How to reduce the cost of heat pumps

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nesta

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1. Introduction and summary

Heat pumps are currently the best low carbon option for heating most homes. They are highly efficient, use electricity which is increasingly generated from renewable sources, and can be adapted to heat almost all homes effectively. However, heat pumps are currently expensive, which makes them unaffordable for many households. This is a major barrier to their widespread adoption.

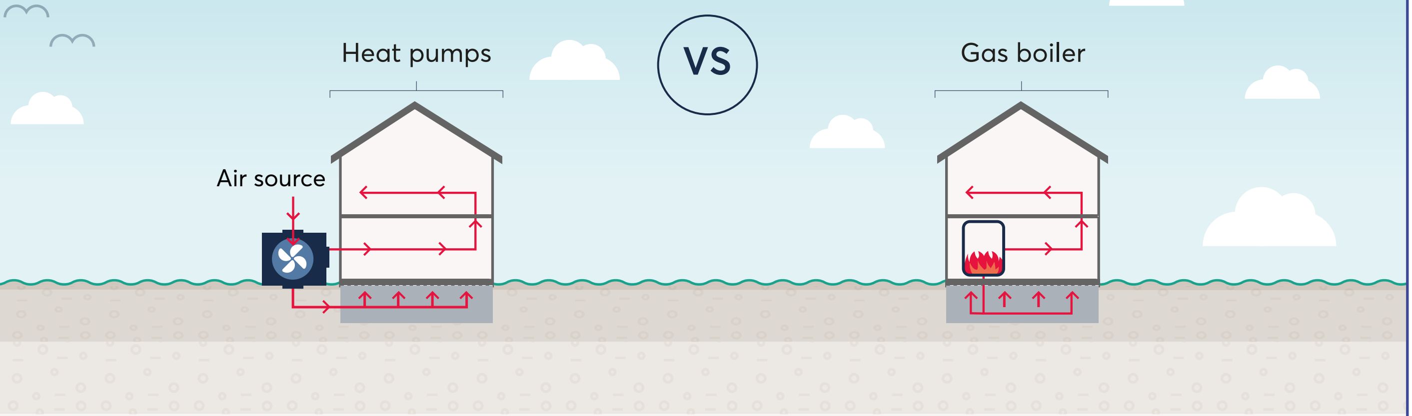
This paper sets out a comprehensive analysis of the cost of heat pumps and the prospects for making them more affordable. Our analysis shows that, while heat pumps are currently more expensive than gas boilers, it would take only relatively modest changes to make heat pumps competitive on price.

In particular, changes to **reduce the running costs** of heat pumps can make a big difference. We find that three changes, which are all realistic under current policy and market conditions, could bring the whole life cost of a typical heat pump to between **£230 and £270 per year more** than a gas boiler.

If these reductions in running costs were combined with a £5,000 reduction in the upfront cost of a heat pump, equivalent to the subsidy offered by the UK government's Boiler Upgrade Scheme, then heat pumps would become **£60 to £110 per year cheaper** than a gas boiler over their lifetime.

The whole life costs of heat pumps compared to gas boilers

(estimates for different types of property)



Heat pumps will become more attractive with running cost savings likely from 2022 onwards

The median of costs for purchasing, installing and running a heat pump are currently higher than those for gas boilers across all property types. However, with policy changes and achievable improvements in installation quality, heat pumps could generate annual running costs savings sufficient to offset the difference in upfront costs within equipment lifetimes.

	Small	Medium	Large
Property type	50-100m² Flats – medium	100-150m² Terrace/Converted flat/ Maisonette; 50-150m² Post-1950s bungalow, Semi-detached	150-200m² Detached – large
Today – **Baseline costs**: Current whole life cost per year for an air-to-water heat pump relative to a gas boiler	£670 more	£840 more	£1,190 more
Future policies or likely scenarios in 2022 – **Reducing running costs**: Increased heat pump efficiency; Energy suppliers offer heat pump tariff; Switch levies from electricity to gas	£270 more	£230 more	£260 more
PLUS **Reducing upfront costs** (Equivalent to the Boiler Upgrade Scheme): Reduces upfront cost by £5,000	£60 less	£110 less	£70 less

Key findings

The cost of heat pumps needs to fall

Heat pumps are currently the best low carbon option for heating most homes, but they are expensive. Air-to-water heat pumps, the most common type in the UK, typically involve a significant upfront cost, from around £9,000 for a flat to £13,000 or more for a larger house. The median cost is around £10,500. The upfront cost of air-to-water heat pumps has been rising in recent years, increasing by over 15 per cent since 2018.

Although heat pumps turn energy into heat much more efficiently than gas boilers, their running costs also tend to be at least as high, because electricity currently costs four to five times more per unit than gas. When upfront and running costs are combined, heat pumps currently cost between **£670 per year for smaller homes** and **£1,190 per year for larger homes**[1] more than gas boilers over their lifetime.

Cost is not the only barrier to the adoption of heat pumps, but it is one of the most significant. If heat pumps are to become widespread, their cost needs to fall. That applies to both the upfront cost of installation and the whole life cost, taking into account energy bills. The UK government has set a goal of installing heat pumps into 600,000 properties a year by 2028, and it is hard to see how this can happen without the costs of heat pumps falling.

The heat and buildings strategies from the UK and Scottish governments have set the right direction for increasing the adoption of heat pumps (with the Welsh government's expected in 2023), but cost remains a critical factor. The new Boiler Upgrade Scheme, which will offer £5,000 subsidies to install a heat pump in England and Wales, and the Home Energy Scotland Loan will help some households on cost. However, the subsidies are only set to run for a limited time and will only benefit a capped number of households. The heat pump market will need to work without large subsidies in the long term, so reducing cost is crucial. Governments across the UK will need to make further changes, including those recommended in this paper, to make this happen.

The cost of a heat pump varies a lot in different homes

One of the unusual features of heat pumps is that their costs vary depending on the home in which they are installed. A heat pump is not just an off-the-shelf solution – it needs to be part of a heating system that is tailored to the home it's in. The size and output of the heat pump, the home improvements required as part of installing it, and the ongoing running costs of a heat pump all vary depending on the specific home. In our analysis, we found wide variation in the cost of installing a heat pump. Around **16 per cent of heat pump installations cost more than £15,000**, while **18 per cent were under £8,000**, and it is hard to explain this variation using obvious variables such as the size of the heat pump or home.

This cost uncertainty affects the development of the market for heat pumps, and may make people less likely to choose them. It makes it harder for householders to know what the 'right' cost of a heat pump should be. This increases the chances of customers paying higher prices, and may reduce trust and confidence in heat pumps. Price uncertainty also makes it harder for suppliers to price their services effectively and riskier to invest and innovate.

Cost reductions will come from many sources, not just the heat pump itself

The full cost of a heat pump is made up of three main components: the heat pump system itself; installation (including labour, radiators and piping); and running costs, primarily the electricity used to run it. **Under current policy and market conditions**, we estimate that **running costs make up 55-65 per cent** of the total cost of a heat pump over its lifetime. The upfront cost of the heat pump system[2] makes up 15-20 per cent, while the installation makes up around 20 per cent.

There is scope for reducing cost in all of these areas, but two stand out as being the most important areas for cost reduction:

> **Installation costs** (i.e. fitting a heating system in a home, not including the heat pump unit's cost itself) – installation costs typically make up half or more of the total upfront cost of a heat pump. Reducing the number of days it takes to install a heat pump is likely the main driver of cost reduction here.

> **Running costs** (i.e. the cost of electricity to run a heat pump) – there is scope for heat pumps to become even more efficient (i.e. use less electricity per unit of heat) and for electricity to become cheaper relative to gas. Reducing the running costs of a heat pump below those of a gas boiler will be crucial, particularly as this will likely make financing offers more viable.

There is a lot of scope for making heat pumps cheaper

Although heat pumps are currently more expensive over their lifetime than gas boilers, it should be possible to close the gap with relatively modest changes. In particular, there is scope to lower the running costs of heat pumps significantly, to make them an attractive option.

We have modelled the impact of three changes:

> Switching environmental levies from electricity to gas.

> Increasing the efficiency of heat pump systems in homes.[3]

> Giving households with heat pumps access to a discounted heat pump tariff for the electricity.[4]

We find that these changes **bring the whole life cost of a heat pump much closer to that of a gas boiler**. This ranges from:

> **£270 per year** more for a heat pump in a **smaller home**.

> **£230 per year** more for a **medium-sized home**.

> **£260 per year** more for a **large home**.

These costs include both the upfront and running costs of a heating system spread over its lifetime.

Reducing upfront costs has less relative impact than reducing running costs. However, if the above savings in running costs could also be combined with a £5,000 reduction in the upfront costs of a heat pump installation (equivalent to the subsidy from the UK government's Boiler Upgrade Scheme), a heat pump would become **between £60 and £110 cheaper** than a gas boiler over its lifetime.

In the future, it is likely that heat pumps will still have a higher upfront cost than gas boilers, but with significantly lower running costs. This will make financing for heat pumps crucial, removing the burden of upfront costs from households while using the lower running costs to repay the cost of finance.

The shape of the market for heat pumps matters

The heat pump market is likely to change over the coming years, with the current split between manufacturers, installers and energy suppliers becoming increasingly blurred, and market competition increasing. This is important, because there has been little evidence of downward cost pressure on heat pumps so far, especially on installation costs. Since 2015, the upfront costs of a heat pump have increased by 15 per cent, but heat pump equipment trade prices have only increased 5 per cent, suggesting installation costs are rising more rapidly. Productivity in the wider home maintenance sector[5] – which includes boiler installers alongside plumbers, electricians and others – has not increased at all in the last 25 years. This suggests a lack of competition or innovation in the installation sector. Whether heat pump installation is done by smaller or larger firms, it needs to be competitive and reward innovation.

The heat pump market also needs more trained installers. The only way for prices to fall while installations increase is to have a sustained increase in supply in the market; without this, extra demand for heat pumps is only likely to push prices up. It is also essential that customers – as well as banks providing finance – can trust heat pumps as a reliable, comfortable and affordable way to heat homes. This can only be achieved if there are enough high-quality heat pump installers in the market.

Recommendations

1. Manufacturers should focus on increasing heat pump efficiency

While the cost of heat pump units is relatively high, the gains to be made by lowering their costs are unlikely to be significant.[6] However, the efficiency of a heat pump – how well it converts electricity into heat – has a direct impact on running costs, which make up a much larger share of lifetime costs. **Increasing heat pump efficiency by 10 per cent typically reduces running costs by around 8 per cent**, equivalent to between **£65 and £150**[7] **per year**. By contrast, reducing the cost of a heat pump unit by 10 per cent would only reduce whole life costs by £15 to £30 per year. There are likely more gains to be had from increasing the efficiency of heat pump installations (system and unit) than reducing their purchase cost.

Efficiency and quality of heat pumps should be an important consideration in government's policies on heat pumps, such as the proposed Market-based Mechanism for Low Carbon Heating. If the government is to mandate heating manufacturers or energy companies to supply a set quota of heat pumps, it is vital that this leads to higher efficiency, quality and longevity of heat pumps.

2. The UK government should adjust the cost of electricity and gas to make heat pumps more affordable to run

In our modelling, the single biggest saving to be made on the running costs of heat pumps is to shift environmental levies from electricity to gas. This switch, which the UK government is already considering, **would reduce the whole life cost per year** of a heat pump relative to a gas boiler by **£260 for a smaller home to £600 for a larger home**. This is equivalent to around 30 per cent of current heat pump running costs. Alternatively, if the government only switches social levies (such as ECO) to gas, while moving the remaining levies from electricity bills into general taxation, the reduction in the relative price of a heat pump would be **£190 to £450**.[8] Implementing this change as soon as possible will be crucial to the development of the heat pump market, although any changes should also protect fuel poor and vulnerable households.[9]

Government should also consider other ways to close the gap between gas and electricity prices. Heat pump adoption has been much faster in other countries, such as France, Norway and Sweden where electricity is less expensive compared to gas. In particular, the UK government should continue to focus on increasing renewable electricity generation and seek ways to weaken the link between natural gas and electricity prices.[10]

More widely, applying a carbon price to fuels for home heating would also make heat pumps significantly more attractive (by raising the price of gas), although it is not considered in this paper.

3. Government should remove VAT on home heating retrofits[11]

Home retrofits currently attract VAT at the full 20 per cent rate for equipment costs, unless equipment costs make up less than 60 per cent of the total cost. This significantly increases the cost of some retrofits, especially considering that VAT on new build homes is charged at the reduced 5 per cent rate. Even in cases where equipment costs are kept low, the 60 per cent threshold may provide an incentive for installers to overstate labour costs, undermining the transparency of the market. As the UK now has the ability to set its own VAT rates, the government should remove all VAT on low carbon home retrofits, or failing that, set a consistent, low rate across all construction activity. This would significantly reduce the cost and complexity of installing heat pumps and other energy efficiency measures.

4. The heat pump market needs more high-quality suppliers

Increasing the number of high-quality installers of heat pumps must be a priority for the governments across the UK and for everyone involved in the heat pump market. There are a number of things needed to make this happen:

- More access to training, including training offers for existing heating engineers and training or apprenticeships for those leaving education.
- Giving confidence to potential installers that the heat pump market will grow.
- Lower barriers to entry, so that it is easier for new companies and workers to become heat pump installers.

Government may also want to consider providing additional incentives to people who train as heat pump installers, alongside its proposed Market-based Mechanism for Low Carbon Heat, which focuses on manufacturers' role in the market.

5. The heat pump market needs to become more transparent

Greater transparency and certainty for consumers about what heat pumps cost – in terms of upfront installation costs and lifetime running costs – is crucial if the heat pump market is to grow. A more transparent market, in which everyone can access information and build trust in heat pumps, is in everyone's interests. The UK Government has taken a step towards this with projects such as the Department for Business Energy and Industrial Strategy's (BEIS) ongoing Electrification of Heat Demonstration with a commitment to monitor and report on the in-situ performance of around 750 heat pumps installed as part of the feasibility study.[12]

There is a need for tools which give customers a better understanding of how much a heat pump could cost in their home, to help them make informed choices about heat pumps. Our research on people's experiences of researching heat pumps[13] identifies getting certainty on cost as a key issue for customers, but there is very little reliable information that can be tailored to a person's home. Existing heat loss calculation tools are a valuable resource to help suppliers estimate the cost of a heat pump, but are too complex for most customers to use.

Manufacturers and installers should also be more open about the prices they charge. For example, providing an itemised breakdown of installation costs, separating the heat pump unit, labour costs and any additional changes to the home should become standard in the industry.

6. Heat pumps need service innovation as much as product innovation

Lowering the upfront costs of heat pumps requires improvement in services as well as in manufacturing. The processes for choosing the right heating system for a home, purchasing it and installing it all need to improve.

Elements of this innovation may include:

- More widespread use of software tools, such as heat loss calculators, to improve productivity and installation quality among installers.
- Manufacturers to support independent (or consortium) advice services for low carbon heating systems and retrofits.
- Industry developing methodologies for reliably reducing heat pump flow temperatures[14] such as standardising a cost-optimal approach for identifying the minimum, critical radiators to replace and innovating to reduce installation time required for ceiling or underfloor emitters.[15]

7. Financial institutions should prioritise green finance products for heat pumps

It is likely that heat pumps will always cost more to install than gas boilers but, in future, higher upfront costs will be offset by lower annual running costs. This will make the provision of finance – enabling households to smooth out the upfront cost over a number of years – both important and attractive to the adoption of heat pumps. Developing fair, customer-friendly finance offers for heat pumps – whether through long-term repayment plans, green mortgages, personal loans, heat-as-a-service offers or government-backed loans – should be a priority for financial institutions such as the UK Infrastructure Bank,[16] Scottish National Investment Bank and the four governments of the UK.

8. Suppliers should aim to make heat pumps much cheaper in smaller homes

The upfront cost of installing a heat pump in a flat is not significantly cheaper than in an old detached house. The median cost for flats is around £9,000, compared to around £13,500 in a pre-1950 detached house. Given the significantly lower amount of heat required in smaller homes, there may be much cheaper solutions for installing heat pumps in flats. These might include using more modular installation processes, or considering alternative types of heat pump, such as air-to-air heat pumps.[17] This may be an area for innovation by heat pump suppliers, or could alternatively be a worthwhile area for a future challenge prize.

Methods and data sources

This paper is primarily informed by data from the Microgeneration Certification Scheme (MCS) and the Energy Performance Certificate (EPC) dataset, which we have linked together to provide insights into the costs of heat pumps in different homes. The sample of the MCS dataset that we used provides data on heat pump installations in 60,000 homes from 2010 to 2021. By linking this to the EPC dataset, we are able to identify data about most of these homes, such as their age, size and property type. (We were able to match around 84 per cent of our sample to the EPC database, although the EPC dataset does not include Northern Ireland.) The MCS data only covers MCS-certified heat pump installations, which may not be representative of all heat pump installations (we estimate that our sample represents around a quarter of all heat pumps installed in homes). We are extremely grateful to MCS for allowing us to use its data for this research.

We also consulted the National Energy Efficiency Database (NEED) to verify actual expected heat demand and used an analysis by Renewable Energy Consumer Code (RECC)[18] on in-situ heat pump performance of UK installations from the Renewable Heating Incentive monitoring programme.

2. Background to this paper

Aims of this paper

At Nesta, our mission to build *a sustainable future* is focused on encouraging, enabling and accelerating the reduction of UK household emissions through venture building, innovative partnerships and system shaping.

We have produced this paper to help understand:

- How much heat pumps cost to install and run in different types of home.
- How these costs have changed over the last decade.
- The drivers of costs, including installation, manufacturing and running costs.
- The prospects for cost reduction in future years.

Our aim is to help inform and steer decisions by heat pump suppliers, policymakers and intermediary bodies involved in home heating. We also hope to identify key areas for further research and action by Nesta and by other organisations.

Heat pumps explained

How a heat pump works

Heat pumps extract heat from a source (air, ground or water) into a working fluid (refrigerant) and transport it into buildings. The process is not too dissimilar to passengers crowding into an underground train carriage and then releasing the pent-up heat at the next station. Heat pumps have been heating buildings since the 1950s with the most significant improvements in the late 1980s. Heat pumps have been the primary component of fridges for even longer. Depending on system design, heat pumps can also provide cooling – a growing consideration for the UK as the climate warms, especially in larger cities.

The most common type of heat pump in UK homes is an electric-powered air source heat pump, transferring heat from outside air to the inside heating system. The system is further specified by the heat delivery method – whether a hydronic (-water) system or a 'warm air' (-air) system. The prevalent type is air-to-water with one external unit that delivers heat to both the central hydronic system (radiators or underfloor)[19] and domestic hot water. Most of our analysis in this paper is based on air-to-water heat pumps. Air-to-air units are less common in UK homes, but are widely used in shops, hotels and other commercial premises. Air-to-air heat pumps are prevalent in Nordic countries and moderately common across Europe.

Efficiency and performance of heat pumps

The majority of air source heat pumps in the UK market are capable of operating even when outdoor temperatures reach -15°C to -20°C (newer models to -28°C). Even in northern Scotland, temperatures have been above -15°C for 99.9 per cent of the time over the past 30 years, with the coldest night in winter being -3°C most years.[20]

Heat pumps are sold according to their heating output capacity and efficiency at specified conditions. Capacity is described in kilowatts (kW)[21] and determines if the particular model will be able to meet a home's heating requirement.[22] Nominal heat pump capacities for UK homes are typically 5kW to 16kW.[23]

The other crucial factor is a heat pump's efficiency – how well it uses electricity to generate heat. There are a few measures of efficiency for a heat pump and the overall heating system:

> **COP (Coefficient of Performance)** – this measures how much heat a heat pump produces per unit of electricity at a particular moment under specified conditions. The COP for an air-to-water heat pump is typically at least three, which means it outputs three times as much heat energy as the electricity it uses as an input.

> **SCOP (Seasonal Coefficient of Performance)** – this adjusts the COP for variations in the climate and other limited operational factors which affect the performance of a heat pump over the year. Because heat pumps get slightly less efficient as the outside temperature drops, the SCOP accounts for this in a model considering one of three climate region profiles. This gives a more accurate view of how efficiently a heat pump will actually perform.[24] A typical air-to-water heat pump has a SCOP of between three and four.

> **SPF (Seasonal Performance Factor)** – SPF is more detailed than SCOP and accounts for additional factors, such as hot water heating demand, UK-specific climate, electricity standby, and a more advanced partial load effect. Air-to-water heat pumps typically have SPFs between 2.3 and 3.2. It is a more comprehensive measure of heat pump performance. However, studies with observed (or simulated) SPFs are less widely available currently and the measure is not formalised within MCS directly. Therefore, although we use SCOP in regards to MCS data, when modelling whole life costs scenarios we use referenced mean SPF values from real-world operation or experiments representative of installations from the past few years (ensuring a more conservative estimation).[25] If interested in calculating a modelled SPF value from current manufacturer-submitted data (SCOP values), see the Domestic Annual Heat Pump System Efficiency (DAHPSE) Estimator by BRE.[26]

The efficiency of a heat pump is crucial to determining its running costs. Increasing the SCOP or SPF of a heat pump by 10 per cent translates directly into lower electricity use, and should lower running costs by around 8 per cent.[27]

Different types of heat pump

There are two types of heat pump installation, relating to whether they are placed inside or outside the home:

> **Monobloc** – majority of components are nested into a single package installed outside the home with, at minimum, a supply and return pipe connection required indoors into the existing heating distribution system (alongside a buffer tank, if required, and a controls interface, if selected).

> **Split** – composed of an external unit (fan, condenser, compressor) and at least one internal unit (evaporator and controls), whether a hydrobox (hydronic systems) or fan coil (warm air systems), connected by pipes with refrigerant as working fluid. A few new systems can control a mix of air and water internal units (similar to commercial models). Splits have previously been slightly more efficient than monoblocs, but this may no longer be true depending on the model. Splits have higher installation costs due to refrigerant charging which requires an F-Gas Certified installer.[28]

Besides air source heat pumps, other sources include:

> **Ground source** – absorb heat from the ground via vertical borehole heat exchangers or loops of flexible hose. Less well known sources include underground railway tunnels, direct incorporation into and under streets, and long-term seasonal storage in larger ground or industrial elements.

> **Water source** – closed loop (i.e. flexible hose in a river) or open loop (water source as the working fluid). Less well known sources include sewers, mines and rainwater runoff.

The two types of compressors within the prevalent vapour-compression design of heat pumps (compressors 'upgrade' the collected heat) are:

> **Variable-speed (inverter-driven)** – primarily used in air source heat pumps to optimise their performance across varying weather conditions, having helped increase efficiency alongside capacity of air source units in cold climates by reducing the need for backup electric heating. More expensive and may have relatively shorter lifetimes (15 years).

> **Fixed speed** – optimal in ground and water source units since the sources have much narrower temperature ranges, yielding higher efficiencies in these conditions. May have longer lifetimes (20 years).

The major alternative types of heat pump system are:

> **Hybrid systems**[29] – a heat pump paired with another system using intelligent controls to optimise energy usage and costs or emissions. Paired systems include gas boilers, solar thermal collectors, thermal stores and solar photovoltaic (PV) panels with battery storage. Although gas boiler hybrids can help alleviate peak demand for the grid, other solutions (network flexibility schemes and storage self-consumption) are likely to be sufficient, within the timeframes considered, while also remaining low carbon and having lower overall whole life costs when paired with deep time-of-use tariffs such as Octopus Go. Additionally, hydrogen is not considered further in this paper due to development over the next decade remaining isolated to selected clusters.

> **Exhaust Air Heat Pumps (EAHP)** – installed indoors with two ports (pipes/ducts) for supply and exhaust air. Supply air could be from a property's ventilation (if there is a high enough flow rate) but is often sourced through a port on an external wall alongside the exhaust. They can cover full heating demand effectively only in well-insulated and/or smaller homes and flats. They may have similar capacity to heat pump units in compact hybrid systems.

> **Air-to-air** – often easier to install at lower cost for the same capacity of an equivalent air-to-water system. Also, enables more effective cooling with less condensation concerns relative to air-to-water. Unfortunately, there is limited data on air-to-air systems within the UK from which to verify performance and suitability,[30] despite a significant presence in climates similar to the UK.[31] Total installation costs will likely range from £2,200 to 10,000. An expected SPF may be 2.4.

> **Low GWP (global warming potential) hot water heat pumps**[32] **or natural refrigerant heat pumps**[33] – used for applications in which hot water demand is very high or close to the space heating requirement (large families, highly insulated homes, or commercial), having higher efficiencies in heating water quickly (+20-30 per cent), along with performance and capacity being less affected by colder climates compared to heat pumps designed with conventional refrigerants. However, for the UK's climate, these will often be less efficient overall (particularly CO_2 models) compared to conventional models (by 7-10 per cent), unless hot water and space heating demand are similar. Propane models have an overall performance closer to conventional currently. Although, with smaller volumes (sizes) required of the compressor (or potential use of ejectors), the capital costs may be lower for these units (depending on manufacturer's design constraints and marketing).

> **High temperature heat pumps** – most heat pumps are capable of supplying 45-55°C heat with moderate efficiency, some exceeding 60°C (this includes the former category of low GWP hot water units). However, high temperature units are primarily composed of cascaded heat pumps (essentially the external components of two heat pumps with different refrigerant or other design factors packaged into one unit). These will have an efficiency penalty compared to conventional, low GWP, and low temperature heat pumps, with running cost increases in nearly all cases being greater than upfront cost savings from less upgrades (no replacement of radiators or improved insulation).

Policy context

Heating homes accounts for 14 per cent of all UK emissions – nearly twice that of the air transport industry (8 per cent, pre-pandemic).[34] This is primarily due to the high prevalence of fossil fuel central heating systems in the UK (+90 per cent), with natural gas boilers as a convenient solution for UK's historically draughty homes.[35] In April 2021, the UK government amended the Climate Change Act (2008) to require the achievement of net-zero emissions by 2050 and adopted an accelerated interim target of 78 per cent reduction (1990 levels) by 2035. The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 committed Scotland to a legally binding target of net zero by 2045. This ambition will require significant adoption of electric heat pumps across UK homes in all scenarios modelled by the Department for Business, Energy and Industrial Strategy (BEIS) and the Committee on Climate Change (CCC). BEIS is aiming to ramp up annual heat pump installations from 35,000 to more than 600,000 by 2028 by:

> Indicating a phase out of new gas and other fossil fuel heating systems by 2026 in off-gas grid homes and by 2035 for most other homes.[36]

> Offering £5,000 grants to adopt a heat pump, known as the Boiler Upgrade Scheme, to run from 2022 to 2025 in England and Wales. A separate scheme is available in Scotland.

> Rebalancing energy prices to ensure that heat pumps are no more expensive to buy and run than gas boilers by 2030.

> Introducing a UK-wide market-based mechanism for increasing the uptake of low carbon heating, which would place an obligation on either boiler manufacturers or energy suppliers to install more heat pumps.

> Accelerating new builds to 300,000 annually (roughly 1.8x peak rate from the last decade);[37] alongside new regulations (the great majority of which will have heat pumps, according to the forthcoming Future Homes Standard, England).

> Investing in research and innovation programmes.

> Additional funding towards continuing government-funded grant schemes targeting off-grid or low EPC homes of social housing residents, and low income and fuel poor households.

All funding announced by the governments of the UK is primarily aimed at encouraging the adoption of air-to-water heat pumps specifically.

The overall goal is to establish a more competitive market and streamlined supply chain by 2025 to enable a 25-50 per cent reduction of heat pump installation costs, reaching 50-75 per cent by 2030. These projected reductions are partially based on previous market research commissioned by BEIS, but appear also to be heavily based on industry announcements. These include Octopus Energy's announcement of its expectation to reduce total upfront costs of air source heat pump installations (in 1970s semi-detached homes) to £5,500 by 2023 compared to the current median of around £10,500.

Development of the market for heat pumps

At present, the market for supplying home heating – primarily gas boilers – is made up of manufacturers, installers and energy suppliers. Manufacturers and energy suppliers are typically larger firms, whereas the installation market is dominated by small, local businesses and self-employed heating engineers.[38] Manufacturers generally do not offer installation services, and although there are examples of energy suppliers offering boiler installation services (for example British Gas), these are not widespread.

To date, the nascent market for heat pumps has followed a similar pattern; however, the prevalence of merchants (such as Wolseley) helping to provide a more timely and comprehensive supply chain experience (and potential discounts) to installers is a bit less developed.[39] Manufacturers are primarily larger businesses – including some existing boiler manufacturers (for example Vaillant) and some new entrant conglomerates (for example Mitsubishi, Samsung). Installers remain smaller firms, typically heating engineers who have diversified into heat pumps.

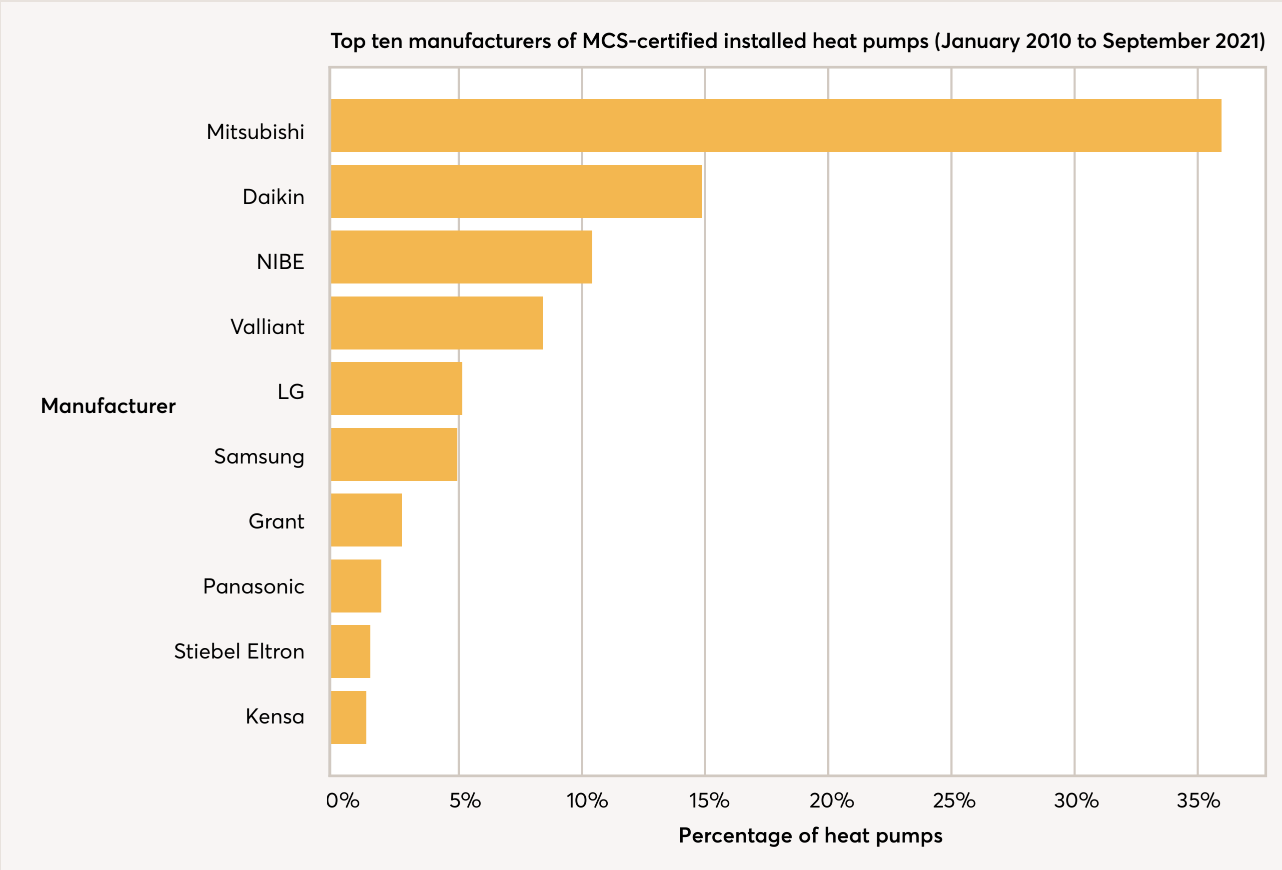


Chart 1. Major manufacturers of heat pumps in UK homes

Source: Nesta analysis of MCS data.

However, some energy suppliers – most notably Octopus Energy – are beginning to enter the installation market. This is significant, because it may shake up the structure of the installation market. Larger companies may be able to find economies of scale, such as bulk buying heat pumps more cheaply or automating some parts of the installation process. They may also face some diseconomies of scale, such as the challenge of providing a standardised service to homes that are all different.

Larger companies entering the market look set to offer installation costs well below the current market rate. If offers like this are successful and can be scaled up significantly, it is likely to drive down costs across the market and possibly drive installers that cannot compete out of the market. However, the key issue will be whether this cheaper installation package can be delivered in homes with different characteristics, and crucially whether it can maintain a good quality of heating. Octopus Energy, for example, has chosen to initially target a limited housing archetype – semi-detached homes built between 1970 and 2000 – to mitigate this concern. However, it is not clear whether other types of homes can expect to see similar cost reductions for heat pumps over the coming years. The rest of this paper explores some of the trends and issues around this question.

The UK government's proposed Market-based Mechanism for Low Carbon Heat may also influence the structure of the heat pump market. It proposes a new obligation on boiler manufacturers (or on energy suppliers instead) to sell a set quota of heat pumps each year, which must be fitted in homes. Depending on whether and how this obligation is introduced, it could lead manufacturers, energy suppliers or both to become more involved in the installation market. Nesta and the Behavioural Insights Team have published a response to the Market-based Mechanism at a similar time to this paper.[40]

Productivity in the heating industry

Over the past 25 years, productivity has grown in the manufacturing sector but stagnated in the installation sector. Chart 2 below shows the change in output per hour since 1997 in the manufacturing subsector, which includes boilers and heat pumps (yellow line; SIC code 24-25), and the construction subsector, which includes heating installers (red line; SIC code 43).

While manufacturing productivity has grown by almost 70 per cent since 1997 – well above the economy-wide level of 30 per cent – the installation sector has seen zero productivity growth over this period. This lack of productivity growth among installers is concerning, and will need to be addressed within the heat pump installation sector, at least if the cost of installations is to fall.

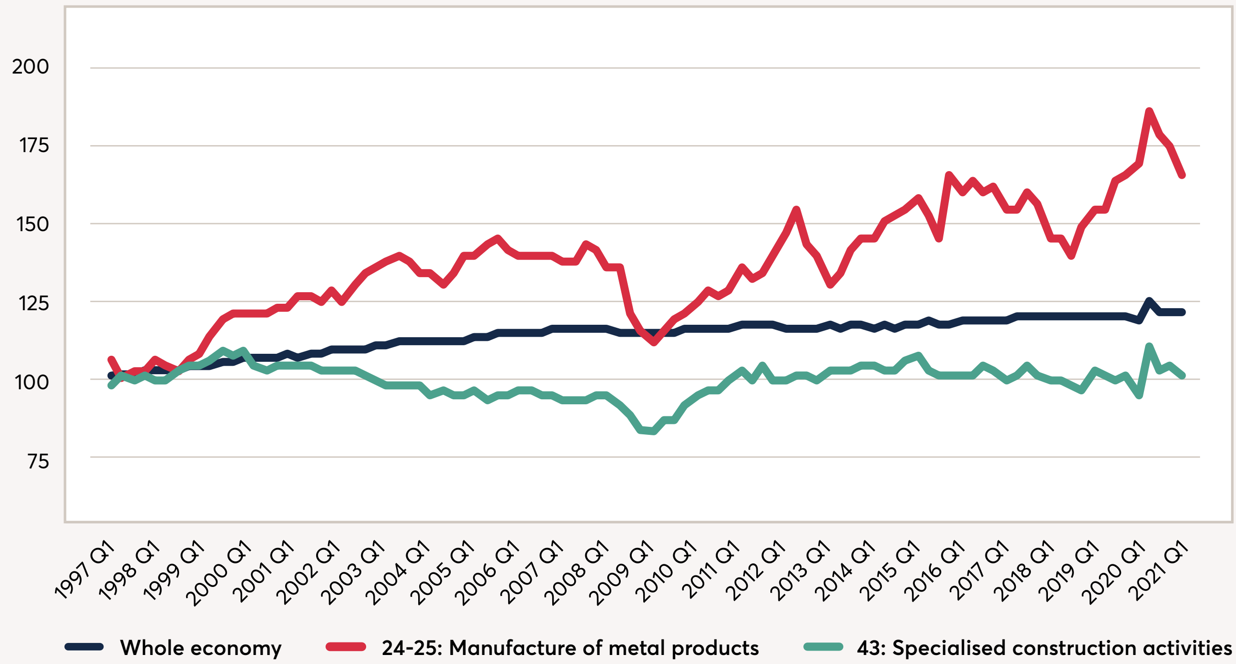


Chart 2. Productivity growth in the manufacturing and installation sectors

Source: ONS Labour productivity statistics for division-level industries. Chart measures output per hour by sector, indexed so that 1997 = 100. SIC code 24-25 covers the manufacture of basic metals and metal products, which includes manufacture of boilers and heating devices. SIC code 43 covers specialised construction activities including heating installers, plumbers, electricians and other trades.

3. How much does a heat pump cost?

This section shows how much heat pumps currently cost to install and run in different types of home, using:

> Data from MCS on the cost of installing heat pumps in recent years.[41]

> Heating demand modelled around home archetypes grouped from the Cost-Optimal Domestic Electrification (CODE) study and verified against the National Energy Efficiency Database (NEED).

> Projection of capped tariff rates for gas and electricity (Great Britain average).

To calculate running costs, we have used tariff rates for electricity and gas modelled over the lifetime of a heat pump and gas boiler. Given the recent spike in energy prices, we have modelled an increase in prices in line with the expected April 2022 price cap,[42] followed by a return to the previous capped levels from 2024 onwards. The price cap increase temporarily narrows the gap between electric and gas. In the long term, we have modelled gas prices remaining constant, with electricity rates decreasing by 3 per cent (from capped levels) based on a conservative estimate of new and cheaper electricity generation coming on stream, among other factors.[43]

In this section, 'upfront cost' refers to the full upfront cost of installing a heat pump, including both the heat pump unit and the cost of the installation work.

Table 1 shows the median upfront cost of a heat pump in eight different types of home, ranging from modern flats to old, detached homes.

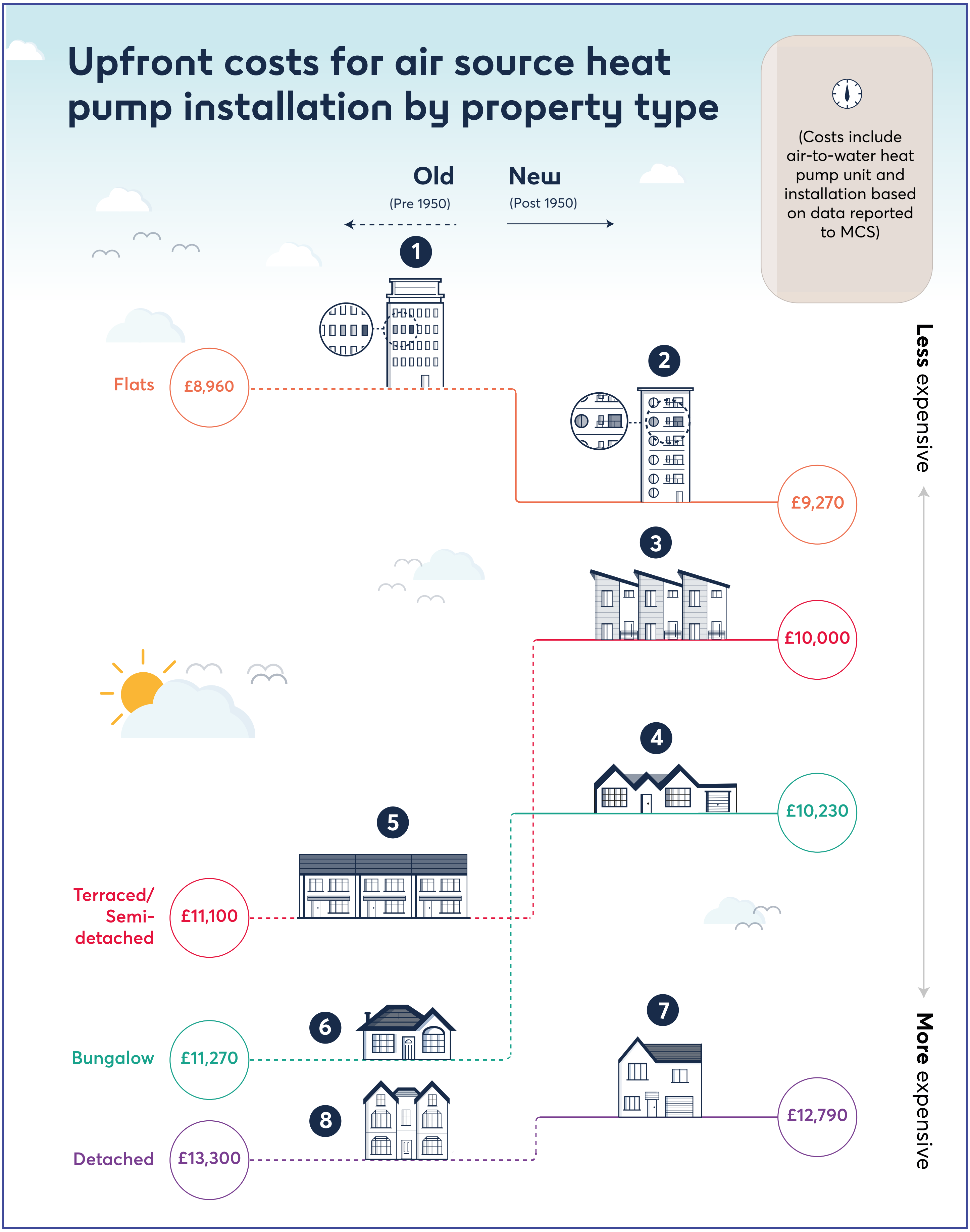


Table 1. Upfront cost for air source heat pump installation by property type

Notes: Heat pump upfront installation costs from Nesta analysis of MCS data, using the median for each type of housing.

Table 2 takes this analysis further by considering the whole life cost of a heat pump, which includes both running costs and upfront costs. It also compares heat pumps to gas boilers. The table simplifies the types of home into three categories: smaller homes, medium homes and larger homes. The size category is used to imply levels of annual heat demand requirement – primarily for demonstrative purposes.[44]

Table 2 shows that air-to-water heat pumps currently cost between £670 and £1,190 per year more than gas boilers over their lifetime. This is because heat pumps have both higher upfront and running costs than gas boilers – and running costs actually play a bigger role than upfront costs in driving this price gap. At present, air-to-water heat pumps typically cost 30-50 per cent more to run than gas boilers.

However, this gap narrows to 9-12 per cent for either low flow temperature installations (which may require radiator, piping, or, occasionally, insulation upgrades) or exceptionally efficient heat pumps in a high-quality installation.[45] This is modelled along with other cost reduction scenarios in more detail in Table 3 later in this report. It should be noted that these are conservative assumptions – median **SPF of 2.71**, which has been derived from in-situ monitoring of heat pumps, and asset **lifetime of 15 years for heat pumps**.[46] The top 20 per cent of installations achieve an SPF of around 3.2, and asset lifetimes for heat pumps often exceed 20 years.[47]

Estimated whole life cost for installing an air source heat pump in 2022

Upfront costs in £ 2021 prices, running costs as capped rates (Ofgem), excludes any grants

Property type	Heat pump	Gas boiler	Heat pump *SPF 2.71*	Gas boiler *Efficiency 85%*	Heat pump 15 year lifetime	Gas boiler 12 year lifetime	Relative price difference
	Upfront cost (£ total)		Running cost (£ per year)		Whole life cost (£ per year) including running costs		
Smaller home Flats – medium (50-100m²) (excl. converted flats; maisonettes)	£9,100	£1,500	£790	£560	£1,440	£770	Heat pump **£670 more**
Medium home Terrace/converted flat/ maisonette (100-150m²) Post-1950s bungalow/ semi-detached (<150m²)	£10,100	£1,800	£1,170	£810	£1,880	£1,040	Heat pump **£840 more**
Large home Detached – large (150-200m²)	£13,100	£2,200	£1,730	£1,190	£2,640	£1,450	Heat pump **£1,190 more**

Table 2. Current cost of a heat pump relative to a gas boiler in three types of home

Estimates in Table 2 are based on RHI monitoring used in RECC's report by Colin Meek[18] and MCS data. As both have a higher proportion of installations in England the analysis here is weighted towards England. Outside temperatures affect heat pump annual seasonal efficiency (both SCOP and SPF measures), and, therefore, running costs. The SPF selected for heat pumps is 2.71, determined from the RECC report and Muhammad Abid[45] within the more comprehensive SEPEMO H4 system boundary.[18] Gas boiler efficiency is modelled as 85 per cent. Occupant assumptions are approximately 1.5, 2.5, and 3.5 (small to large home).

We would expect a slight difference in heat pump performance in Scotland, particularly in the north of the country resulting in slightly higher running costs (and whole life costs) per year would be expected ranging +7-12 per cent £110-£280.

Heat pump upfront installation costs are from Nesta analysis of MCS data, using the median for each type of home. Annual heating demand is modelled from archetypes in BEIS's research report CODE,[106] with assumptions from above, and verified with National Energy Efficiency Data-Framework gas consumption figures. Small, medium, and large heat demand (kWh per year): 9,500; 14,500; 22,000. Running costs include annual maintenance of £120 for heat pumps (for five years while under warranty, otherwise £0) and £80 for gas boilers (lifetime).

Energy rates are based on Ofgem's capped rates (GB average) within the previously mentioned forecast. See previous text section and endnotes 42-43 for greater detail. Decommissioning costs for gas line to the home (capping) and associated reduction in running costs were not considered, but typically over 10-15 years these would cancel each other.

Gas boiler installation costs were based on BEIS (2017),[107] Delta-EE for BEIS (2018)[108] adjusted to £ 2021 prices and Heatable.

All values in the table are fixed in 2021 prices. No discounting has been applied to future years, to keep this as a purely financial analysis.

Breaking down the cost of a heat pump and installation

There are several different aspects to the cost of a heat pump system. The main ones are:

> The heat pump unit itself.

> The installation cost for the heat pump, including any changes needed to the home such as replacement radiators and buffer or hot water tank.

> Annual running costs, primarily the electricity used to run the heat pump.

At present, heat pumps are more expensive than gas boilers on each of these costs, particularly the upfront costs of the heat pump unit and installing it. And while heat pumps use far less energy than gas boilers, they, typically, have slightly higher running costs than gas boilers, as electricity is far more expensive per kWh (4-5x).

From market research and sources referenced in the charts below, the heat pump unit[48] (5-16kW) is estimated as 30-40 per cent of MCS installation costs, ranging from £2,500 to £5,500 (market trade prices), if we assume that the majority of installations from recent years are modern, inverter-driven, variable-speed, vapour-compression type heat pumps. Lower cost models, such as those with fixed-speed compressors (optimal for ground or water source, but less optimal for air source) can be found in a range of £2,000-4,000. Full equipment costs are around 55-60 per cent of overall installation costs. A 'typical' breakdown is detailed in Chart 3. This breakdown was aligned to previous estimates by Delta-EE[49] used by BEIS, but corrected as detailed in the chart's notes, finding only minimal differences in percentages (2 per cent).

Equipment – 60%		Non equipment – 40%	
Heat pump – 55% (60% of equipment)	**Installation – 25%**	**Heat pump – 25%** (60% of non-equipment)	**Other – 15%**

Installation equipment costs include	Other non-equipment costs include
~5% each: Buffer tank, hot water cylinder, emitters, piping/valves	**~3% each:** Travel, distribution, commissioning, design/specification
~2% each: Electrical connection, controls, mounting/construction, heat meters	**~2% each:** Admin/overhead, project management

Chart 3. Breakdown of unit and installation costs for a typical air-to-water heat pump (8kW, variable-speed compressor, minor system upgrades)

Source: Estimates for the breakdown of the main components listed (equipment, non-equipment, heat pump unit, cylinder, buffer tanks, etc) are from collected market rates, comparisons across literature, and BEIS reports by Cambridge Architectural Research[109] and Delta-EE (2016)[49] regarding domestic retrofits then fitted across the median and upper and lower quartiles of MCS installation costs. The percentage listed for labour and most non-equipment costs are from a previous report for DECC by Delta-EE.

The use of the word, 'typical' may be misleading, however, as the composition of costs can vary widely depending on consumer preferences, previous heating system, and grant scheme requirements; and more moderately by property heat loss rate or specific installer(s) and region. Some examples of situations that usually vary the cost of an installation are given below.

Customer preferences

> **Maximisation of thermal comfort or lower running costs** – customers may opt either for underfloor heating (or ceiling radiant panels) or insulation (energy efficiency) upgrades to enable the lowest flow temperatures and smooth heating. This normally increases upfront costs significantly, **15-35 per cent**, but often leads to greatly decreased running costs and improved health outcomes.

> **External appearance of system (preference or planning requirement)** – if a home requires a heating capacity greater than 10kW, but the customer prefers (or planning requires) a smaller external unit, this typically adds a premium of around **15 per cent to the heat pump unit cost**.

Previous heating system

> **Hot water cylinder already present and compatible with selected heat pump** – this typically lowers upfront costs by around 6 per cent, but is a less frequent occurrence.

> **Radiators undersized 45-55°C or small diameter piping (microbore[50])** – if a home's existing radiators are too small to work with a heat pump's flow temperature, it may be necessary to replace either a few critical radiators or all radiators and piping. This can have a moderate or major effect on upfront costs with higher amounts attributed (or similar) to underfloor heating (up to 35 per cent).

Grant scheme requirements

> **MCS and consumer code certification** – to be eligible for Renewable Heat Incentive or the Boiler Upgrade Scheme, installers must be MCS certified and members of a consumer code. Works funded by ECO also require following PAS 2035 standards. This increases upfront costs through certain required efficiency works,[51] overhead, commissioning and project management. However, the consumer protection and intended higher quality installation should result in improved running costs savings and reduced rework. An absolute minimum non-equipment MCS installer premium to expect might be around £100.[52]

Property layout, energy efficiency and thermal mass

> **Buffer tank niche** – buffer tanks are often capable of being designed out of most installations without impacting thermal comfort or system efficiency significantly. However, they may be beneficial for homes with low insulation or thermal mass if they also have several bedrooms (needing various setback temperatures) or small volumes of water in the heating circuit, particularly if the installed heat pump has a fixed-speed compressor.[53] Future flexibility schemes may lead to a minor uptick in buffer tank installations.

> **Number and size of rooms** – more rooms may lead to replacement fittings and radiators or, for air-to-air, more fan coil units with costs potentially approaching air-to-water. Larger rooms or open floor plans may have the opportunity for air-to-air to be cost-optimal or underfloor to improve its cost benefit.

> **Efficiency improvements on moderate to well-insulated homes could result in modest ventilation measures being needed** – new standards on ventilation and overheating are reducing the likelihood of this being unexpected (or causing rework).

Specific installer and regional market

> **Installer relationships with heat-pump-specific distributors and manufacturers** can be important in early markets and may enable equipment discounts or trials and rebates.

> **Whether consumer or installer (firm) takes on project management role** – as heat pump installations often require more than one installer.

Chart 4 shows how the composition of upfront costs could vary for a domestic heat pump installation in a medium home within the same property type and heat demand requirements considering the factors above.

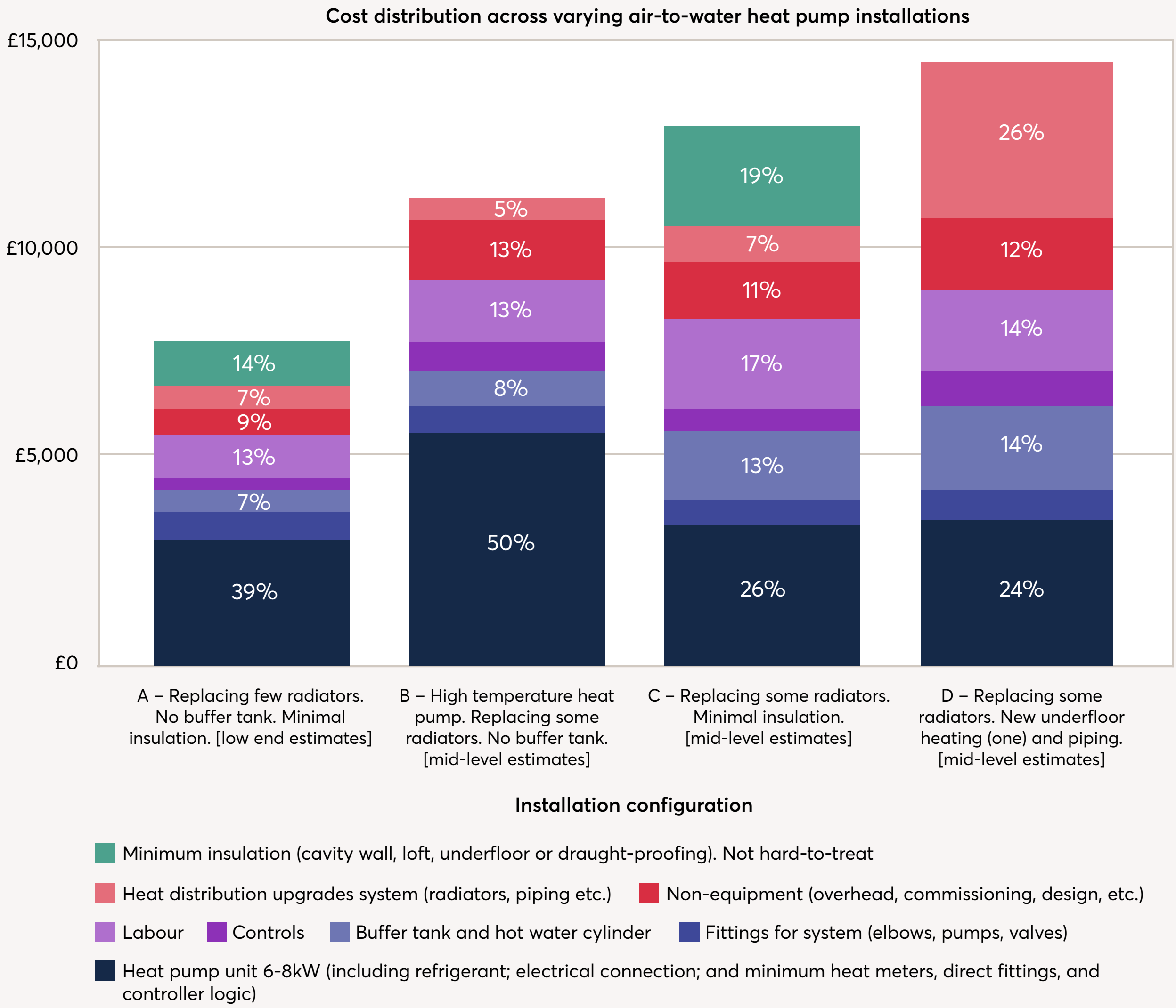


Chart 4. Varying costs depending on installation measures required and preferences

Source: data primarily from Cost of Domestic Retrofit Measures Report by Delta-EE (2018)[108] (commissioned by BEIS in 2018) with costs adjusted for inflation and corrected by market research, values across literature, and MCS installation data.[54]

Chart represents potential variance of upfront costs for an installation for the same medium-sized property (heat demand/loss) with different approaches. Configuration 'A' is a best case in which the installer is local (or in a competitive area for low carbon installations) and receives discounts on equipment (or reduced VAT), only the most critical radiators are replaced, and design excludes a buffer tank. Configurations 'B'-'D' represent the more prevalent, less-competitive, regions and considers different priorities and pathways. 'B' is for a high-temperature heat pump. 'C' increases insulation levels to reduce the heat pump capacity required and reduce radiator upgrades. 'D' upgrades the heating distribution with one level of underfloor heating to enable low flow temperatures. 'C' and 'D' consider efficiency and running cost savings or thermal comfort more evenly with upfront costs.

In terms of the heat pump unit itself, most of the cost is embedded in a few components, with half of the cost attributed to the compressor and the electrical controls combined. Chart 5 shows this breakdown for a variable-speed vapour-compression air-to-water heat pump unit. The highest raw material amounts by weight for the typical air source unit include reinforcing steel around 40-50 per cent (compressor), copper 15-20 per cent (piping, fittings), and low-alloyed steel 15-20 per cent (heat exchangers).[55] Relative to a gas boiler unit, heat pumps are more sensitive to copper prices and less sensitive to low-alloyed steel prices.[56]

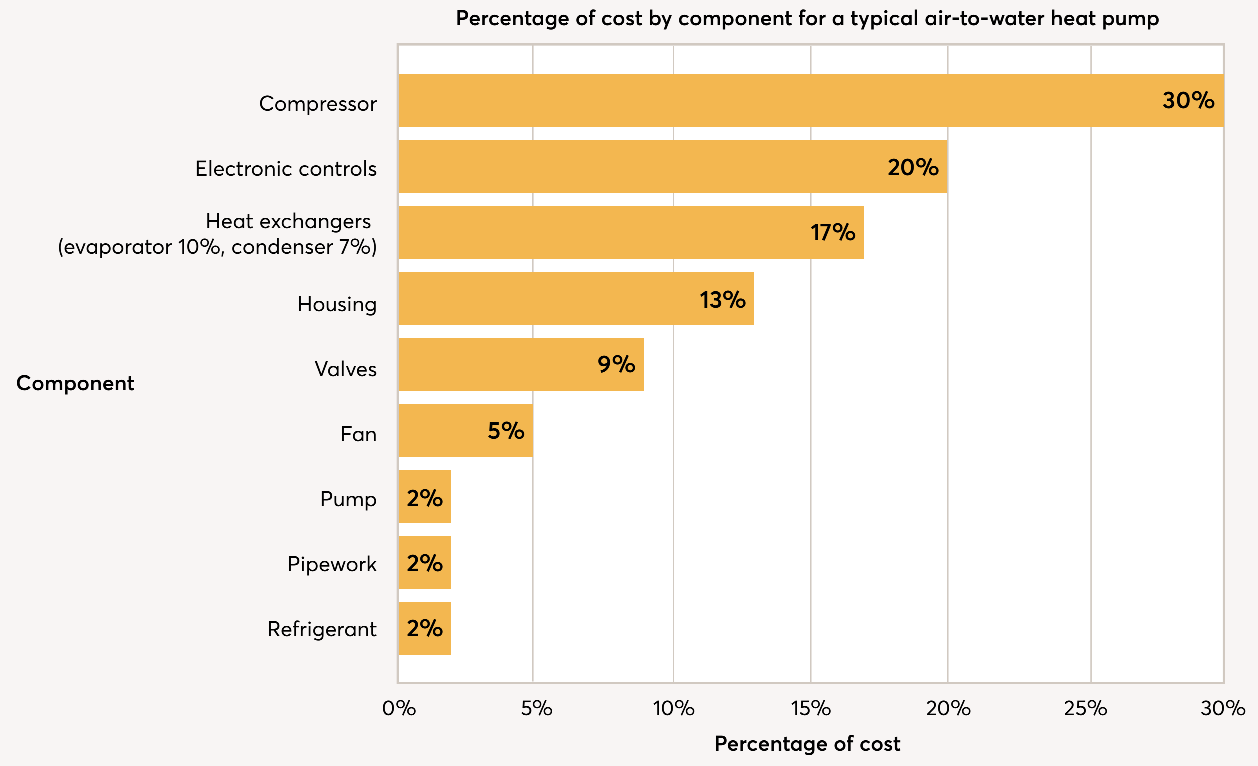


Chart 5. Breakdown of costs by component for typical air-to-water heat pumps

Source: market research commissioned by BEIS (Eunomia, 2020)[96] and cost equation estimates (Liu, J. and Lin, Z. 2021).[110]

Chart shows the breakdown of component costs for a typical inverter-driven vapour-compression air-to-water heat pump using conventional refrigerant (such as R32). For the same type of heat pump, the design and component costs will vary somewhat according to the specific conditions for which the heat pump is optimised including climate, low temperature, high temperature, or domestic hot water (varying the plant ratio, heat exchanger and compressor sizing). It is expected that for higher efficiencies within a similar system design, the percentage of overall cost attributed to heat exchangers would increase from that in the chart as the heat exchangers will either increase in size or change in design (manufacturing complexity, advanced materials). Low GWP (high pressure) systems, which use smaller compressors, will have a lower percentage for the compressor (possibly by half). Hybrid and high temperature units will have a higher percentage attributed to controls.

How much have recent heat pump installations cost?

We have analysed our linked MCS and EPC dataset of heat pump installations to assess the upfront cost of heat pump installations over the last few years. In this section, 'upfront cost' refers to the full upfront cost of installing a heat pump, including both the heat pump unit and the cost of the installation work. As indicated in the previous section, installation work may sometimes include upgrades to the home such as new radiators. The costs for such upgrades are assumed as included within the costs reported to MCS, excluding significant insulation works (unless integrated directly into a heating upgrade such as underfloor heating).[57]

The upfront cost of air source heat pumps has risen slightly in the last few years

Chart 6 shows that the median cost of an air source heat pump has increased slightly over recent years, **from around £9,000 in 2015 to £10,500 in 2021, an increase of 15 per cent** (rounding for deviation). Ground source heat pumps, which are much less common, have remained close to £20,000.

Over the same time period, heat pump equipment costs (market trade prices) have only increased by around 5 per cent. This implies that either installation requirements (less suitable homes requiring more upgrades, increased quality) or non-equipment costs (labour, overhead, commissioning, distribution) are putting greater upward pressure on installation prices. The fact that upfront costs are rising, not falling, is a concerning feature given the need to expand heat pump adoption. Chart 6 and previously stated figures were adjusted for inflation in household appliances.[58]

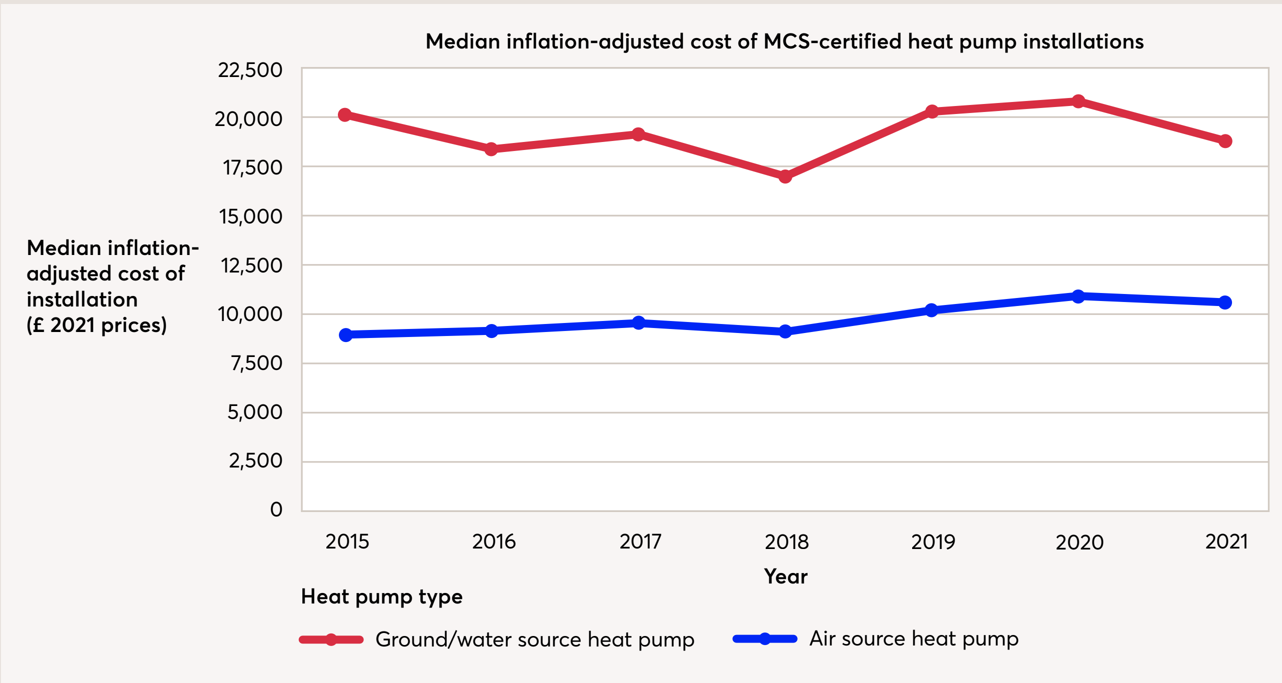


Chart 6. Median upfront cost of heat pumps since 2015

But heat pumps have become slightly more efficient

Although the upfront cost is rising, heat pumps are becoming slightly more efficient over time. This is important, because it translates directly into lower running costs. However, the increase in efficiency, at around 1-2 per cent a year, is relatively modest.[59]

Chart 7 below shows SCOP, a measure of how effectively heat pumps convert electricity into heat, at different flow temperatures. Lower flow temperatures, generally, result in more efficient performance,[60] though sometimes require larger radiators. The most common flow temperatures are 45°C and 50°C. While there are many reasons to choose a specific flow temperature, this may mean homes are missing out on a more efficient system with lower running costs.

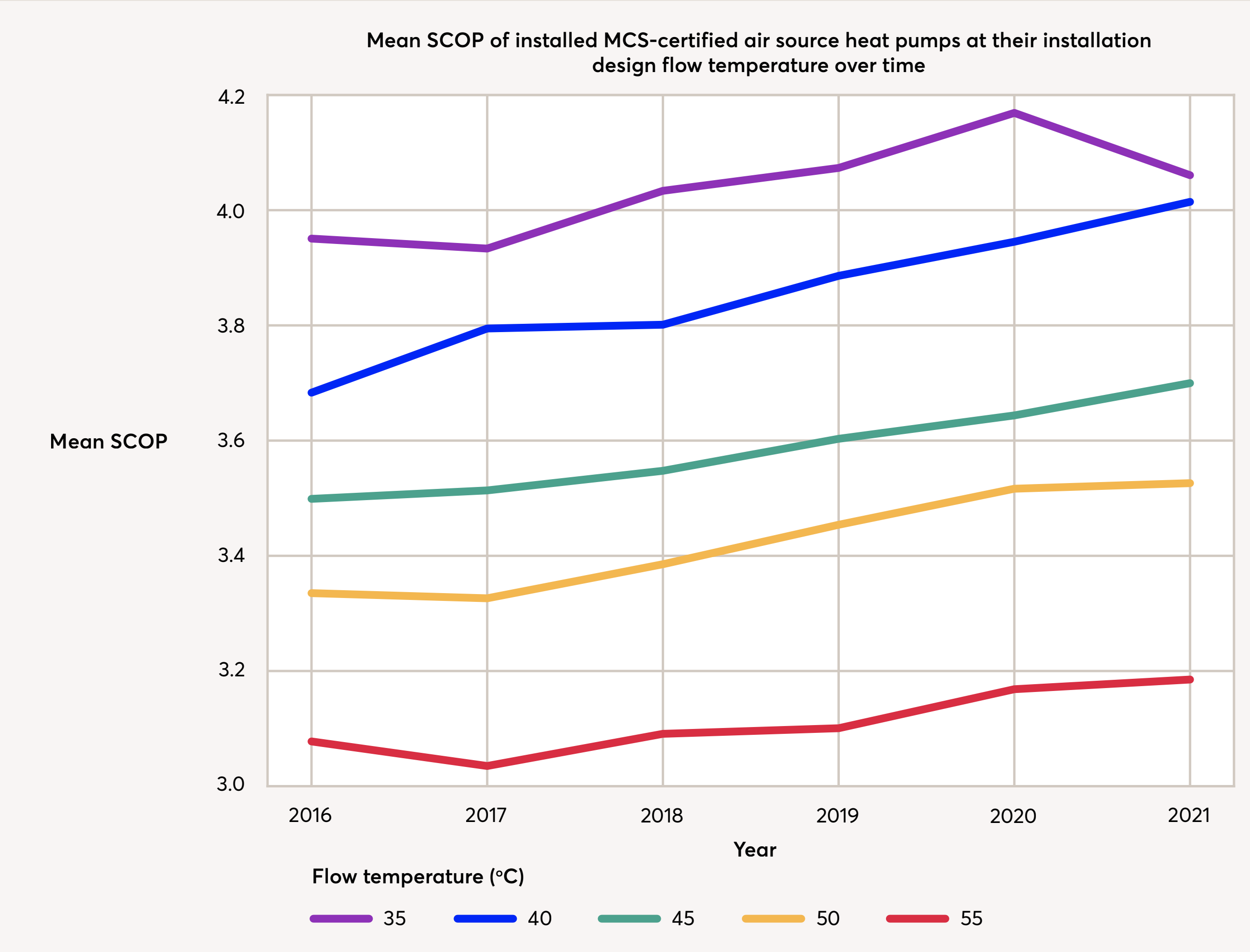


Chart 7. Mean SCOP (efficiency) of heat pumps at installed design flow temperatures over time

The size of a heat pump makes only a small difference to upfront costs

Larger heat pumps (measured by their kW input) are more expensive to install overall, but only slightly more than smaller heat pumps. For example, a system with an 8kW heat pump has a median cost just under £10,000, compared with around £13,000 for a 16kW heat pump: twice the heating capacity for only 30 per cent extra cost.

The variation in cost within heat pump size bands is also quite large. A 16kW heat pump package, for example, ranges from £4,000 to 8,500; however, the installed cost can vary from a few thousand pounds to over £30,000.[61] This reinforces how hard it is to predict the cost of installing a heat pump for any given home and suggests that most of the variation in upfront cost comes from the installation works.

Chart 8 below is a box plot, and shows the variation in costs for heat pumps of the same capacity. For each capacity band:

> The orange line shows the median cost of a heat pump at that capacity.

> The boxes show the interquartile range, or the middle 50 per cent of heat pump costs.

> The lines ('whiskers') show one-and-a-half times the interquartile range above and below the box.

> The black dots represent outliers, with each dot representing one heat pump installation of unusually high or low cost.

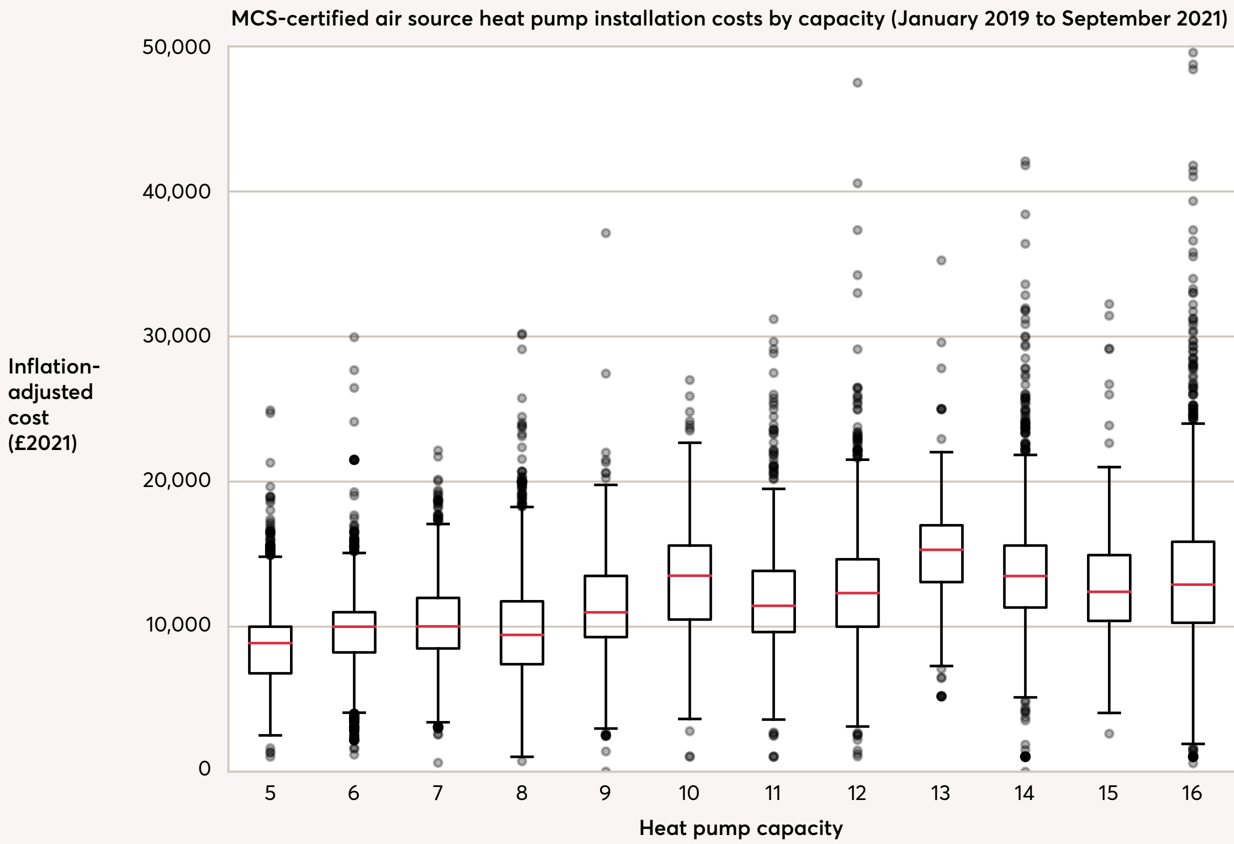


Chart 8. Distribution of air source heat pump costs by heat pump capacity

Bigger, older homes generally have bigger heat pumps installed

Older, larger homes generally have larger heat pumps installed. The median heat pump in a post-1950 flat is 5kW (typically the smallest heat pump on the market), whereas median capacity for a heat pump in a pre-1950s detached house is around 14kW. This result is not surprising, and reflects the fact that larger, older homes generally require more heat. Chart 9 shows this data as a box plot, with median, interquartile range and outliers.

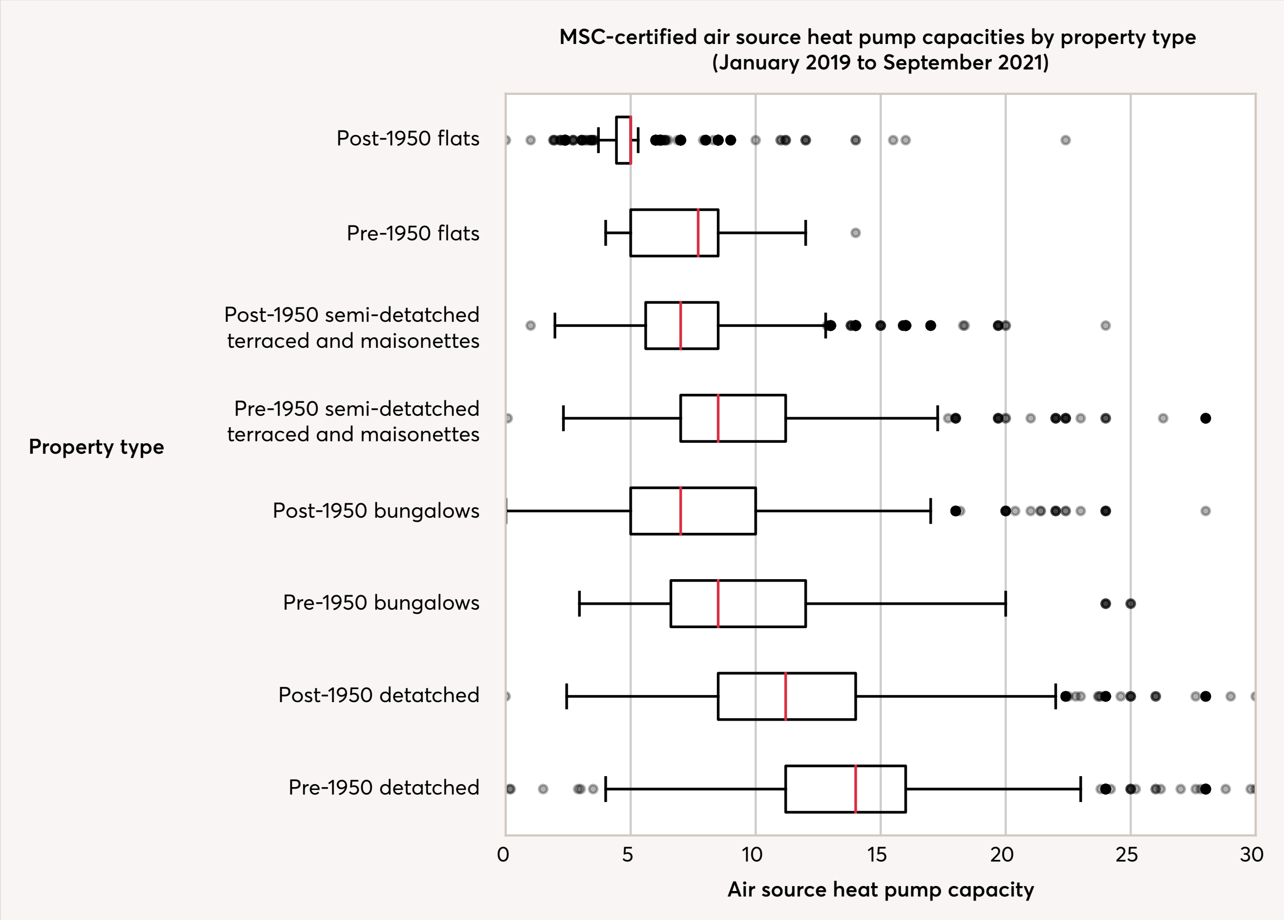


Chart 9. Capacity of air source heat pumps installed by property type

But the median cost does not vary much as homes get older and bigger

The upfront cost of installing a heat pump does not vary that much between smaller and larger properties. The median cost of installation in a post-1950 flat is around £9,000, compared to around £13,500 for a pre-1950s detached house.

This is a surprising result, and suggests that costs are not especially closely related to the amount of heat a property needs, nor the size of the home or heat pump.

There are several possible reasons why this could be the case – including high fixed costs for all homes, the influence of subsidies or a lack of cost-effective solutions for smaller homes – but it suggests that there may be scope for significant cost reductions for smaller homes. This is especially important as upfront costs make up a bigger share of lifetime costs for smaller homes (because running costs are considerably lower). Finding solutions which significantly lower upfront costs in flats and smaller homes is a key recommendation of this paper.

The variation in the cost of a heat pump is also very wide, especially for larger homes, which again reinforces the uncertainties involved in buying a heat pump.

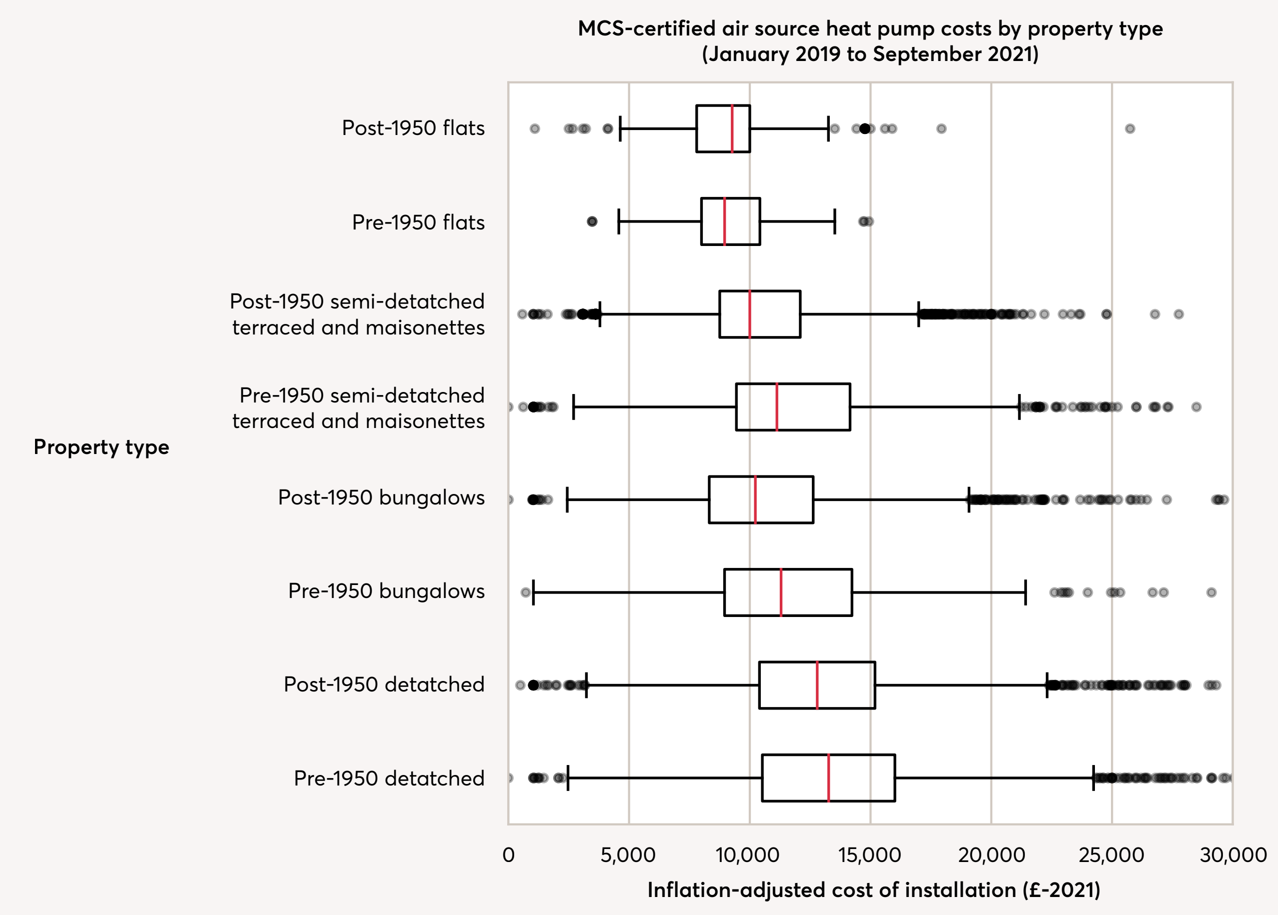


Chart 10. Distribution of air source heat pump costs by property type

Note: some extreme costs (<0.5 per cent of points) have been excluded from the plot to aid readability.

Upfront costs are important, but running costs also have a big bearing on heat pump adoption

While upfront costs are a large and uncertain part of the cost of a heat pump, annual running costs are also significant. A typical heat pump's life is at least 15 years, with running costs ranging from around £800 to £1,800 per year (see Table 2), which means many households will spend more running a heat pump over its life than installing it.

Evidence from other countries around Europe shows the importance of this effect. Countries with lower electricity prices relative to gas generally have much higher rates of heat pump use, often with high penetration of air-to-air. There are other factors, such as the availability of gas (generally the cheapest fossil fuel home heating option) or market share of high inefficiency boilers, but where electricity is relatively cheap, heat pumps tend to be more popular.

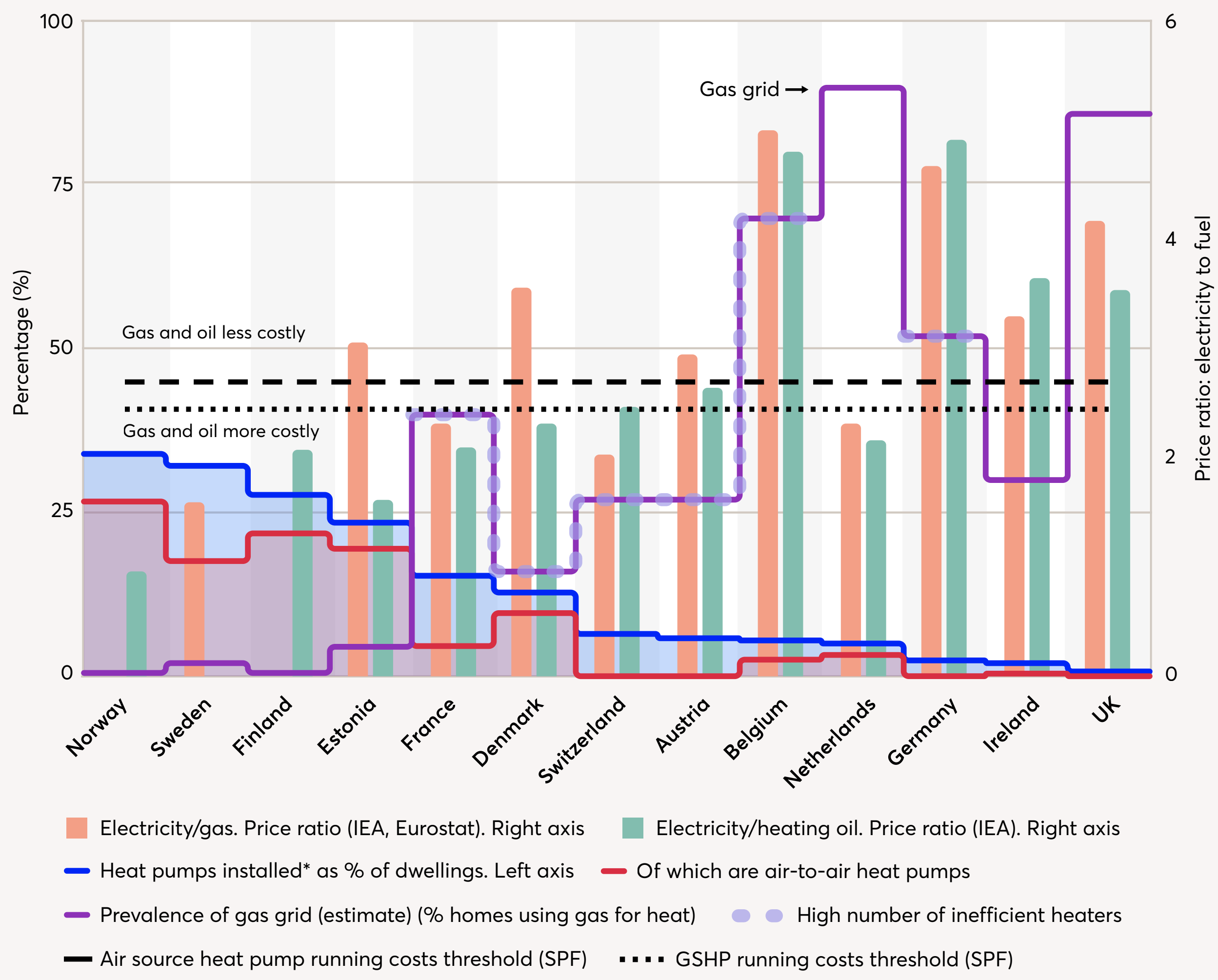


Chart 11. Heat pump adoption by country with overlays of fuel cost ratios (2019) and gas grid infrastructure

Note: higher heat pump adoption left to right. If a price ratio column is lower than the heat pump running cost threshold, that means the fossil fuel is more expensive than heat pumps.
Main sources: European Heat Pump Association, EurObserv'ER, International Energy Association. Heat pump SPF median values.

4. Prospects for reducing costs

Although the cost of heat pumps is currently high and variable, there is significant scope for cost reduction. This section looks at the prospects for cost reductions, as well as barriers to achieving them and lessons from other countries.

There are three main areas to focus on in trying to reduce the cost of heat pumps:

> **Heat pump unit costs** – we estimate that heat pump units themselves make up around 15-20 per cent of the total lifetime costs of a heat pump.

> **Installation service costs** – we estimate that the cost of installing the heat pump, including labour and adjustments to the home, make up around 25 per cent of the total lifetime cost of a heat pump.

> **Running costs** – we estimate that the electricity needed to run a heat pump makes up around 55 per cent of the total lifetime cost of a heat pump.[62]

Modelling cost scenarios for a 2022 installation

Key cost reduction scenarios

Although heat pumps are currently significantly more expensive than gas boilers, there is scope for closing this gap – whether by energy policies, design optimisation accessibility, installation quality, or additional services. The easiest way to do this appears to be lowering the running costs of heat pumps relative to gas boilers. Table 3 below shows the impact on a heat pump installed in 2022 of three running cost saving scenarios (or conditions). We have modelled these scenarios because they are relatively easy to achieve within current government policy or have a good chance of happening under current market conditions.

These scenarios are:

1. **Shifting environmental levies from electricity bills to gas bills**. This would reduce the whole life cost per year of a heat pump by between **£260** (smaller home) and **£600** (larger home), and is the single biggest saving we have modelled.
2. **An improvement in the quality of heat pump installations to make them run more efficiently in homes**. We have modelled efficiency improvements as either: an installation enabling a 10°C reduction in mean flow temperature below the typical 45-50°C; or an exceptionally efficient heat pump in a high-quality installation (proxied by SPF of top 20 per cent of installations). Achieving either of these efficiency improvements without significantly increasing current installation costs could reduce the relative whole life cost of heat pumps by **£110 to £260 per year**. Lowering this temperature may be enabled by additional (or larger) heat emitters (radiators or ceiling/underfloor), reduction of heat loss rates through improved insulation, or higher mass flow rates. See endnote[63] or Table 6 for estimates based on low and high upgrade costs.
3. **Households adopting a heat pump tariff for their electricity**, which offers a discount against either capped or market rates.[64] Prior to the energy price spike, energy suppliers such as Good Energy offered heat pump tariffs at around 8 per cent off the average market rate for Great Britain (equivalent to around 15 per cent off the capped rate). While these rates are not currently on offer, we expect them to return after 2023 if energy prices stabilise. An analysis on the dynamic time-of-use tariff Octopus Agile revealed it to yield a similar annualised rate.[65] These rates typically save a household around 10 per cent on energy bills compared to the standard capped electricity tariff (which we use as the baseline in our model).

We have chosen these three scenarios because they are all realistically achievable within a timeframe of a few years, and because they reflect the key priorities of making electricity cheaper and increasing the efficiency of heat pumps.

If all three of these scenarios occur together, it would close the gap such that a heat pump, relative to a gas boiler over its lifetime, would cost only **£230 to £270 more** per year. Heat pumps would still involve a much higher upfront cost – typically five times higher – than gas boilers in this scenario, but would have significantly lower running costs, making their whole life costs much closer.

The running cost savings have a larger overall benefit for larger homes than smaller homes for two reasons:

a. Larger homes have higher heat demands, so save much more from reducing running costs.

b. Upfront installation costs are only slightly lower in smaller homes than larger homes (roughly £9,000 versus £13,000), which makes upfront costs a greater share of the whole life cost in smaller homes.

Property type	**Baseline** Current (excluding any grants, policy changes or improvements)	**Shift levies from electricity to gas in 2022**	**Increased efficiency of heat pump systems** Upgrades enable flow temp. 10°C lower than nominal	**Heat pump tariff** ~10 per cent discount to market rate	**With all three conditions implemented, how do heat pumps compare to gas boilers?**
Costing format	Whole life cost per year relative to gas (£)	Whole life cost per year relative to gas (£) – [with cost reduction to baseline in brackets]			Whole life cost per year relative to gas (£)
Smaller home Flats – medium (50-100m^2) (excl. converted flats or maisonettes)	Heat pump **£670 more**	£410 [£260]	£560 (£110]	£590 [£80]	Heat pump **£270 more**
Medium home Terrace/converted flat/ maisonette (100-150m^2) Post-1950s bungalow, semi-detached (<150m^2)	Heat pump **£840 more**	£440 [£400]	£660 [£170]	£720 [£120]	Heat pump **£230 more**
Large home Detached – large (150-200m^2)	Heat pump **£1,190 more**	£580 [£600]	£930 [£260]	£1,010 [£180]	Heat pump **£260 more**

Table 3. Impact of lowering running costs on whole life cost of heat pumps

Notes: see text under Table 2 for baseline assumptions. See Box 1 below for more detail on scenario conditions. Positive values for whole life cost relative to gas means that a heat pump is estimated to cost more money within the scenario compared to a gas boiler installed in 2022 by that amount per year over its expected lifetime.

The impact of reducing upfront costs

Table 4 combines the reductions in running costs with a drop in upfront costs of £5,000, equivalent to the UK government's planned Boiler Upgrade Scheme subsidy. The subsidy itself actually reduces whole life costs by less than the changes to running costs we outline in Table 3.

When the two effects are combined – a £5,000 reduction in upfront costs and the three lowered running cost scenarios – heat pumps become substantially cheaper than gas boilers over their lifetime, by **£60 to £110 per year**.

Property type	**Baseline** Current (without subsidies, grants, policy changes or improvements)	**Reduce the upfront cost of a heat pump by £5,000** (Equivalent to Boiler Upgrade Scheme)	**PLUS** **All three running cost scenarios combined** Shift levies in 2022, increased efficiency, and heat pump tariff
	Whole life cost per year relative to gas (£)		
Smaller home Flats – medium (50-100m²) (excl. converted flats or maisonettes)	Heat pump **£670 more**	Heat pump **£340 more**	Heat pump **£60 less**
Medium home Terrace/converted flat/ maisonette (100-150m²) Post-1950s bungalow, semi-detached (<150m²)	Heat pump **£840 more**	Heat pump **£500 more**	Heat pump **£110 less**
Large home Detached – large (150-200m²)	Heat pump **£1,190 more**	Heat pump **£850 more**	Heat pump **£70 less**

Table 4. Impact of lowering upfront costs and running costs

Notes: see Table 2 notes and Box 1 below for notes, sources, and assumptions.

Box 1: Notes on Tables 3, 4 and 6

See Table 2 for baseline assumptions. This box includes more detail on scenario conditions.

Positive value for whole life cost per year relative to gas means that a heat pump is estimated to cost more money within the scenario compared to a gas boiler installed in 2022.

Baseline energy rates used are based on the regional average of Ofgem's capped rates – using the expected increased rates of April 2022 from 2022-23, then a return to October 2021 rates from 2024-35 with a slow 3 per cent decrease in electricity rates through to 2035 (from a conservative minimum projection of reduction in levelised costs for electricity generation with new wind and solar farms coming online from 2025-35 limited by capacity considerations).

The Heat Pump Tariff electricity rate is based on the discount that Good Energy's heat pump tariff (from April 2021) provided off the GB regional average of market rates (January 2020 to October 2021). Levy shifting is completed in a manner which maintains the absolute amount of the levy (rather than imposing the same percentage levels from electricity onto gas). Levy shifting can be representative of other policies which may affect gas/electric bills similarly (economy-wide carbon tax) or expected further reductions in electric generation levelised costs from baseline through 2035 as attributed from discounts achieved with high flexibility and grid services.

A lower 'mean flow temperature' refers to the heating distribution system's temperature. Lowering may be enabled either by additional (or larger) heat emitters (radiators or ceiling/underfloor), improved insulation, and higher mass flow rates. The values displayed in the table assume an optimal scenario in which no significant upgrade costs are required. Incorporating a level of upgrade costs would change the last column for whole life cost per year relative to gas for small/medium/large homes to £30 less/£40 less/£30 more (break even) at low costs and £190 more/£180 more/£280 more (no savings) at high costs. Cost values were derived from (BEIS, 2017),[107] (Delta-EE, 2018),[108] and limited market research, adjusted to £ 2021 prices.

The higher SPF of 3.2 (2.9 for Scotland) is derived from an average between the quantification of performance improvement expected per degree reduced in flow temperature and from observed efficiency achieved by the top 20 per cent of installations from the previously mentioned RECC report by Colin Meek.[18] The lower flow temperature scenario may also be indicative (to a limited extent) of purchasing a high-end heat pump with exceptional efficiency or a high-quality installation which may include optimal selection of heat pump type, optimal controls setup with weather compensation and minimisation of cycling, and pipe lagging.

Note that the 'Combined' scenarios do not equal the cumulative of the individual price differences due to the overlapping variable of efficiency being different in the two price difference groups (levies and quality) for both gas and electricity.

Other possible cost reductions for a heat pump in 2022

The following reductions have not been included in our central analysis, but could also further reduce the relative cost of heat pumps:

4. **Aggregated demand side response schemes and other grid services including flexibility from smart thermostats** – consumers may be able to earn **£60 per year** by participating in schemes offered by their distribution network operator or energy supplier[66] (and third-party companies).[67] If a smart hot water tank with grid services compatibility has been installed, such as Mixergy, this may increase to +£100 per annum (however, steep prices currently limit applicability to those with very high hot water demand[68]). Regulations preventing participation beyond certain thresholds (high thermal comfort standards) will likely be required for equity considerations. A hybrid heat pump and gas boiler system may also have access to enhanced services leading to similar rates.

5. **Solar PV installations with battery storage sized to cover both home nominal electric load and a portion of heating demand** – from a simplified model excluding grants, heat pumps can enable savings inaccessible to gas boiler homes from the electrification of heat demand by increasing solar self-consumption.[69] Dependent on the home's nominal electrical usage (2,000-7,000 kWh/yr) and heat demand (among other factors), an optimised installation is estimated to enable a reduction in whole life costs relative to gas boilers of **£160-£300 per year** (small homes may need an electrical consumption base of +4,000kWh to realise savings).[70] However, if considering other heating options with solar PV, installing an electric boiler with integrated thermal storage, instead, may yield lower whole life costs at this time.[71] For heat pumps, although the addition of solar PV and battery storage increases the upfront cost barrier (£12,000-£22,000), financial mechanisms are more established for solar PV packages. From a wider context, however, encouraging solar PV self-consumption has several distributional equity considerations which must be balanced with future policy coordination to minimise the potential for negatively affecting vulnerable groups.[72]

6. **Group purchasing platforms (or neighbourhood campaigns)** – enabling homeowners of existing builds within a community to access co-located installation price discounts and potential bulk purchase discounts. Such platforms exist already for rooftop solar panels[73] and community energy generation, and are likely to be attempted for retrofitting heat pumps. Discounts should result in **15-20 per cent savings on market prices** for installed costs.

7. **Removing gas tariff standing charges** – households could reduce whole life costs for heat pumps by a further £0–£60 per year relative to gas boilers by having their gas line capped and gas meter removed. Gas standing charges are typically 23p to 26p per day, and switching to a heat pump should remove the need for any gas connection. However, savings are dependent on whether the hob or range requires replacement (£150–£600) and/or supplier charges household for meter removal (£300–500, though not applicable to all households). Running (cooking) costs for an average household are estimated to be £25–£30 higher for electric hobs, which is included in our whole life cost estimate.

Estimating future reductions in the cost of heat pumps

As shown previously in this paper (and others[74]), the median cost for an air source heat pump installation has been increasing rather than decreasing over the past few years. Although true, it is possible that this is due to an increasing number of larger and older homes installing heat pumps (or ones with higher heat demand, treatment considerations, or more rooms and radiators). One indicator that this may be true is the trend of more installations occurring increasingly in larger properties as seen on Chart 12 and the increasing number of installations at higher designed mean flow temperatures.

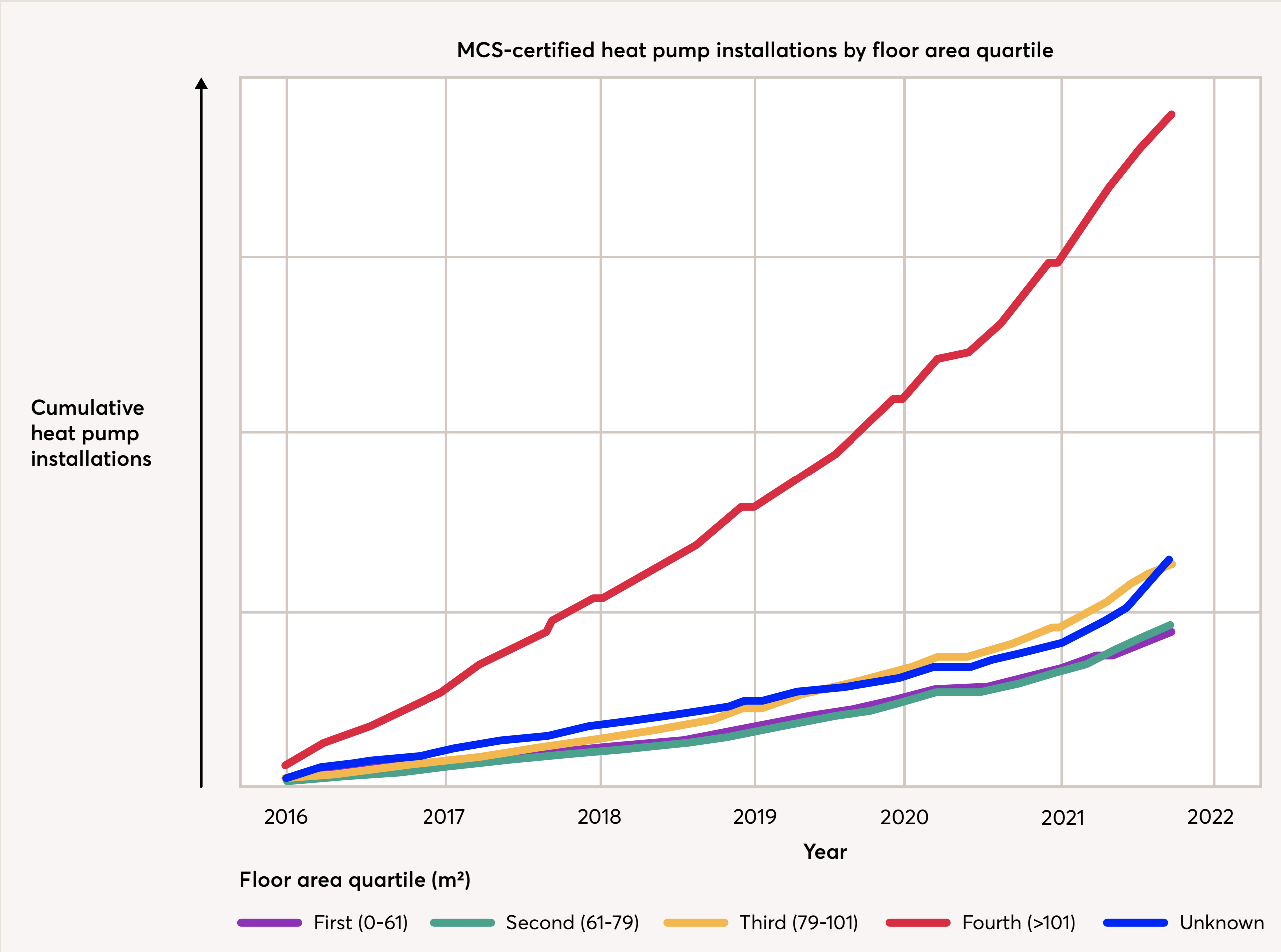


Chart 12. Cumulative number of heat pump installations by floor area quartile

Sources: MCS data with selected floor area quartiles estimated from EPC data.

Floor area quartiles from EPC data may underestimate actual quartiles within UK housing stock since EPC data is likely biased towards rented properties which are smaller overall.[75]

Estimating future cost reductions using experience and learning rates

To determine the potential level of further cost reductions to expect in the future for a selected technology, we can use experience or learning curves[76] to estimate experience and learning rates. The experience curve is an empirical model based on historical fits of price and/or cost data, with the experience rate indicating the fractional drop in price for each doubling of production volume.[77]

For the UK, similar learning rates for unit prices of combi gas boilers and air source heat pumps have been observed from 2010 to 2019 of 5 per cent and 6 per cent[78] respectively.[79] However, there is some doubt in the long-term accuracy of the rate for air source units.[80]

Although the upfront costs of heat pumps have increased in recent years, there are a number of temporary factors which may explain this, including steps to reduce the noise and improve the efficiency of heat pumps.[81] In contrast, prices for the slightly more mature fixed-speed units[82] have remained the same or decreased slightly relative to inflation.

Modest learning rates for heat pumps, across literature, are near 10 per cent, while optimistic experience rates are around 20 per cent.[83] A brief overview of relevant learning or experience rates from accessible literature is provided by NYSERDA.[84] A conservative estimate would be 3 per cent, representative of a more mature market, based on a paper which explored experience rates for Sweden.[85]

Experience rates for the installation costs (equipment and non-equipment) of a few heating system types within the UK market have been estimated by another paper using MCS data from 2010 to 2019 and compared with additional data from various countries.[86] Through discounting price reductions and weighting against experience rates with greater quantity of data points or time periods, a value of 5 per cent[87] could potentially be taken as a maximum experience rate to expect from the learnings within the installation process itself for heating systems, representative of installations which are becoming both more standardised and more competitive, which might apply to heat pumps from 2022 onwards.[88]

The learning rate method can also be applied to estimate the projected increases for the average efficiency of heat pumps (COP, SCOP, SPF). Using the limited data available on SPF values for UK-specific installations[89] (2009-2018), a learning rate of 13 per cent is calculated against the estimated number of cumulative domestic retrofits. If simplifying performance to COP, learning rates with more extensive data are available with some ranging 5-8 per cent.[90]

If several key policy and industry decisions are determined in 2022 (shifting levies, market-based mechanisms), followed quickly by implementation of elements which are ready (SAP 10.3, training programmes), then it would be reasonable to expect installation costs to begin falling once again.

In Table 5, these estimated experience (and learning) rates are applied across a projection for heat pump adoption (determining the number of times the installed base will double).[91] The government's goal of a 25-50 per cent reduction in installed costs by 2025 is aligned with Delta-EE's figures (25-30 per cent); however, both appear quite ambitious in comparison to those calculated from selected rates in Table 5, with such reductions not being realised until later in 2035.[92] Element Energy's forecast is similar to the 'Moderate' scenario, around one-third of the government's goal rate (if incorporating the selected learning rate for 'other').[93]

Using these assumptions, we can estimate a reduction in upfront costs of 41 per cent by 2035 in the most optimistic scenario, with a 26 per cent reduction in a moderate scenario and 6 per cent in the most conservative scenario. In similar scenario order, running costs, by 2035, may fall by either 57 per cent, 22 per cent, or 17 per cent. Even with the most optimistic levels of cost reduction by 2035, heat pumps would still have greater than twice the upfront costs of gas boilers, but, now, with running cost savings sufficient to outcompete gas boilers in overall whole life costs.

If limiting to the 'conservative' scenario, when we apply the running costs reduction conditions from Table 3 for a 2035 installation, both medium and large homes are found to have lower whole life costs for heat pumps (without the need for a grant). This is true for all three home categories from 2030 onwards in the 'moderate' scenario.

Cost reduction from baseline	2025	2030	2035	Basis: Experience (or learning) rate	Basis: Annual rate	Basis: Scenario
Upfront costs	14%	27%	41%	10% (unit) 5% (other)	–	**Optimistic** If the 'optimistic' running costs scenario is applicable, this upfront costs scenario is less likely.
	9%	17%	26%	3% (unit) 5% (other)	–	**Moderate**
	2%	4%	6%	3% (unit)	–	**Conservative** Aligned with CCC's 2019 analysis.[94] Scenario could represent limited innovation in manufacturing and installations or higher electricity rates requiring more efficient systems.
Running costs (SPF)	20% (3.4)	36% (3.9)	57% (4.3)	13%	–	**Optimistic** Most likely would limit upfront cost reductions to the 'moderate' scenario estimate.
	8% (3.0)	15% (3.2)	22% (3.4)	5%	–	**Moderate** Learning rate of 5% application was found to be similar to that from an annual improvement estimate which discounted from a theoretical maximum SPF of 5.3
	4% (2.8)	10% (3.0)	17% (3.2)	–	1.5%	**Conservative** Based on current MCS SCOP improvement rates and COP improvement rates from the United States and Switzerland. Scenario could represent if improvements are limited to international manufacturing and minimal from installation process or quality.

Table 5. Future cost reductions expected for air source heat pumps based on experience rates or empirically derived rates per year

Note: upfront costs include overall installation costs with 'other' indicating costs for equipment other than the heat pump and includes non-equipment (labour) as well. The adoption rate for heat pump installation quantities is based on a forecast in line with the UK government's goals of 600,000 per year in 2028 and 1.7 million per year in 2035. However, the applied quantity is limited to an estimated fraction belonging to domestic retrofit installations. Heat pumps and installations for new builds are considered as categories requiring separation from retrofit due to lower heat demand requirements (different design optimisation) and more straightforward installation with less relevant or shared learnings to domestic. Running cost savings from increases in SPF are discounted 17 per cent for estimated standing charges and excludes maintenance costs.

Financing the upfront cost of heat pumps

Even with cost reductions, heat pumps are likely to always have higher upfront costs. For a majority of households, this upfront cost is likely to remain a barrier to buying a heat pump, even if the lifetime cost is significantly cheaper. For this reason, finance offers which spread the upfront cost over many years are likely to be particularly important in the heat pump market.

For financing to work effectively, it is crucial that the annual running costs of heat pumps can be brought well below those of a gas boiler, so there is a large enough saving to offset the upfront cost. Ideally, the length of the loan should match the life of a heat pump (15-20 years), so that the costs can be spread more evenly.

There are several ways a financing offer could be structured. These include:

- **A green mortgage** – where a home buyer is offered some additional borrowing on top of their mortgage to spend on green home improvements, such as a heat pump. This is likely to be an attractive option, because mortgages tend to match the 20-year life of a heat pump, are secured against a home, and may be more convenient for customers.
- **A standalone personal loan** – a separate bank loan used to buy a heat pump. This is a less attractive option, as it may have a shorter timeframe, be more risky and therefore attract a higher interest rate.
- **Government-backed loans** – government may consider offering loans directly for heat pumps, or through an intermediary such as the UK Infrastructure Bank. This option could be cheap and long-term for customers, and although it is likely to involve a cost to the government, this may be cheaper for government than relying on upfront subsidies.
- **Heat-as-a-service (HaaS) offers** – government could mitigate a minimum level of risk to enable HaaS offers to gain momentum from industry, such as by restructuring ECO4 to allow HaaS contracts to count towards a higher portion of credits. The market-based mechanism[95] has potential to encourage such offers as well.

Barriers to cost reductions

Although the scope for reducing the cost of heat pumps is significant, there are some important barriers to doing this.

Barriers affecting manufacturing

> **Domestic manufacturing limitations**.

The UK has a modest domestic heat pump manufacturing sector, with around 30 per cent of the market currently met by domestic manufacturing.[96] This is especially pertinent because the UK has a very small heat pump market compared to Europe.[97] The small UK manufacturing base presents issues including:

- Low automation, specialisation and economies of scale.[98]
- Poor levels of similar components in manufacture and use.
- Largest manufacturer of each sub-sector holding >30 per cent share, low competition.

And although manufacturers (domestic and abroad) are confident in the ability to scale production, more competition in local manufacturing could provide:

- Innovation in heat pump efficiency through UK-(climate) specific design optimisation.[99]
- Broader standardisation in controls and alignment with UK-specific demand-response protocols.
- Reductions in maintenance costs (parts).
- Stronger relationships to installers and customers with fewer delays.

UK boiler manufacturers, having 55 per cent domestic presence, could provide a substantial transitional growth opportunity – retooling workforce, component supply chains, and experience – however; since most are large international organisations with modest heat pump offerings already, there is only marginal incentive to anticipate demand earlier and may require schemes such as the market-based mechanism to create momentum.[100]

Barriers affecting installation

> **The state of the UK housing stock**

The UK has the oldest housing stock in Europe (and probably the world too), with more than half of UK homes dating from before 1965.[101] This means many homes have poor thermal efficiency and may need changes to the home (typically larger radiators and pipes alone are sufficient) as part of a heat pump installation. While these changes can be good for long-term energy efficiency and occupier health, they also increase upfront costs. Better sharing of information and standardising across property types could help to reduce this cost.

> **Differential VAT treatment across low carbon technologies**

Complex rules for discounting VAT on heat pumps in retrofits in comparison to new builds creating incentives for prices to be skewed and market transparency reduced.

> **The fragmented installation market**

The heat pump installation sector is generally characterised by small companies and individual sole traders usually isolated to specific regions.[102] They typically operate with no clear centralised or efficient platforms and mechanisms for sharing information, which reduces transparency on cost. There is also typically slow diffusion of best practices and standardisation among installers, and limited competition between installers in specific localities.

> **Small number of installers**

There are too few installers currently, which can drive up prices, lead installers to turn down more complex jobs (creating an impression that some homes are not suitable), and result in customers choosing another system due to prolonged booking periods.

> **Limited availability of training for installers**

While requirements for heat pump qualifications have grown, there is limited awareness of how to access suitable training. The cost of training and lack of subsidies may also be a barrier to securing qualifications, with current programmes, while growing in capacity,[103] still often striking an insufficient balance against time and income lost.

> **Lack of stability in subsidies**

Regular changes in the scale and terms of subsidies may be reducing confidence in demand in the heat pump market.

> **Long assessment times for designing heating systems**

Home assessments for heating systems typically take a long time and require specialist skills. However, innovation is occurring, with several businesses reducing assessments to within two hours (under ideal conditions). But opportunities exist to optimise further and encourage open data practices, iterating on a larger scale to confirm design efficiency and capacity matches actual performance.

> **Planning constraints**

The planning system often restricts heat pump exterior unit size while also requiring low noise. This increases upfront costs for consumers by 5-15 per cent (premium on high capacity heat pumps in smaller monobloc size, planning permission process, or more expensive location).

> **Controls and logic settings – increased complexity with lower margin for errors for heat pumps than gas boilers**

5. Conclusions and next steps

The analysis in this paper makes it clear that while heat pumps are currently held back by their high cost, there is a lot of scope to make them significantly cheaper. While heat pumps are always likely to involve a higher upfront cost than gas boilers, they offer many advantages in return. They are around four times more efficient than boilers, last longer and require less maintenance; and that is even before considering their huge benefits to the climate.

The UK's governments and everyone involved in the heat pump market has a role to play in making heat pumps more affordable. This means reducing running costs by lowering the price of electricity relative to gas and increasing heat pump efficiency even further. It also means reducing the cost of installing heat pumps, which is a more complex area. The heat pump market needs more innovation, more competition and more skilled installers.

This report makes eight recommendations which would make heat pumps more affordable.

Reducing running costs of heat pumps

1. Manufacturers should focus on increasing heat pump efficiency.
2. Government should adjust the cost of electricity and gas to make heat pumps more affordable to run.

Reducing installation costs of heat pumps

3. Government should remove VAT on home heating retrofits.
4. The heat pump market needs more high-quality suppliers.
5. The heat pump market needs to become more transparent.
6. Heat pumps need service innovation as much as product innovation.
7. Heat pumps should get much cheaper in smaller homes.

Making the upfront cost of heat pumps more affordable

8. Financial institutions should prioritise green finance products for heat pumps.

Nesta's plans for future work

As part of our Sustainable Future mission, Nesta is pursuing a range of projects to help accelerate the UK's switch to low carbon heating. By bringing together our specialist expertise in areas such as data science, design, behavioural insights and experimentation, we aim to find new solutions to the biggest challenges involved in decarbonising home heating. We currently have four areas of focus within the mission:

> Make heat pumps more **affordable** to people across the income spectrum.

> Reduce the **hassle** in getting and using a heat pump.

> Build the **supply capacity** of the heat pump sector.

> Shift **electricity demand** to reduce peaks and make better use of renewables.

This paper has set out a clear agenda for further work on the first area of focus, making heat pumps more affordable. Our current and future work under this theme includes:

> Estimating people's **willingness to pay** for heat pumps at different prices and with different information, to give a better idea of how big the heat pump market could be as prices fall.

> Designing and testing **green loans** and other financial products, which give people upfront finance to install a heat pump or take other low carbon measures in their home.

> Developing **tools to better estimate the cost** of a heat pump in any given home, helping to give a more bespoke and impartial understanding of the likely costs involved (this also supports our 'reduced hassle' area of focus).

Based on the analysis in this paper, we will also consider what role we can play in:

> Promoting the use of **software** and other forms of **service innovation** by heat pump installers.

> Developing and testing **local delivery models** which help to reduce the cost and hassle involved.

This paper also has relevance to our area of focus on building the capacity of the heat pump industry. Our work in this area is likely to include:

> Testing incentives for **existing heating engineers** to train and enter the heat pump market.

> Identifying models for increasing the availability and uptake of **apprenticeships and training** in heat pumps for people early in their careers.

Appendix

Property type	Baseline		If levies shifted to gas linearly 2022-35	Levies removed from electricity with only social levies added on to gas in 2022	If full levies shifted to gas in 2022	If heat pump installation enables a flow temperature 10°C lower than nominal (45-50°C) compared to gas boiler (+55°C) (temperature limiting condensing)		
						High upgrade cost[104]	Low upgrade cost	Zero upgrade cost
	Costing format: Whole life cost per year relative to gas (£) [Cost reduction relative to England baseline in brackets]							
	Climate							
	England	Scotland	England					
Smaller home Flats – medium (50-100m²) (excl. converted flats or maisonettes)	£670	£780	£520 [£150]	£480 [£190]	£410 [£260]	£810 [-£130][105]	£590 [£80]	£560 [£150]
Medium home Terrace/converted flat/ maisonette (100-150m²) Post-1950s bungalow, semi-detached (<150m²)	£840	£1,010	£600 [£230]	£540 [£300]	£440 [£400]	£950 [-£110]*	£730 [£100]	£660 [£230]
Large home Detached – large (150-200m²)	£1,190	£1,470	£840 [£350]	£740 [£450]	£580 [£600]	£1,280 [-£90]*	£1,030 [£160]	£930 [£350]

Table 6. Impact of variations within running cost scenarios on the whole life cost of heat pumps

Endnotes

1. The size of home category is used as a simplification for levels of annual heat demand requirement. More details are provided in Section 3 of this report.
2. Including the minimum of fittings and refrigerant, with buffer tank assumed optional and partially weighted in our calculation.
3. We have modelled efficiency improvements as either an installation enabling a 10°C reduction in mean flow temperature below the typical 45-50°C or an exceptionally efficient heat pump in a high-quality installation (proxied by the seasonal performance factor of the top 20 per cent of installations).
4. Value to energy suppliers would be either from flexibility scheme participation, possible ECO4 credits or financing margins. ECO4 could be updated to allow suppliers to receive a minor credit for offering a heat pump tariff (dynamic or static) to properties with a new installation or to an existing one if it is the first offer. Similar to the Renewable Heating Incentive but at reduced costs and administrative burden.
5. Defined as SIC 43: specialised construction activities. This includes various home maintenance trades such as heating engineers, plumbers and electricians, so is wider than just the heating industry.
6. Heat pump unit only being 35-40 per cent installed costs (15-20 per cent whole life costs), as modelled by mapping market trade prices into MCS installation costs.
7. If not stated elsewhere, ranges reference low to high heat demand as modelled (9,500-22,000 kWh) with the home size category of small to large as a simplification.
8. If only social levies are added to gas, environmental levies would be placed into general taxation. Social: Environmental taken as 30:70 split.
9. If levies are not fully shifted, heat pump owners eligible for the Warm Home Discount could be given a default increase of ~£90 on the £140 discount (up to ~£400 on verification, tiered by annual heat demand from EPC). Also, a separate Cold Weather Payments programme could be established, eligible to all households with heat pumps (no fossil fuel hybrids), funded from environmental levies or taxes (not social levies). These would continue through ECO4 to 2026 or until levies are shifted.
10. Alternatively, BEIS could encourage a discounted heat pump tariff through ECO4 as stated earlier.
11. For a more detailed case for reducing VAT on home retrofits, see MCS Charitable Foundation's *New report reveals that the Chancellor should zero rate VAT on heat pumps and energy efficiency measures* (26 October 2021).
12. As stated by BEIS in the Boiler Upgrade Scheme (2021) regarding the Electrification of Heat Demonstration (2020). Initial highlights from installations have been reported by ESC (2022).
13. See Nesta research on understanding the heat pump user journey.
14. Manuel Lämmle et al, *Performance of air and ground source heat pumps retrofitted to radiator heating systems and measures to reduce space heating temperatures in existing buildings* (March 2022).
15. Also, advancements in thermal comfort measurement accuracy with inclusion of radiatiative effects and fluid dynamic considerations and larger sample sizes for verification in field trials.
16. For more details on the role the UK Infrastructure Bank should play in low carbon heating, see Juliet Phillips for E3G, *Making markets through the UK Infrastructure Bank: The green homes infrastructure opportunity* (13 December 2021).
17. BEIS's research report CODE (2021) highlights some installations in which air-to-air heat pumps may be cost-optimal (if installed with proper thermal comfort and homeowner behavioural preferences considerations). A relatively recent field trial (albeit with limited data) was completed by National Energy Action on Park Homes (n=30) with floor areas 30-50m² – finding over 75 per cent satisfied with thermal comfort and savings provided by a 6kW external unit and only a single indoor fan coil. Installed cost was £2,300 (excluding project management, which may be estimated as +£200-£400). The report does highlight some poor placement of the indoor fan coil considerations, however.
18. Colin Meek, *Heat pumps and UK's decarbonisation: lessons from an Ofgem dataset of more than 2,000 domestic installations* (January 2021).
19. For further explanation of heat pumps, see: SEAI's *Heat Pump Technology Guide*, HPA's *What is a heat pump?* (with glossary), Zheng Wang et al's *State of the Art on Heat Pumps for Residential Buildings* or John Cantor *Heat Pumps*.
20. Data from Meteoblue.com, Degreedays.net and Met Office.
21. The main capacity (and coefficient of performance) listed for a heat pump is the value under 'nominal' conditions. For air-to-water heat pumps, nominal is 7°C ambient (outdoors) and 35°C delivery (radiators). At lower outdoor air temperatures, capacity is reduced; but this is limited for modern heat pumps: at -15°C the capacity is reduced only ~one-fifth of nominal.
22. As long as the heating distribution system (pipes and radiators) is sized sufficiently (i.e. sufficient heat transfer rates against home heat loss rates).
23. MCS and RHI data – total installed capacity. Note that >16kW units usually require three-phase power but this could be bypassed by installing two separate external units. Therefore, although this range may reflect a price or design preference (avoiding upgrade cost of three-phase), it does not imply a capacity limitation for homes.
24. The three options for climate profile (under EN and BIS standards) are based on three EU profiles, rather than the UK specifically, but the differences are modest.

25. Meek, *Heat pumps and UK's decarbonisation*.
26. BRE DAHPSE Tool (2021).
27. Ratio is not 1:1 with SPF increase due primarily to electricity standing charges.
28. The preference for monobloc heat pumps in the UK (more than across Europe) exists partly from the (relatively) low number of F-Gas Certified engineers at present.
29. Combi gas plus full air source heat pump with external unit – Mitsubishi Hydrobox, Daikin Altherma Hybrid, Vaillant aroTHERM. Combi gas plus internal (indoors) air source heat pump – Murelle Revolution (4kW), HyCompact Trial (~2kW). Freedom Project (2019) – at gas rates estimated to follow the April 2022 capped rate increases, a gas boiler hybrid with a 5kW air source heat pump could potentially cover 50 per cent of a home's heating demand while still near the system's optimal running costs. Installed costs for hybrids with a new gas boiler and a 5kW air source heat pump might be in the range of ~£7,500 and £9,500.
30. A primary factor being a lack of support from the Renewable Heat Incentive scheme (ineligible).
31. National Energy Action – Air-to-air heat pumps for Park Homes, Basingstoke (2017); Poland air-to-air heat pumps (2019); Nordic air-to-air heat pumps review (2019).
32. ECO2 Systems Sanden SANCO2, R744, Mitsubishi Ecodan QUHZ.
33. Vaillant AroTHERM Plus (R290).
34. BEIS statistics, ONS UK Environmental Accounts.
35. BRE Trust – note that oil is still more widespread than gas in Northern Ireland.
36. No legislation underpinning, however, only as a stated aim.
37. Autumn Budget 2017.
38. Data from a 2016 Gas Safe Register Survey; Catrin Maby and Julie Gwilliam, *Integrating energy efficiency into private home repair, maintenance and improvement practice in England and Wales* (July 2021); Gavin Killip and Alice Owen, *The construction industry as agents of energy demand configuration in the existing housing stock* (2020).
39. 2019 Heat Pump Association Survey.
40. Behavioural Insights Team and Nesta, forthcoming in February 2022.
41. Installation costs are as reported to MCS by installers and include equipment and non-equipment costs. It is unclear if VAT discounts have been applied when used by installers.
42. We have used: electricity – 26.5p/kWh, 23.5p/day; gas – 6p/kWh, 24.5p/day from 2022 until 2024; and from 2024 onwards: electricity – 19.8p/kWh, 23.5p/day; gas – 3.9p/kWh, 24.5p/day.
43. We have kept the relative difference between gas and electricity constant from 2022–2023, assuming that gas prices will set electricity prices in the short term. The projected reduction in the electric rate, 3 per cent from 2024–2035, is based on cheaper levelised costs (including supplier operations) resulting from technology improvements, installation advancements, the Contracts for Difference scheme and other factors. These were kept within constraints of capacity available to be displaced by the cumulative generation of new plants (primarily wind). Our estimate takes into account BEIS levelised costs (2020), BEIS energy portfolio, RenewableUK construction timelines (2020), and ECIU insights (2021). It is also assumed that, in 2035, gas-fired generation plants are still required for peak demand, around 25 per cent (SSE 2019). The cost reductions were kept conservative and did not factor in gains from new and increased flexibility across the grid from demand-side response programmes, smart monitoring, virtual power plants and a more distributed system.
44. Although archetypes are based on those formalised in BEIS's CODE Electrification Study (2021) (verified with National Energy Efficiency Data-Framework gas consumption figures), the groupings are broader and have potential for more outliers being observed, such as small homes with particularly poor insulation and high heat demand similar to large homes with great insulation.
45. Muhammad Abid, *Domestic Retrofit Assessment of the Heat Pump System Considering the Impact of Heat Supply Temperature and Operating Mode of Control – A Case Study* (2021).
46. Lifetimes of heat pumps and boilers are based on conservative estimates from multiple references and a few installer experiences. Heat pumps – EST; CIBSE; Aalborg Universitet; ASHRAE; EFCTC. Gas Boilers – Frazer Nash Consultancy (2018a); BSRIA; Carbon Trust; Jason Palmer and Alexander Rice (2014). Gas boilers tend to cycle more, alongside their parts experiencing greater temperature differentials. If specifying fixed-speed heat pump lifetimes specifically, these extend slightly further with 20 years as the minimum expected (similar to your fridge).
47. Meek, Heat pumps and UK's decarbonisation.
48. In this paper, heat pump units refer to the individual boxed equipment form of the external unit and, if applicable (for split systems), internal unit, including simple controls, refrigerant, and only the minimum amount of fittings and piping required to connect to the home heating distribution system. Heat pump packages refer to the heat pump unit along with buffer tank and minimum fittings required for buffer (assumed optional, therefore weighted by dividing buffer tank prices by two).
49. Delta-EE for DECC (2016) and Delta-EE (2021a).
50. May be most common in 1970s homes.

51. Currently, PAS 2035 standards still allow for practical limitations, only recommending work where more cost effective when weighted against funding available, future expected works, and risks to thermal comfort and environmental considerations (condensation, mould conservation, etc).
52. Membership fees for MCS and Consumer Code scheme together may range around £600-£1,100 per year (for one to three technologies), with additional training potentially costing a minimum of £500. If installer is able to perform conservatively one installation per week (50 weeks), this, along with a certificate fee, would incur around £70–£80 per installation.
53. Having the potential to extend the compressor lifetime or decrease performance degradation by preventing short and repeated on/off cycles or excessive throttling.
54. Other sources include Delta-EE (2021b), Delta-EE for DECC (2016), market research (manufacturer/distributor price lists and limited interviews), literature investigation and analysis of MCS installation data.
55. Sevindik, S. et al. (2021).
56. May be less true for high temperature and low GWP models.
57. Although further data analysis may have helped confirm the extent of the presence of these additional costs (parameterisation etc), this has been left for potential future works. The fit of equipment and non-equipment costs from collected market (trade) rates and values reported in other studies referenced proved sufficient to confirm.
58. Adjusted using Consumer Price Index series 5.3 from Office for National Statistics.
59. It should be noted that the current definition of SCOP has been shown to have a poor correlation with actual performance (SPF) at the level of individual installations, but as an aggregate may still be useful in trends observations.
60. Performance will be optimised further with selection of a low temperature or conventional heat pump.
61. However, the range could be narrowed by a few accessible considerations as discussed previously, including ~£2,000–£3,000, depending simply on whether a hot water tank is already present, number of rooms as upper limit for radiators, and smaller things such as if an advanced thermostat or other compatible controls are already present as well.
62. This breakdown between running and upfront costs was also observed to match the majority of home types from the CODE report (2021) – see page 71. Notably, archetypes with extremes of lower demand (flats) and higher demand (detached or sprawling) deviate from the expected breakdown due to air-to-air units being modelled within those properties as they were found to be cost-optimal.
63. If moderate upgrades are required, the reduction in relative whole life cost per year to a typical heat pump installation would lessen to £80–£160 (low upgrade cost) or become cost increases of +£90–£140' (high upgrade cost). High costs (£3,710–£5,300) model cavity and loft insulation or underfloor insulation alongside replacement of several or all radiators, piping and valves. Low costs (£530–£1,590) model replacing specific radiators and minimal insulation or draught-proofing. Cost values used were derived from BEIS (2017), Delta-EE (2018), and limited market research, adjusted to £ 2021 prices. Note that although the high cost scenario is such that the running cost savings are insufficient to discount over the heat pump lifetime, it may be found that the improved thermal comfort and decreased heat pump wear is worth the extra ~£100 per year (alongside deeper emission savings!).
64. See endnote 4.
65. Note that despite thermal storage often being associated with time-of-use tariffs, at current prices, capacity densities, and home size constraints, capital costs for the addition of a typical thermal store (buffer tank or Sunamp) into a heat pump installation is not modelled to breakeven for domestic applications.
66. Multi-Asset Demand Execution Project – Interim Report (2019). Also, note that such savings may end up being incorporated into heating-as-a-service or heat pump tariff offerings.
67. Equiwatt (operating in the UK currently) and Google Nest's Rush Hour Rewards (currently US only, but likely to expand to the UK in a few years). These schemes are expected to become more widespread following the market-wide implementation of half-hourly smart meter settlements in 2025 (BEIS, 2021), earning a minimum of £20 per annum. Also, for equity considerations, rates may be required to either have capacity limits or reduce with increasing capacity.
68. Smart hot water storage tanks should see prices reduced in 2024 with new competition expected from OSO Hotwater. Current cost for installation range: ~£1,400–£1,800.
69. Estimates for solar yield, panel efficiency, roof size, equipment lifetime, electric usage profiles, and installation and maintenance costs from Dhimish. et al. (2018), BEIS (2021), CAT (2022), EST (2022), Bioregional and Etude (2021), MCS (2012), Solar Energy UK (2021). Energy prices, heat demand and house types modelled as previously mentioned in this paper. Some key figures include capacity factor (10 per cent), PV and battery storage lifetime (25yr and 12.5yr), and an assumed percent of annual electrical usage able to fit into peak sun hours (15 per cent, 3-4hrs, 3.5kW enabling) – conservative compared to 24 per cent observed by Eoghan McKenna, Jacquelyn Pless and Sarah J. Darby (2018). Without solar PV, homes with a heat pump and access to a time-of-use tariff similar to Octopus Go (or other EV tariffs) with average or lower nominal electricity usage(<4,000 kWh/yr) may find thermal storage, such as SunAmp, to yield marginally greater whole life cost reductions than battery storage, if able to cover the majority of daily heat demand on one charge (while still fitting into the physical space limitations, as most likely more than one SunAmp will be needed). The opposite applies for homes with high electricity usage.

70. Without heat pumps, homes may need higher than average electrical usage (+5,000 kWh/yr) to make batteries worthwhile (within equipment lifetime), until more comprehensive and widespread demand response schemes evolve. Flats and smaller-medium terraced homes may be too space constrained (roof) to benefit sufficiently. Some homes with older wiring may require upgrades which decrease the savings. This scenario was found to be more favourable than in BEIS's CODE report because costs are over the full lifetime, larger battery(ies) or PV capacity was allowed, and PV was oversized with assumption that it can simultaneously charge battery(ies) and cover (on average) 15 per cent of home demand during peak sun hours.

71. Such as Tepeo's Zero Emission Boiler (ZEB), at its current estimated price of £5,500 for 40kW capacity with electricity costs at minimum returning to October 2021 capped rates, and as long as its capacity can cover greater than 40-60 per cent of the daily heating demand (for small-large homes) on a single charge with whole life costs over the same lifetime as heat pumps (15 years). However, continuing reductions in electric battery prices paired with the potential for broader and more substantial forms of demand-side response will most likely see batteries outcompete such storage electric boilers in the future, perhaps by 2030.

72. Wadim Strielkowski, Dalia Štreimikienė and Yuriy Bilan, *Network charging and residential tariffs: A case of household photovoltaics in the United Kingdom* (2017); Benjamin K. Sovacool, Matthew M. Lipson and Rose Chard, *Temporality, vulnerability, and energy justice in household low carbon innovations* (May 2019); Sovacool, B. et al. (2019), Fabian Feger, Nicola Pavanini and Doina Radulescu, *Welfare and Redistribution in Residential Electricity Markets with Solar Power* (January 2018, revised September 2021).

73. An independent group-purchasing provider, iChoosr, has achieved a stated minimum average of 20 per cent savings for consumers on market prices across its nine UK Solar Together schemes for solar PV and battery storage involving ~330 homes per scheme. iChoosr *Annual Report 2020* – the 20 per cent savings is across nine schemes involving 3,000 homes (~10 per cent of registrants able to complete the scheme).

74. Other reports (Renaldi Renaldi et al, Experience rates of low-carbon domestic heating technologies in the United Kingdom, September 2021) have noted increasing costs per installation of air source heat pump, in general, as well; however, stated reports do not differentiate between property types and other house attributes.

75. Quartiles in Chart 13 refer to group divisions with an equal number of properties when looking across the UK housing stock within EPC data.

76. Although learning rates (LRs) usually refer to a single company, while experience rates (ERs) refer to an industry, we use ERs in this paper to refer to those including costs for installation (learnings across the process of installation) while LRs refer to those only including heat pump unit prices (manufacturing learnings). Also, note that most experience curves for heating/generation (sometimes with expanded learning rates) will be based on the averaged costs per capacity (£/kW) for an installation (or equipment) at a cumulative installed capacity (increasing across a time period). While standard, using capacity is not as relevant for the UK market and the mostly mature heat pump market since the costs for the installation process (and heating distribution upgrades) are currently larger than heat pump unit costs. Therefore, it is more relevant to calculate LRs across the number of installations (or sales) that are specifically retrofit installations (as new build installations involve fewer steps and not a direct overlap in training and peer networks).

77. See US DOE EERE Overview of Learning & Experience Curves (2011) for further explanation.

78. If this analysis is now extended through 2021, the learning rate for air source heat pumps will have reduced closer to 4 per cent.

79. A learning rate (LR) of ~6 per cent for air source heat pump units (2011–2019) in the UK was observed by Renaldi Renaldi et al, *Experience rates of low-carbon domestic heating technologies in the United Kingdom* (September 2021) and found to be similar to the relative difference between LRs for combi gas boiler unit prices of the Netherlands and the UK as applied toward heat pumps. LR for gas boiler prices in the Netherlands – 13 per cent (1981–2017), the UK – 4.9 per cent (2004–2016). LR for air source heat pump unit prices in the Netherlands – 18 per cent (2011–2017) (Martin Jakob et al, 'Chapter 11 – Heating and cooling in the built environment', in *Technological Learning in the Transition to a Low-Carbon Energy System: Conceptual Issues, Empirical Findings, and Use in Energy Modeling*, ed Martin Junginger and Atse Louwen, (Cambridge, MA: Academic Press, 2020)).

80. Doubt in the rate arises from the current flat to negative rate for the past few years and its relatively short time period and starting point scale for doubling (10 years, 8 doublings). Disaggregating into separate rates or weighting market factors could improve. An example is the lack of discounting of high prices from 2011–2012 during a more exploratory, market-shaping period for UK heat pumps, marked both by the establishment of the Renewable Heat Incentive (RHI) policy in 2011 (for non-domestic properties) and the start of Mitsubishi manufacturing its popular air-to-water model, Ecodan, in Livingston, Scotland.

81. The price increase has been driven up by a few factors including: manufacturers addressing noise concerns extensively; re-optimising designs for refrigerants with a lower climate impact; improving methods for defrost cycles (removing the need for a backup electric heater in several models and circumstances); incorporation of additional monitoring or controls features for remote troubleshooting; and, for monobloc units, increasing the capacity and efficiency to be on par with or greater than that for split system models.

82. Note: fixed-speed compressors, when used within ground or water source systems, are more efficient than variable-speed units (and may last longer), but are less efficient when used in air source systems.

83. Lawrence Berkeley National Laboratory (2012).

84. NYSERDA (New York State Energy Research and Development Authority), Renewable Heating and Cooling Policy Framework: Options to advance industry growth and markets in New York (February 2017). Although comparisons of experience curves across countries which incorporate industries of greater variation can be less accurate, it is still unfortunate that there have been few for heating systems which include installation costs. Additionally, these experience rates would need to be calculated on number of installations rather than overall installed capacity to be more directly relevant. Variations refer to the shape of an industry or workforce such as the higher structural differences in the heating and plumbing workforces from one country to another (due to national certifications and licensing, higher sole-trader levels etc) in comparison to the potentially more uniform manufacturing industry.

85. (Martin Jakob et al, 'Chapter 11 – Heating and cooling in the built environment', in *Technological Learning in the Transition to a Low-Carbon Energy System: Conceptual Issues, Empirical Findings, and Use in Energy Modeling*, ed Martin Junginger and Atse Louwen, (Cambridge, MA: Academic Press, 2020)); Bernadett Kiss, Lena Neij and Martin Jakob, 'Heat Pumps: A comparative assessment of innovation and diffusion policies in Sweden and Switzerland. Historical Case Studies of Energy Technology Innovation', in: *The Global Energy Assessment*, Global Energy Assessment Writing Team (Cambridge: Cambridge University Press, 2012), chapter 24. The authors also made an interesting observation regarding subsidies, finding that for one scheme there was an inverse effect on prices, with subsidies raising them temporarily for two to three years due possibly to a saturated market or manufacturing capacity limitations since Sweden's supply chain was heavily local (rather unique). This may be similar to a condition in the UK market created by a few barriers. However, with non-equipment installation costs (and additional works) increasing more rapidly than equipment costs (10 per cent compared to 5 per cent from 2014), a saturation from subsidies (RHI) signals to the condition of too few MCS-certified installers for too quick an increase in consumer demand (insufficient training programmes or motivating factors inflating installer overhead and labour prices).

86. Renaldi Renaldi et al, *Experience rates of low-carbon domestic heating technologies in the United Kingdom* (September 2021).

87. Experience rates for heat pumps and biomass boilers in the UK were observed to be either flat or slightly negative (indicating slowly rising costs) while solar thermal had an experience rate of 13 per cent. An experience rate over a longer time period was calculated for Germany's combi solar thermal installations and found to be 8 per cent. If the average between them is taken and the equipment price reductions for the UK are discounted (by the learning rate, as a simplification), this would yield an experience rate of 5 per cent (ibid).

88. If assuming only minimal (or well-distributed) updates to PAS2035:2019 will occur.

89. Meek, *Heat pumps and UK's decarbonisation*.

90. (Martin Jakob et al, 'Chapter 11 – Heating and cooling in the built environment', in *Technological Learning in the Transition to a Low-Carbon Energy System: Conceptual Issues, Empirical Findings, and Use in Energy Modeling*, ed Martin Junginger and Atse Louwen, (Cambridge, MA: Academic Press, 2020)). Note: learning rates for COP may be best measured against cumulative installed (or sales) capacity (GW) rather than number of installations (in contrast to SPF).

91. Although the majority of experience rates for heating equipment are applied over a cumulative installed capacity base (GW), the UK market may be better mapped using the number of installations instead, since costs for the installation process and non-equipment prices have been increasing more rapidly than equipment prices (in the short to medium term).

92. Delta-EE (2021a).

93. Element Energy (2020).

94. The Climate Change Committee included an assumption in its 2019 analysis for an 11 per cent cost reduction on upfront installation costs for air source heat pumps, excluding distribution system upgrades (replacing radiators) from 2025 to 2050. Cross-referenced from Amy Trask, Richard Hanna and Aidan Rhodes, *The Future of Home Heating: The roles of heat pumps and hydrogen* (January 2022).

95. Market-based mechanism for low carbon heat.

96. BEIS Heat Pump Manufacturing Supply Chain Research Project.

97. The UK has around 30,000 installations per year compared to more than a million in Europe.

98. Relative to similar regions such as the Netherlands.

99. Some manufacturer interviewees suggested there is potential to develop heat pumps for the UK specifically, but higher sales volumes would be required. Others suggested current models across Europe are suitable enough for the UK.

100. Market-based mechanism for low carbon heat.

101. Tado (2021); BRE – 'Poor Housing in Europe', 'The Housing Stock of the UK', 'Cost of poor housing in England'; NEA – 'The Cold Man of Europe'.

102. Composition from a 2019 Heat Pump Association Survey (n=827): 50 per cent sole traders, 40 per cent small companies (2-10 employees). Data from a 2016 Gas Safe Register Survey (n=2,814): 77 per cent sole traders (up from 73 per cent in 2011), 17 per cent 2-5 employees, 5 per cent >6 employees. Comprehensive profiling of renewable and fossil fuel heating system installers remains ambiguous to an extent but does appear to be dominated by sole traders and small companies – most likely similar to the repair-improve-maintain subsector (general construction) as profiled by Catrin Maby and Julie Gwilliam, *Integrating energy efficiency into private home repair, maintenance and improvement practice in England and Wales* (July 2021); and Gavin Killip and Alice Owen, *The construction industry as agents of energy demand configuration in the existing housing stock* (2020).

103. Three-day course offered by the Heat Pump Association is stated as having capacity for 40,000 participants per year although, in mid-2021, only ~1,000 had signed up (FETA, 2021).

104. The increase upfront within the high cost upgrade scenario (£3,710–£5,300) models properties that require either cavity and loft insulation or underfloor insulation alongside replacement of several or all radiators, piping and TRVs; or underfloor heating with minimal insulation and radiator replacements. The low cost scenario (£530–£1,590) models the replacement of a few radiators and minimal insulation or draught-proofing. Cost values used were derived from Cambridge Architectural Research (CAR) for BEIS (2017) and Delta-EE for BEIS (2018), adjusted to £ 2021 prices, and current online estimates for quotes.

105. (*) Note that the higher upfront costs for homes requiring extensive upgrades to allow for operation at low flow temperatures (35-40°C) is such that the running cost savings are insufficient to discount over heat pump lifetime; however, it may be found that the improved thermal comfort and decreased heat pump wear (potentially extending equipment lifetimes) is worth the extra ~£100 per year.

106. BEIS CODE final report (2021).

107. BEIS (2017).

108. Delta-EE (2018).

109. Cambridge Architectural Research (CAR) for BEIS (2017).

110. Jian Liu and Zhang Lin, *A novel dual-temperature ejector-compression heat pump cycle – exergetic and economic analyses* (2021).

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