

At nine sites ‘medium’ interventions were undertaken. These included simple plumbing improvements (such as the installation of a buffer tank and high efficiency circulation pumps). Sites with medium interventions also achieved significant improvements in performance compared with Phase 1.

The minor interventions showed very little impact on heat pump system efficiency across the sample during the second year of monitoring. This indicates that such interventions, including changes to customer control regimes and annual service checks, caused little impact to system efficiency if they were not combined with a major or medium intervention. This does not mean that minor interventions would always have a small effect; for example, disabling the auxiliary heater could have a large effect for a very poorly controlled site. As expected, the control group showed relatively similar results in Phase 1 and Phase 2.

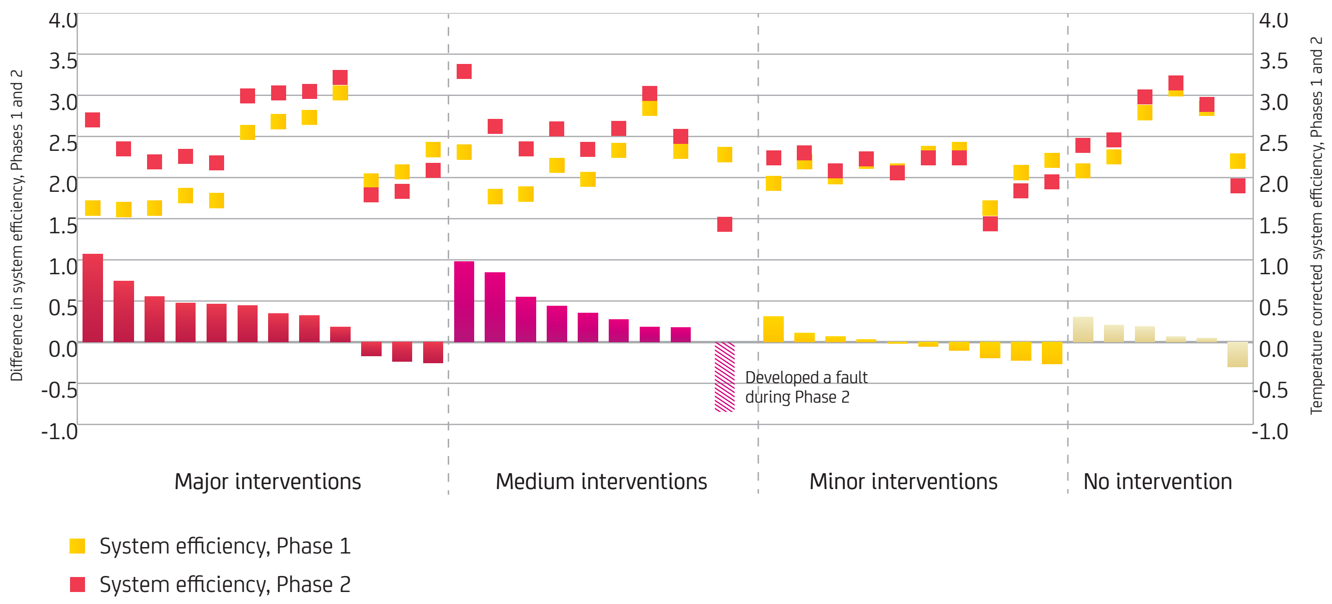
Examples of heat pump interventions

Table 3

Major (12 sites)	Medium (9 sites)	Minor (11 sites)
Replacement with new heat pump	Re-filling ground loop	Changing control pattern
Reduce the area heated by heat pump	Installation of new hot water tank	Adding extra insulation
Repair a leak to the ground loop	Connection of shower to heat pump system	Disabling auxiliary heater
Recharging refrigerant	Installing new radiators	Adding insulation to pipes
	Installing new circulation pumps	

Change in temperature-corrected system efficiency from Phase 1 to Phase 2[7]

Figure 5



7 One site with faulty data from Phase 1 was removed from the minor intervention category

The majority of interventions undertaken in Phase 2 have led to demonstrated improvements in heat pump operating performance. This suggests that knowledge and understanding of the factors that impact heat pump performance has improved throughout the course of the field trial. Improvements at sites with major interventions may indicate that recent improvements to installer standards, including system design and use of auxiliary and immersion heaters may have had a positive impact.

However, some sites did not improve, even with major and medium interventions. The interventions chosen for these sites may not have been the most effective – an alternative may have been better. In some cases the behaviour of the consumer changed between Phase 1 and 2, which led to a worse performance. These changes in behaviour particularly involved reduced hot water consumption and greater electric immersion use.

Even though system efficiency has improved at a majority of sites in Phase 2, the range of performance is still varied. Table 4 illustrates the averages of both system efficiency and SPF_{H2} and SPF_{H4} across the sample for both ASHP and GSHP.

The figures for average system performance differ for each system boundary. SPF_{H2} is higher than SPF_{H4} or system efficiency because it includes electricity consumption from fewer components.

SPF_{H4} is the recommended definition of system performance by DECC. The heat pumps monitored in Phase 2 delivered good SPF_{H4} measurements (for both ground source and air source systems). The average for ASHPs was 2.45; and GSHPs had a higher average of 2.82.

The calculated system efficiencies for the Phase 2 sites are also shown. The difference in measured SPF_{H4} and system efficiency is apparent because of the system boundaries used in the calculations. The reasons for lower system efficiency measurements than SPF_{H4} largely lie in the household's use of hot water produced by the heat pump and the losses of the storage tank. It is not thought that these variables should be included when comparing heat pump performance with other heating technologies.

Figure 6 indicates that the majority of sites included in Phase 2 would be deemed renewable by the EU RES directive. The directive states that a heat pump must achieve a minimum SPF_{H2} performance of 2.5.

Of the 21 ground source heat pumps where SPF_{H2} could be calculated, 20 can be deemed renewable, as well as nine of the 15 air source systems.

Further, five out of the six newly installed air source heat pumps should be deemed renewable. Of all of the sites in the sample, these most closely adhered to the current MCS installer standards. This indicates that air source heat pumps designed and installed in compliance with the current standards should perform to a 'renewable' standard.

Heat pump performance: SPF_{H4}

The distribution of measured SPF_{H4} results is wide for both GSHP and ASHPs. These wide distributions continue from Phase 1. The varying levels of performance measured in Phase 1 and Phase 2 indicate that installer practice and customer behaviour can still impact efficiency.

Phase 2 performance – SPF H2 and SPF H4

Phase 2 performance of heat pumps by system boundary

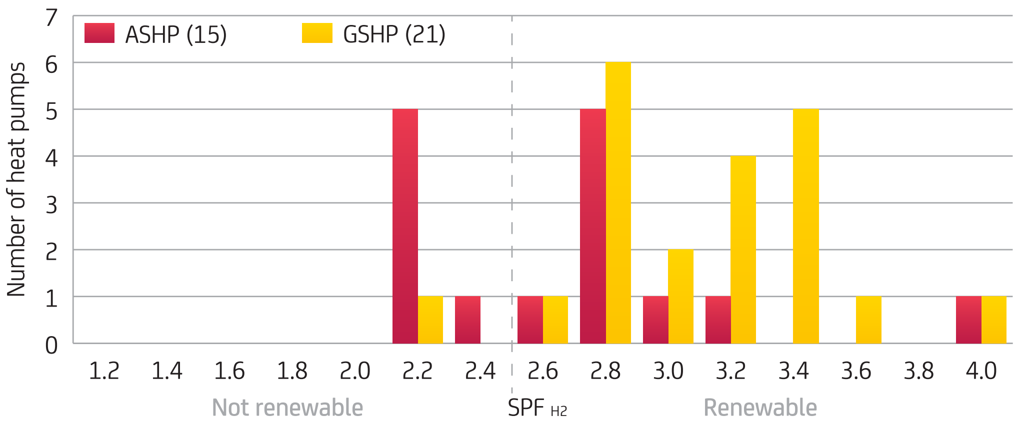
Table 4

		SPF H2	SPF H4	System efficiency
Air Source Heat Pumps	Average	2.68	2.45	2.11
	Number of systems	15	15	17
Ground Source Heat Pumps	Average	3.1	2.82*	2.3
	Number of systems	21	22	27

*One GSHP developed a fault in Phase 2 and had high auxiliary electricity use. This is shown as a shaded point in Figure 5, but is excluded in the SPF H4 and system efficiency columns of Table 4. SPF H2 is not affected by use of the auxiliary electricity and so SPF H4 results from this heat pump are included.

Heat pump performance as SPF H2 showing the number of systems that are deemed renewable

Figure 6



Heat pump performance: SPF_{H4}

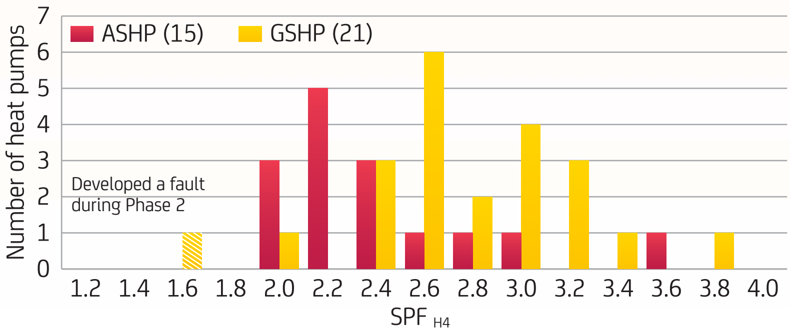
The distribution of measured SPF_{H4} results is wide for both GSHP and ASHPs. These wide distributions continue from Phase 1. The varying levels of performance measured in Phase 1 and Phase 2 indicate that installer practice and customer behaviour can still impact efficiency.

When the performance is calculated using the SPF_{H4} system boundary (Figure 7), measured performance figures are lower than for SPF_{H2}. This is because the boundary includes more variables and electricity consumption. This boundary includes the heat produced and electricity used by auxiliary and immersion heaters and electricity used by additional fans and pumps.

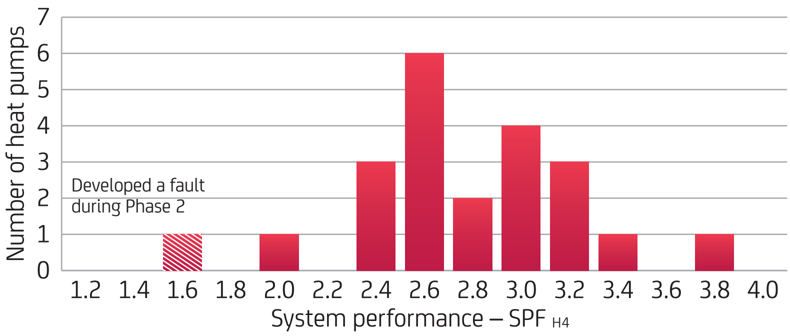
Ground source heat pumps have largely produced good performance in the second phase of monitoring. A number of systems have performed to a SPF_{H4} of over 3; only two GSHPs recorded results of less than 2.4. The highest performing site recorded 3.89; this site supplied underfloor heating and domestic hot water.

Air source systems also performed well. No system recorded an SPF_{H4} lower than 2. The distribution of ASHPs was lower than GSHPs. Two air source systems achieved results of 3 or higher. The best performing site reached a SPF_{H4} of 3.6; this heat pump supplied underfloor heating.

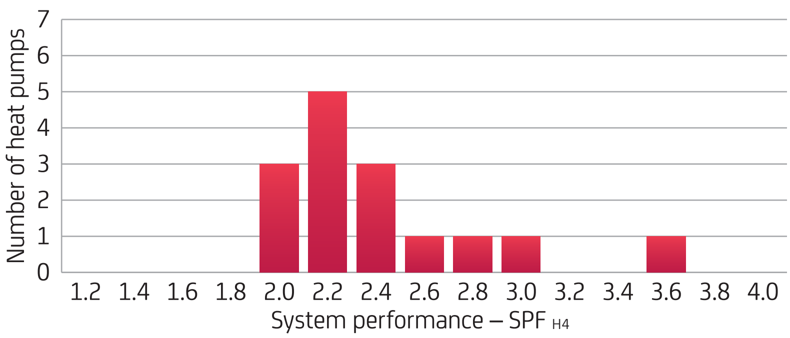
Phase 2 performance as SPF_{H4} Figure 7



Phase 2 SPF_{H4} performance of GSHPs Figure 8



Phase 2 SPF_{H4} performance of ASHPs Figure 9



Summary of technical performance monitoring

2.82
GSHP average SPF $_{H4}$
The range of measured SPF $_{H4}$ was 1.6 to 3.8.

2.45
ASHP average SPF $_{H4}$
The range of measured SPF $_{H4}$ was 2.0 to 3.6.

20/32 heat pumps undergoing interventions between Phase 1 and 2 achieved improvements in performance.

The remainder achieved similar or slightly lower performance. These improvements to performance were due to a range of technical and behavioural interventions at the sites.

36 cases were able to have their performance estimated as SPF $_{H2}$.

20/21 GSHPs and 9/15 ASHPs achieved SPF $_{H2}$ figures of 2.5 or greater. These installations would be classified as renewable under the EU Renewable Energy Sources Directive definition.

5/6 Newly-installed air source systems could be classified as renewable. This is important so customers know they are purchasing a classified, renewable energy technology.

As with Phase 1, the design, commission and installation quality was shown to impact performance. The heat pumps that experienced major interventions, in accordance with more up-to-date installer standards, achieved improved performance. This indicates that improvements to installer standards through the MCS have helped to achieve consistent and high-quality heat pump installations.

Conclusion

The Energy Saving Trust's heat pump field trial, which ran in two phases between 2008 and 2013, provides useful insight into the in-situ performance of the technology when installed in UK homes.

Phase 1 illustrated that many of the monitored heat pumps did not perform as well as anticipated. Through the results presented in this report, Phase 2 indicates that a number of interventions, including applying updated installation methods, can improve the performance of both ground and air source systems. This supports the theory that improvements in heat pump installation practices, following the introduction and improvements of MCS installer guidelines, should lead to better in-situ performance.

The largest improvements were measured in sites that had 'major' and 'medium' interventions, including redesigns of heat pump installations. Minor interventions, including changes to control regimes and annual service checks, had minimal (but still positive) impacts on monitored system performance. This suggests that heat pump performance has the potential to improve as the UK market continues to evolve and adopt more rigorous installer standards.

Improvements in the technical performance of heat pumps have been mirrored in the satisfaction displayed by customers. The majority of customers are pleased with the heating and hot water delivered by their systems and many would recommend their heat pumps to a friend.

It should be noted that none of the sites included in this trial were fully installed under the current MCS installer standards. It is expected that utilising the current practices would lead to even better technical performance and customer satisfaction.

Summary of conclusions

Heat pumps can provide an efficient alternative for householders.

The technical data obtained and the users' feedback indicates that well installed and operated heat pumps can perform to a very high standard in UK homes.

Heat pumps are sensitive to design and commissioning, but standards have improved.

The field trial provides early indications that the reasons for underperformance are understood and have been addressed by the new MCS installer standards.

Customers provide positive feedback but require more information.

The majority of customers were satisfied with the heating and hot water provided by their systems, but there were varying levels of understanding. Initial interaction with the supply chain is important in developing customer understanding of the system.

Different aspects of a heat pump system impact performance.

Based upon a number of performance calculations, different aspects of the heat pump system can impact efficiency. Customers may benefit from feedback about which parts of the system impact operating efficiency, particularly auxiliary and immersion heaters.

Various control strategies can result in a high performing heat pump.

Customers utilise different measures of control to meet heating and hot water needs. The majority of systems were run continuously using weather compensation and internal thermostats. A number of well-performing systems were controlled non-continuously and delivered high levels of customer satisfaction.

The differences in measured performance suggest that behaviour impacts heat pump systems.

A broader system boundary, which incorporates auxiliary and immersion heaters and pumps, etc., enables the impacts of control and use to be calculated. SPF_{H4} appears to be the most relevant method to calculate performance as it is less sensitive to end-user hot water usage patterns than system efficiency.

Advice for consumers

Consumers who are considering purchasing a heat pump need assurance that the system will deliver the promised benefits. The Energy Saving Trust has developed the following guidance which is based on findings from this field study and the latest information from UK Government support schemes.

How do heat pumps perform in UK homes?
The evidence obtained through this study indicates that correctly installed and operated heat pumps can perform to a very high standard in UK homes. Our methodology focused on measuring the efficiency of the monitored heat pumps by calculating Seasonal Performance Factor (SPF). This is simply defined as the amount of heat the heat pump produces compared with the amount of electricity needed to run the system (including auxiliary, immersion heaters and circulation pumps). The average SPF for an air source heat pump was found to be 2.45. For ground source heat pumps it was found to be 2.82. Heat pumps are much more efficient than direct electric heating.

What are the key factors affecting performance?
Different parts of the heat pump system can impact efficiency, and thus performance. Most specifically, use of auxiliary and immersion heaters can have an adverse effect on SPF. End-users interviewed as part of the study stated that they would like greater feedback about how to maximise efficiency of these auxiliary systems. Crucially, heat pumps are sensitive to design and commissioning, but standards from the MCS have improved. Recently, the largest improvements to standards have focused on appropriate heat pump sizing, design of ground loops, and selection of radiators. It is important to note that the SPFs measured in these trials were from heat pump systems which were installed before the most up-to-date MCS standards were applied.

The performance of a system also depends upon the user's understanding of the system and its controls. The trial indicated that the users who best understood their system achieved the greatest performance. Consumers are advised to discuss their system and how to use it with their MCS installer.

How much can be saved with a heat pump?
Heat pumps have the potential to reduce running costs compared with oil, direct electric, LPG, or solid fuel, and can provide substantial carbon savings over their lifetime. Depending on the fuel displaced, an air source heat pump could save between £150 (replacing oil) and £530 (replacing electric economy 7 storage heating) per year with 1,400 – 5,700 kgCO_2 saved per year respectively. A ground source heat pump could save between £300 (oil) and £685 (electric) per year with 1,900 – 6,300 kgCO_2 saved per year respectively. These figures are based upon an average performing heat pump (2.45 ASHP and 2.82 GSHP – based on trial SPF_{H4} data) installed in a well-insulated, detached home[8].

8 Savings assume an oil price of 6.02 p/kWh and that the home has an oil boiler with an average efficiency. Electricity prices are 9.08 p/kWh off peak and 15.32 p/kWh standard rate.

What is the UK Government's Renewable Heat Incentive (RHI)? Are heat pumps eligible?

The domestic RHI is a financial support scheme for renewable heat, targeted at, but not limited to, off-gas grid households. The support will be paid at a set rate per unit of renewable heat produced (kilowatt hour or kWh), for seven years, to the owner of the heating system. The scheme will support air source heat pumps, ground source heat pumps, biomass systems and solar thermal technologies. The support rates vary depending on the technology installed:

	ASHP	Biomass	GSHP	Solar Thermal
Tariff (p/kWh renewable heat)	7.3	12.2	18.8	19.2

The scheme will cover single domestic dwellings and will be open to owner-occupiers, private landlords, social landlords, third party owners of heating systems and self-builders. It will not be open to new build properties other than self-build. In addition, the scheme will be open to anyone in these groups who installed an eligible technology since 15 July 2009, provided they meet the eligibility criteria of the scheme. Any previous public funding (e.g. RHPP) will be deducted from the RHI payments.

The renewable heat generated will be estimated in most cases. For heat pumps, it will be based on an estimated figure of heat demand from an Energy Performance Certificate. This will be combined with an estimate of the heat pump's efficiency to determine the renewable proportion of the heat. Those applying for a space heating system who have a back-up heating system, such as an oil boiler, or people applying for a second home, will need to install a heat meter on which the RHI payments can be based.

There will be an extra incentive for applicants who install metering and monitoring service packages that meet the scheme's requirements; this will be £230 per year for heat pumps. Packages will be available on a first come, first served basis to 2,500 applicants in the first year of the scheme, across biomass and heat pump systems. An installer will fit an advanced set of meters to the new heating system so that the householder and installer will be able to view measured data from their system over the internet.

This measure has been introduced to provide end users (and installers) with assurance that each installation is working as expected; to enable the installer to continually improve performance where possible; and also to diagnose common problems.

The tariff paid will not be affected by the measured efficiency – householders will still be paid on deemed renewable heat regardless of the performance of their heat pump.

The Government intends that the scheme will open for applications in spring 2014. Guidance will be available before launch on how to apply and the information that will need to be provided.

All applicants will be required to complete a Green Deal Assessment before applying and to ensure they meet minimum energy efficiency requirements of loft and cavity insulation where required. This is because heat pumps perform better in insulated buildings, so there will be lower heat demand and as a result the system will be more efficient.

Are heat pumps part of the UK Government's Green Deal?
Both ground and air source heat pumps are eligible measures under the Green Deal. If seeking Green Deal finance householders should be aware that, as the finance borrowed under the Green Deal must be equal to or less than the savings made over the lifetime of the technology (known as "the Golden Rule"), it is unlikely that full funding for the heat pump will be available. Instead, it is likely that only partial Green Deal finance may be available. Therefore you may be able to get a proportion of the capital cost covered by the Green Deal.

A Green Deal Assessment is also required to access both the Renewable Heat Incentive and the Green Deal (although for the RHI, not all "recommended measures" need to be installed before receipt of the tariff). The Green Deal Assessment would identify the potential financial and carbon savings that a heat pump may bring. Following the Assessment, householders can request a Green Deal Plan which would detail the financial arrangements for any money borrowed under the Green Deal. Additional funding may also be available through the Energy Company Obligation (ECO) for low income and vulnerable households. For more information about the Green Deal, please telephone the Energy Saving Advice Service on: **0300 123 1234**. In Scotland, phone Home Energy Scotland on: **0808 808 2282**.

What to expect from a heat pump installer.
Householders should check that the installer is a member of the two industry led and government approved schemes: the Microgeneration Certification Scheme (MCS) and Renewable Energy Consumer Code (RECC). The MCS scheme will cover any technical related issues while the REAL Assurance Scheme (which manages RECC) covers all contractual related disputes, including deposit protection and workmanship guarantees. Installers should:

- Be MCS certified and comply with the latest standards
- Visit in person and complete a technical survey before quotation.
- Explain how the heat demand of the property was calculated.
- Explain how the system will be installed and if there will be any disruption to the property.
- Explain the efficiency of the installation based upon the star rating
- Supply clear, easy to understand and detailed information and advice on how best to use the system and operating instructions.
- Provide clear, easy to understand information on product and workmanship warranties including information on insurance backed schemes.
- Provide a full breakdown of costs in their quote and include the terms and conditions.
- Not ask for more than a 25% deposit. Householders have the right to cancel the contract within seven days with no penalty.

Further advice and information

Energy Saving Trust
energysavingtrust.org.uk

Microgeneration Certification Scheme
microgenerationcertification.org

Renewable Energy Consumer Code
recc.org.uk

The Heat Pump Association
heatpumps.org.uk

Ground Source Heat Pump Association
gshp.org.uk

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21 Dartmouth Street
London, SW1H 9BP

energysavingtrust.org.uk