Heat Pump Consumer Guide

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October 2024

1 What are heat pumps?

Heat pumps are a system for heating your home that use electricity to move heat from the outside air to warm up your home. They are also used for hot water. By using this technique, they are several times more efficient than other types of heating, which saves energy. For every unit of energy you use to power them, you might get 3 or 4 units of heat out. For more information about how they work, see Section 2.

Almost all homes can have a heat pump installed, although in some cases it will require improving insulation, to keep bills low, or installing new radiators. For more information about whether a heat pump is right for you, see Section 3.

There are many different kinds of heat pump, and choosing between them again depends on your circumstances. A qualified heat pump installer will give you advice on what kind is best for you. Learn more about choosing a heat pump from Section 4.

To learn how to make a heat pump as efficient as possible, and keep your home as comfortable as you want it, see Section 5.

A heat pump might cost a similar amount to run compared to a gas boiler. However, a well installed system combined with the right electricity tariff can offer major savings. A heat pump will almost always emit less greenhouse gases than any other method of heating. For some examples on how much a heat pump will cost to run and install, see Section 6. As a rough guide, you can probably expect somewhere between £6000 to £20000 for purchase and installation, depending on the size of the property and complexity of installation. In terms of running costs, it will likely be comparable to gas heating, unless adjustments to your home's energy efficiency are made, which could result in significant savings.

For information on other environmentally friendly heating systems, see Section 7.

2 How do heat pumps work?

A heat pump is a device that moves heat from a space which the user wants to be cooler, into a space that the user wants to be hotter. Usually, when we use the term 'heat pump', we are referring to using this process to heat a building or hot water. However, several other devices can be correctly referred to as a heat pump, such as refrigerators, cooling modules for computers, and air conditioning. In this document, I will use 'heat pump' to refer specifically to a heating device.

When we think about heat, we typically conflate it with the concept of temperature. Heat is a transfer of what we call 'thermal energy'. Without getting too technical, this thermal energy is what causes things to feel hot or cold. The relevance of this is that even if an object is very cold, it still contains some thermal energy. In natural processes, thermal energy is transferred from a hotter object to a colder one, however we can manipulate this process in clever ways to instead move heat from a cold object to a hot one, and this is what a heat pump does: it absorbs heat from the outside air, slightly cooling the air down, and it re-emits this heat into your nice warm home.

So how can we cause heat to be transferred from a cold object to a hot object, without breaking any of the laws of physics? There are a number of ways, but they all require us to put in some energy of our own into the system to facilitate this, usually in the form of electricity. The amount of heat transferred is usually several times more than the amount of electrical energy used, and this is quantified as the Coefficient of Performance (COP) which is a measure of efficiency. A COP of 3.5, for example, would correspond to a heat pump outputting 3500W of heat for every 1000W of electricity, the remaining 2500W coming from the outside air.

By far the most common way of doing this is to use a refrigeration cycle, so called because this is how refrigerators work. These involve cycling a fluid called a refrigerant through a closed loop, and causing it to absorb heat where we want it to be absorbed (from the outside air) and then releasing the heat where we want it to be emitted (inside the building). This is accomplished by using the behaviours of these refrigerants at different temperatures and pressures to cause it to boil and condense using a compressor and an evaporator. This is called the vapour-compression cycle.

There are 4 main components in the vapour-compression cycle, depicted in Figure 1; a mechanical compressor, a condenser, an expansion valve, and an evaporator. As it is a cycle, there is no beginning or end point to consider, so this description will begin with the refrigerant between the evaporator and the compressor. At this point the refrigerant is a gas, having been evaporated. It is then passed through the compressor, which squeezes it into a much smaller space, causing it to get very hot. This is where the the electrical energy is used; it takes some energy to compress the vapour. This hot gas is now passed into the condenser. In a heat pump, the condenser is a heat exchanger, which will be a coil where the refrigerant slowly runs through, being cooled either by air or by water. This air or water is where you get your heat out; the heat naturally flows from the very hot refrigerant into the cooler air or water, and this becomes the hot water or warm air in your home. Returning to the refrigerant, it has now been significantly cooled, and condensed back into a liquid. Passing through the expansion valve, it cools further and some of it evaporates, caused by a low pressure. This cold liquid and gas mixture is pumped through the evaporator. The evaporator is another heat exchanger, this time outside, which lets the cold refrigerant get warmed up by the outside air and evaporate, returning the refrigerant to the state it was in when we started this cycle, prior to going through the compressor.

One important thing to note about this process that it becomes less efficient when working against a greater temperature gradient. In simple terms, this means that the colder the outside air is, and the warmer you want your house to be, the less efficient this process gets. This is essentially because if there is less heat energy available in the air for the heat pump to extract the system has to work harder to capture that limited heat. Similarly, when the heat pump is trying to heat the refrigerant hotter, the compressor has to work extra hard, and has to increase the pressure further, which takes more energy. If you are struggling to picture why this makes it less efficient, consider this analogy: if you were cycling to the shop at 10mph, you would use a certain amount of energy. However, if it was an uphill journey, not only would you have to spend more energy (this is the equivalent of having to heat to a higher temperature), your legs would also get more tired,

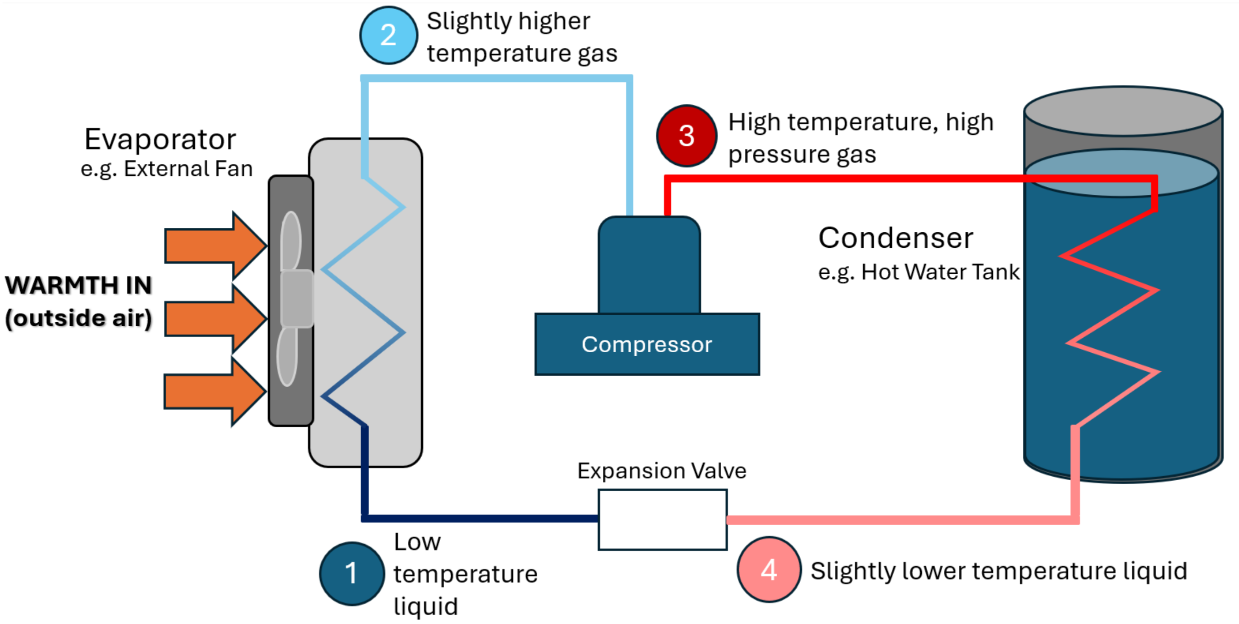

Figure 1: The refrigeration cycle found in domestic heat pumps. The refrigerant flows clockwise, drawing heat from the evaporator and depositing it in the hot water tank. The compressor is run by electrical energy, which also circulates the refrigerant. The heat released in the hot water tank is a combination of that absorbed in the evaporator and the energy put in through the compressor - meaning the output of heat from the cycle is more than you put in as electricity.

so you would cycle less efficiently (this is the corresponding drop in efficiency).

2.1 Types of heat pump

There are a few different types of heat pumps. One of the most important differences is in the source of heat. Some common options are shown in Figure 2. The most common of these types is the ubiquitous air source heat pump (ASHP). This simply involves a fan blowing the outside air across the evaporator. These systems are the simplest to install, and can be installed almost anywhere, with only minor considerations about airflow.

The other common type is the ground source heat pump (GSHP). Rather than a fan blowing air over an evaporator, a pipe containing a thermal transfer fluid (a mixture of water and antifreeze) is buried underground and this is how the heat pump absorbs heat. This results in the GSHP being more efficient, as the ground stays relatively warm year round. The downsides of this are that they are far more difficult to install requiring a system of trenches tens of meters long, or a very deep borehole. This results in a much greater space requirement and/or installation costs, the borehole option requiring much less space but will have a price tag in the tens of thousands.

Water source heat pumps also exist, and have similar benefits to the GSHP. These require access to a lake, river or other body of water and are therefore much rarer.

There is also a decision to be made about how the heat is delivered to the home. In the UK, the most common option is to deliver the heat to a hot water tank. This hot water is used directly to satisfy hot water

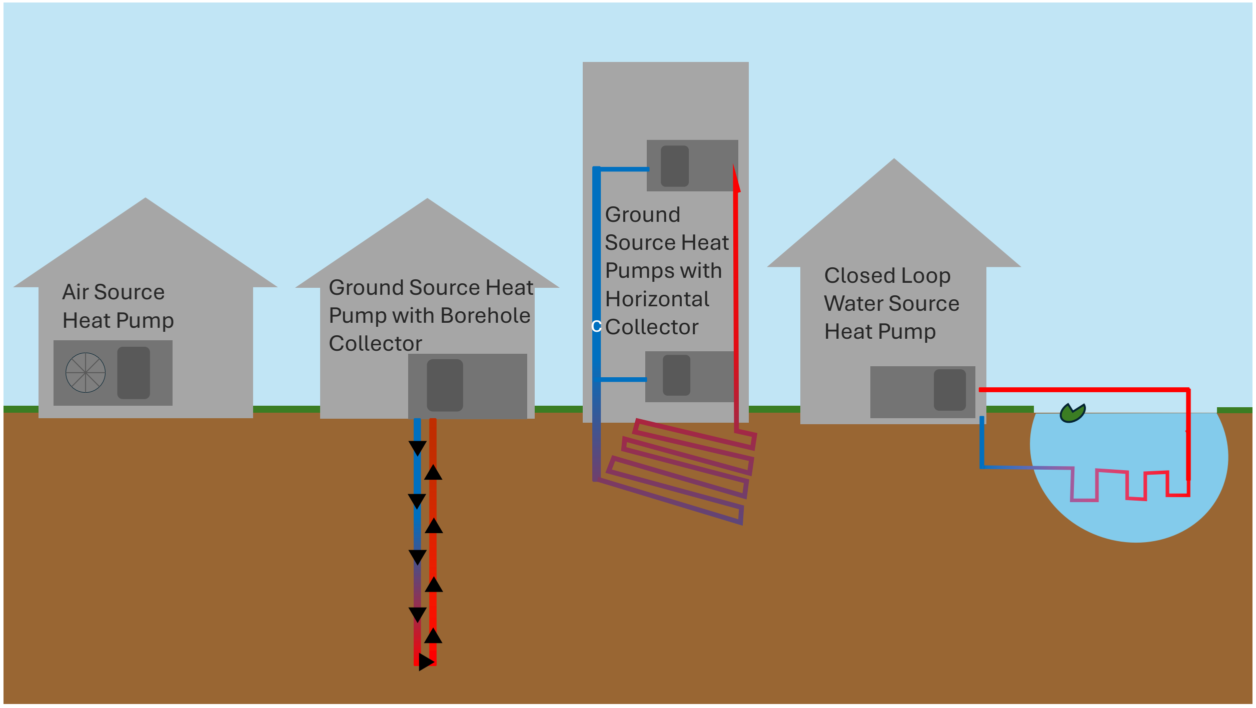

Figure 2: The heat used in a heat pump can come from several sources. The most common is the Air Source Heat Pump, due to simplicity of installation. However, by using a source of heat such as the ground or a large body of water, which stay warmer in the winter, the system will be more efficient.

needs, and is also used to provide space heating, through radiators. The other option is to install an air-to-air heat pump which directly heats the air in the house. The two main types of these are ducted systems which use ducts between rooms and air vents in each room to move hot air around the house, and multi-splits which have one indoor unit for each area that is to be heated, all connected to one outdoor unit which provides them with refrigerant. While air-to-air systems cannot provide hot water, they do have one particularly notable advantage: if you get a model with a reversing valve, they can provide air conditioning as well as heating.

There are also two types of heat pump commonly used when other heat pumps are deemed to be unsuitable. One of these is the high temperature heat pump. These can heat water to a higher temperature, usually defined as 65°C. They do this by making use of a number of innovations, for example cascade systems which use two refrigerant cycles at different temperatures, and also using a different refrigerant which performs better at higher temperatures. They are typically more expensive than other heat pumps. They are expected to be less efficient overall as most of the time they will be operating at a lower temperature than they are designed for.

The other option, which is considered somewhat of a last resort, is a hybrid system. These simply use a heat pump in combination with some other kind of heating system, such as a gas boiler or an electric water heater. One common choice is to use the heat pump for space heating, and the other system for hot water. These may be used for particularly large and poorly insulated houses, or in very cold climates.

3 Is a heat pump right for me?

There is no simple answer to the question posed in the title of this section, as there are numerous factors to consider. Ultimately, a judgement must be made by a qualified installer or other technician after taking into account the particulars of any installation site. However, there are many factors that consumers must consider themselves.

3.1 Why get a heat pump?

The importance of decarbonising the home heating sector is clear. In 2021, 18% of the UK's greenhouse gas emissions were caused by heating homes (National Audit Office). In Brampton, this is likely to be slightly greater than average due to the increased frequency of detached and semi-detached homes which are less well insulated than terraced homes and flats, and in addition to this, some homes are poorly insulated - solid walls common in older properties are costlier and more difficult to insulate. Furthermore, a small portion of Brampton homes are not connected to the gas grid and therefore rely on heavily emitting heating oil; these may be the properties which would benefit most from changing to a heat pump.

From a consumer perspective, there are three main considerations behind a decision to upgrade a heating system; comfort, the effect on climate change, and the money.

Beginning with the climate considerations, a heat pump is the most climate-friendly option on the market in almost every case (LETI Retrofit Guide, Home Retrofit Planner). I shall be comparing primarily with a central heating system run by a gas boiler, as this is by far the most common source of heating in the UK at around 74% of homes (2021 Census). Heating oil is more emitting than gas, and so from a climate perspective, these should be prioritised for replacement. Historically, oil has also been more expensive, although in 2021 gas became more expensive due to supply chain issues.

A heat pump has two main advantages over a gas boiler in terms of greenhouse gas emissions and pollution. Firstly, a heat pump is by its very nature far more energy efficient than any other option, with their COP (a measure of efficiency) usually exceeding 3 for well designed systems. The second point is that heat pumps use electricity as their energy source, which is less carbon intensive than burning gas, at around 162g/kWh in 2023 (carbonbrief.org) compared to 213g/kWh from gas (Energy Saving Trust). That means per unit of heat generated, heat pumps release less than a quarter as much greenhouse gases than a modern, efficient gas boiler, and less than a third as much as electric heating. It is also worth noting that as renewable electricity generation expands over the coming years, this carbon intensity will continue to fall.

Turning next to the economic considerations, this is a much more complicated question, and depends on individual circumstances. The short answer is that the cost of running a heat pump will in most cases be comparable to the gas bill which it replaces, although some savings or extra costs will occur depending on the details of the property. The primary factor affecting this is how well insulated the property is. This is relevant due to an important aspect of how heat pumps work. Heat pumps are less efficient at heating water to a higher temperature. Figure 3 shows that a less well insulated building requires more total heat output, and assuming the same sized radiators, the only option to output more heat is to increase the water temperature, which decreases the efficiency. Therefore, while both the heat pump and the gas boiler need to increase their heat output for a poorly insulated home, the heat pump system suffers more from this than the gas boiler in terms of cost, due to the fact that the efficiency takes a hit.

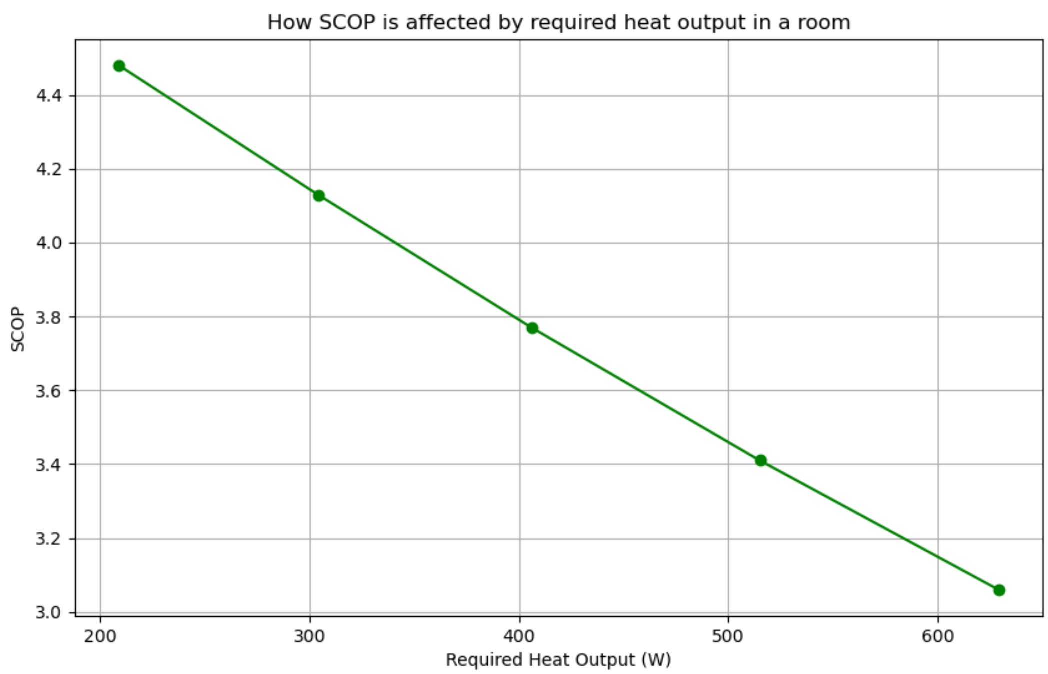

Figure 3: As the required radiator temperature increases, the efficiency (SCOP) of a heat pump decreases. This graph shows how insulating a room can increase the performance of a heat pump, by reducing the required heat output. However, this graph assumes the radiator being used is a certain size - if you increase the size of your radiators, you can get more heat out at any flow temperature, increasing your efficiency.

To reiterate, because this is important: a poorly insulated property will cost more money to heat, no matter your heating system. With a gas boiler, this is simply because you need to burn more gas to make up for the heat escaping from the house. However, as heat pumps are most efficient operating at a lower temperature, by increasing the heat demand in the house you also increase the required radiator temperature, which will reduce the efficiency of the heat pump. This will result in higher bills - you need to make up for the heat escaping the house, and this extra heat will take more electricity to produce.

There are measures that can be taken to mitigate this. First and foremost, investing in improvements to insulation, draft-proofing and improving one's doors and windows can make a large difference by decreasing bills and emissions, whether or not the switch to a heat pump is made. These measures should at least be considered no matter the circumstances. Secondly, in the process of getting a heat pump installed, a recommendation will likely be made that some or all radiators be replaced, and this should be considered carefully; they can allow a lower water temperature to be used, improving efficiency.

Again, this is important. Using a larger radiator means that you can use a lower temperature of water in the radiators, and keep the room the same temperature. For a heat pump, this makes a large difference - using a lower radiator temperature will reduce the energy cost significantly by increasing the efficiency. Some people have suggested that larger radiators also help with a slight improvement in comfort, as they result in a more even temperature within a room as well as possibly reducing air currents caused by convection.

Another thing that boosts the cost effectiveness of a heat pump is that there may be additional savings available by using variable tariffs. These facilitate charging different prices for electricity at different times of day. Some electricity providers even offer variable tariffs designed specifically for heat pump users, which may save hundreds of pounds on electricity bills if some heating is shifted to take advantage of the cheapest times. If you combine this with PV solar panels and a home battery, this could result in, for example, free hot water throughout the summer and reduced bills year round.

Briefly, very similar arguments apply to other forms of heating. Traditional electric heating is far less efficient than a heat pump, and other fossil fuel based systems are likely to be even costlier and more polluting than a gas boiler. Other 'green' alternatives may involve different considerations, for example solar thermal panels which, while providing easy and extraordinarily cheap hot water, are unlikely to provide all the heat required to heat a home or enough hot water, which means they are often used in conjunction with other heating systems. See Section 7 for other heating options.

Finally, considering comfort, if a sufficiently sized heat pump is installed, your home will remain a comfortable temperature year round. However, it may be more efficient to keep it at a consistent temperature all the time, which may or may not be to your taste - some people prefer the house to be cooler at night, for example. Decreasing the temperature overnight is possible with a heat pump and, depending on your circumstances may or may not reduce your overall bills. For details on this see Section 5 and Appendix B. Many users of heat pumps find that the consistent temperature improves their comfort as they will never wake up cold, though this is up to personal preference.

In summary, installing a heat pump to replace a gas boiler will result in a massive reduction in the greenhouse gas emissions caused by heating a home. They may provide some savings in heating costs, however this typically depends on usage and how energy efficient a home is.

3.2 Is a heat pump suitable for my property?

The short answer is that a heat pump is possible to install in most homes.

First: the space, access, electricity and pipework requirements for the actual heat pump unit. Air source heat pumps can be installed to the external wall of a building or on the ground near it. If installed on the ground, it needs to be installed on a solid and flat surface, typically a concrete plinth. They are relatively small, and the largest space requirement is that they need approximately 1 square meter to be clear around them in order to have sufficient airflow to function properly. A heating engineer will ideally ensure good airflow in the area prior to installation. If the heat pump is to be used for hot water in addition to space heating, there will also need to be space for a hot water cylinder. This may need to be somewhat larger than a cylinder for a different heating system due to the lower temperature, although this is not always true. An 80cm by 80cm cupboard space will usually suffice, as will loft or basement space.

However, there are other products available which may take less space. One of these is a heat battery. These use something called Phase Change Materials, which can absorb and remit a lot more heat for the amount of space used. These are more expensive than a water cylinder. Another option, which is new to the market at the time of writing, is a mini heat store. These use a very small cylinder full of hot water, which is used to heat water as it flows through a coil in the cylinder, effectively producing on-demand hot water with a very limited space, such as beneath a kitchen counter-top. At the time of writing, only one company is commercially producing these, although they may become more available in future. They are only recommended to be used when you absolutely do not have enough space for a water cylinder, as they will result in lower heat pump efficiency due to using a higher flow temperature, and also may require an oversized heat pump, or users to decrease their shower pressure, for example.

In the case of ground source heat pumps, there are two common types. Horizontal systems require around 700 square meters of space which is significantly larger than the average UK garden, and therefore these are typically unsuitable for a single home development, however are more likely to be applicable for projects such as district heating or for rural properties, and also this space is primarily underground and therefore the space can still be used for other purposes. Vertical systems are more expensive to install but require much less space, with the boreholes being only 20cm across, however there must be enough space for the drilling rig to enter the site.

Moving on to another common concern about heat pumps among consumers: the question about whether or not the home would need renovation in order to install a heat pump. Again, this depends on the home. Most homes have some measures which could be implemented to improve their energy efficiency and make them more suitable for a heat pump, and in a minority of homes, these improvements would be necessary to ensure comfort and safety - ordinary heat pumps will not be able to put out enough heat for a particularly badly insulated, drafty and spacious home. If this is the case, and further improvement of insulation is impossible, a high-temperature heat pump could be installed. For further information about this topic, see the preceding section about what factors make a heat pump more economical.

4 Choosing a heat pump

The decision to install a heat pump, and what kind, should only be taken with the advice of a qualified installer, who has access to the particular details of your home. When choosing an installer, make sure to find someone who is well reviewed and recommended by other customers. They also must be MCS certified if you plan to get a government Boiler Upgrade Scheme grant (more about that later). There are a number of training schemes which will certify installers, so consider finding an installer who has completed one of these. If you choose an expert, they can use their expertise to help you choose the most suitable system for you.

However, this section will discuss some of the decisions that you will take, so you know what to expect when you make the jump and decide to talk to an installer. It will also help you have a more informed discussion with the installer. Bear in mind that they likely have a lot more experience with heat pumps than you do so you should take their suggestions and concerns seriously.

The first decision you are likely to make is the type of heat pump. For more detail, please refer to Section 2.1. Briefly, though, a GSHP will offer you better energy efficiency than an ASHP, especially in winter. This will result in decreased energy bills and even fewer greenhouse gas emissions. The cost of this is a much greater initial investment, and some disruption as the heat pump installation will involve digging trenches or a borehole.

The next decision is whether you'll use a water heating system or an air-to-air heat pump. This decision will probably seem fairly obvious to you; if you already have ducts in the house you will want to go with air-to-air, and if there are already radiators or underfloor heating in the house, then an air-to-water system will seem the obvious choice.

Another choice about the type of heat pump is choosing whether or not to install a high-temperature heat pump. These can get the water temperature higher, which can be useful where there is a higher heat demand and large radiators or underfloor heating cannot be installed. Theoretically, these should be less efficient than other heat pumps, as they need to overcome a greater temperature difference, and they will spend less time operating at their design temperature. However, a UK government report (Electrification of Heat Demonstration Project) indicated that high-temperature ASHPs were no less efficient across a long time span of measurement. This could be due to differences in usage or due to inefficiencies related to installation outweighing the difference between using a high-temperature ASHP and an ordinary ASHP. High temperature models are usually more expensive to purchase.

With regard to radiators, this is something you will have to consider. The flow temperature (temperature of hot water) will be lower with a heat pump than with other heating systems, to maximise the efficiency. The lower, the better, but it will typically be between 35°C and 55°C. This may mean that some or all of the radiators in your house will need to be replaced; a larger radiator puts out more heat. Often, a radiator can be replaced with a double panel radiator which has more output for the same amount of wall space, or simply a taller radiator.

Another thing to decide is the size of heat pump. In the UK, we usually describe this with a power output, measured in kW. A rough rule of thumb is that you will need 5kW per 100m^2 of floor space. The installer should perform something called a block load calculation, or something similar. This is a calculation that determines how much heating power your house needs, taking into account things like floor space and number of rooms, but also the level of insulation, number and quality of doors and windows. This calculation is crucial - it is important to choose the right size; too small a heat pump and you'll end up cold in the winter, and if you choose one that is too large, you'll spend more money than necessary, and it may hurt the efficiency. Too large a heat pump may also cause 'short cycling', which is where the system turns on and off too frequently, reducing efficiency. A visualisation of this is shown in Figure 4. This is one of the most common mistakes made when installing a heat pump, so make sure to ask your installer whether their

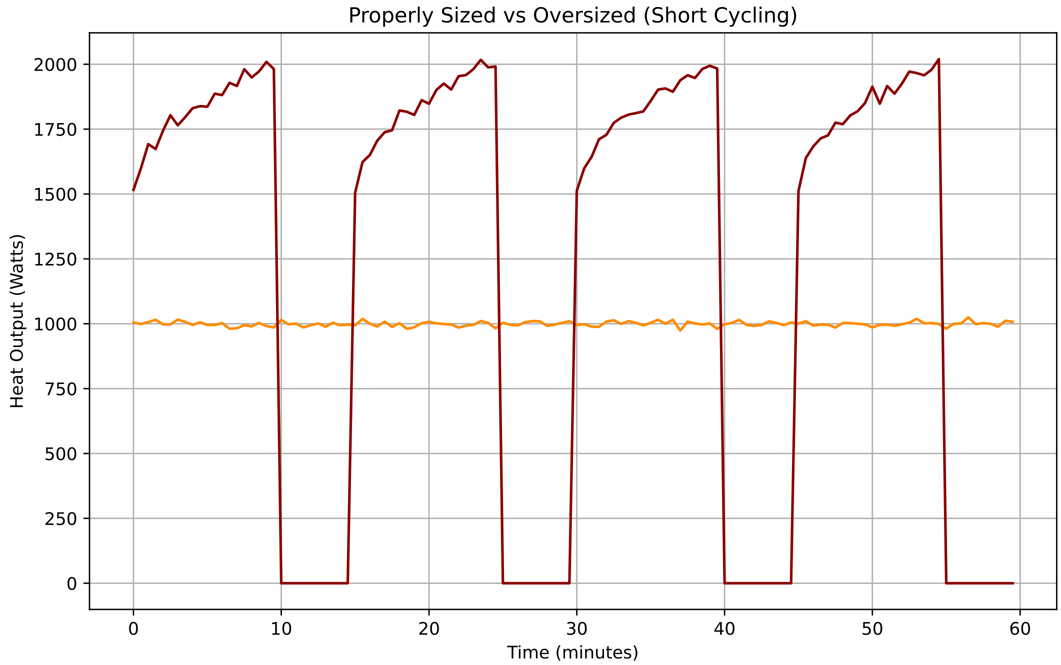

Figure 4: When a heat pump is oversized and cannot put out a low enough power to precisely supply the heat needs of a house, it must turn on and off more frequently than a properly sized model. As it takes some time for the heat pump to reach full efficiency, this results in a lot of waste.

choice is oversized.

The last decision to make is another that will primarily be recommended by your installer. This is which refrigerant will be used. There are a couple of situational factors that should be considered. Refrigerants are selected based on their ability to efficiently transfer heat at the right temperatures and pressures. These properties can have a large impact on the efficiency of the heat pump. This impacts the decision, because depending on the flow temperature the system is being designed around, some refrigerants will be better than others. There are also environmental considerations to be made. Some of the refrigerants that were historically used the most were proven to be depleting the ozone layer, or have very high global warming potential. Many of these have been outlawed or heavily regulated. It is important to avoid these, not just because we don't want to contribute to climate change, but also because if the refrigerant becomes more heavily regulated in future, any repairs or maintenance to your heat pump will become more expensive. Some people are concerned about using certain refrigerants such as R290 (propane), as they may be explosive under certain conditions. While it is an important factor to consider, and is an example of why only trained individuals should perform maintenance on a heat pump, the explosive potential is very limited due to the small quantities of refrigerant used. Also note that, as a heat pump is a sealed unit, this is significantly less of a risk than widely used gas and propane based heating systems, which often involve transporting the fuel a long distance in pipes or tanks, and then lighting it on fire!

5 Operating a heat pump

When a heat pump is installed, the settings do not need to be changed often, as it will have been set up to operate efficiently. However, there are several variables that can be measured and considered, if you wish to take a more active role in running your new heating system, or simply measure its performance.

The most important thing to keep an eye on is the Coefficient of Performance (COP), and related, the Seasonal COP (SCOP). The COP is simply a measure of efficiency; the quantity of heat output for every unit electrical power input. So, for example, if your heat pump was using 1kW of power, and your hot water tank was receiving 3.3kW of heat, that would be a COP of 3.3. The SCOP can be considered the longer term version of the same thing, measured across a whole year. This is useful to know, as it will give an accurate representation of how much electricity you will actually use heating your house, accounting for differences in temperature between winter and summer.

There are a few things you can do to try and improve the COP and make your system more efficient. As you might expect, the most beneficial measures involve improving your house's insulation, whether it be walls, windows, loft space or draft proofing. This will give the dual benefit of both reducing your required heating output, and reducing your bills that way, but also reducing the required flow temperature of your system. A lower flow temperature results directly in a higher COP. You can also reduce the necessary flow temperature by making adjustments to radiators; with larger radiators or underfloor heating, you can use a lower flow temperature and still get the same heat out, with a better COP.

Keeping the thermostat at a consistent temperature is usually recommended. If the system needs to rapidly heat up the house, the heat pump will need to work harder than necessary. Keeping adjustments to the thermostat small can give a boost to efficiency. In fact, using a thermostat to control a heat pump is not ideal - thermostats typically work by completely switching on and off the heating, which does not work well with heat pumps. For more information, see Appendix B.

One setting on a heat pump is the 'heating curve', also known as the weather compensation curve. This determines what flow temperature your heat pump will aim for at a given outdoor temperature, as you need a higher flow temperature to keep the house warm when it is cold outside. Sometimes, installers set this curve conservatively (higher than necessary), to make sure your house can get hot quickly, even on the coldest day in winter. Your house should never actually be in the situation where it needs to suddenly heat the house up by several degrees - and if for some strange reason it is, heat pumps typically include a 'boost' setting which can temporarily increase the flow temperature. It may be possible to adjust this heating curve, and make savings on the electricity cost. The Energy Saving Trust recommends "turning it down in one degree increments throughout winter until you're confident you feel your home is too cold. Then put it back up one degree to stay comfortable."

6 How much will a heat pump cost me?

Hopefully, this report has explored some of the many benefits that can be found by installing a heat pump in your house. However, getting one will cost you. There will be a upfront cost associated with the purchase and installation of the heat pump itself. Depending on the circumstances, there may also be some further costs, involving insulation, radiators, or maybe a new water tank. Then there are the running costs. While this cost will probably be similar or cheaper than your existing fuel bill, this should be carefully considered so you are not surprised by unexpected costs.

There are also grants which can be applied to reduce installation costs. An example of this is the UK government's Boiler Upgrade Scheme, which applies to homes in England and Wales which are replacing a fossil fuel heating system. This can provide a discount of up to £7500 at the time of writing. There is a similar scheme in Scotland - the Home Energy Scotland Grant and Loan. There are also grants for low-income households. For up to date information on grant funding, visit `https://www.find-government-grants.service.gov.uk/`.

Clearly, there are a very wide range of living situations, and so we cannot possibly cover every detail. We will take the approach of considering 3 representative case studies that will hopefully provide you with some insight. Note that these stories are not descriptions of real individuals but rather a generalised situation that may reflect aspects of real cases.

Case study 1: Space heating in a flat.
Sandra lives in a one bedroom flat with a balcony in a block of flats, with space heating and an electric shower. The flat is installed with double glazing and is surrounded by other flats, which act as very good insulation. There is not a lot of hot water demand - just a shower every morning. She decided to get an air-to-air heat pump which is installed on the outside wall, accessible from the balcony. She chose a double-head unit in the bedroom and living room, as the kitchen stayed warm year round just from using the cooker. She found a certified installer who surveyed the property to see whether it was suitable. They recommended a 3.5kW model which she had installed. The heat pump was £4500 including installation. Unfortunately air-to-air heat pumps are not covered by the Boiler Upgrade Scheme, so she couldn't apply for that grant. Her electricity bill fell from £1600 per year to £800, thanks to the increased efficiency of the air source heat pump. Furthermore, the carbon emissions from heating her home were reduced to less than half their previous value. She also has the option to use the heat pump for cooling on the hottest days of summer.

Case study 2: Big old home.
An older couple live in a 5 bedroom detached house built in the 1920s. It has solid walls (which are very expensive to insulate) and no loft insulation. They chose to get an air source heat pump rather than a ground source one, as they did not want to have trenches dug in their garden. They decided that they would invest in 200mm loft insulation, and as they had double glazing, the heat pump installer they found informed them that their house was sufficiently well insulated and ready for a heat pump. The installer measured their heat loss and measured that they needed a 12kW heat pump. The couple had decided that the most important factor for them was lowering their carbon emissions by getting as high an efficiency as possible, so they decided to invest the extra money to hire a very well recommended installer, and use the most efficient model of heat pump and water cylinder available. They also replaced most of the radiators in their home, which meant they could use a lower flow temperature of the water in the radiator, and also would make the rooms stay a more even temperature. The system managed to get a very good SCOP of 4.0, despite the age of the property. They also switched electricity tariff to one designed for heat pump users and shifted their electricity usage to take advantage of this. Thanks to this efficiency, their overall energy bill from heating reduced from £1800 to £735. They spent more than £20000 on their initial installation, reduced by £7500 through the Boiler Upgrade Scheme, meaning it will take around 10-12 years for them to recover the cost. However, when these years are up, they will still be saving this money, and all the while they've massively decreased their carbon footprint.

Case study 3: Terraced family home.
A young family lived in a modern 3 bed terraced family home. It had insulated cavity walls, double glazing

and loft insulation. However, they had limited wall space and didn't want to replace their radiators with larger ones. They were surprised to learn when they had an installer do a survey, that due to the quality of insulation in their house, their house was still suitable for a heat pump, although they had to use a slightly higher flow temperature. They were recommended a 5kW heat pump. They saw no significant change in their energy bill, but they did not need to worry about a gas bill so it simplified their household logistics. They also enjoyed the knowledge that they weren't contributing as much to climate change - their greenhouse gas emissions from heating were 5 times lower! Years later, they had solar panels installed on their roof, along with a battery, and discovered that this had a good synergy with the heat pump; the free electricity from their roof was going a lot further when used in their heat pump. This made the pay back time on their solar panels much shorter than their neighbours'.

For more information on these case studies, see Appendix A.

7 Other heating options

If you have read the preceding sections and have decided that your house is in the small minority of properties that is not suitable for a heat pump, you should consider the following suggestions for a heating system that is better for the environment than a fossil fuel boiler.

There are a variety of heat sources that are better for the environment than burning fossil fuels. They vary widely in efficiency, cost effectiveness and suitability in terms of geographical factors. Some options are shown in in Figure 5.

Direct solar heating, also known as solar thermal systems, use a solar collector, usually a system of pipes on the roof, to collect heat energy from the sunlight using a liquid, usually a mixture of water and antifreeze. This heat energy is then transferred into a hot water tank, to be used for domestic hot water, space heating or both. They are highly efficient, extracting much more energy from the sunlight falling on them than a solar PV panel would, although the versatility of the PV producing electricity should not be underestimated. Solar thermal systems have the distinct advantage of almost zero running costs, as they get all the energy they need from sunlight. There are also downsides, though. In the winter, the solar thermal will be unlikely to provide all the hot water you will use unless you have very low demand, so there should always be some other hot water system to cover the shortfall. Often, this is done with direct electric heating.

Direct electric heating is a system which uses electricity to heat your hot water and for space heating, without using a heat pump. For hot water, it uses resistive heating; simply passing a current through a heating element which gets hot, like the element in an electric kettle. Space heating is provided from electric radiators on the wall, which again are resistive heaters. Electric radiators are standalone units which can be used to heat particular rooms. They are 100% efficient, as all the electricity is converted into heat (this might sound surprising, but the usual waste product from electrical equipment is heat anyway). However, as electricity is, at the time of writing, several times more expensive than gas, they will usually cost quite a lot more than other systems to run. The upsides you get to using this more expensive system are cheap installation costs, very few moving parts so low maintenance costs, and a slight reduction of greenhouse gas emissions over fossil fuels, which will improve as the electricity grid decarbonises further.

Biomass heating is similar to fossil fuel boilers in that it involved burning fuel to heat water and then using that hot water in the house. Usually, this fuel is some form of wood, although there are other options such as biodiesel which uses food products processed into a liquid fuel. Biomass can be considered a

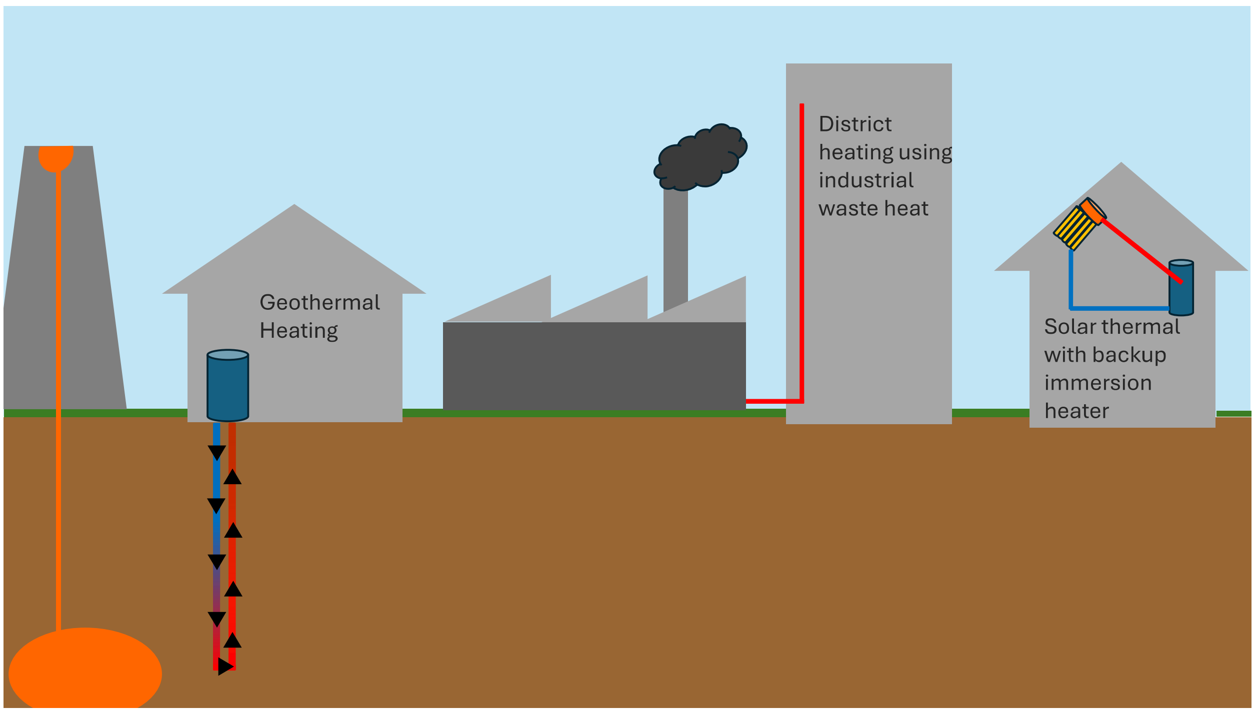

Figure 5: While heat pumps are very versatile and applicable to a wide range of situations, in some situations, other options may be superior. For example solar thermal, geothermal, and collecting waste heat can provide essentially free heat, where they are applicable.

renewable resource, as the fuel is continually produced, compared to fossil fuels which are removed from ever-depleting underground supplies. It can also, if fuel is managed carefully, be carbon neutral, as the carbon dioxide emitted is absorbed by the plants from the atmosphere when they are growing. The downsides include the potential to emit particulates, lowering air quality. This is a particular concern in urban areas - some kinds of biomass heating such as wood burning stoves cannot be used in certain cities for this reason. There are also concerns about poor fuel management resulting in deforestation, or reducing land available for other agricultural production. There is also a requirement for a large space for fuel storage.

Hydrogen boilers are often claimed to be the future of home heating. The principle is that it would use existing natural gas infrastructure to transport and deliver fuel, but the fuel would be hydrogen, produced with electrolysis (splitting water molecules) using renewable electricity. Hydrogen burns very cleanly, the only by-product being water, and if produced using renewable electricity the greenhouse gas emissions would be almost none. The National Infrastructure Commission has done a review of the technology, and they recommend against it: "The Commission's analysis demonstrates that there is no public policy case for hydrogen to be used to heat individual buildings. It should be ruled out as an option to enable an exclusive focus on switching to electrified heat." There are several reasons for this, the most obvious being efficiency. The efficiency of a hydrogen system is limited to below 100%, and as the hydrogen production uses electricity to produce, it is far more economical and sensible to use this electricity to directly produce heat, preferably through a heat pump. The upside of hydrogen over a heat pump is that they can achieve higher flow temperatures, but modern systems should be - and usually are - designed around relatively low flow temperature.

Geothermal is a very cheap and effective system of heating, offering almost no running costs beyond maintenance and practically zero greenhouse gas emissions. Unfortunately, there are some downsides: the cost of installing, and the geographical limitations to where they can be installed. In order to use geothermal energy to directly provide hot water, the property must be located somewhere with substantial underground heat reserves. These are used to great effect in Iceland, and also there is potential in other places with high tectonic activity, such as the Western United States. While there are significant geothermal heat resources anywhere, in most places it would be prohibitively expensive to drill deep enough to tap into these reserves. The solution to this is to make use of ground source heat pumps. These, as described earlier, use shallow geothermal resources found anywhere on the planet to achieve a heat pump efficiency even greater than that found in an air source heat pump.

For some areas, District Heating or Community Heating may be the ideal solution. This involves centralised heat generation, heating large quantities of water, which are then piped to individual users through insulated pipework. These generally offer a valuable service as the space requirements are centralised, saving space from water storage or heat generation units in individual homes, and may be cheaper to run and install due to economies of scale. They can also make use of unconventional heat sources, for example waste heat from industrial processes, or large scale water source heat pumps. However, they usually require a great deal of planning and infrastructure to be installed. A smaller scale version of this is to install a few ground source heat pumps to heat an entire block of flats, for example.

A Appendix: Economical Calculations

A.1 Case study 1: Space heating in a flat

Using a representative floor plan, the maximum heat requirement was calculated to be 2354W. However, some extra redundancy is needed; as there were no emitters in bathroom or kitchen, the overall system would need to be hotter in order to keep those rooms at a comfortable temperature. Also, if neighbours leave their heating off, for example if they go on holiday then there is extra heat loss. Unheated upstairs and downstairs neighbours increases estimate to 2797W at external temperature of -3C. For an air-to-air heat pump, a COP of 3.0 is reasonable on a cold day. On warmer days, it is likely to be better than this, however there is not a lot of good data on air-to-air models as it is very difficult to measure their heat output. I therefore model this with a SCOP of 3.0. Annual space heating demand was calculated as 5119kWh assuming unheated neighbouring flats year round, however this is clearly an overestimate. Using October 2024's electricity price cap (24.5p/kWh), and assuming 5000 kWh of annual usage, switching from space heating to the heat pump would reduce heating related electricity bills from £1225 to £408.33. She may increase her usage due to the increased convenience and possibility to perform cooling, but I will assume this is covered by the underestimate in SCOP. The numbers given in the report assume an additional £400 per year, to cover the electric shower, other lifestyle uses, and the standing charge. The greenhouse gas emissions associated with this heating demonstrate a decrease from 810kg to 270kg CO_2e - a factor of 1/3 due to the coefficient of performance.

A.2 Case study 2: Big old home

Big homes come in a wide variety of layouts and sizes, so it is difficult to imagine a representative example. This case study was designed to show the possibilities for what can be achieved in terms of efficiency, so inspiration was taken from the top ranked systems on `heatpumpmonitor.org`. Most (but not all) of the highest rated systems had a flow temperature around 35°C. Some had no wall insulation, showing it is possible. A common anecdote from the installers of these systems is that the high efficiency is partially down to keeping the system as simple as possible. For example, keeping the number of buffers, mixing valves, and different zones in the house as low as possible can decrease the mixing of hot water with cold water which will allow the heat pump to run at a lower temperature. This kind of knowledge is not yet universal among heat pump installers, however third party training schemes are gaining popularity.

The numbers used for the bills were calculated through the following methodology. Starting with a greater than average gas bill of £1800, the boiler was assumed to be about 80% efficient, which is common for 15 year old boilers. This gave a heat usage of around 19,600 kWh/annum. Then, using the stated SCOP of 4, this gives electricity usage for heating 4900kWh/annum. A commercial electricity tariff was chosen which offers 15p/kWh for heat pump usage, which gives a total electricity bill for heating of £735.

A.3 Case study 3: Terraced house with no new emitters

As the homeowners in this (imaginary) scenario decided not to install any new radiators or underfloor heating, their heat output was limited by the radiators. As such, they had to use a flow temperature of nearly 50°C in their radiators. The heat pump efficiency associated with this flow temperature can reach COP of 3.4 on a cold day according to manufacturer's guidelines for one brand of heat pump. With a well designed installation, this could result in a SCOP above 3.5 year round. At this flow temperature a modern condensing gas boiler would have an efficiency of 90%. Assuming annual heat demand of 15000kWh (no detailed heat loss calculation was performed here but this is typical for a 3 bed terrace), using October 2024 electricity

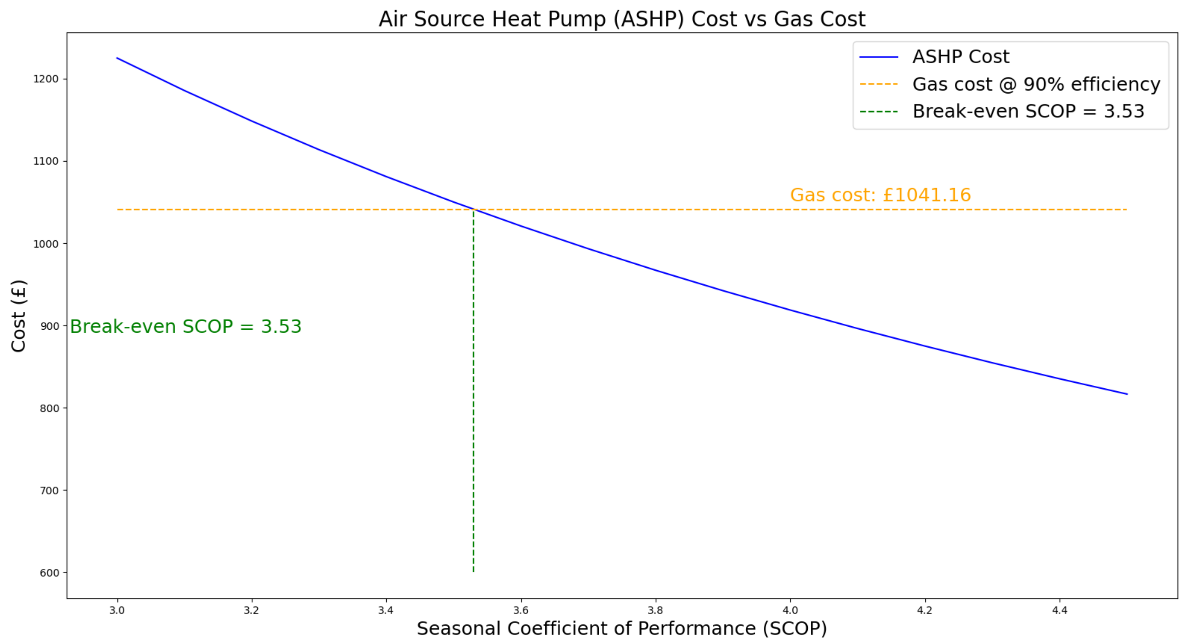

Figure 6: Air Source Heat Pumps (ASHP) can be cheaper to run than gas boilers, provided the system is efficient enough. This example is fairly typical for how the costs will compare for the most modern gas boilers operating at a good efficiency - and this implicitly assumes a low flow temperature which should improve the ASHP efficiency towards the higher values on this graph. Note that this example assumes the price paid for electricity and gas are the UK energy price cap in October 2024 - these prices can be easily beaten by finding the correct tariff, which can often make a heat pump the far cheaper option.

(24.5p/kWh) and gas price cap (6.24p/kWh), in order to break even for this home would require an SCOP of 3.53, including standing gas charges of 31.7p/day, so it is likely they would be paying slightly more for the heat pump than gas, but only if they had one of the most modern and efficient combination gas boilers. They could save up to £200 a year by using better emitters and achieving a higher SCOP. If they changed to a variable tariff and shifted their electrical load to a lower price time, they would make hundreds more in savings. When they get their solar panels, they will save the full price of electricity, rather than the slightly lower export tariff, meaning their solar panels will be more valuable to them than their neighbours without a heat pump.

When the switch is made to the heat pump, their greenhouse gas emissions from heating fall from 3550kg to 694.3kg CO_2e, assuming 213g/kWh for gas and 162g/kWh for electricity. This is a good example of just how much better a heat pump is in terms of climate; this is a 5-fold decrease!

B Appendix: Heating Curves

When you set the thermostat to a certain temperature, the heating system will work hard to heat up your house to that temperature. When it is reached, the system will turn off, as it is no longer needed. The temperature will drop over time, below the set temperature, so the thermostat tells the heating to switch back on, and off, and so on. This is called hysteresis.

However, with heat pumps, this is not ideal. The reason is that heat pumps generally perform better and more efficiently at a lower ‘flow temperature’ - the temperature of the water in the radiators, but a lower flow temperature means a lower heat output, so your system will be operating most effectively if the radiators are putting the most heat that they can, at the lowest temperature possible, i.e. they are on, all the time - and the inside temperature is neither increasing or decreasing. While running the system in a different way is possible, it will cost slightly more and use more energy.

So, how do we achieve this? With something called a heating curve, or weather compensation curve. This helps your house stay at the right temperature when the weather outside changes. With a thermostat system, your heating would simply stay on longer when it is colder outside, but a weather compensation curve instead heats up your radiators to a hotter flow temperature. This curve tells your heat pump what flow temperature your radiators should be for a given outside temperature. If it’s calibrated correctly, your radiators will always be on, and your house will stay at the same temperature, year round.

With boilers or other heating systems, people often use something called a set-back temperature where the heating is turned down to a lower temperature, for example at night time when people are asleep, or when people are at work. This saves energy as there is less heat emitted overall. However, it requires increasing the power to a greater level later in order to heat the house back up to the higher temperature. This means that, for a heat pump, the system will be operating at a higher temperature during this ‘boost’ phase, and for a heat pump this makes the system less efficient. Depending how long the set-back period is and how much power is used during the boost phase, it may or may not save money. However, the savings or extra cost is likely to be marginal, so the best option is to maximise your comfort, however you like your home.

C Appendix: References and resources

This report was created for Brampton 2 Zero (B2Z), a Community Interest Company based in Brampton, Cumberland. For more information, visit `https://www.brampton2zero.org.uk`. Here are some of the author’s recommendations to learn more about heat pumps. Please note that these organisations are not affiliated with B2Z and their views and content do not reflect B2Z.:

- Heat Geek consumer advice: A list of articles and videos mostly discussing heat pump efficiency.
- Energy Saving Trust: Advice articles about insulation, heat pumps, or other energy saving measures.
- Open Energy Monitor: Provides case-studies, theory and calculators related to heat pumps.
- Heat Pump Monitor: An open source website showing details and live heat pump performance of different heat pump intallations.
- Cumbria Action for Sustainability: Penrith based organisation offering home energy and retrofit advice.