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Evidence gathering – Low Carbon Heating Technologies

Domestic High Temperature Heat Pumps

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Prepared for DECC by:

The Carbon Trust and Rawlings Support Services

The views expressed in this report are those of the authors, and do not necessarily reflect those of the Department of Energy and Climate Change. This report was commissioned to inform DECC's evidence base for future policy development.

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Acronyms

CCC	Committee on climate change
COP	Coefficient of performance
DECC	Department of energy and climate change
DHW	Domestic hot water
DNO	Distribution network operator
ErP	Energy related products (Ecodesign)
EVI	Enhanced vapour injection
GWP	Global warming potential
HARP	Home-heating appliance register of performance
LPG	Liquefied petroleum gas
MCS	Microgeneration certification scheme
NCV	Net calorific value
SAP	Standard assessment procedure
SCOP	Seasonal coefficient of performance
SEER	Seasonal energy efficiency
SPER	Seasonal primary energy ratio
SPF	Seasonal performance factor
SSCEE	Seasonal space cooling energy efficiency
SSHEE	Seasonal space heating energy efficiency
VDI	Verein Deutscher Ingenieure
VHTHPs	Very high temperature heat pumps

Contents

1. Executive summary

Introduction

Most low carbon pathways suggest that heat pumps will play a large role in decarbonising the UK economy. The Committee on Climate Change (CCC) have suggested that the overall cost-effective uptake of heat pumps in UK homes could reach 2.3 million by 2030[1].

This study was undertaken by the Carbon Trust for the Department of Energy and Climate Change (DECC) to inform their evidence base on domestic high temperature heat pumps. The purpose is to help explore the role high temperature heat pumps may play in the market and inform future UK policy intervention relating to low carbon heating technologies.

This study was conducted from September 2015 to December 2015 using desk-based research, interviews with experts and stakeholders, and a stakeholder workshop. Experts from 41 organisations were interviewed across both the demand and supply side.

The Technology

For the purpose of this study, high temperature heat pumps are considered to be products capable of producing an output temperature of at least 65°C[2]. We have focussed on air and ground source heat pumps with a capacity of less than 45kW capacity.

There are a number of heat pump designs capable of achieving high temperature outputs, including:

- Products with optimised design for specific refrigerants.
- Cascade systems with two separate refrigeration cycles.
- Enhanced Vapour Injection (EVI).

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[1] Sectoral scenarios for the Fifth Carbon Budget, Technical report, *Committee on Climate Change, 2015*

[2] In the heat pump performance standard, BS EN 14511:2013, an output temperature of 55°C would be defined as 'high temperature' and 65°C would be defined as 'very high temperature'. However, in the next revision it is expected that 'high temperature' will be re-defined as an output temperature of 65°C.

- Use of natural refrigerants and sorption products.

Whilst these products have been specifically designed for high temperature operation, the designs of “conventional” heat pumps are increasingly being improved to reach 60-65°C at reasonable efficiency.

Current State of Market and Future Market Potential

High temperature heat pumps are suitable for retrofit to existing properties as they can be used with existing, high temperature distribution systems (e.g. existing radiators) and are also capable of meeting hot water demand. However, as the performance of heat pumps reduces with increasing output temperature, most suppliers will first try to specify systems that can run at lower temperatures for increased efficiency (even where that requires some heat emitters to be upgraded).

The current market is niche, and estimated annual sales are approximately 2% of total heat pump sales, numbering a few hundred units per year. Interviews with manufacturers, distributors and installers indicated that the products are typically specified to heat large, old, or listed properties, often off the gas grid (where the cost required to connect to the gas grid makes these heat pumps more cost competitive), and also with high domestic hot water demand. High temperature heat pumps are expected to remain a niche product in the short term.

We have identified a wide range of manufacturers offering products designed and marketed as high temperature heat pumps. Over 80 products were identified that are available in the UK market, from 12 manufacturers.

Costs and Performance

The price of high temperature heat pumps ranges from 20% to 35% more than standard heat pumps, but the price premium based on fully installed costs is closer to 10-20%. The product price for high temperature heat pumps ranges from £3,000 - £7,000 (air source), with the fully installed price ranging from £6,000 to £14,000.This compares with a typical gas fired boiler replacement cost of £2,500.

Overall, stakeholders indicated that 30-40% energy cost savings could be achieved compared to an oil fired boiler (at 2014/15 prices), although these may have reduced with recent significant reductions in oil price. Small cost savings are possible relative to a gas fired boiler, but these would be unlikely to give an economic payback period at current energy prices in the absence of incentives.

High temperature heat pumps are well covered by existing heat pump standards and regulations for performance and design.

COPs[3] from 2.2 to 3.1 were quoted at A7/W65 (ambient air source at 7°C and water output at 65°C) for the air source products studied. Few products quote a Seasonal

[3] Coefficient of performance (COP) is a measure of steady state performance of a heat pump at specific source and sink temperatures.

Space Heating Energy Efficiency (SSHEE)[4] at 65°C water output temperature, but air source SSHEEs at 55°C vary from 102% to 135%. Ground source SSHEEs at 55°C have been found as high as 173%. SSHEE 55°C values for high temperature products are comparable with those of standard heat pumps.

Information gathered from a number of trials has shown that high temperature heat pumps generally perform satisfactorily, however particular care is needed with design and controls. It is hard to draw quantitative conclusions on the relationship between lab and in-use performance, due to the limited availability of trial data.

Barriers and Drivers for Deployment

A number of barriers exist to large scale uptake of heat pumps, however high temperature heat pump technology can help to mitigate some of the traditional barriers. As high temperature heat pumps can provide the high temperature space heating outputs that customers expect, and supply domestic hot water, they could help overcome the consumer inertia which favours conventional gas boilers. High temperature heat pumps can avoid the need to upgrade domestic heat distribution systems, including radiators and hot water tanks, reducing the cost and disruption of installing heat pump technology.

However they have some additional barriers to overcome compared to standard heat pumps, such as high upfront cost, and lower awareness. They are new to the market and there is a lack of trial information, so the cost benefits and performance are unproven.

High temperature products also suffer from other commonly quoted barriers to heat pumps, such as concerns over performance of earlier heat pump installations, and the need for additional space.

Gap Analysis

In general, confidence in the information collected is good. Stakeholders have been willing to share information across the full range of topics considered, and this information has been cross-checked against previous studies with good consistency across different sources.

As these technologies are new to market, although there is good published performance information based on standard conditions, in-situ verified results are limited. Further trials and modelling would be helpful to more accurately determine the potential cost and carbon savings across the range of different property types in the UK. This information may also help to stimulate demand by convincing the demand side about real-world performance.

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[4] The seasonal space heating energy efficiency (SSHEE) is a measure of performance averaged across a defined load profile, which is designed to represent real life use. It is defined in Commission regulation (EU) No 813/2013.

Conclusions

High temperature heat pumps offer some advantages over standard heat pumps, but it is not clear that these advantages are sufficient to overcome barriers that prevent wider uptake of standard heat pumps.

It is difficult to achieve high COPs at high temperatures, so where possible installers prefer to specify systems with lower heating temperatures (even where that means upgrading one or more radiators). Standard heat pumps are increasingly able to achieve 60-65°C more efficiently than previously.

High temperature heat pumps may remain a niche market in the short term. Their target market tends to be large, old, or listed properties (i.e. with high heat loss), often off the gas grid and with high domestic hot water demand.

2. Introduction and Context

This study for the Department of Energy and Climate Change (DECC) serves to inform their evidence base on Domestic High Temperature Heat Pumps, to help inform potential future UK policy intervention relating to low carbon heating technologies. It has been carried out by the Carbon Trust, who have consulted widely with demand and supply side stakeholders.

Specifically, this report seeks to:

- Give an overview of the current state of the art
- Review the current UK market and future market potential
- Review relevant technical standards
- Gather information on system performance (rated and in-use)
- Gather evidence on current costs and the potential for future cost reduction
- Discuss the barriers to deployment
- Identify where major gaps in evidence currently exist and measures to fill these gaps

The above topics form Chapters 4 to 10 of this report.

Scope

Geographical scope

The focus of this report is on products that are already available in the UK market. In our literature review we examined sources from across the world to inform our research approach, particularly uptake in the European market.

Technology scope

The technology category addressed by this project is high temperature heat pumps designed for domestic use.

A heat pump is a device that can transfer heat from a low temperature source, such as ambient air, water, the ground or waste heat, and raise it to a higher useful temperature.

Domestic high temperature heat pumps

In the heat pump performance standard, BS EN 14511:2013 an output temperature of 55°C would be defined as ‘high temperature’ and 65°C would be defined as 'very high temperature'. However, in the next revision it is expected that ‘high temperature’ will be re-defined as an output temperature of 65°C. Within the relevant Eco-design regulations (see section 6) high temperature heat pumps are not specifically defined, however medium temperature is defined with a water output temperature of 55°C.

Therefore for the purposes of this study, we have focussed on air and ground source heat pumps with a capacity of less than 45kW capacity that are **capable of producing output temperatures of 65°C**. These are referred to throughout this report as high temperature heat pumps.

Efficient, high temperature heat pumps are mostly marketed for domestic applications, and are capable of being used with existing high temperature distribution systems (e.g. existing radiators), and therefore could provide a viable alternative to boilers in the retrofit market.

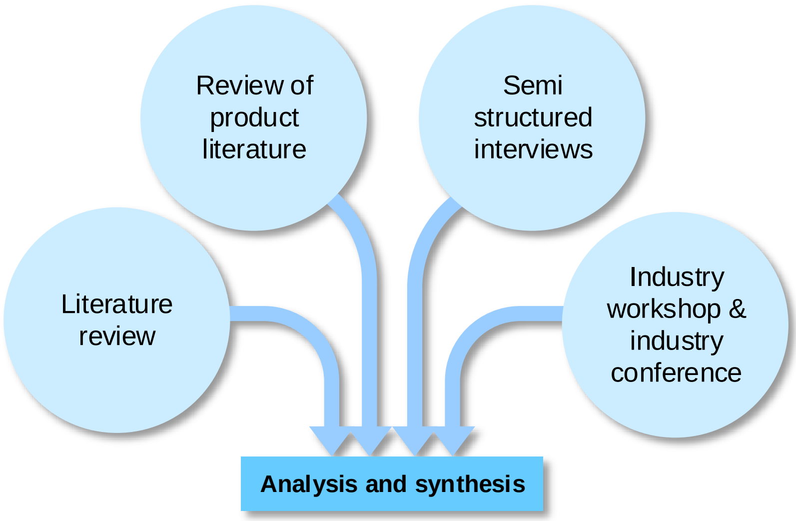
Standard air to water and ground source brine to water heat pumps operate at much lower temperatures than gas or oil boilers, and therefore installation of heat pumps can require significant modifications to the heat distribution system (pipework, radiators etc.). High temperature heat pumps can negate some or all of the need for this, reducing disruption and installation costs.

3. Methodology

Research and Analysis

Our approach to this study was to divide the work into four activity streams. We began with a desk-based literature review to gather insights from published material. We also undertook an in-depth study of supplier product information (sales material and technical data). We then spoke to key stakeholders in a series of semi structured interviews. This was followed up with an industry workshop to present the initial findings and seek feedback. Using these different sources of information allowed the project team to triangulate the findings and strengthen the confidence in the resulting project findings. Figure 1 summarises the research process.

Figure 1 Summary of the research process



The four activity streams were used to inform the main study areas defined by DECC which can broadly be summarised as:

- State of the art
- Market potential
- Technical standards
- System performance
- Costs
- Barriers
- Gap analysis

Figure 2 summarises the activities employed in the research stages and which key study areas they informed.

Figure 2 An outline of the key activities and focus areas for each research method

	Desk based research	Review of product literature	Semi structured interviews	Industry workshop
Activities	• Extract publicly available information • Review academic research • Access current and applicable standards • Source field trial information	• Access manufacturer's websites and catalogues and Ecodesign information	• Talk to key stakeholders from the supply side, demand side and other stakeholders	• Present interim findings to key stakeholders • Encourage discussion between manufacturers and end users
Key study areas	• Technical standards • Barriers • Technology	• Technology • System performance • State of the art	• Barriers • Costs and market • System performance	• Market potential • Barriers • Gap analysis

Evidence gathering process

Literature review

We reviewed over 150 documents relating to both high temperature heat pumps and general heat pump technology. These provided information on the technology variants, claimed performance, market information and standards. The amount of information specifically relating to high temperature products was limited, but we have extrapolated from general heat pump information where appropriate.

Product review

We also collated product information and performance data from supplier sales brochures, technical and installation brochures, and technical data sheets. These were obtained from manufacturer and supplier websites, and from direct contact with suppliers.

During the course of the project the deadline for manufacturers to publish technical performance information under the Ecodesign (ErP) regulations passed. We therefore hoped to be able to obtain standardised manufacturer SSHEE (see section 7) data from manufacturer websites. However, this information was difficult to locate, and often not immediately accessible through the websites. In many cases it was necessary to identify and speak to relevant people within the organisation to find the information.

Semi-structured interviews

The Carbon Trust interviewed 41 key stakeholders for this study. In the interviews we critiqued our findings from the literature reviews and collected commercial information (e.g. product costs, sales), and data on in-use performance. We also discussed the current status of the market and potential for high temperature heat pumps.

The interviews were structured to examine each of the key study areas. Figure 3 shows an outline topic guide for the demand side and supply side interviews.

Figure 3 Example of interview structure according to the stakeholder's experience with the technology.

Supply side (e.g. manufacturers; installers)	Demand side (e.g. housing developers)
Products on sale and in the pipeline	Discussion of experience with heat pumps in general
Lab and in situ performance	In situ performance
Installation process	Installation process
Product maintenance schedules	Product maintenance schedules
Costs	Costs, running costs and payback periods
Market structure and demand	Barriers
Innovation and R&D	Discussion of specific experience with the technologies
Barriers	

We interviewed a wide range of stakeholders including: manufacturers, installers, trade associations, utilities companies and housing associations (see Figure 4).

Our sampling was structured, using existing Carbon Trust contacts and establishing contacts with manufacturers that have relevant heat pumps in the UK or international markets. We particularly sought out stakeholders that had supplied, installed or carried out field trials of high temperature heat pumps.

Figure 4 Shows the distribution of 41 interviews carried out

		Interviewees
Supply side	Installers Manufacturers Distributors	15
Other stakeholders	Test houses & standards bodies Utility companies Researchers/academics	10
Demand side	Local authorities Housing associations Housing developers	16
	Total	41

Stakeholder workshop

At the workshop we brought together supply and demand side stakeholders from across the heat pump sector to present our interim findings and sought to capture their feedback. The workshop was attended by 14 stakeholders.

As stakeholders were aware that the final outputs from this study could inform future policy there was a risk of gaming and bias from the participating stakeholders. To mitigate this, all figures provided have been sense checked, and compared with published information e.g. market studies, performance data, price lists etc. We sought opinions from a wide variety of stakeholders to ensure triangulation of the feedback.

4. Current State of the Art

Whilst domestic heat pumps can now provide hot water at 80°C, approaching hot water boiler temperatures, they are not commonly operated at these temperatures for domestic heating.

- **High temperature heat pumps are defined here as products that can heat water to 65°C or above. Cascade products can reach temperatures of 80°C.**
- **There are a number of heat pump system designs that are capable of achieving high output temperatures. Techniques include dual refrigeration cycle cascade products, products with optimised design for specific refrigerants, Enhanced Vapour Injection (EVI), use of natural refrigerants and sorption products.**
- **Whilst these products have been specifically designed for high temperature operation, the designs of "standard" heat pumps are being optimised to reach 60-65°C at reasonable efficiency.**
- **High temperature heat pumps can be used with existing high temperature distribution systems (saving money, and reducing the time for installation, and disruption). They can provide hot water as well as space heating, using a standard hot water cylinder.**

Available Systems & System Diagrams

Within this section we describe the design and operation of high temperature heat pumps, along with their typical configurations and applications, and pros and cons. The principle of heat pump operation is described first, using a standard heat pump to illustrate.

Standard heat pumps

A heat pump transfers heat from a low temperature source such as ambient air, water, the ground or waste heat, and raises it to a higher useful temperature. Most heat pumps use a mechanical vapour compression cycle with the compressor driven by an electric motor. They make use of the fact that:

- When a substance evaporates it absorbs a large amount of energy which is then emitted as it condenses
- The temperature at which a liquid boils increases as the surrounding pressure increases

- The amount of energy required to transfer the heat is relatively small compared to the total energy transferred. Heat pumps can therefore provide an energy efficient, low carbon form of heating

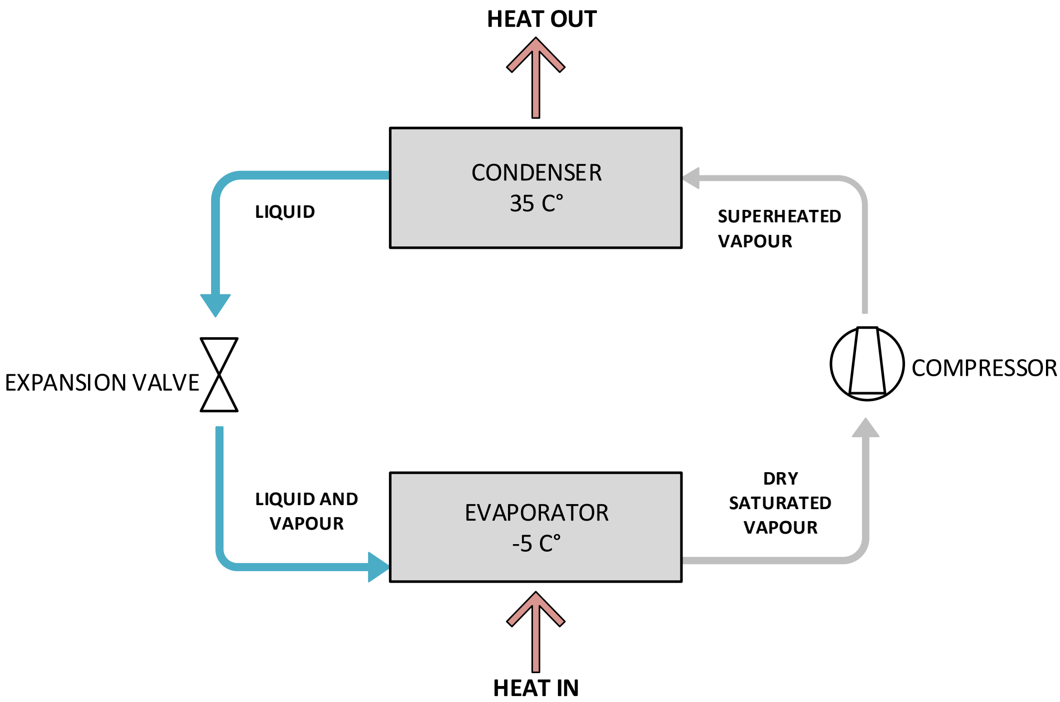
Standard vapour compression heat pumps work by alternately evaporating and condensing a refrigerant. The main components are shown in Figure 5 and include: an evaporator, a compressor, a condenser, an expansion valve and a refrigerant such as R410A. Standard low temperature heat pumps are able to efficiently provide water flow temperatures of up to 55°C.

The performance of a heat pump is limited by the source and output temperatures which respectively need to be as high and as low as possible to minimise the temperature lift the heat pump has to provide. For example, a heat pump system using the ground (which has a higher average temperature than the air in winter) as a source supplying underfloor heating at an output temperature of 35°C, will have a higher efficiency than one using ambient air as the source and supplying radiators at an output temperature of 55°C.

The steady state performance of a heat pump is measured by the coefficient of performance (COP) which is the ratio of the heating capacity to the effective power input of the unit. The COP is measured in terms of delivered electricity. The seasonal space heating energy efficiency (SSHEE) is a measure of performance averaged across a defined load profile, which is designed to represent real life use[5]. SSHEE is measured in primary energy terms (before any conversion or delivery losses, for example electricity generation losses) which allows comparison of different technologies using different energy sources.

[5] As explained in Commission regulation (EU) No 813/2013, accessed November 2015, available here: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0813&from=EN

Figure 5 Standard vapour compression heat pump circuit



High temperature heat pumps

For the purposes of this study, we have focussed on air and ground source heat pumps with a capacity of less than 45kW capacity that are capable of producing output temperatures of 65°C. It should be noted that in the heat pump performance standard, BS EN 14511:2013 an output temperature of 65°C would currently be defined as 'very high temperature'. However in the next revision, and in Ecodesign regulations, it is expected that 'high temperature' will be re-defined as an output temperature of 65°C.

There are a number of heat pump system designs that are capable of achieving high output temperatures, which include:

- Products with optimised design for specific refrigerants
- Cascade systems with two separate refrigeration cycles
- Enhanced Vapour Injection (EVI)
- Sorption

Descriptions of each method, along with indicative system diagrams where appropriate, can be found below.

Product design optimised for specific refrigerants

The most common refrigerants used in heat pumps today are R410A, R134a and R407C. Until recently the maximum output temperature for domestic heat pumps using these refrigerants was about 55°C with R134a achieving slightly higher temperatures, however now temperatures above 60°C can be achieved. By using slightly different temperature and pressure characteristics the refrigerant can be flashed off at a higher temperature, increasing the output temperature, although this can reduce the overall thermal output. The maximum temperature is determined by the critical temperature of the refrigerant (the value above which it cannot form a liquid). As this temperature is approached in the condenser the performance of the vapour compression cycle deteriorates and the refrigerant can start to breakdown chemically.

Modifications to the refrigerant cycle such as EVI or cascading refrigerant cycles can be used to increase the output temperature further up to 80°C with these refrigerants. Carbon dioxide, propane and ammonia are natural refrigerants which have higher critical temperatures and can also be used to reach higher output temperatures up to 80°C. Alternatively, a sorption rather than a vapour compression cycle can be used. These techniques will be described below. Table 1 describes the key characteristics of the main refrigerants currently available.

Table 1 Refrigerants capable of reaching higher temperatures

Refrigerant	Composition	Max Temp. (°C)	Critical Pressure (kPa)	Critical Temp. (°C)	Benefits	Limitations
R407C	23% R32 25% R125 52% R134a	65	4629.8	86.74		Not desirable for higher pressures because cycle efficiency falls and compressor discharge temperature becomes a limiting factor. Refrigerant is being phased out.
R410A	50%/50% R32/R125	72.5	4902.6	72.13	Exhibits higher pressure than R407C resulting in smaller components and less refrigerant charge.	The maximum heating temperature will be limited both by compressor discharge temperature and the relatively low critical temperature of 72.5°C.
R134a	100% R134a	70	4059.3	101.08		Exhibits lower pressures than R407C therefore a 50% larger compressor displacement required for a similar capacity - can make the compressor more costly.
R744	Carbon Dioxide (CO_2)	80	7377.3	31.80	Low global warming potential	A transcritical cycle is necessary. This makes it most suited to domestic hot water (DHW) when heating incoming mains water to a relatively high temperature.
R717	Ammonia (NH_3)	80	11333.0	132.25	No effect on global warming or ozone depletion. It has a high critical temperature and low critical pressure.	Highly toxic and mildly flammable. Used in commercial applications but not domestic except as part of a working pair in absorption heat pumps.
R290	Propane (C_3H_6)	70	4251.12	96.74	No effect on global warming or ozone depletion	Highly flammable. Used elsewhere for small systems installed outside.

Natural refrigerants

Natural refrigerants are not currently in use in domestic heat pumps in the UK. Ammonia is toxic, however is used in sorption heat pumps[6] within sealed systems, which are located outdoors. Propane is only suitable for small heat pumps which have to be sited outside because of the refrigerant's high flammability. Propane based products are available in Europe.

CO_2 is in use in the UK in larger air to water heat pumps for sanitary water heating in commercial premises, and is being considered for domestic heat pumps by some manufacturers. It is used for domestic heat pump water heaters in Asia, and there is a very large market in Japan.

Apart from the use of ammonia in absorption heat pumps these refrigerants will not be considered further in this report.

Cascade systems

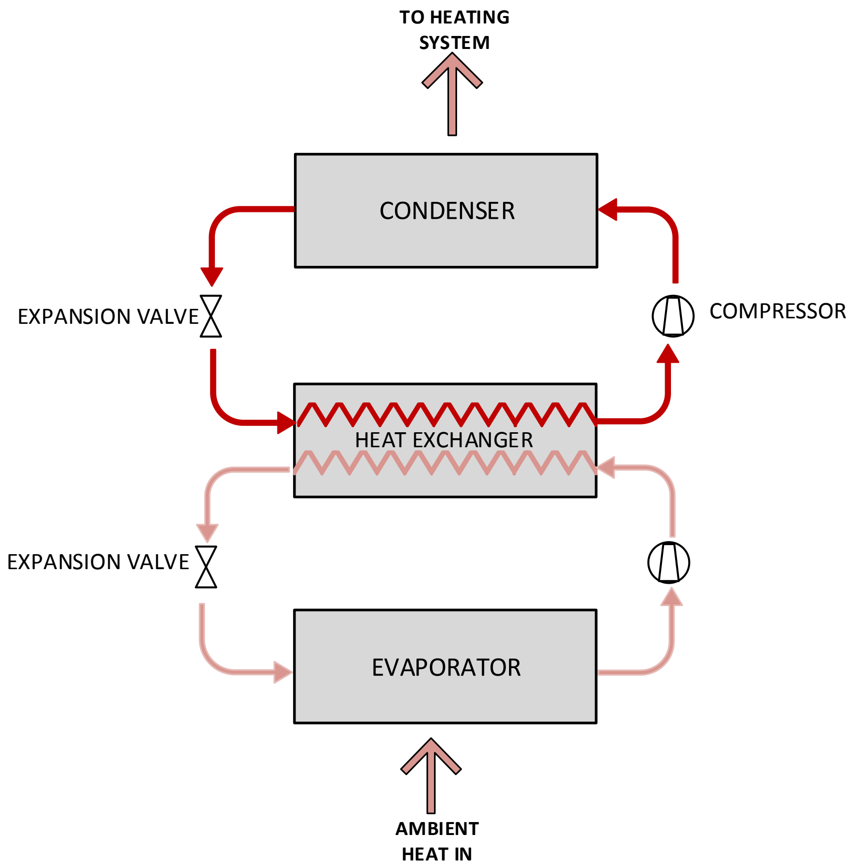
A cascade system consists of two single-stage cycles (a low temperature and a high temperature cycle using different refrigerants) which are thermally connected by an intermediate heat exchanger, as shown in

Figure 6. The low temperature cycle uses the refrigerant R-410a which is able to evaporate at a very low air temperature and condenses in the intermediate heat exchanger at a relatively low pressure and a temperature of about 45°C. This process transfers heat to the evaporator of the high temperature cycle which induces the evaporation of the second refrigerant R-134a. This refrigerant is then able to condense at a pressure that is not too high to affect performance.

Cascade systems are capable of reaching temperatures of up to 80°C. Some systems are able to fluctuate between using both cycles together, and using just a single-stage cycle to optimise performance.

[6] Further details in Evidence gathering – Low Carbon Heating Technologies, Gas driven heat pumps, *DECC, 2016*

Figure 6 Cascade system diagram



Enhanced vapour injection (EVI)

The EVI technique requires an additional loop to be added to the standard heat pump cycle. This loop enables a small proportion of the condensed refrigerant to be extracted and expanded through an expansion valve and into a counter flow heat exchanger which acts as a subcooler. The additional subcooling increases the evaporator capacity. The resulting superheated vapour is then injected into the compressor part way through the compression process as shown in Figure 7. The result is a significant gain in heating capacity due to the increased refrigerant mass flowing through the condenser for the same size of compressor. There is also an increase in power use, but the overall effect is to increase the COP. The cooling provided by the gas injection allows the operation of the compressor over a larger envelope compared to a conventional single stage cycle, providing higher output temperatures at low evaporating temperatures (also shown in Figure 7 and Figure 8).

Figure 7 EVI cycle and the effect on the refrigeration thermodynamics

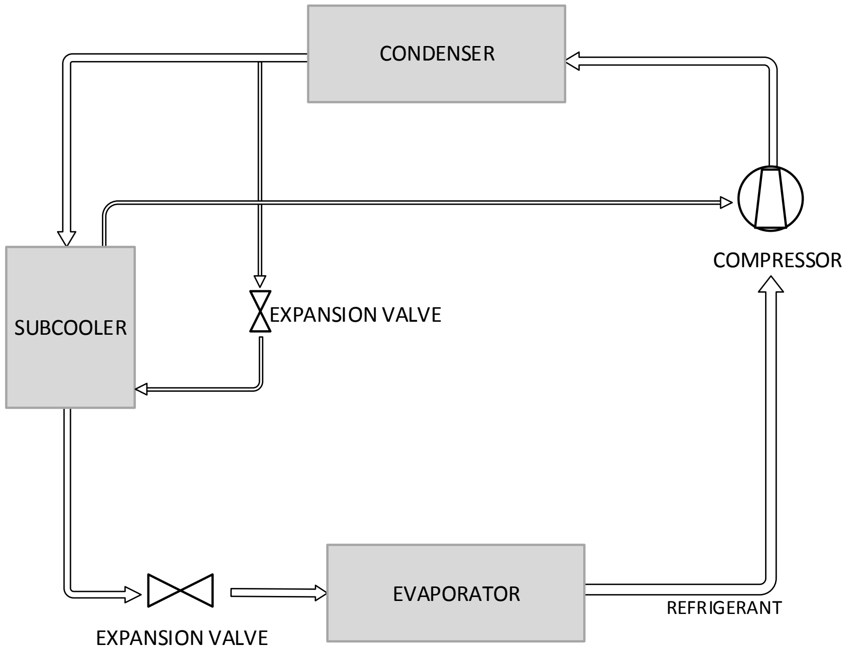
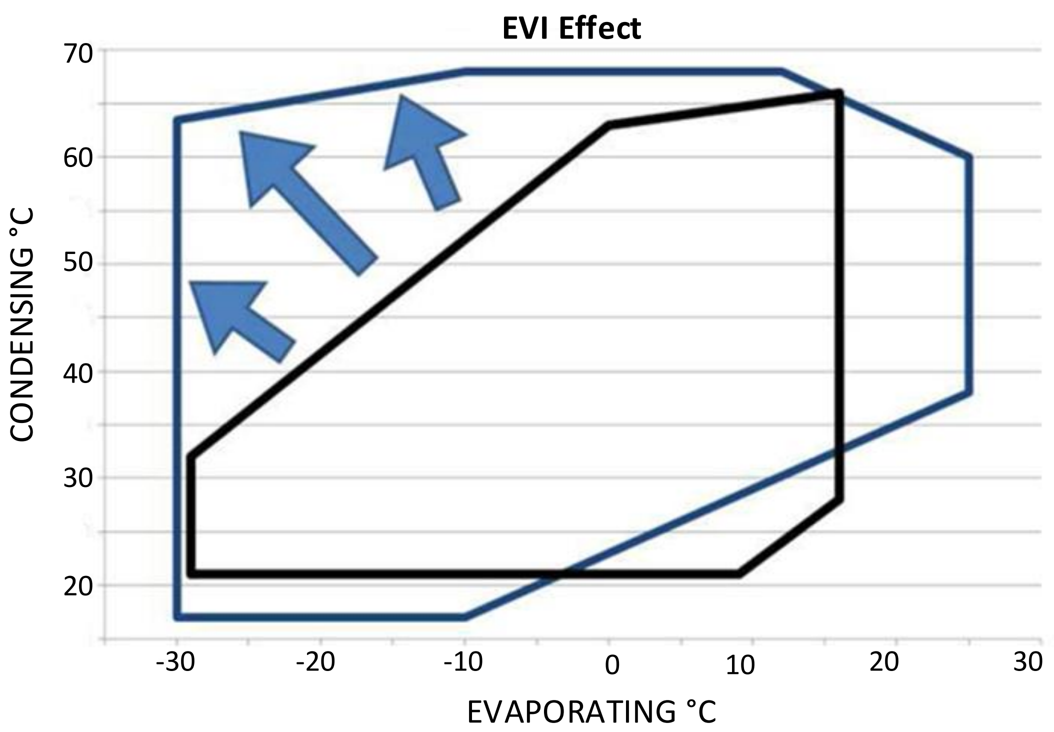


Figure 8 The effect of EVI on the thermodynamic cycle



Sorption

Sorption products are gas driven heat pumps. In a sorption cycle the mechanical compressor found in a standard electric heat pump is replaced by a thermal compressor. A working pair of refrigerant and sorbent is used instead of the single refrigerant used in a conventional heat pump. For an absorption cycle, refrigerant vapour is drawn into a liquid sorbent, allowing them to combine chemically. The resulting solution is then pumped up to the condenser pressure and the refrigerant driven out of the sorbent in the generator by direct heating.

In an adsorption cycle the refrigerant vapour (usually water) is adsorbed by a solid sorbent (usually zeolite). The sorbent then has to be heated to release the refrigerant so adsorption in usually a batch process. In an absorption cycle the refrigerant and sorbent combine chemically whereas in an adsorption cycle they do not. The use of appropriate refrigerant/sorbent working pairs, and the fact that they can recover waste heat from gas burner providing direct heat, allows this technology to reach output temperatures above 60°C.

There are no domestic scale sorption heat pumps currently on the market in the UK and they will not be covered further in this report. Further details of sorption heat pumps can be found in the gas driven heat pump report in this series[7].

System Configuration

The high temperature heat pump may be either monobloc or split. With a monobloc, the refrigeration cycle is contained entirely within a single box and heat is transferred to the property using a mixture of water and glycol (to protect it from freezing). A further heat exchanger (mounted in the ‘hydrobox’ shown in diagrams) is usually used to transfer heat to the domestic heating water distribution circuit. The hydrobox also usually incorporates the system controller and contains the expansion vessel and pump.

In split heat pumps, the evaporator is contained in a unit located outdoors, and the condenser is placed in an indoor unit. The two units are connected by refrigerant pipework. In this case there is sometimes no need for a separate hydrobox as the condenser can provide heat directly to the domestic heating water circuit.

Figure 9 shows a monobloc heat pump and

Figure 10 shows a split heat pump, both providing hot water and space heating.

[7] Evidence gathering – Low Carbon Heating Technologies - Gas Driven Heat Pumps, *DECC, 2016*

Figure 9 A monobloc high temperature heat pump system

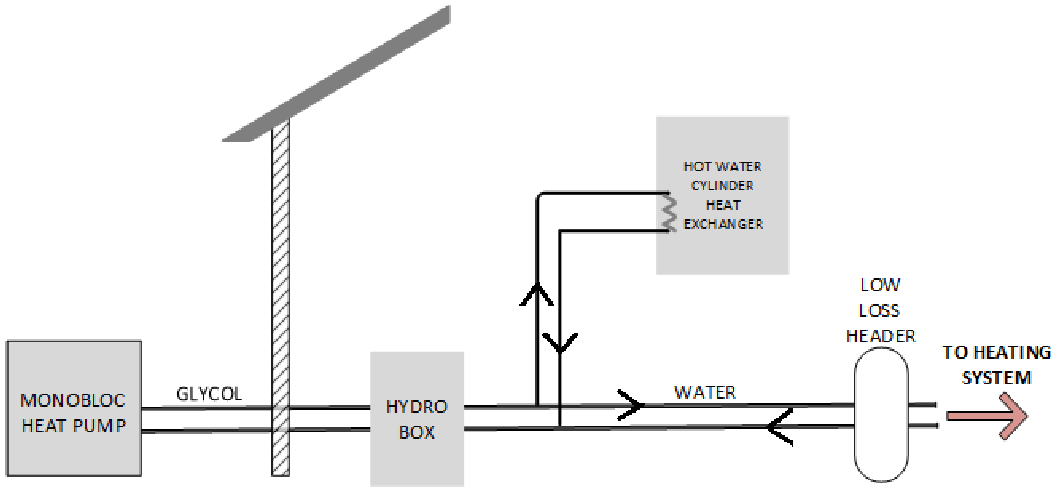
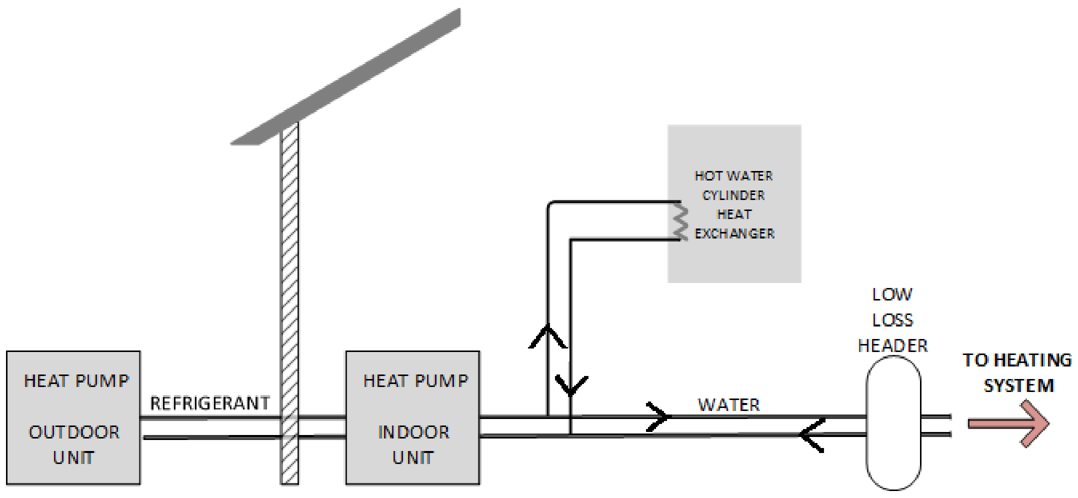


Figure 10 A split high temperature heat pump system



System Applications

High temperature heat pumps, which can be used in conjunction with a high temperature heating distribution system, are most suited to the retrofit market as they can make use of the existing infrastructure. They are typically specified for domestic properties which are hard to heat, older or listed. These property types often have higher heat loss, and therefore the heating water temperature needs to be higher (e.g.70˚C flow/45 ˚C return) than those provided by a standard heat pump (maximum flow temperature of 55 ˚C). Often the properties were previously running on oil or liquefied petroleum gas (LPG) (or even biomass), as larger savings can be achieved than compared to gas heating (see section 7). High temperature heat pumps are more suited to producing domestic hot water than a standard heat pump and most appropriate in situations where there is a high, all year requirement for hot water especially where they may be replacing use of an electric immersion heater.

A further benefit is the ability to heat domestic hot water above 60°C which is advised for legionella control. Stakeholders reported that the frequency at which the water needs to be raised to this temperature is not defined in regulations for domestic dwellings – unlike in the commercial sector.

Increasing the output temperature does inevitably reduce the efficiency and this needs to be taken into account when selecting high temperature heat pumps. The cost and CO_2 savings need to be carefully evaluated against the fuel being displaced. A system using weather compensation (which is required for MCS certification – see section 6) will run at lower temperatures for much of the time so improving seasonal performance..

Despite the availability of some products which can operate at temperatures approaching those produced by a hot water boiler, most manufacturers and suppliers stressed that they typically recommend improving insulation, modifying the heat distribution system and upgrading heat emitters (radiators), where possible. Then the heat pump can be configured to run at lower temperatures most of the time, and will operate with a higher efficiency. Installers said that in many cases existing radiators are oversized, and in order to be able to reduce the flow temperature by 10°C they often only needed to change 2 or 3 radiators.

It is possible to increase the output of radiators by replacing single panels with dual panels, which can have the same length and breadth but are around 10cm deep rather than 6 cm, so the space implications and practical impact are minimal. This can result in the output increasing by 50% to 60% and therefore the efficiency improving.

High temperature heat pumps are not generally thought to be appropriate for new build applications. New domestic properties are more efficient when designed to run with a low temperature heating system for example a standard air to water heat pump with underfloor heating.

The market for high temperature heat pumps is currently niche. A number of stakeholders felt this is unlikely to change in the short term because of the cost of these products, which is higher than standard heat pumps. Additionally, a widely held view is that it is better to educate users to accept lower temperature heating distribution wherever possible, as this is more efficient, even if it requires additional insulation or radiator upgrades. Table 2 explores the relative advantages and disadvantages of different types of high temperature heat pumps.

Table 2 Advantages and disadvantages of different types of high temperature heat pumps

System Variation	Advantage(s)	Disadvantage(s)
Optimised design for refrigerant	• Little modification of standard heat pump required	• Improvements to heat pump components (compressors, heat exchangers etc.) can improve efficiencies incrementally but there are still fundamental limits on the range of operating temperatures and temperature lift each refrigerant can provide
Cascade	• Can reach temperatures up to 80˚C • The performance of each cycle can be optimised and the amount of lift for each cycle is reduced	• Two separate refrigerants required in two separate cycles so higher capital cost • More complex system • Larger space requirement
EVI	• Can reach high temperatures in one system with a single refrigerant (70-75˚C) • May also improve efficiency at lower temperatures	• More complex and expensive than standard cycle
Sorption	• Working pair of refrigerant and sorbent can allow high temperatures to be reached • Additional heat recovery from the boiler at high temperature	• Efficiencies may be lower than for vapour compression heat pumps

Potential Innovation

High temperature heat pumps which use alternative low global warming potential refrigerants such as hydrofluoro olefins (HFOs) etc. may enter the market and are capable of reaching 65°C or over.

Heat pumps using CO_2 are already used in the commercial sector, especially for domestic hot water, and some manufacturers are considering this technology for domestic products.

There are also innovative technologies under development using alternative refrigeration technology[8].

[8] Evidence gathering – Low Carbon Heating Technologies - Gas Driven Heat Pumps, *DECC, 2016*

5. Market and Product Review

We have identified a wide range of manufacturers offering products designed and marketed as high temperature heat pumps.

- **Product data has been collected for 83 products from 12 manufacturers.**
- **Most manufacturers offer a range of 3 to 5 capacities. Some offer both split and monobloc products, fixed and variable compressor versions, and single and three phase units.**
- **Interviews with the manufacturers, distributors and installers indicated that the products are typically specified to heat large or listed properties, often off the gas grid, and also with high domestic hot water demand.**
- **The current market is niche, and estimated annual sales in high temperature applications are just a few percent of heat pump sales, numbering a few hundred units per year.**
- **Significant market uptake of space heating heat pumps has been predicted over the next 15-35 years. High temperature heat pumps could provide an attractive option, particularly for off-grid properties, as they can operate with existing heat distribution systems and provide domestic hot water.**
- **The potential market could be 29,000-60,000 dwellings per year.**
- **However, there are considerable inertia barriers to overcome, and they will be in competition with other technology solutions including hybrid and gas driven heat pumps.**

Product Review

There are a number of high temperature heat pump products on the market that are capable of reaching 65°C for the purpose of space heating. A sample of the manufacturers and products can be found in Table 3. Where possible we have included, for each product range, the range of COPs (tested at full load to EN14511) at A7/W65 or B0/W65 (brine at 0°C/ output water at 65°C) and the SSHEE at 55°C output temperature under average climatic conditions (tested at part load to EN14825).

Table 3 Manufacturers and product ranges

Manufacturer	Product range	System type	Refrigerant	Rated output (kW)	Space heating max temp (°C)	Monobloc or split	Ground or air source	COP (A7/W65; B0/W65)*	SSHEE range (%)**	Additional information
Carrier	61AF	Optimised design for refrigerant	R407C	14 or 19	65	Monobloc	Air	2.48-2.54	Not given	
Climaveneta	AW HT	EVI	R407C	11, 15, 20 31 or 37	65	Monobloc	Air	2.44-2.71	104 – 114	
Climaveneta	BW HT	Optimised design for refrigerant	R410A	22, 26, 30, 34, 37, 39 or 43	65	Monobloc	Ground	N/A***	144 - 156	
Daikin	Altherma High Temp.	Cascade	R410A & R134a	11, 14 or 16	65	Split	Air	2.87-3.08	102-103	Requires an additional tank for DHW. Can reach 80°C but limited to 65°C in UK to increase efficiency
Dimplex	A-Class	EVI	R410A	8, 12 or 15	65	Monobloc	Air	2.5-2.7	129 – 135	Can also provide DHW

Manufacturer	Product range	System type	Refrigerant	Rated output (kW)	Space heating max temp (°C)	Monobloc or split	Ground or air source	COP (A7/W65; B0/W65)*	SSHEE range (%)**	Additional information
Dimplex	SIH	Optimised design for refrigerant	R134a	4, 6, 9 or 11	70	Monobloc	Ground	2.7-2.8	114 – 118	System has a direct compressor
Hitachi	Yutaki – S80	Cascade	R410A & R134a	10, 12 or 14	80	Split	Air	2.5-2.56	118 – 121	Advised output temperature is 60-65°C. These products are typically specified for hard to heat, large or listed properties.
Kensa	High Temp. Single and Twin Range	Optimised design for refrigerant	R134a	4, 6, 7, 8, 11 or 16	65	Monobloc	Ground	N/A***	104 – 123	Typically specified to replace night storage heaters or solid fuels in areas off the gas grid.
Nibe	F2300	Optimised design for refrigerant	R407C	13 or 17	65	Monobloc	Air	N/A***	122 – 128	
Nibe	F1345	Optimised design for refrigerant	R407C	28, 35 or 46	65	Monobloc	Ground	N/A***	137 – 143	

Manufacturer	Product range	System type	Refrigerant	Rated output (kW)	Space heating max temp (°C)	Monobloc or split	Ground or air source	COP (A7/W65; B0/W65)*	SSHEE range (%)**	Additional information
Panasonic	Aquarea HT KIT	Optimised design for refrigerant	R407C	9 or 10	65	Split	Air	2.68 – 2.97	125	Has electrical back-up primarily to avoid the risk of freezing, but can provide backup heat if necessary.
Panasonic	Aquarea G Generation HT	Optimised design for refrigerant	R407C	9 or 10	65	Monobloc	Air	2.2-2.27	125	Typically specified where radiators cannot easily be changed or in off gas grid properties to replace oil, LPG or propane.
Stiebel Eltron	Inverter air WPL 33 HT(S)	Optimised design for refrigerant	R407C	15	75	Monobloc	Air	2.4	122	The system has twin inverter variable speed compressors
Stiebel Eltron	Inverter air WPL 15 – 25 A(S)	EVI	R410A	8 or 15	65	Monobloc	Air	2.36	122 - 130	
Stiebel Eltron	WPF 27 HT	Optimised design for refrigerant	R134a	25	75	Monobloc	Ground	N/A***	131	

Manufacturer	Product range	System type	Refrigerant	Rated output (kW)	Space heating max temp (°C)	Monobloc or split	Ground or air source	COP (A7/W65; B0/W65)*	SSHEE range (%)**	Additional information
Toshiba	Estia High Temp	Optimised design for refrigerant	R410A	5 or 9	75	Split	Air	N/A***	122 - 130	Outdoor units can be paired with four different indoor units and three different sized water cylinders. The indoor units have different sized back up heaters which do not affect performance.
Viessmann	Vitocal 300-A	Optimised design for refrigerant	R410A	12 or 13	65	Monobloc	Air	2.56-2.67	120 - 124	
Viessmann	Vitocal 350-A	EVI	R407C	14 or 20	65	Monobloc	Air	2.26-2.45	108 - 122	

Manufacturer	Product range	System type	Refrigerant	Rated output (kW)	Space heating max temp (°C)	Monobloc or split	Ground or air source	COP (A7/W65; B0/W65)*	SSHEE range (%)**	Additional information
Viessmann	Vitocal 300-G	Optimised design for refrigerant	R410A	11, 14 or 17	65	Monobloc	Ground	N/A***	146 - 173	
Viessmann	Vitocal 350-G	Optimised design for refrigerant	R134a	7	75	Monobloc	Ground	N/A***	139	
Viessmann	Vitocal 350-G+	EVI	R410A	23, 34, 38, 49, 23, 34, 38 or 49	70	Monobloc	Ground	N/A***	152 - 156	

* Coefficient of Performance (COP) is at the standard rating condition measured according to EN14511

** Seasonal performance is the Seasonal Space Heating Energy Efficiency (SSHEE) for an output water temperature of 55˚C and average climate conditions measured according to EN14825

***Data available at other ambient/out-put temperatures or measured at part load conditions from the Ecodesign data fiche

Market Review

Market size and potential

In the UK the overall domestic heat pump market is small. The heating market is dominated by boilers (which make up 85% of the market[9]) and by far the most widely installed type of boiler is the gas condensing boiler. Heat pumps have gained more traction in other countries. According to the European Heat Pump Association heat pump sales (of all types) in key European markets in 2014 were[10]:

- France – 193,100 units
- Sweden – 95,500 units
- Germany – 68,400 units
- UK – 18,700 units

The current UK heat pump market suffers from high capital cost, a low awareness of the product and some mistrust in the technology, especially when the competing technologies are so well established.

Previous predictions of uptake for domestic heat pumps have not been achieved for reasons we explore in section 9. The estimated current market size in the UK is summarised in Table 4. This data was derived from BSRIA figures for total annual sales volume for air to water and ground to water heat pumps, along with an estimate of the proportion operating at above 60°C. The results are consistent with the sales data provided by stakeholders.

The overall air source and ground source heat pump markets have been flat for the last 2 years and current low oil prices have depressed the market for high temperature heat pumps.

[9]RHI Evidence Report: Gas Driven Heat Pumps, *2014, DECC*

[10]European heat pump markets and statistics report, *Thomas Nowak, EHPA, 2015*

Table 4 The estimated sales of domestic high temperature heat pumps in the UK in 2014

Heat pump category	Annual heat pump sales volume (domestic & commercial)	Annual domestic sales volume	Estimated proportion high temperature	Estimated sales volume high temperature
Air to water	16,500	~ 15,900	2%	~320
Ground/water to water	2,200	~ 1,800	2%	~40

Market potential

The future high temperature domestic heat pump market is difficult to predict. Manufacturers in the stakeholder workshops expressed that there are too many variables to make firm predictions of market potential, such as the future balance of incentive schemes and the relative prices of gas, oil and electricity which affect the competitiveness of heat pumps. They suggested that if current incentives and oil prices remain the same then the market is likely to remain stable. It was suggested that heat pumps are not currently considered a feasible option for mainstream consumers.

In terms of the potential market, the Committee on Climate Change (CCC) suggested that the overall cost-effective uptake of heat pumps in UK homes could reach 2.3 million by 2030[11]. To estimate the proportion of this number which might be high temperature we have to look at their application, how they are marketed, the potential consumers, and how these areas may develop.

Potential in current applications

One way of looking at the potential market size in the UK is to look at current purchasers of domestic high temperature heat pumps. From our research we have found that the current application of these technologies is mostly limited to retrofit markets and houses which are not connected to the gas grid.

As more standard heat pumps (that are not specifically being marketed for ‘high temperature’ applications) are capable of heating water to 60°C or higher, the need for the highest temperature (i.e. 70-80°C) heat pumps is reduced further, and likely to remain niche.

[11] Sectoral scenarios for the Fifth Carbon Budget, Technical report, *Committee on Climate Change, 2015*

Installers interviewed stated that the market potential of these technologies is closely linked to oil prices. If oil prices remain low or fall further the cost savings through use of a heat pump are further reduced.

Potential for diversifying the end user

In an average domestic dwelling a standard air to water heat pump can be installed but it is more expensive than the alternative heating solution, and is likely to require the replacement of some radiators and pipework. This is because the heat distribution in the UK building stock is dominated by high flow temperature radiator systems, running at 70°C and above. It is estimated that 90-95% of existing buildings are equipped with such radiator systems[12].

In interviews, utility companies stated that a well installed high temperature heat pump should not require the replacement of radiators. As well as reduced installation cost, this also means reduced disruption which may be a more attractive choice for consumers, and has the potential to increase the proportion of high temperature sales upwards from 2%.

However, at current gas and electricity prices, the installation of high temperature heat pumps to replace gas fired boilers is unlikely to be cost effective, and therefore this market is not predicted to increase in the short term. Stakeholders reported that the operating costs would be comparable, but any savings would not be sufficient to overcome the additional capital cost, even where the boiler already needed replacement. In addition, for this scenario there is competition from hybrid and gas driven heat pumps.

High temperature heat pumps are not competitive for new build properties, on or off the gas grid, where it is best practice to install a heat pump which operates at low temperatures. Figure 11 illustrates the market potential.

[12] IEA HPP Annex 42: Heat Pumps in Smart Grids, *Delta-ee, 2014*

Figure 11 Market segments suitable for high temperature heat pumps

Off the gas grid	Not recommended	Current market
On the gas grid	Not recommended	Potential market
	New build	Retrofit

Increasing the market for high temperature products would involve not just addressing the cost barriers, but also the other barriers discussed in section 9.

Estimate of effective market potential

In order to estimate the potential size of the market opportunity for heat pumps, we undertook a high level assessment of the impacts of property type, property age (i.e. to create an estimate driven by property physical space limitations), and the composition of annual heating replacements in the market. Given the coarse nature of this assessment we sought to establish a range of possible outcomes.

There are approximately 27 million domestic dwellings in the UK (excluding NI) and in approximately 23 million (85%) of these, gas boilers are used to provide heating and/or hot water[13]. Heating and hot water for the remaining dwellings are supplied through off-gas-grid means such as solid fuel, oil or electricity. Industry sentiment suggests that high temperature heat pump technology will mainly be a cost effective replacement for the 15% of dwellings which are not on the gas grid. Our analyses of various data from the CCC, the Valuation Office Agency, and DECC reports shows that the number of off gas grid properties is between 4.1 and 4.6 million dwellings.

Separately, the Committee on Climate Change (CCC) has estimated that by 2030, around 13% of dwellings could use low carbon heat sources including heat pumps and heat networks[14]. Our own estimate of the total potential addressable market for high temperature heat pumps is 25-50% of off gas grid dwellings.

[13] Sub-national consumption statistics, *DECC, 2014*

[14] The Fifth Carbon Budget. The next step towards a low-carbon economy. Committee on Climate Change, 2015 - Middle scenario suggest heat pumps and heat networks from low-carbon sources provide heat for around 13% of homes

The annual market for domestic heating replacements is approximately 1.67 million units[15] of which 1.5 million units are of gas boilers[16]. Comparison with the total stock of UK domestic dwellings gives an annual replacement rate of 6.5% of the installed base. However, analysis of research undertaken by Ipsos MORI and the Energy Saving Trust[17] on drivers for homeowners' desire to purchase a new heating solution (e.g. distress purchases, replacement parts hard to find for existing solution, refurbishment) indicates that only 44% of the time would the heat pump supply chain be likely to meet the customer's needs.

Factoring in the annual replacement rate, and the drivers for heating system purchases, to the size of the potential addressable market gives annual market potential of between 29,000 and 66,000 dwellings (all off gas grid opportunities).

This number assumes there will be no restriction in terms of grid capacity. All heat pump connections must be approved by the distribution network operator (DNO) and already some customers are being asked to pay for grid improvement before installing a heat pump. In addition, the use of single phase electricity places a limit on the heat pump capacity so it may not be possible to meet the full demand for some larger properties. These factors could further reduce the effective market.

Product availability

The limited availability of products is a limitation for the development of the market, as it means they have low visibility in a market dominated by conventional heating technology. During our research we found that the visibility of high temperature heat pumps in particular was very low, even amongst those who currently purchase heat pumps.

Market Segmentation and Competition

Where a property is off the gas grid there are several heating options, including oil fired heaters, LPG and electric heating systems. Biomass heating, room heaters and stoves are also a competitor to high temperature heat pumps.

Another alternative to a high temperature heat pump in place of an oil boiler, is to install a small hybrid heat pump alongside the existing (or new) boiler. If the existing boiler has a reasonable lifetime, this can allow the use of a heat pump, whilst retaining the domestic hot water advantages of the boiler.

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[15] Report IEA HPP Annex 42: Heat Pumps in Smart Grids. Task 1 (i): Market Overview United Kingdom, 2014 Delta Energy & Environment.

[16] Gas driven heat pumps: Market potential, support measure and barriers to development of the UK market, *R.E Critoph, Warwick University, 2013*

[17] Homeowners' Willingness To Take Up More Efficient Heating Systems, *Ipsos MORI and the Energy Saving Trust, 2013*

The UK has an extensive gas infrastructure. Where gas is available in a property the main competition is the gas fired condensing boiler, a trusted technology which has become increasingly efficient.

If the property is on the gas grid, a hybrid heat pump may be a more popular alternative with consumers to a high temperature electric heat pump at the current time, although these also face a number of barriers to shift the market away from gas-fired condensing boilers.

6. Standards Review

High temperature heat pumps are well covered by existing heat pump standards and regulations for performance and design.

- **BS EN 14511 is a well-established standard for testing of steady state performance of heat pumps across a variety of rating conditions. BS EN 14825 is a related standard and defines the conditions for measuring seasonal performance. There are also BS EN standards governing the design and performance measurement of systems as a whole, as well as specific aspects such as safety and noise.**
- **All products must now meet the requirements of the Ecodesign Directive (2009/125/EC), notably the Ecodesign and Energy labelling requirements for space heaters and, where relevant, water heaters. All heat pumps on the EU market must meet minimum standards for seasonal space heating efficiency energy (SSHEE) and must have an energy label shown prominently, and a data fiche including the calculated value of SSHEE.**
- **Both UK building regulations, and the Microgeneration Certification Scheme (MCS) discourage the use of (very) high temperature heat pumps as they require that high temperature heat pumps should only be considered where low temperature heat pumps are not feasible.**

Overview of Standards

High temperature heat pumps are generally similar to standard heat pumps but operate over an extended temperature range and are well covered by existing British Standards most of which are also European standards.

Current UK and EU Standards

The following standards apply to high temperature heat pumps:

Rated performance (electrically driven heat pumps)

BS EN 14511: 2013 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers using electrically driven compressors

This standard provides a method for determining the performance of units operating under steady state conditions at their rated capacity. The rated performance measured as the COP is used for product specification and comparison. The test conditions for four heating modes are specified; low temperature (35°C), medium temperature (45°C), high temperature (55°C) and very high temperature (65°C). The standard does not specify any test condition for temperatures above 65°C (the full test conditions are given in Table 6). The standard is currently being revised to align it with the requirements of Ecodesign (ErP) Directive and it is proposed to change the names of these heating modes to low, intermediate, medium and high.

Seasonal performance (electrically driven heat pumps)

BS EN 14825: 2013 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling.

Testing and rating at part load conditions and calculation of seasonal performance. The standard provides the calculation measures and test methods for determining the seasonal energy efficiency (SEER), and seasonal coefficient of performance (SCOP). Coverage is similar to that for EN 14511 and conditions are defined for determination of the SCOP at the same four application temperatures as EN14511. Seasonal performance is a more realistic measure of in-use performance than the COP which only measures performance at a single operating condition. This standard is also under revision to align it with the requirements of ErP and to include new calculations of seasonal performance and fossil fuel back-up.

Rated and seasonal performance (gas fired sorption heat pumps)

BS EN 12309: 2014/2015 Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW.

As well as covering rated and seasonal performance this standard also considers safety and provisions for hybrid appliances. The same application temperatures apply as for EN14511.

Performance for water heating (electrically driven heat pumps)

BS EN 16147:2011 Heat pumps with electrically driven compressors. Testing and requirements for marking of domestic hot water units.

The standard covers water heaters and combination water heaters connected to or including a water storage tank. The COP_{dhw} and the water heating energy efficiency η_{wh} are determined using a range of standard load profiles. This standard is currently being revised to align fully with ErP legislation.

There is no current standard covering the performance for water heating of gas driven sorption heat pumps.

Design of heat pump systems

BS EN 15450:2007 Heating systems in buildings. Design of heat pump heating systems.

System efficiency

BS EN 15316-4-2:2008 Heating systems and water based cooling systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 4-2. Space heating generation systems, heat pump systems.

This calculates the energy efficiency of a heat pump heat generating system. This standard is being revised to cover hourly and monthly calculation.

Other relevant standards

There are a number of standards which cover specific aspects such noise, safety and environmental issues etc. Details of these are included in a more comprehensive list of standards in Appendix B.

Ecodesign for Energy Related Products Directive (ErP)

All products must meet the requirements of the Ecodesign Directive (2009/125/EC). The directive requires manufacturers to produce products that meet minimum performance standards and that these products are clearly labelled using a standard methodology. This is implemented through specific Ecodesign regulations and the Energy labelling regulations. The regulations covering high temperature heat pumps are:

- Commission regulation (EU) No 813/2013 Ecodesign requirements for space and combination heaters setting minimum performance requirements for heat pumps for water based space heating up to 400 kW.
- Commission delegated regulation (EU) No 811/2013 Energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device setting requirements for energy labelling and product data for heat pumps providing water heating up to 400 kW.
- Commission regulation (EU) No 814/2013 Ecodesign requirements for water heaters and hot water storage tanks setting minimum water heating energy efficiency requirements for products with a rated output up to 400 kW and hot water storage tanks with a volume up to 2000 l.
- Commission delegated regulation (EU) No 812/2013 Energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device setting requirements for energy labelling and product data.

These regulations came into force on 26th September 2015.

Reversible heat pump products that can also provide cooling will also need to meet minimum performance requirements for cooling. These come under Lot 21 of the Ecodesign regulations and the final draft of these regulations has been sent out for public consultation. It is proposed that they come into force on the 1st January 2018.

Table 5 shows the current and proposed minimum energy performance requirements that high temperature air to water, water to water and ground to water heat pumps need to meet. The minimum SSHEE requirement is shown in the "other" column, as high temperature heat pumps currently aren't specifically defined in the Ecodesign directive.

Table 5 Minimum energy performance requirements of high temperature heat pumps

Date implemented	Minimum heating requirement SSHEE		Minimum cooling requirement SSCEE	
	Low temperature*	Other **	GWP>150	GWP≤150
26 Sept 2015	115%	100%		
26 Sept 2017	125%	110%		
Proposed: 1 Jan 2018			149%	134%
Proposed: 1 Jan 2021			161%	145%

***** Low-temperature heat pump means a heat pump space heater that is specifically designed for low-temperature application, and that cannot deliver heating water with an outlet temperature of 52°C at an inlet dry (wet) bulb temperature of -7°C (-8°C) in the reference design conditions for average climate.
** Other includes heat pumps that are not low-temperature, i.e. it applies to the high temperature heat pumps covered in this report

Building Regulations

There are no specific requirements with respect to heat pumps in the Building Regulations but recommendations on heat pumps are provided in the Domestic Building Services Compliance Guide[18]. This recommends that the supply water temperature for radiators should be in the range 40–55°C for air to water, water to water, and ground to water heat pump systems, **and therefore discourages the use of high temperature heat pumps**.

The current default values used for water heating from heat pumps are not representative of high temperature heat pumps (it is assumed that 50% of the heating is supplied using direct electric heating).

Standard assessment procedure (SAP) Appendix Q is a database of product performance which allows the use of specific performance data in the SAP (2012) calculations of building performance to confirm they meet Part L of building regulations and to calculate building energy performance certificates. Appendix Q is currently being updated to accept Ecodesign data and to use the methodology

[18] Domestic Building Services Compliance Guide, *HM Government, 2013*

proposed in the revised version of EN 15316-4-2 which proposes an hourly calculation method rather than the current bin method. The changes are likely to be implemented early in 2016 in SAP 2016. SAP does not specifically include high temperature heat pumps. It currently has 3 temperature classes: 35, 45 and 55°C.

UK and European Guidance on Design and Installation

Although heat pump design is covered by BS EN15450 additional guidance is provided in the UK for domestic installations by the Microgeneration Certification Scheme. Many European countries also provide specific national guidance. This in not detailed here except for the Guidance information from Verein Deutscher Ingenieure (VDI) which was widely used outside Germany.

Microgeneration Certification Scheme (MCS)

MCS was set up to provide assurance on microgeneration technologies used to produce electricity and heat from renewable sources, and on the standard of installation of these technologies. It provides product certification for heat pumps not exceeding 45 kW_{th} and installer individual and company certification. Participation is voluntary and fees are charged. There are fees for the assessment of product eligibility, and initial and annual fees for assessment of installers. The assessment is carried out by an independent accredited certification body. The product certification scheme includes a specific category for very high temperature air to water heat pumps and products have to meet the minimum energy performance requirements set by Ecodesign. MCS requires manufacturers to use a spreadsheet they have developed to calculate the SCOP and SSHEE, and products must have weather compensation. Evidence of actual testing to determine the rating and performance at a rating condition with a flow temperature of 61°C and an outdoor air temperature of 7°C is required.

MCS in collaboration with industry has developed an installer standard for heat pumps which covers supply, design, installation, set to work, commissioning, and handover of heat pump systems. To be eligible to receive Renewable Heat Incentive (RHI) payments, systems need to be installed according to this standard. The standard provides specific guidance on high temperature heat pumps. It says that the “selection of Very High Temperature Heat Pumps (VHTHPs)[19] should be avoided” unless the limitations of the system design offer no alternative other than to use a higher than normal flow temperature; for example listed buildings or design limitations preventing the use of larger heat emitters. If offering a VHTHP, evidence of this work and design, including an example for a low temperature system, should be shown by the MCS Contractor and changes to the efficiency explained to the householder allowing them the choice to select a heat pump in these circumstances as being able to operate at Very High Temperature conditions as specified in MCS

[19] MCS currently defines VHTHPs, in line with BS EN 14511:2013, as those that can deliver output temperatures of 65 degrees. These are likely to be redefined as High temperature heat pumps in the next version of the standard – in accordance with the definition used in this document.

007. The maximum flow temperature selected for very high temperature heat pumps shall not exceed 65°C at the relevant outside design temperature.

European guidance from the Association of German Engineers, (VDI)

A number of European countries have developed national standards especially relating to the design and installation of heat pumps. They will not be listed here except for the guidance produced by the Association of German Engineers as this has been widely used throughout Europe.

This guidance is widely used:

VDI 4650 -1 2014 Calculation of the seasonal performance of heat pumps. Electric heat pumps for space heating and DHW.

UK Heat Pump Product Test Facilities

BSRIA have accreditation by the UK Accreditation Service (UKAS) to test heat pumps up to about 30 kW capacity according to EN14511 and are seeking UKAS accreditation for testing at part load to EN14825. Their facilities can test over a wide range of temperatures and, as they use the water enthalpy method, they can test at high temperatures. They have two chambers so can test split or monobloc products.

BRE have test facilities for heat pumps and are accredited to EN14511 for air source heat pump testing (including conditions for the Home-heating Appliance Register of Performance, HARP, in Ireland) and also can test to EN14825 and EN16147 (Domestic Hot Water units).

KIWA provide MCS certification for air and ground source heat pumps.

European Product Certification

A number of other countries have set up their own product certification schemes for heat pumps

Eurovent Certita

This voluntary, fee-based scheme covers a wide range of HVAC products. Reversible air to water heat pumps have been included under the Liquid Chilling Packages and Heat Pumps (LCP-HP) programme for some time but coverage has increased since the incorporation of the French NF Heat Pump Mark which is now offered alongside the Eurovent Certification mark, and a Euro Heat Pump programme was started in 2015. Eurovent product certification is based initially on self-verification but then subject to independent surveillance. It covers air to water, water to water and ground to water electrically driven or sorption heat pumps (since 2014) (air to water up to 100 kW at -7°C, water to water up to 1500 kW). They publish or are about to publish SCOP, SEER and SPER and the next regulations will include seasonal space heating energy efficiency (SSHEE) and seasonal space cooling energy efficiency (SSCEE).

CEN Heat pump Keymark

The European Heat Pump Association agreed in December 2015 to set up the Heat Pump Keymark, a product certification scheme which is expected to be recognised throughout Europe. It will initially cover heat pumps included in Ecodesign Lot 1.

7. System Performance

A range of SSHEE and COP data has been analysed for high temperature heat pumps and there is a wide spread of performance for some categories. There is a lack of in-use performance data.

- **The standardised testing and reporting of performance information should make it easier to differentiate between high temperature products, and compare high temperature with standard products.**
- **Lab tested performance data was collected from product brochures, ErP data fiches and manufacturer interviews.**
- **COPs from 2.2 to 3.1 were quoted at A7/W65 for the air source products studied. Few products quote a SSHEE at 65°C, but SSHEE 55°C varies from 102% to 135% for air source products. Ground source SSHEEs at 55°C have been found as high as 173%. For comparison new condensing gas boiler SSHEEs are typically 92-93%**
- **There is no obvious relationship between SSHEE and capacity or split/monobloc type but, based on a small sample, product/refrigerant type does appear to have an impact, with EVI products using R410A having highest efficiencies.**
- **SSHEE 55°C values for high temperature products are comparable with those of standard products.**
- **Information gathered from a number of trials showed that high temperature heat pumps generally performed satisfactorily, however particular care is needed with design and controls. It is hard to draw quantitative conclusions on the relationship between lab and in-use performance**
- **In trials, system design for application and control was critical to ensure good performance.**

Laboratory-Tested Performance

The rated performance of high temperature heat pumps is tested according to EN 14511. The test conditions for air to water heat pumps are shown in Table 6.

Table 6 Test conditions for air to water heat pumps

Heat pump type	Outdoor heat exchanger		Indoor heat exchanger	
	Inlet dry bulb temperature °C	Inlet wet bulb temperature °C	Inlet temperature °C	Outlet temperature °C
Air to water, low temperature	7	6	30	35
Air to water, medium temperature	7	6	40	45
Air to water, high temperature	7	6	47	55
Air to water, very high temperature	7	6	55	65

Ground to water heat pumps and water to water heat pumps are tested with the same indoor heat exchanger temperatures as air to water heat pumps but the outdoor heat exchanger temperatures are different. For ground to water heat pumps the outdoor heat exchanger temperatures are inlet temperature 0°C and outlet temperature -3°C and for water to water they are inlet temperature 10°C and outlet temperature 7°C.

Figure 12 shows how the rated COP for a typical high temperature air to water heat pump varies with air temperature and output temperature, and Figure 13 shows how the rated COP of a typical ground to water heat pump varies with the brine temperature and the output temperature. The data is taken from manufacturer capacity tables. They both show how COP improves when the air temperature is higher and output flow temperature is lower.

Figure 12 Rated COP versus air temperature for a typical air to water heat pump at different water output temperatures

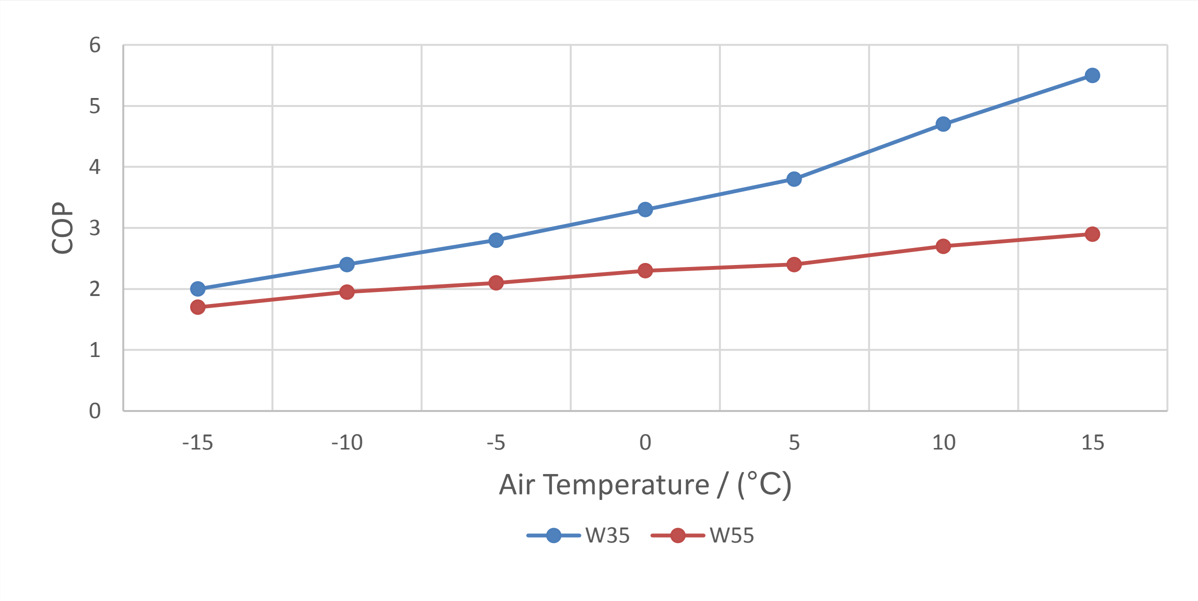


Figure 13 Rated COP versus brine temperature for a typical ground to water heat pump at varying water output temperatures

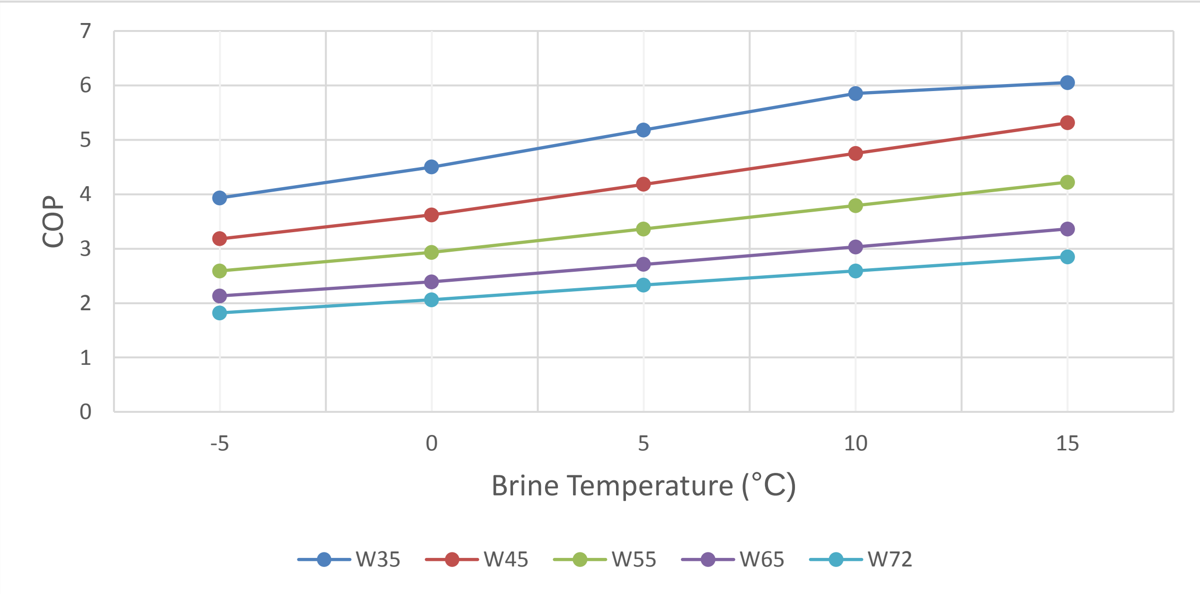


Figure 14 and Figure 15 respectively show the COP values for some of the air to water and ground to water high temperature heat pump products identified for this study, with an output water temperature of 65°C, plotted against heat pump capacity.

The average COP at A7/W65 for the high temperature air to water heat pump identified was 2.54 but there was a wide range in performance from 2.2 to 3.08. For high temperature ground source heat pumps the average COP at B0/W65 was 2.31 and the range was from 2.08 to 2.70.

Within this limited sample there is no notable variation in COP with capacity. The monobloc heat pumps appear to show slightly higher COPs.

Figure 14 Rated COP values for high temperature air source heat pumps at 7°C air temperature / 65°C water output, plotted against capacity

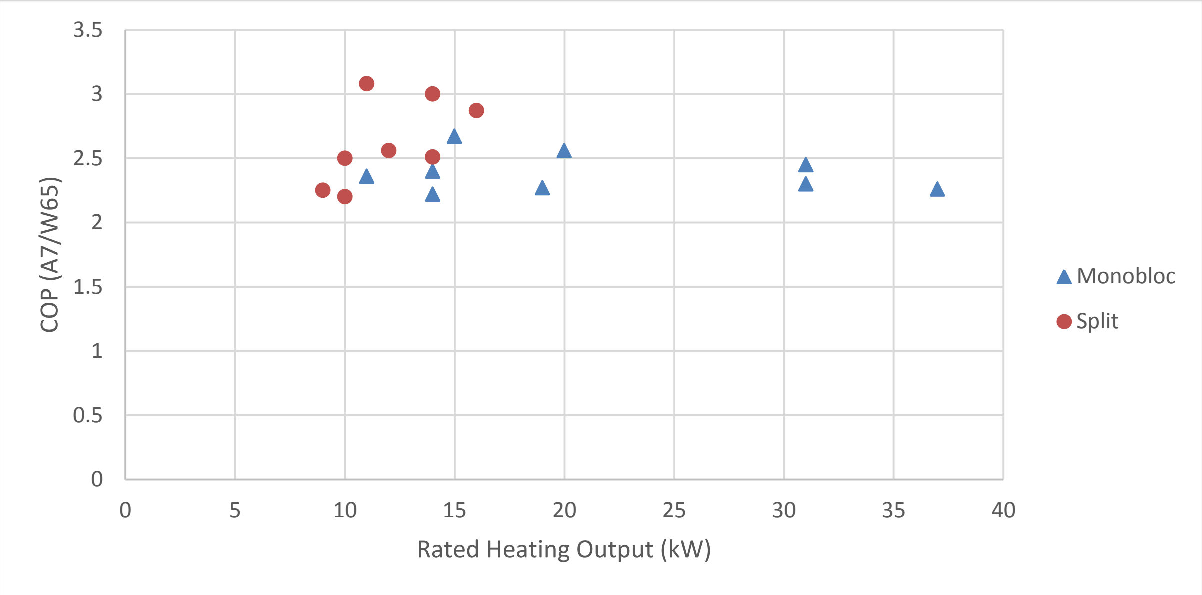
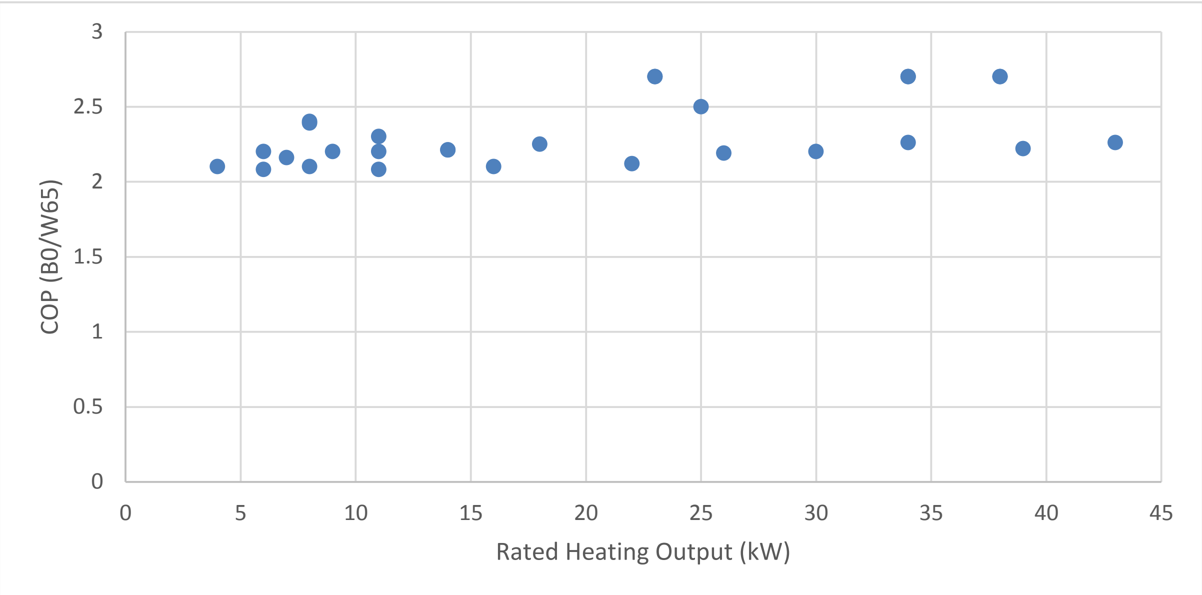


Figure 15 Rated COP values for high temperature ground source heat pumps at 0°C brine temperature / 65°C water output, plotted against capacity



The Ecodesign legislation setting minimum performance and labelling requirements came into force on the 26th September 2015. This requires manufacturers to provide data on the seasonal performance of products measured as the seasonal space heating energy efficiency (SSHEE) according to BS EN 14825.

SSHEE values (at 55°C output temperature) for the air to water high temperature heat pumps identified in this study are shown in Figure 16 and Figure 17. The SSHEE values for ground source heat pumps are shown in Figure 18. For comparison new condensing gas boiler SSHEEs are typically 92-93%. The SSHEE values appear to be lower for some of the cascade products, which also do not improve at higher ambient temperatures. This could possibly be related to the products running two compressors, even when the ambient temperature is warm. It should be noted that the cascade products are designed to produce output temperatures up to 80°C so the SSHEE at 55°C does not reflect their performance at these higher output temperatures.

Figure 16 SSHEE values of split high temperature air source heat pumps (dotted lines represent cascade products)

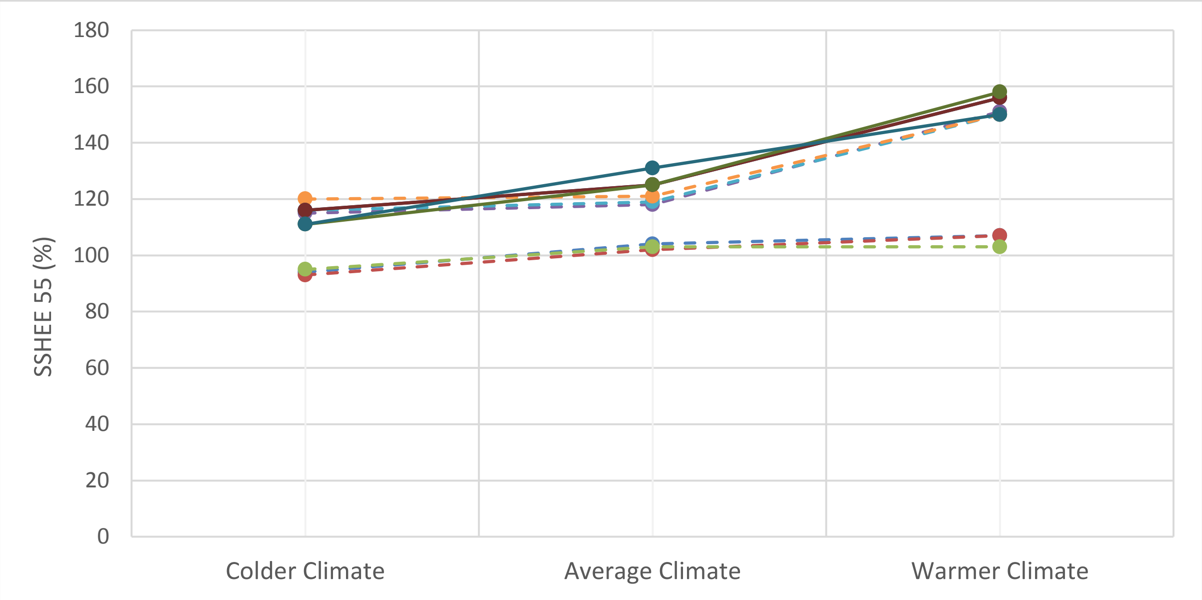


Figure 17 SSHEE values of monobloc high temperature air source heat pumps

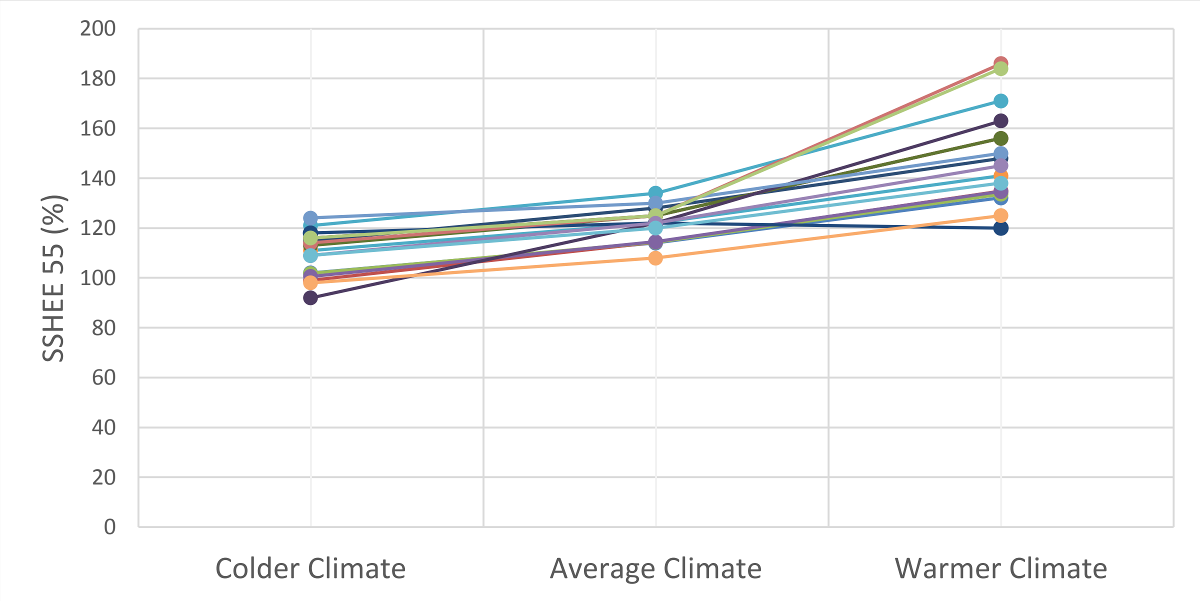
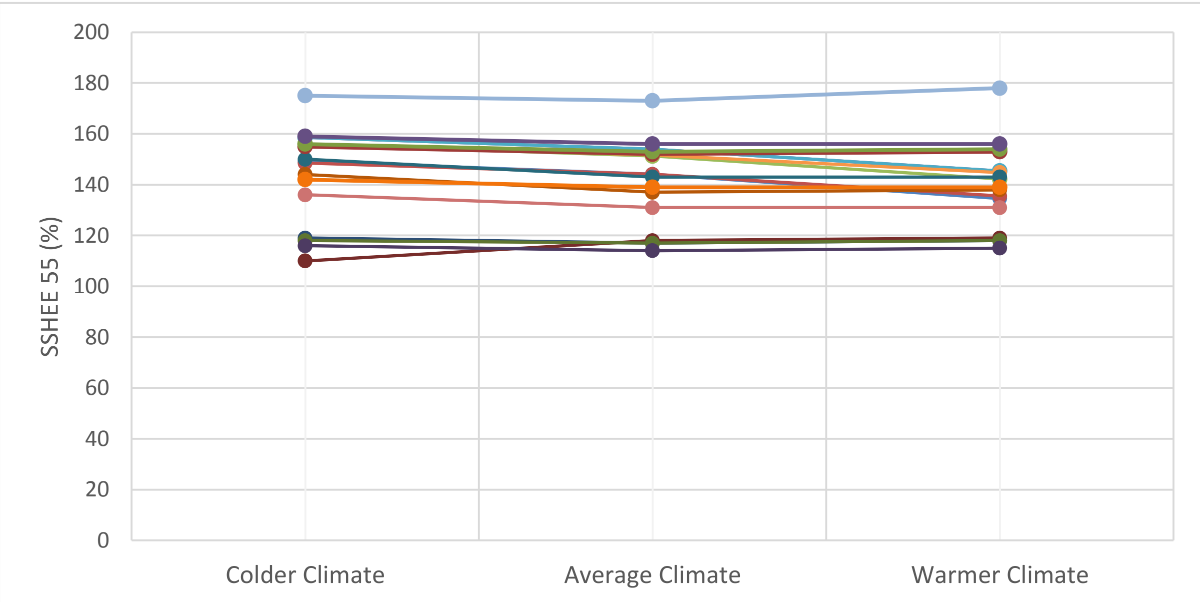


Figure 18 SSHEE values of high temperature ground source heat pumps



There is a considerable spread in performance in the SSHEE values for air and ground source products, although the sample is fairly small.

Figure 19**Error! Reference source not found.** and Figure 20 show the COP values plotted with the SSHEE values for each product at 55°C output temperature. It can be seen that there is some correspondence between them for ground source products, however, for air source, the COPs are fairly even as the SSHEEs increase.

Figure 19 COP values of high temperature air source heat pumps with a flow temperature of 55°C plotted with their SSHEE 55 values in average climate

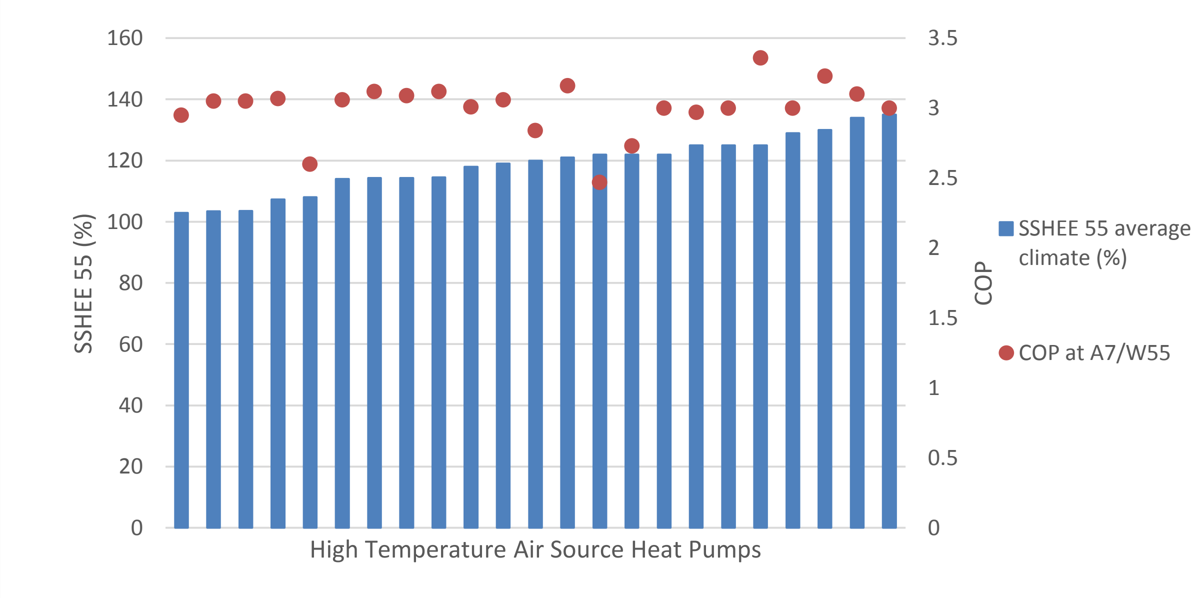
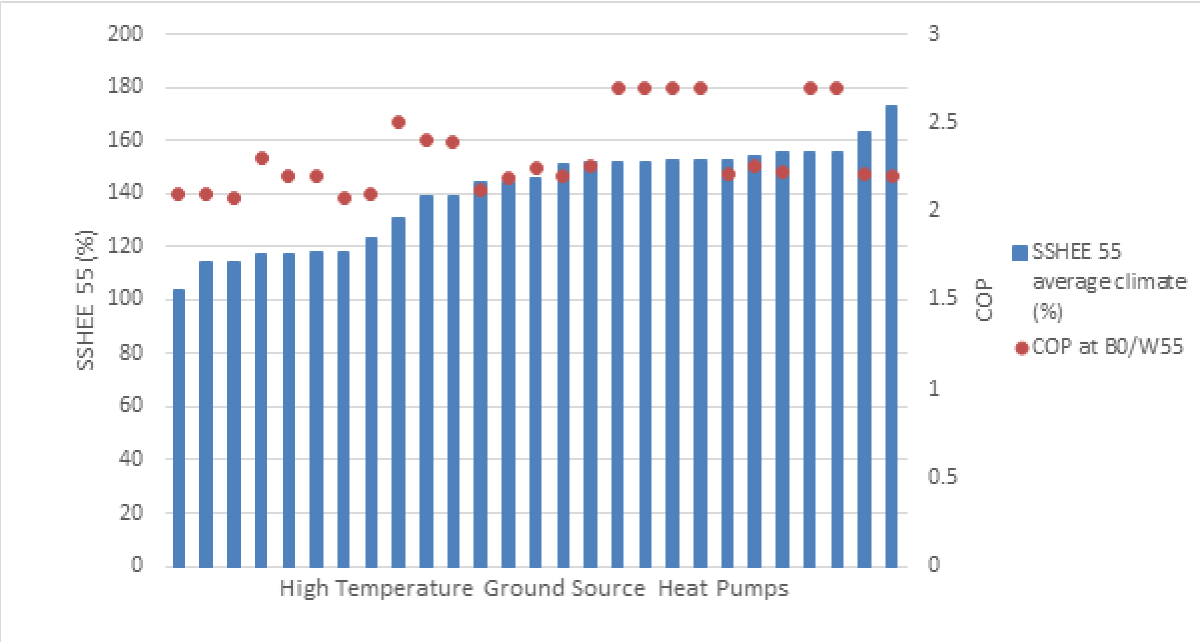


Figure 20 COP values of high temperature ground source heat pumps with a flow temperature of 55°C plotted with their SSHEE values



Some possible reasons for the spread in SSHEE performance were investigated. Figure 21 and

Figure 22 show SSHEE at 55°C for air to water and ground to water high temperature heat pumps respectively, plotted against rated heating output. Details of the refrigerant and refrigeration circuit are also shown.

For air source products, some cascade products have lower SSHEE, whereas R410A EVI systems have the highest SSHEEs irrespective of heating output. There is no apparent trend in efficiency with increasing or decreasing rated heating output

For ground source products cascade and EVI systems using R410A have the highest SSHEE values, and R134a are lower (although these are mostly smaller products). We found there was not any significant variation in SSHEE between products with fixed and variable speed compressors (not shown here).

Figure 21 Rated heating outputs of high temperature air source heat pumps, their SSHEE performance and the refrigerant used

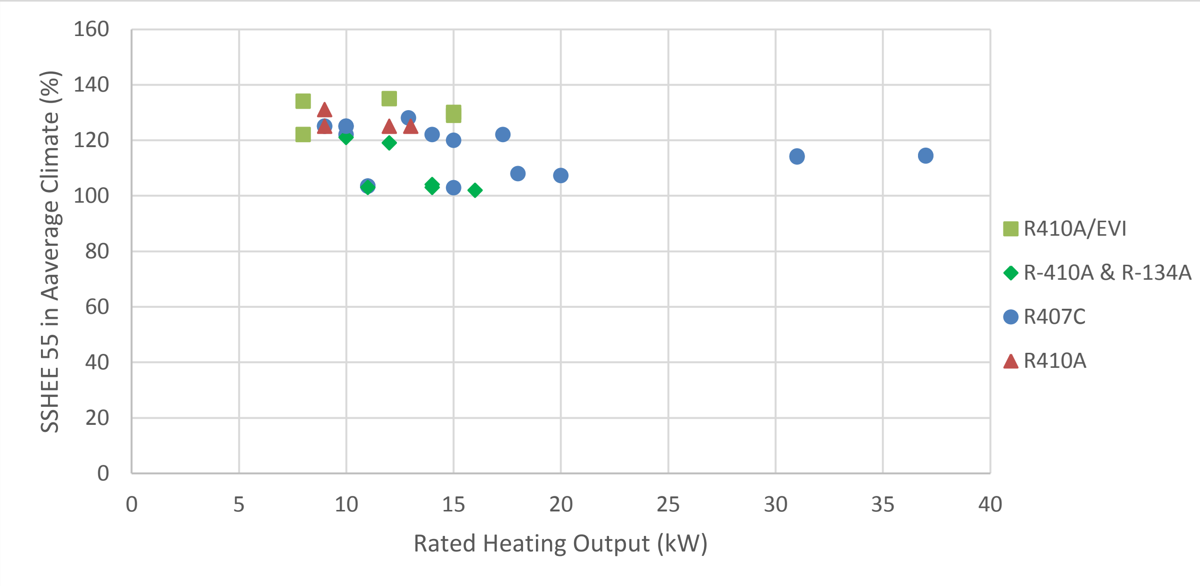
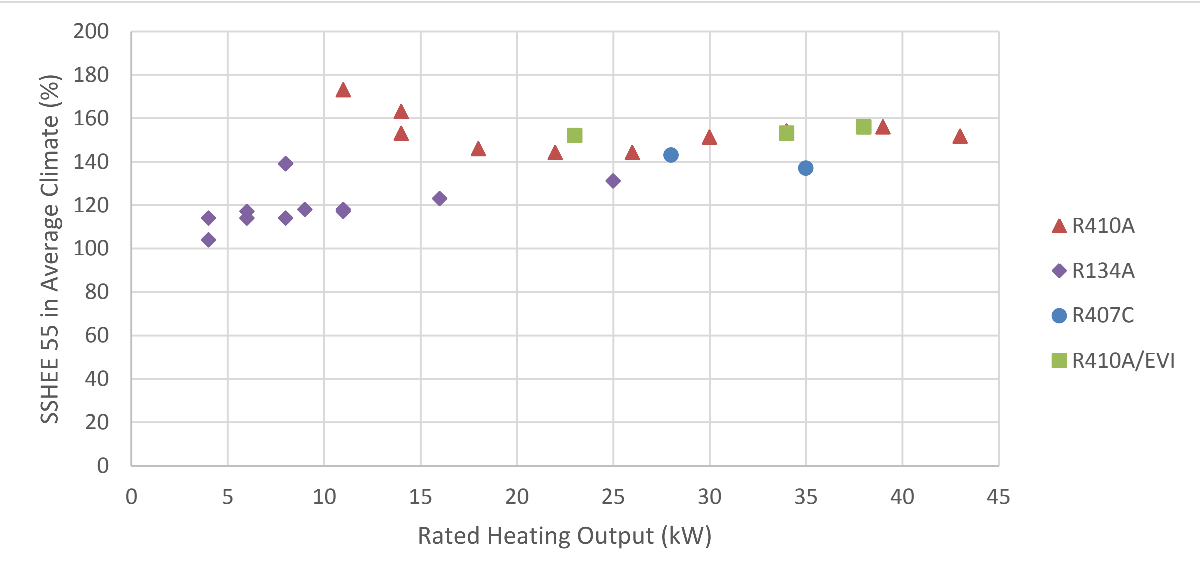
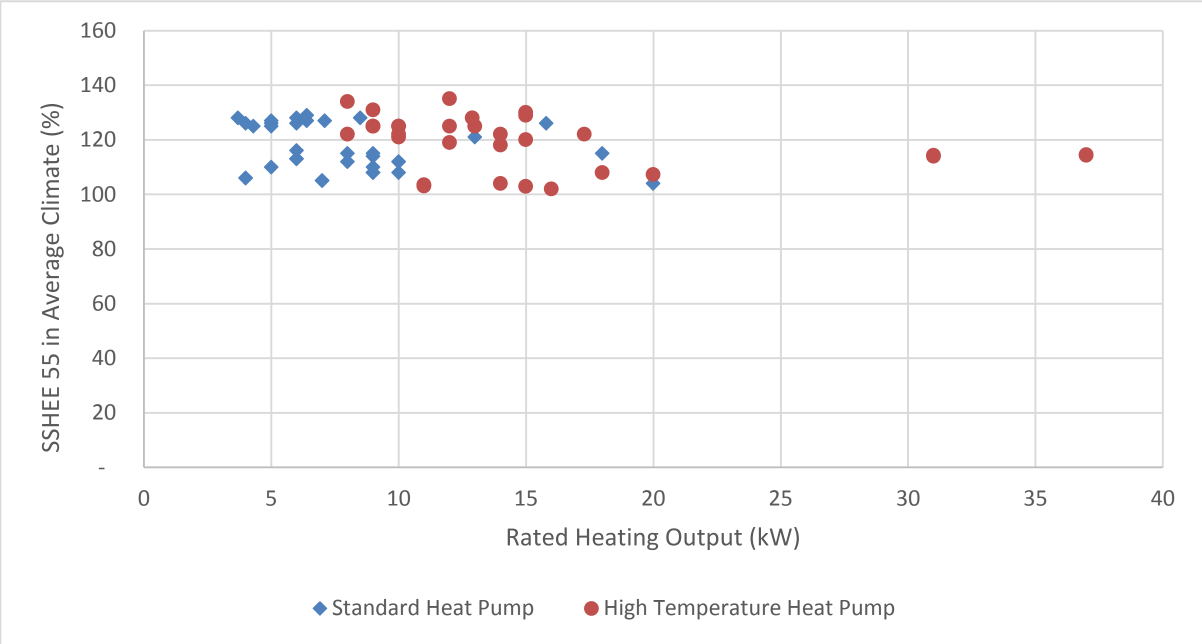


Figure 22 Rated heating outputs of high temperature ground source heat pumps, their SSHEE performance and the refrigerant used



Although some manufacturers have suggested that high temperature heat pumps might perform better than standard products when operating at the range of temperatures for those products, acknowledging that there is limited data, there is no obvious indication that the seasonal performance of high temperature products are any different to standard heat pumps. This can be seen in Figure 23.

Figure 23 Comparison of SSHEE 55 for high temperature and standard heat pumps plotted against rated capacity.



In-Use Performance

Evidence of in-use performance is limited. However, a number of trials were identified and are listed below, based on interviews with stakeholders.

University of Ulster

Detailed performance trials are currently being carried out by the University of Ulster on an 11 kW cascade high temperature heat pump, which has been installed as a direct replacement for a gas condensing boiler in a test house built to 1900 specification. The house is occupied. Results from running the heat pump as a direct replacement for the boiler from November 2014 to February 2015 show that daily COPs varied from 1.82 to 2.38 with an average of 2.07. It is expected that the efficiency will improve in the summer when the system is just providing domestic hot water but it is unclear whether a seasonal performance factor (SPF) of 2.5, as required for RHI, will be reached. The controls for the boiler have been used with a delivery temperature of 75°C and no weather compensation, and the internal temperature was 21°C.

The occupants were generally pleased with the system but when the air temperature dropped below 2°C it was found that the heat pump could struggle to maintain comfort. This was due to the lower temperature and frequent defrosting in certain weather conditions. When the system included a thermal store, COPs were reduced because the heat pump output temperature needs to be slightly higher, but the store did allow for faster response to changes in demand. Trials showed that use of the store also had good potential for reducing peak electrical loads. The performance of the unit was also measured in the laboratory and the measured COP values were found to be lower than the manufacturer's figures. The difference is being investigated.

Stiebel Eltron

One manufacturer, Stiebel Eltron, has carried out field trials with a utility company on 2 high temperature heat pumps running at 75°C, replacing oil boilers, which showed the products performed well. However, they do not currently install these products to provide space heating using high temperature radiators. The company feel that the COP at high temperatures is too low for the products to provide high temperature space heating efficiently. They do use them for water heating.

EON

Utility company E.ON has carried out laboratory testing (seasonal performance and COP) and looked at integration into different house types, and carried out detailed monitoring and investigation of factors affecting performance. They have generally found heat pump performances to be encouraging but high capital costs make them economically unattractive compared to a gas boiler. They carried out initial detailed trials on four heat pumps using CO_2 as the refrigerant which showed the steady state performance was as expected but that there was a problem with the overall control strategy so overall performance was lower than expected.

They have recently finished a one year trial monitoring 12 heat pumps retrofitted in a range of buildings to work with existing high temperature radiators. The occupants always obtained the heating they needed and were satisfied with the systems but again there were some system design issues. EON felt that system design was very important and that when the components were designed as an integrated package efficiencies were likely to be higher. Control was also critical.

Hitachi

One manufacturer, Hitachi, is installing 48 (60˚C) units for the Smart Community Manchester project. However, no results are available yet.

Affinity Sutton

A housing association, Affinity Sutton, described a project where they had installed air source heat pumps (capable of reaching temperatures above 60°C but not specifically 'high temperature' products) capable of providing all the heating and hot water in a new off gas grid development of 15 dwellings. They had had a poor experience with heat pumps previously but found that by taking particular care with sizing and installation, and by providing training to the users both before and after occupation, the residents were very satisfied with the systems. The importance of managing the users' expectations was stressed by several interviewees.

Summary

The number of trials is small but the results indicate that high temperature heat pumps work reliably and can provide satisfactory heating, however particular care is needed with design and controls. There was also evidence from a number of trials that heat pumps with flow temperatures of between 60 and 65°C could also provide satisfactory heating using high temperature radiators systems with little modification.

Feedback from stakeholders involved in trials

A point made by many of the stakeholders was that they would normally try to install as low a temperature system as possible. They would consider the potential to reduce energy losses and the possibility of running the existing high temperature heat distribution system at a lower temperature before suggesting the use of a high temperature heat pump. Radiators may already be oversized, perhaps to allow for intermittent heating or because of improvements that have been made to the building, in which case running them with a heat pump at a lower temperature but for longer periods can sometimes provide adequate heating. Alternatively changing one or two radiators in critical areas where a fast response is needed, such as a kitchen/diner or hallway, may allow the whole system to run at 10°C lower temperature.

System sensitivities

The performance of high temperature heat pumps is more sensitive to poor design, installation and operation than a standard heat pump. The system designer can often help with the installation, and commissioning may be done by a specialist. High temperature heat pumps should be installed with weather compensation to help match the output to demand. Where a heat pump using a cascade cycle is used it may be more efficient if a single cycle can be run at lower loads.

An overview of the system sensitivities is given in Table 7.

Table 7 Overview of system sensitivities

Sensitivity	Description	Scale of sensitivity	Comment
Design	Accurate sizing	***	Should be designed as an integrated system
Installation	Correct installation especially as retrofit	**	Most commissioning is done by a specialist Some distributors sell installation packages
Maintenance	Standard maintenance is low but can require F-gas trained personnel	**	Only one visit a year and relatively simple but can cost more than gas due to lack of trained personnel
Control	The system is more sensitive to operating conditions than a boiler	***	Weather compensation should be used to keep the heating flow temperature as low as possible.
User interaction	Training user in correct operation of the system	***	The systems are particularly sensitive to control so performance is easily affected if the settings are disturbed

Key: *** = performance very sensitive to variable * = little sensitivity to variable

Expected technology lifetimes

The lifetime of a high temperature heat pump should be similar to that of a standard heat pump at 15 to 20 years. No evidence was found that the lifetime varied with size but products are too new to be able to assess lifetime fully yet. The life of a ground source heat pump should be longer than an air source one (as it does not have a fan, and is frequently installed inside rather than outside), and a ground collector should have a lifetime in excess of 60 years. In theory the life of an absorption high temperature heat pump will be longer than that of one with a mechanical compressor

Energy and Carbon Performance

The energy extracted from an ambient source can be considered as renewable. What fraction this forms of the delivered heat will depend on the efficiency of the high temperature heat pump.

Assuming that the electricity used by the heat pump is generated using fossil fuels, the fraction of delivered heat that will be renewable will be given by (1-1/SPF) where the SPF is the seasonal performance factor.

For high temperature heat pumps the average SSHEE found from our product survey was 118% for air source products. This equates to a SPF of 2.95 (multiply SSHEE by 2.5to account for electricity generation losses). Therefore the proportion of energy supplied that can be considered renewable is 66%.

CO_2 savings

In order to estimate indicative CO_2 and cost savings, we have developed a generic scenario, and considered three possible counterfactuals – a gas boiler, an oil boiler, and an electric air to water heat pump. The oil counterfactual is included because the current and foreseeable future market for high temperature heat pumps is focussed on properties off the gas grid.

The potential CO_2 reduction can be found by comparing the CO_2 emissions for two products to meet the annual space heating and water load for a typical building.

Assumptions

For this example we have assumed 12,000 kWh space heating and 2,000 kWh domestic hot water. Based on a typical load factor of 17%, this would require a high temperature heat pump of around 10kW or larger. Although the heat pump can deliver high temperature water, we have used SSHEE at 55°C as the performance measure (as much of the time, the output temperature will be this temperature or lower).

Carbon conversion factors and energy prices are shown in Table 8, taken from DECC Green Book guidance[20]

[20] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, Data tables 1-20: supporting the toolkit and the guidance, DECC, 2016, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483282/Data_tables_1-20_supporting_the_toolkit_and_the_guidance.xlsx

Table 8 Carbon conversions and energy prices from DECC green book guidance[20]

Carbon conversion factors:		
Gas*	0.185	$kgCO_2/kWh$
Burning oil	0.247	$kgCO_2/kWh$
Electricity**	0.333	$kgCO_2/kWh$
Energy prices:		
Gas*	4.11	p/kWh
Burning oil***	3.61	p/kWh
Electricity	14.83	p/kWh

* Fuel factors and prices based on kWh calculated based on gross calorific value

** Long run marginal factor used for electricity

*** Calculated from an oil price of 37.1p/litre

We have assumed that the high temperature heat pump will provide 100% of the space heating and DHW demand, and so will the gas or oil boiler counterfactuals, but the standard electric heat pump counterfactual only provides 85% of the space heating (as it cannot reach the same high temperatures) and 80% of the DHW, with the rest provided by direct electric back-up (because it will not reach the temperatures required to protect against legionella bacteria).

As a simplification, we have assumed that SSHEE is all allocated to the primary fuel (e.g. we have not accounted separately for the electricity use by the boilers).

The SSHEE and also Water Heating Energy Efficiency (WHEE) data in Table 9 has been extracted from our review of heat pump products, and a brief survey of a sample of gas and oil boilers.

The simplified £/tCO_2 calculation has been calculated assuming an average installed cost of £11,500 for a high temperature heat pump, £2,300 for a gas boiler counterfactual and £3,500 for an oil boiler counterfactual. For simplicity, a product lifetime of 15 years has been assumed for both. Variations to annual running costs have not been included due to uncertainties over future energy prices.

Table 9 Min, Max and average SSHEE and WHEE values across a range of heat pumps and boilers (from survey of Ecodesign fiche data)

	Minimum	Maximum	Average
SSHEE55 (%) / SPF			
High temp heat pump	102	135	118
Gas boiler			92.5
Oil boiler			90
Standard electric heat pump			119
WHEE (%) / SPF			
High temp heat pump	65	115	85
Gas boiler			82
Oil boiler			76
Standard electric heat pump			101

Energy use and savings

In Table 10 the energy use, cost and carbon emissions are calculated for high temperature heat pumps, based on the range of SSHEEs and WHEEs found in our survey of available products.

The equivalent results for gas and oil boiler counterfactuals and a standard electric heat pump counterfactual are also shown. The savings for the high temperature heat pump relative to the counterfactuals are shown underneath. The ranges of savings relate solely to the range of high temperature product efficiencies used. All other variables (such as the counterfactual efficiencies) are averages, and are constant. Negative values denote that the savings are greater for the counterfactual.

Table 10 Energy use, carbon emissions and savings for high temperature heat pumps versus oil boilers and standard electric heat pumps

	High temperature heat pump	Gas boiler counterfactual	Oil boiler counterfactual	Standard electric heat pump counterfactual
Total space heating consumption, kWh/yr	3,560 to 4,700	12,970	13,330	5,230
Total water heating consumption, kWh/yr	700 to 1,230	2,440	2,630	1,030
Total energy consumption kWh/yr	4,250 to 5,940	15,400	15,960	6,260
Total carbon emissions, kg/CO_2/yr	1,420 to 1,980	2,840	3,940	2,090
Total energy cost £/yr	630 to 880	630	580	930
		Savings using a high temp heat pump:		
Energy saving kWh/yr		9,480 to 11,160 (61 to 72%)	10,030 to 11,710 (63 to 73%)	330 to 2,010 (5 to 32%)
Carbon saving, kgCO_2 /yr		870 to 1,430 (30 to 50%)	1,960 to 2,520 (50 to 64%)	110 to 670 (5 to 32%)
Cost saving £/yr		-250 to +3 (-39 to 0%)	-300 to -50 (-53 to -9%)	50 to 300 (5 to 32%)
£/tCO_2 saved relative to counterfactual		520	240	

Nb indicative values only, subject to rounding errors

In the scenario modelled the high temperature heat pump achieves energy and carbon savings relative to oil or gas boilers of over 50%, but doesn't result in a cost saving due to the relative prices of oil/gas and electricity, reflecting current low oil and gas prices.

There are cost (and energy and carbon) savings of between 5% and 32% compared to a standard electric heat pump because a higher proportion of the heating is provided by the high temperature heat pump.

Simple carbon abatement costs of £520/tCO_2 and £240/tCO_2 respectively have been calculated i.e. the additional cost of purchasing and running a high temperature heat pump compared to a gas boiler or oil boiler, per tonne of CO_2 saved over the product lifetime.

It should be noted that the carbon emissions factor for electricity is expected to fall in subsequent years, and so the carbon emissions associated with electric heat pumps are likely to come down over time.

8. Costs

The price of high temperature heat pumps ranges from 20% to 35% more than standard heat pumps; but the price premium based on fully installed costs is more like 10-20%.

- **The price of high temperature heat pumps ranges from £3,000 - £7,000 (air source) or £250 – 650/kW, depending on product type.**
- **The fully installed price identified in this study is broadly consistent with other recent studies, ranging from £6,000 to £14,000, for air source products. Installed costs for ground source versions can be anywhere between £10,000 - £40,000 depending on the type and size of ground collector used.**
- **The price premium for air source products is mitigated but rarely exceeded by the reduced need for replacing heat emitters.**
- **The additional cost for a larger product in a range is generally small. Therefore cost per kW varies significantly with product size.**
- **Under a high deployment scenario, it is probable that prices would reduce, but it is likely this would be in an incremental fashion rather than a significant or step-change reduction.**

Heat pump costs

High temperature heat pump systems have the same cost elements as standard heat pumps as shown in Table 11.

Table 11 Cost items for high temperature heat pumps

Capital cost	Installation cost	Running costs
• The heat pump itself • For a split system, the refrigerant pipework between the units • A domestic hot water tank – if needed • A buffer tank – if	• System design • Installation of the heat pump • Installation of refrigerant pipework • Installation of hot water tank and/or	• Annual maintenance • Electricity cost

needed • Controls and meters • Pipework, insulation, pumps etc. associated with any heating and hot water system • For ground source heat pumps, the ground collector • Upgrades to some heat emitters (radiators) – although this is not always required for a high temperature system	buffer tank – if needed • Installation of pipework. • Electrical connection • For ground source heat pumps, the ground works (trenches etc.) • Installation of heat emitters if required	

Various components of costs have been identified, but it has not been possible to accurately break down the costs for all the various components separately, given the data collected. Nevertheless, the typical overall product and installation costs identified within this study, are consistent with those from other studies, as described below

The product cost of high temperature heat pumps has been found to be higher than standard heat pumps by 20-35%.The price premium is to some extent a function of the technology used, and the temperatures reached.

For cascade based systems (which can achieve output temperatures of 80°C), there is a price premium related to the fact that they effectively comprise two heat pumps, including two compressors, additional heat exchangers etc.

The cost increase is mitigated to some extent by the reduced need for replacing heat emitters.

The typical costs found in this study are shown in Table 12 and described further in the following section.

Table 12 Typical costs of high temperature heat pumps

Product type (°C)	Air or Ground	Capacity (kW)	Product cost (£)	Product cost (£/kW)	Installation cost (£)	DHW cylinder & accessories cost (£)	Assumed rads cost (£)	Total cost (£)	Total cost (£/kW)
80+	Air	10-16	5k-7k	400-550	3k-5k	0 – 2k	-	9k – 13k	650 – 1,100
70+	Air	6-13	3,5k – 7k	300-650	2k-5k	0 – 2k	300-800	6k – 14k	500 – 1,400
65	Air	9-15	3k-5k	250-400	2k-5k	0 – 2k	500-1,500	6k – 13k	500 – 1,200
65	Ground	6-30	4,5k – 15k	350-1,000	5k-20k	0 – 2k	600-3,000	10k – 40k	1k – 2.2k

Product costs – Air source heat pumps

For cascade based products the product price to the end user is generally within the range of £5,000 – 7,000 (for products sizes of 10-16kW).

This gives a typical product only capital cost of £400-550/kW.

The product price premium relative to standard air source heat pumps is estimated at 25-35%, which equates to £1,000-2000.

For products with EVI or equivalent technology which can achieve output temperatures of over 70°C, the product cost has been found to vary from £3,500 - £7,000 (for product capacities of 6-13kW). This gives a typical product cost of £300-650/kW. The product price premium for these heat pumps is estimated to be around 20-35%.

It should be noted that these high temperature systems, compared with standard heat pumps, reduce or eliminate the need to replace existing radiators. However, stakeholders agreed that from a purely cost point of view, the reduced cost of heat emitters would rarely exceed, and may not offset the price premium for a high temperature heat pump.

In addition, running costs may be higher over the product lifetime when running at higher temperatures (with lower COPs).

Therefore, with current energy prices and incentives, the choice of a high temperature heat pump over a standard one is likely to be based on other factors (e.g. user preferences, avoiding disruption of replacing radiators, lack of space for bigger heat emitters etc.). Further details of barriers can be found in section 10.

For other products which can provide output temperatures of 65°C, the product prices range between £3,000 and £5,000 for units with capacities of 9 – 15kW. This gives a range of product costs per kW, of £250 – 400/kW.

The estimated premium for these products is around 10-20%. However, for these products, there is an increased likelihood of needing to replace one or more heat emitters, in order to run the heat pump efficiently at a suitable temperature.

Product costs – Ground source heat pumps

The prices for ground source products collected in this study had a much wider range of values, across a wider range of capacities.

The prices quoted ranged from £4,500-15,000 for products ranging from 6–30kW. This gives a product price per kW of £350-1,000.

Price premium for high temperature products

Where stakeholders were prepared to quote a price premium for high temperature products, it was typically around 10%. We believe this relates to the installed costs, or full capital costs including DHW tank etc. For some products it was possible to make a comparison between directly equivalent low and high temperature products from the same manufacturer, using published price lists. Table 13 shows published prices (solely for the heat pump, and excluding any discounts) for three ranges of low temperature, and equivalent high temperature products. The product price premium for these ranges varies between 15% to 35%.

Table 13 Published prices for three ranges of low (LT) and high temperature (HT)

	Product capacity (kW)	Price of low temperature product (£)	Price of high temperature product (£)	Price premium
Manufacturer 1	11	4,000	5,500	36%
	14	4,400	5,800	34%
	16	4,600	6,100	33%
Manufacturer 2	9	2,700	3,400	24%
	12	3,500	4,200	22%
Manufacturer 3	9	2,500	3,100	29%
	12	3,000	3,700	23%
	15	3,500	4,000	15%

Other capital costs

Manufacturers offer a range of options which provide additional functionality for increased cost. This is used as a way of keeping the cost down for price sensitive projects, whilst allowing improved options, usability and control for premium installations:

With a high temperature heat pump, especially for the highest temperature models, it may be possible to retain an existing domestic hot water tank. However, if a purpose designed hot water tank is needed, this generally costs in the range of £900-1,300. A buffer tank may also be required in some cases.

The control system for a high temperature heat pump is usually built-in, and in many cases the controller can also operate a boiler to form a bivalent or hybrid system. However, where a separate controller is required, this is normally of the order of £100-200.

A range of other accessories are available for high temperature heat pumps which could add anything from £100 to £1,000 to the cost.

The cost of upgrading the heat emitters is very site dependent, and also dependent on the control strategy implemented by the installer. Some installers of the highest efficiency products stated that they rarely upgrade the heating system, preferring to run the heat pumps at lower temperatures for longer durations, in order to maximise the operational COP of the heat pump. In these cases, the high temperature function of the heat pump is reserved for the provision of DHW and days with very high demand.

The majority of suppliers and installers stated that it is usually recommended to upgrade a few of the key radiators – often between one and four. A typical cost for this of £1,500 was quoted. For the cost analysis above a basic assumption has been made for a radiator upgrade cost of £100 per kW of heat pump capacity installed for products reaching 65°C. For the cascade products which can operate at 80°C, it has been assumed that no radiator upgrade is required and for the EVI products a middle value of £50/kW installed has been assumed.

Installation costs

Installation costs reported by stakeholders varied much more widely than product costs. In general the variation in installation costs were not related to the fact that the products are high temperature, or the specific product type.

The typical installation cost reported by stakeholders for an air source system was £1,000-5,000 excluding the cost of changes to radiators. This cost is usually higher for split systems than monoblocs because of the need to have an installer qualified to handle refrigerants.

For the purposes of this study, the installation costs for air source heat pumps have been assumed to be around £2,000 for monobloc products and £3,000-4,000 for split systems across the three categories of products, in order to avoid compounding error bands relating to the product cost with the variation in stakeholder estimates for the installation costs.

The installation cost reported for ground source systems varied between £3,000 and £15,000. For the purposes of this report, we have used a very rough approximation of £700-800 per kW capacity installed.

Fully installed cost

Based on the data and assumptions detailed above we have plotted the capital cost and likely installation cost for a range of high temperature products of different sizes, and from different manufacturers

For products that reach 80°C, the installed cost is estimated at between £9,000 – £13,000 or £650 – £1,100 per kW

For product reaching over 70°C costs are estimated at 6,000 – 14,000 or £500 – £1,400/kW

For products which reach 65°C, the installed costs are similar at £6,000 - £13,000, or £500 – £1200/kW

For Ground source products the total installed cost is estimated at between £10,000 and £40,000, or £1,000 - £2,000/kW

As the product price is only a proportion of the fully installed price, and because the cost of installation for a high temperature heat pump is generally no higher than a standard one, the percentage price premium for the fully installed cost is considerably lower than that for the product only, at between 10-20%.

Figure 24 and Figure 25 below illustrates a range of product costs by capacity and indicates the proportion of product costs against the total installed cost.

Figure 24 Range of air source heat pump product costs and total installed costs by capacity

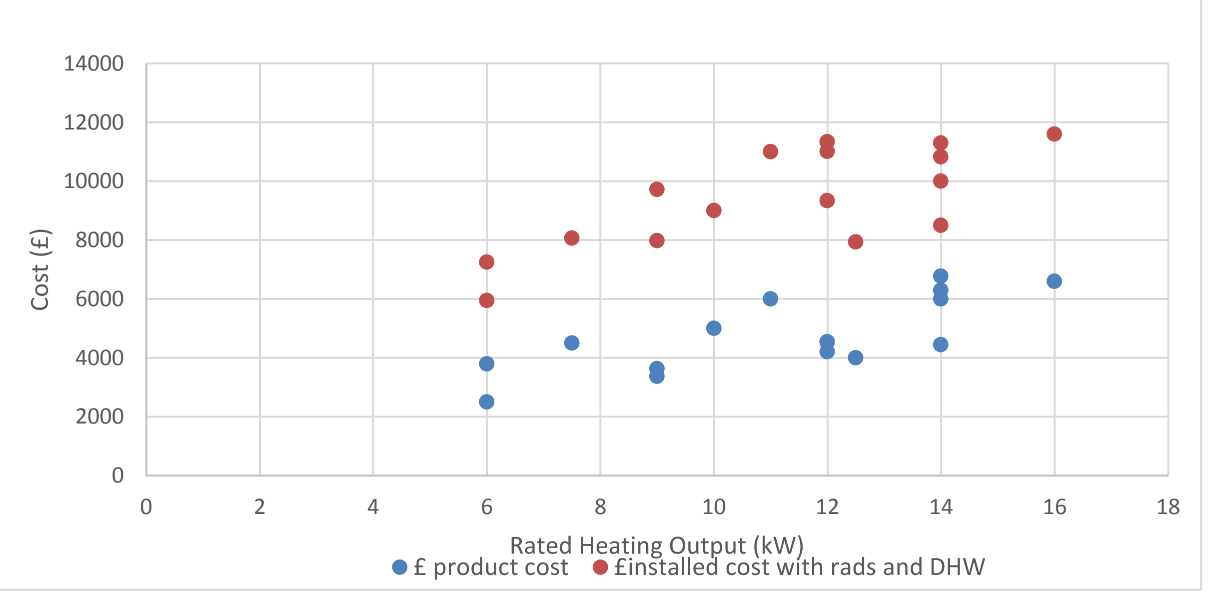
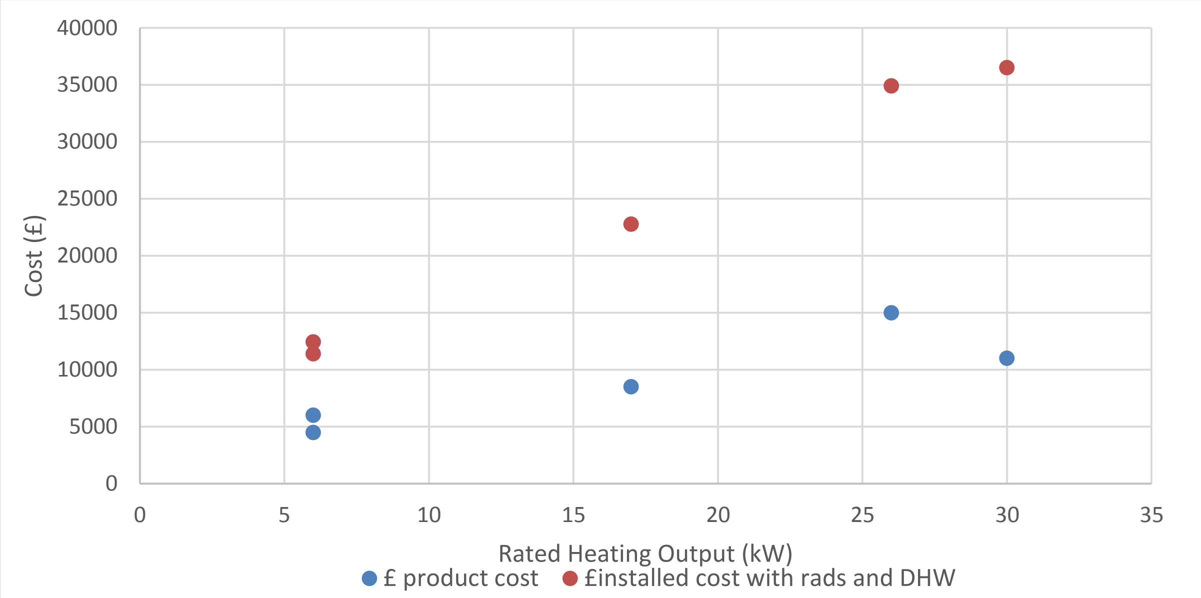


Figure 25 Range of ground source heat pump products and total installed costs by capacity



It should be noted that for both air source and ground source heat pumps, the cost of larger products is generally not significantly higher than smaller products. For air source heat pumps the installation cost is also not reported to be significantly higher for larger products.

Therefore the variations in cost per kW relates more to the range of products sizes available, than to the variations between product types. For this reason cost per kW is a rather poor indicator for comparing performance across types. Care should be taken when comparing cost per kW for different product sizes – and indeed when comparing cost data from different sources.

Comparison with Other Studies

The cost of installing domestic heat pumps have been reported widely.

A wide range of costs were reported in the Sweett group report[21] for standard air to water heat pumps, from £556/kw for 10-20kW products up to £1187/kW for 5-10kW.

The findings of this report of high temperatures products are comparable ranging from £500/kw to £1,200/kW for air source products. As the installed cost price premium is only 10-20% significantly higher total costs wouldn't be expected.

The total costs of £6,000-13,000 for air source and £10,000 to £40,000 for ground source are also comparable with the values of £5,000-£15,000 and £8,000 to £23,000 quoted in the Committee on Climate Change (CCC) report[22].

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[21] Research on the costs and performance of heating and cooling technologies, *Sweett Group for DECC, 2013*. Available on .gov.uk

The reason for the higher installed ground source costs probably relates to the large properties in which these products are often installed, for which the payback times compared with an oil boiler have been better.

Operating Costs

The ongoing operating costs comprise the electricity to drive the heat pump, and maintenance charges.

The cost of maintenance is has been found to be broadly similar to maintenance for a gas or oil boiler. Many companies offer an annual maintenance contract – and this is sometimes a requirement to validate the warranty.

For a monobloc air source heat pump the maintenance requirement is very simple and low cost. As there is no gas (unless the system is hybrid or bivalent), it does not require a registered Gas Safe Engineer.

For a split air source heat pump however, the maintenance engineer will need to be qualified to work with refrigerant gases.

And for a ground source system, the engineer must have the skills to verify the integrity and performance of the ground loop.

Maintenance charges can vary from £100 per year to £1,000 per year depending on level of cover, size of system etc. For this study we have assumed a typical annual maintenance charge of £200 per year.

Cost Savings

Overall, stakeholders indicated that 30-40% energy cost savings have been achieved compared to an oil fired boiler (at 2014/15 prices) – although this may have deteriorated with recent significant reductions in oil price. However, our model scenario in Section 7 found that the high temperature heat pump was at least 10% more expensive than a typical oil boiler.

Small cost savings can be achievable relative to a gas fired boiler, but these would be unlikely to give an economic payback period.

Opportunities for Cost Reduction

Stakeholders were divided over the opportunities to reduce costs. Manufacturers in general felt that prices are currently similar across Europe where sales volumes are higher. Prices have remained fairly steady over ten years (and have therefore reduced a little in real terms). Under a low growth rate scenario, this trend is expected to continue.

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[22] Fourth Carbon Budget Review -technical report, *Committee on Climate Change, 2013*

Under a high deployment scenario, then there was a consensus view that prices would reduce, but it was generally thought this would be in an incremental fashion rather than a significant or step-change reduction.

The findings of this study support those of the CCC report[23] which state that stakeholders "generally consider the opportunity for reducing equipment costs limited, with no significant economies of scale expected to result from growth of the heat pump industry. Some learning is expected to bring down installation costs, equivalent to 10% of the installed cost by 2030".

A similar finding is stated in the Delta EE report[24] which predicted potential for a "10-15% reduction in equipment cost in a mass market scenario compared to 2014" for a 12kW domestic heat pump.

Price changes for high temperature products are likely to be in line with the overall trends for air to water heat pumps.

However it should be noted that several stakeholders believed that more significant cost reductions were possible given a high deployment scenario. They equated the market with the air conditioning market in which heat pump technology with mass market take-up has come down to a few hundred pounds.

And it was highlighted that significantly cheaper products are available in China, which could disrupt the market, although the quality and performance of these has not yet been determined.

It is certain that, for the foreseeable future, there will be a price premium for very high temperature heat pumps using a cascade approach as they are effectively two heat pumps in one.

[23] Fourth Carbon Budget Review -technical report, *Committee on Climate Change, 2013*

[24] Potential Cost Reductions for Air Source Heat Pumps, *Delta-ee for DECC, 2014*

9. Barriers and drivers to deployment

High temperature heat pump technology helps to mitigate some of the traditional barriers to the wider uptake of standard heat pumps, however, it is not clear that the benefits are sufficient to overcome the major barriers.

- **High temperature heat pumps could help overcome consumer inertia as they are able to provide the high temperature heat outputs customers expect, and supply domestic hot water. They reduce the need to upgrade domestic heat distribution systems.**
- **However they have some additional barriers to overcome compared to standard heat pumps such as high upfront cost, and lower awareness compared to standard heat pumps.**
- **High temperature heat pumps are new to the market and there is a lack of trial information, and so the cost benefits and performance are unproven.**
- **They also suffer from other commonly quoted barriers to heat pumps, such as concerns over performance of earlier heat pump installations, and the need for additional space.**

This section first gives a brief overview of the drivers for the uptake of this technology, and then discusses the barriers to uptake.

Research showed that many of the same barriers which prevent the rapid uptake of standard heat pumps are also applicable to this technology. The findings on barriers are therefore presented in terms of the well-known barriers to standard heat pumps; and then the impact of high temperature technology is described for each barrier (i.e. whether it mitigates or exacerbates this barrier).

This section was compiled from a review of literature, along with discussions with all of the stakeholders interviewed.

Drivers for deployment

High temperature heat pumps have a number of advantages over standard heat pumps that mean they could find a market in the UK. These strengths include:

- The ability to provide high temperature space heating and hot water
- Better response time for heating and domestic hot water

- The ability to be retrofitted to standard heating distribution systems (saving money, and reducing the time and disruption for installation)
- The ability to use a standard size hot water cylinder (rather than a bigger one with a large exchange coil required for standard heat pumps)
- The potential to reduce carbon emissions and costs for ‘hard to heat’ homes where it may not be cost effective to improve insulation

Summary of Key Barriers

Standard heat pump barriers are summarised in Table 14 which gives a brief summary of the barrier and the impact of high temperature technology on the barrier, along with an indication of the strength of that barrier. The barrier strength is our assessment based on a combination of expert opinion, and how frequently the barrier was mentioned by stakeholders, and highlighted in the literature search.

Our assessment of the impact of high temperature technology relative to standard heat pumps is colour coded, where green shading designates a positive impact, and red a negative impact. Items shaded blue mean that the barrier is not significantly different for high temperature heat pumps compared to standard products.

The barriers where high temperature heat pumps have an impact compared to standard heat pumps (red or green) are then discussed further in the following sections, segmented into consumer, technical, installation, and market barriers. It should be noted that some barriers may fall across one or more of these categories. Further details of the other barriers (in blue) are shown in Annex C.

Table 14 Summary of common heat pump barriers and the impact of high temperature technology

Key:

Technology's impact on standard heat pump barrier: **Green - positive impact; blue - no impact; red - negative impact**

Barrier Strength: * - Minor barrier; * * - Moderate barrier; * * * - Major barrier

Barrier	Description	Technology's impact on standard heat pump barrier	Barrier strength
High upfront cost	High up-front cost is the major barrier for demand	High temp heat pumps tend to be more expensive than standard HPs by 10-20% (installed)	* * *
Consumer inertia	Consumers are reluctant to move away from the convenience of gas boilers	The ability for more comparable operation to a gas boiler (high temperature output; ability to provide domestic hot water) may reduce this barrier	* * *
Low technology awareness	Low level of knowledge / awareness about heat pumps	There was a general lack of awareness around high temperature heat pumps from demand-side interviewees	* * *
Lack of confidence	Lack of robust / comparable performance data and previous negative experiences with heat pumps	Similar to low temperature heat pumps, although there is less performance data available for high temperature products	* * *
Aesthetics	Aesthetics are a major barrier for consumers	Similar to low temperature heat pumps	* * *
Space constraints and planning permission	Space constraints (for the heat pump unit and hot water tank), including planning requirements	High temperature heat pumps tend to be larger, but require a smaller heating tank	* * *

Barrier	Description	Technology's impact on standard heat pump barrier	Barrier strength
High electricity price / low gas price	A relatively large differential between electricity and gas per unit of energy reduces potential savings compared to other countries	Similar to low temperature heat pumps	* * *
Uncertainty over performance / savings	Current performance metrics are not reflective of in-use performance and it is difficult to calculate savings, even with the Ecodesign Directive performance data recording regulations	Ecodesign Directive data fiches record data at 55°C (medium temperature) rather than 65°C (high temperature). Trial results are limited.	* *
Number of players in supply chain	Given the large number of players in the supply chain, it is not clear who is incentivised to ensure proper installation	Similar to low temperature heat pumps	* *
Thermal efficiency of housing stock	The UK's existing housing stock includes a significant proportion of thermally inefficient properties.	High temperature heat pumps can produce sufficient heat levels to heat properties with a high heat loss (although insulation may be a more effective solution)	* *
Shortage of necessary skills	Lack of skilled and experienced technicians / engineers to install and maintain systems	Situation has improved. Similar to low temperature heat pumps.	*
Speed of installation	Heat pumps take considerably longer to	Similar to low temperature heat pumps	*

Barrier	Description	Technology's impact on standard heat pump barrier	Barrier strength
	install than a gas boiler		
Low replacement opportunities	Existing gas boilers have long useful lives of 10-15 years.	Similar to low temperature heat pumps	*
Noise	Heat pumps can be noisier than other heating types such as gas boilers	High temperature heat pumps can be noisier than standard heat pumps	*
Network electricity capacity	Heat pumps will add significant demand to the electricity network (both at a local and national level)	High temperature heat pumps increase the potential network demand	*
Suitability of incumbent heating distribution systems	Widespread use of heating distribution systems with high flow / return temperature which are not suitable for heat pumps is a barrier for retrofit	High temperature heat pumps are suitable for retrofit to incumbent high temperature heating systems	*
Lack of highest temperature products	There is a lack of choice of capacities so it may be difficult to match demand efficiently.	There are increasing numbers of products that can reach 65, but difficult to maintain high efficiency at higher temperatures, and therefore fewer high temperature products available.	*

Key:

Technology's impact on standard heat pump barrier: **Green - positive impact; blue - no impact; red - negative impact**

Barrier Strength: * - Minor barrier * * - Moderate barrier * * * - Major barrier

Consumer Barriers

High up-front cost

In general, high up-front cost compared to gas-condensing boilers is a **major barrier** for standard heat pumps, especially when considered alongside uncertainty on in-use savings. However, the effect of cost varies depending on the market segment considered:

- **Housing developers** – cost is a major barrier for housing developers. The cost of a heat pump is not fully reflected by a proportionate increase in the value of a property. For this reason, housing developers are more likely to install gas-condensing boilers to maximise their return. Housing developers told us that there are more cost-effective ways for architects/engineers to increase the score in SAP or meet other building regulations, such as improving the building fabric and solar.
- **Buy-to-let landlords** – cost is a major barrier for landlords due to the landlord-tenant divide. Landlords are not incentivised to pay the high up-front cost as the tenant will be the financial beneficiary (through lower heating bills).
- **Homeowners** – cost is a major barrier for homeowners.
- **Housing associations** – is also significant for housing associations, who are often incentivised to reduce the ongoing cost of living for occupiers.

Cost is a less significant barrier for properties off the gas grid, where the cost of connection to the grid for gas fired boilers, or the cost of installing and running an oil fired boiler or using electric heating or LPG can make heat pumps more cost competitive.

High temperature heat pumps tend to be 20-35% more expensive than standard heat pumps.

Consumer inertia

Consumer reluctance to switch from the familiarity and convenience of incumbent technology (mainly gas boilers) is a **major barrier** to the uptake of standard heat pumps. This reluctance is reinforced by the ability of gas boilers to quickly heat a home and provide hot water on demand. Consumers are often concerned about the 'quality' of the heat from standard heat pumps (i.e. a concern that low heat levels are insufficient to heat a home). The complexity of heat pump control systems compared to gas-condensing boilers adds to this inertia. Research has suggested that for the choice of system the 'key determinant was the technology itself (dictating 54% of choices)'[25].

Several stakeholders felt that current messaging around heat pumps would benefit from highlighting convenience benefits (such as longer product lifespans and lower maintenance requirements) alongside potential cost savings.

High temperature heat pumps should have a positive impact on consumer inertia. Consumers in the UK (due to the prevalence of gas boilers) are used to a heating system that delivers high water temperatures to the radiators when required, as well as providing hot water effectively. High temperature heat pumps have an advantage over standard heat pumps in this regard.

Consumer awareness, confidence and trust

Consumer awareness of heat pumps in general is very low and is therefore a **major barrier**. In a survey of householders, 12% had heard of air source heat pumps and understand what they are, with the figure being 28% for ground source heat pumps[26]. Similar scales of awareness have been found in other studies[27].

Feedback from manufacturers is that they cannot justify the funding to run significant awareness raising campaigns themselves – that the current heat pump market in the UK is not large enough. In Germany, for example, utilities have been very successful in driving awareness[28].

In general, a number of demand-side interviewees were not familiar with high temperature technology, meaning that consumer awareness is even lower than for standard heat pumps.

Uncertainty over performance/savings

Lab performance metrics can never be fully reflective of in-use performance and it is difficult for consumers to calculate savings. This is a **moderate barrier**. Since 26th September 2015, the Ecodesign Directive has stipulated that seasonal performance data for heat pump units (which should more closely represent in-use performance) must be published and readily available to consumers. However, currently we have found this data is difficult to locate and the level of technical knowledge required to use this performance data is high.

For high temperature heat pumps, the impact of this barrier is greater, as the Ecodesign Directive stipulates that performance data must be recorded at an output

[25] Homeowners' willingness to take up more efficient heating systems, *Ipsos MORI and the Energy Saving Trust, 2013*

[26] Pathways to High Penetration of Heat Pumps, *Frontier Economics, 2013*

[27] Homeowners' willingness to take up more efficient heating systems, *Ipsos MORI and the Energy Saving Trust, 2013*

[28]Overcoming the human barriers to heat pumps, *Delta-ee, 2015,* available here; http://www.delta-ee.com/images/downloads/pdfs/2015/ARTICLES_HPT_Jan15.pdf,

temperature of 55˚C, whereas for high temperature heat pumps, the performance at 65˚C may be more relevant.

Technical Barriers

Noise

The noise produced by heat pumps has been a significant barrier, however considerable work has been carried out to reduce noise levels, and regulations are in place to limit the decibel output. With good design and effective siting, this is now considered to be a **minor barrier**.

High temperature heat pumps can be noisier than standard heat pumps. Analysis of Ecodesign fiche data for the products reviewed in this study showed a noise range for indoor units of 30-62dB for standard heat pumps and 33-71dB for high temperature heat pumps. The outdoor noise levels are 43-86dB and 42-76dB respectively. However the average noise for both indoor and outdoor units differs by only 3-4dB.

Market Barriers

Relative price of gas and electricity (spark gap)

The extensive gas network and relatively high cost of electricity per unit of energy compared to gas in the UK is a **major barrier** as it means that in-use cost savings from heat pumps are potentially lower compared to other countries[29]. Volatility around energy prices adds to uncertainty around savings.

This barrier remains for high temperature heat pumps.

Suitability of incumbent heating distribution systems

Widespread use of heating distribution systems with high flow / return temperature which are not suitable for heat pumps is a **minor barrier** for retrofit of standard heat pumps[30]. Heat pump suppliers commented that a high proportion of customers are reluctant to change their radiators to low temperature alternatives.

Due to the high temperatures this technology can achieve, it has a positive impact on this barrier as it can be retrofitted with incumbent heating distribution systems.

Electricity grid constraints

This is a **minor barrier** that may limit deployment with increased uptake of heat pumps. This barrier can be a constraint due to both the capacity of a local grid connection, as well as a longer term constraint due to limitations on total electricity generation capacity if a significant proportion of the UK's heating demand were

[29] IEA HPP Annex 42: Heat Pumps in Smart Grids – Market Overview, *Delta-ee, 2014*

[30] The Future of Heating: Meeting the Challenge, *DECC, 2013*

electrified. In addition, the single phase supply in the UK means that many international products designed for three phase supply are unsuitable. The single phase supply also places a maximum on the heat pump capacity that can be installed so that in some situations not all of the load can be met.

This barrier is likely to be **minor** whilst deployment is low but could increase to **major** if large numbers of heat pumps are installed in the same area.

High temperature heat pumps have a negative impact on this barrier as they have a higher power requirement.

Thermal efficiency of housing stock

The UK's existing housing stock includes a significant proportion of old properties, which tend to be thermally inefficient. In 2012, nearly 60% of dwelling were built before 1964, and over 20% aged before 1919[31]. Standard heat pumps work best in well insulated, thermally efficient properties, so maintenance work to increase the efficiency of a property is often carried out before fitting a standard heat pump. This adds cost and disruption to the project, and so is a **moderate** barrier**.**

High temperature heat pumps have a positive impact on this barrier as they are able to reach high temperatures, therefore heat loss is not such a significant issue.

Planning and space

Planning constraints exist but are not insurmountable, therefore this is a **minor barrier**. For an installation outside, the space used must not exceed $6m^3$, noise level restrictions apply and there are regulations stipulating how close to a boundary line the unit can be sited. For listed properties, more stringent regulations apply.

Lack of space can be a **major barrier** depending on the property type and location**.** External space is usually required for the heat pump unit, as well as internal space for a water tank. The effect of this barrier will vary by property type. Non-urban properties are less likely to have space restrictions than high-density urban dwellings.

For high temperature heat pumps, this barrier is slightly more significant as their larger size and higher noise levels mean that these restrictions must be considered more carefully to ensure compliance.

[31] English Housing Survey Headline Report 2010-11, *DCLG*, *2012*

10. Gap Analysis

Information has been collected across the full range of issues requested by DECC. In general confidence in the information is reasonable to good. However, in situ performance information is limited, and site specific.

- **Stakeholders have been willing to share information across the full range of topics considered.**
- **Stakeholder information has been cross checked against previous studies, and published information and data, and there is good consistency.**
- **As these technologies are new to market, although there is good published performance information based on standard conditions, in situ verified results are limited.**
- **Further trials and modelling would be helpful to more accurately determine the potential cost and carbon savings across the range of different property types in the UK.**

At the outset of this study a wide range of questions were provided by DECC, and a key aspect of the research was to identify where gaps exist in the available information, or where information is available, but not to a good level of confidence. Recommendations for filling these gaps through further study were also requested.

We have therefore assessed below each of the key sections above to examine the data quality and gaps.

State of the art

As this is a relatively new application of heat pump technology, manufactures are keen to explain how the technology works, and the various applications and configurations in which it can be used.

Therefore there is good information on the current status of technology, and in general suppliers have been open about product developments that are expected to reach the market in the next 1-2 years.

Product review

We have carried out a comprehensive review of products available in the market and included a description of the key features of each, along with a spreadsheet containing more comprehensive information on each product, including operating temperatures, 1 vs 3 phase, refrigerant type, COPs and SSHEEs. A few data points appear to be unexpected, but confidence in the data generally is high.

We have focused on products specifically marketed as High Temperature, but we are aware that some other manufacturers offer products which can reach 65°C, but are not typically used for high temperature operation. Further desk research could identify all of the products which could reach 65°C.

Market size review

Current market data is imprecise. Due to the limited number of players in the market, the absence of sales data from one or two manufacturers (on confidentiality grounds) makes it difficult to assess the actual number of products being sold. Therefore estimated values may be subject to a significant uncertainty. Nevertheless, confidence is high that the figures presented in this report do show the correct order of magnitude for the current market.

In particular, the segmentation between the different product types has been difficult to determine due to manufacturer sensitivities. Some market reports are produced based on data collected from manufacturers but the granularity of the questions isn't sufficient to distinguish between Cascade, EVI and other high temperature heat pumps.

DECC could seek to approach suppliers directly, under NDA, to obtain a more detailed and granular view of current sales figures. DECC could also consider discussions with bodies collecting market data regarding collecting more granular information within market reports. However, it is likely that the order of magnitude of numbers collected are sufficient to establish that current take up is low.

Standards review

Good information has been available regarding current standards and those under development, and this is presented within the report. Confidence in this information is high.

System performance

Comprehensive data has been collected from manufacturers for COPs and SSHEEs for a wide range of products. This data is quoted according to standard rating conditions. However, most manufacturers don't lab test all products at all conditions, and so some of the data is calculated using manufacturer selection software. As provision of SSHEE information is compulsory under Ecodesign, and minimum performance standards exist, along with market surveillance, it is likely that manufactures are conservative in quoting SSHEE values. We therefore have reasonable confidence in the lab performance values presented in the report.

Field trials have been carried out by a number of organisations across a variety of manufacturer's products. However, the amount of performance data available is limited, and there is a lack of consistency in the measurement of results within these trials. The format of the trials and parameters measured depend on the organisations conducting them, as they have different drivers. For example, housing associations focus closely on the cost savings and occupier satisfaction, whereas for utility companies and installers the accurate and repeatable measurement of in-situ performance and comparison with lab performance is more critical. The monitoring results are currently not sufficient to evaluate the accuracy of the published COP/SSHEE data across the range of conditions.

Only a few of the trials covered in this report specifically referred to products designed to operate at high temperatures. The other products are capable of reaching 60°C, but were not specified to deliver high temperatures in the trials. In addition, several of the trials are very small scale involving just one or two products. These can give a very detailed assessment of the operation and results in specific circumstances. They give good qualitative information on the factors (control etc.) which affect performance but the results are specific to properties/users concerned, and it may not be realistic to extrapolate the results to the wider market.

If DECC wishes to obtain better data regarding the in situ performance of high temperature products then they should firstly seek to obtain direct access to the monitoring data for trials that have been / are being carried out, under NDA if appropriate. Secondly, in order to better quantify the difference between the published seasonal performance indicators, and actual in use performance, further, more comprehensive trials, based in the UK, with detailed monitoring are likely to be needed, across a wider range of property types, and conditions.

Costs

Good data has been collected on the cost to the end user across the range of product sizes and types. This includes the cost of extras and accessories, including controls, alongside the typical capital, installation and maintenance costs. Confidence in capital and maintenance cost data is high. Confidence in the average cost of extras and accessories and installation is reasonable, however in order to confirm the potential range of these costs, a number of detailed scenarios could be created, and installers could be asked to provide guidance and pricing for the best and most likely options against these scenarios.

Whilst an indication of the energy and cost savings has been provided, this is clearly very dependent on the individual property concerned. Therefore detailed analysis of the profile of potential cost savings for different product types has not been undertaken. This could be carried out through modelling of housing stock, heat demands and scenario analysis to determine the potential of different solutions. Alternatively, an exercise could be undertaken to identify a range of real properties (maybe with the help of manufacturers, installers and other stakeholders), document their characteristics (type, fabric, current heating system, current energy use/spend) and then model the impact of the technology options on this range of real properties.

One aspect that was questioned by a number of stakeholders during this study was the value in providing heating hot water above 60°C. One proposal considered during this project would be a more in depth analysis of the cost balance of running heating at high temperature vs the cost of installing extra radiators based on modelling, or a series of case study properties, or further trials. The extra cost of a high temperature heat pump, the cost of operating at higher temperatures and the alternative cost of installing radiators can all be quantified. The study would need to quantify in some way the benefit of reduced disruption for the customer.

Barriers to deployment

Good information has been collected and reported on the wide range of barriers to the increased uptake of heat pumps in general, and high temperature heat pumps in particular.

Annex A – list of standards

Standards applicable to air to water, ground to water and water to water high temperature heat pump

Standard/Regulation	Comment
BS EN 14511:2013 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers using electrically driven compressors.	Topic: Rated performance (steady state) Coverage: Electrically driven heat pumps for space heating and/or cooling, using air, water or ground heat sources. Four parts: 1.Terms and conditions 2. Test conditions 3. Test methods 4. Operating requirements, marking and instructions. Currently under revision - projected date for publication 2017
BS EN 14825: 2013 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling. Testing and rating at part load conditions and calculation of seasonal performance.	Topic: Seasonal performance. Coverage: Electrically driven heat pumps for space heating and/or cooling, using air, water or ground heat sources. Currently being revised to align with ErP legislation and to include new calculations of seasonal performance and fossil fuel back-up. Publication imminent
BS EN 12309: 2014/2015 Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW.	Topic: Rated and seasonal performance and safety Coverage: Sorption heat pumps including use in hybrid appliances. Seven parts: 1 Terms and definitions 2. Safety 3. Test conditions 4.Test methods 5. Requirements 6. Calculation of seasonal performance; 7. Specific provisions for hybrid appliances.
prEN 16905: Gas-fired endothermic engine heat pumps	Topic: Rated and seasonal performance and safety Coverage: Gas-fired endothermic heat pumps Five parts: 1. Terms and definitions; 2. Safety; 3. Test conditions; 4. Test

	methods; 5. Calculation of seasonal performances in heating and cooling mode. Currently under development - projected date for publication 2017
BS EN 16147:2011 Heat pumps with electrically driven compressors. Testing and requirements for marking of domestic hot water units.	Topic: Performance for water heating Coverage: Electrically driven heat pump water heaters Currently being revised to align fully with ErP legislation. Projected date for publication 2017
BS EN 15450:2007 Heating systems in buildings. Design of heat pump heating systems.	Topic: Design of heat pump heating systems. Probably need updating. Coverage: Air, water and ground source.
BS EN 378:2008+A2:2012 Refrigerating systems and heat pumps. Safety and environmental requirements	Topic: Safety and environmental requirements mostly related to refrigerants Four parts: 1. Basic requirements, definitions, classification and selection criteria 2. Design, construction, testing, marking and documentation 3. Installation site and personal protection 4. Operation, maintenance repair and recovery. Currently being revised - close to publication
BS EN 12102:2013 Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling. Measurement of airborne noise. Determination of the sound power level.	Topic: Noise measurement Coverage: electrically driven heat pumps
BS EN 15316-4-2:2008 Heating systems and water based cooling systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 4-2. Space heating generation systems, heat pump systems.	Topic: System efficiency (SPF) Coverage: All heat pump types. Currently being revised to provide hourly and monthly calculation.
BS EN 13313:2010 Refrigerating systems and heat pumps. Competence of personnel.	Topic: Competence requirements
Commission regulation (EU) No 813/2013 Ecodesign requirements for	Topic: Sets minimum seasonal space heating energy efficiency (SSHEE, η_s)

space and combination heaters	requirements and requirements for product data Coverage: Products with an output ≤ 400 kW. No minimum performance requirements are set for sorption heat pumps. Only covers products providing water based heating.
Commission delegated regulation (EU) No 811/2013 Energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device	Topic: Requirements for energy labelling and product data Coverage: Heat pumps≤70 kW
Commission regulation (EU) No 814/2013 Ecodesign requirements for water heaters and hot water storage tanks	Topic: Sets minimum water heating energy efficiency requirements and requirements for product data. Coverage: Heat pumps with a rated output ≤ 400 kW and hot water storage tanks with a storage volume ≤ 2000 l.
Commission delegated regulation (EU) No 812/2013 Energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device	Topic: Requirements for energy labelling and data fiche Coverage: Heat pumps ≤70 kW with an integral or separate storage volume ≤ 500 l
Number not available - Ecodesign requirements for air heating products, cooling products and high temperature process chillers energy related To be added latest details of Lot 21	Topic: sets minimum seasonal space cooling energy efficiency requirements Coverage: Heat pumps with a rated heating capacity up to 1 MW and a rated cooling capacity up to 2MW. Currently awaiting approval with implementation in January 2018
Microgeneration Certification Scheme (MCS) Guidance	MIS 3005 Installer standard for heat pumps MCS007 Product Heat pump standard MCS 026 - SCOP and SSHEE Calculator MCS 027 - SPER and SSHEE Calculator MCS 028 - DHW Calculator
Ground Source Heat Pump Association (GSHPA) Guidance documents	Shallow ground source standard Vertical borehole standard Thermal pile standard Thermal Transfer Fluid Standard (under development) Open Loop Standard (under development).

Annex B – Standard heat pump barriers

In this Annex we list the barriers identified for standard heat pumps (See section 9), which are also relevant for high temperature products, with a similar level of relevance and magnitude.

Consumer Barriers

Consumer confidence / trust

The reputation of standard heat pumps has suffered because of previous poor installed performance in the market. For example, one housing developer interviewed has an ‘absolute prohibition’ on using ASHP due to negative experiences from previous schemes, and will only consider them in exceptional circumstances. This is a **major barrier**. Research suggested that poor performance was either due to poor installation[32] or incorrect operation, both of which can be overcome.

This barrier is common to heat pumps more generally, and acceptable performance would need to be demonstrated for this technology.

Aesthetics

Aesthetics are a **major barrier**. Feedback from demand-side interviewees suggested that real-world buyers care more about aesthetics than marginal energy savings. This can be less of an issue in the countryside or for properties with more space, where units can potentially be concealed behind bushes or fences, or further away from buildings.

High temperature heat pumps have no discernible difference to standard heat pumps in this regard.

Technical Barriers

Space

Lack of space is a **major barrier** (and could also be considered a market barrier due to the nature of UK housing stock). External space is required for the heat pump unit, as well as internal space for a water tank. The effect of this barrier will vary by property type. Non-urban properties are less likely to have space restrictions than high-density urban dwellings. This is a major barrier in parts of the market with space constraints.

[32] Expert interviews; Residential heat pump installations: the role of vocational education and training, *Colin Patrick Gleeson, 2015*

While high temperature heat pumps are bigger than standard heat pumps, they usually require a smaller hot water tank.

Installation and Maintenance Challenges

Poor installation of standard heat pumps had a very negative impact on their reputation in the market. To avoid a similar situation with high temperature heat pumps (if the market is even able to distinguish between them), it is important that similar poor installation is avoided as the market grows.

Shortage of necessary skills

There has been a lack of capacity of trained installers for electric heat pumps[33]. This is a **minor barrier** that could hold back supply once demand grows. Given the importance of installation quality on in-use performance[34], poor performance of early installations could be a barrier to further uptake of heat pumps (as has proved to be the case with standard heat pumps). Consumers may also be concerned about a skills shortage for maintenance.

The skills shortage has improved and many manufacturers run training courses or have special relationships with groups of installers. However, some stakeholders still raised this as an issue during interviews for this research.

The skillset required for installation of both standard and high temperature heat pumps is similar.

Speed of installation

When the boiler is a 'distress' purchase, speed of installation forms a significant part of the purchasing decision for a replacement. The gas boiler market is mature, with a number of experienced heating engineers in the market which would allow a boiler to be bought and installed in under a day[35]. Installation of a high temperature heat pump will typically take a similar amount of time to a standard product, however there is less likely to be a need to alter the heat distribution system or radiators, which can shorten overall system installation time. This is a **minor barrier.**

Number of players in the supply chain

Feedback from interviews was that there are too many players in the supply chain, often resulting in poor specification or installation. A number of interviewees questioned why manufacturers are not involved in the design and installation of units. There was confusion as to why a manufacturer may not even perform a health check post-installation. This is a **minor barrier**.

High temperature heat pumps do not differ from standard heat pumps for this barrier.

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[33] Pathways to High Penetration of Heat Pumps, *Frontier Economics, 2013*

[34] Expert interviews

[35] The Future of Heating: Meeting the Challenge, *DECC, 2013*

Market Barriers

Readily accessible and low-cost gas network in UK

The extensive gas network and relatively high cost of electricity per unit of energy compared to gas in the UK is a **major barrier** as it means that that in-use cost savings from heat pumps are potentially lower compared to other countries[36]. Volatility around energy prices adds to uncertainty around savings.

This barrier remains for high temperature heat pumps.

Low Replacement Opportunities

Gas boilers have long useful lives of 10 – 15 years, and consumers are reluctant to replace them unless they are coming to the end of their life. This is a **minor barrier** that is not limiting the market.

This barrier is similar for high temperature heat pumps.

[36] IEA HPP Annex 42: Heat Pumps in Smart Grids – Market Overview, *Delta-ee, 2014*

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