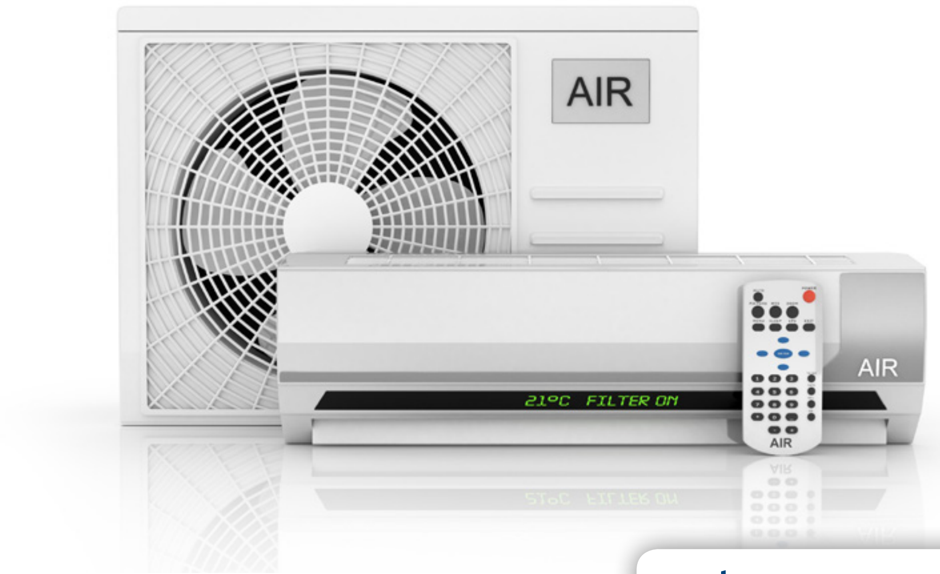
CARBON TRUST

Heat pumps

Opportunities for lower carbon heating



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Preface

Heating homes, businesses and industry accounts for nearly half of the energy used in the UK, and a third of its carbon emissions[1]. As businesses look to save energy and move away from fossil fuels in the fight against climate change, an efficient means of providing this heat is essential.

The Carbon Trust works with organisations to address these challenges and deliver on our mission – to accelerate the move to a sustainable, low carbon economy.

This overview introduces heat pumps as a technology and helps readers to assess whether using heat pumps is a viable option for their business.

[1] The Clean Growth Strategy, HM Government, April 2018

Contents

Introduction

For most businesses, heat is generated by burning fossil fuels, and the most common fossil fuel is natural gas (burning natural gas generates nearly 70 per cent of the heat used in the UK). Traditionally, gas-fired heating has generated fewer carbon emissions than electrically powered heating.

Due to increased use of renewables, and reduced use of coal, the official average carbon intensity of grid electricity in Great Britain decreased by approximately 15% from 2016 to 2017. Using electricity as a source of energy for heat has therefore also become less carbon intensive, and based on current grid projections this trend is set to continue. While grid supplied electricity continues to become less carbon intensive, natural gas (and most other fossil fuels) has remained relatively static, with only small variations.

Electrically powered heat sources such as heat pumps could potentially become much more common as a means for providing low carbon heat to both domestic and commercial properties[2]. It is therefore essential that businesses have a good understanding of heat pump types, applications, finances and ongoing operational requirements. Firstly to know when to consider selecting heat pumps, and secondly to ensure systems are properly implemented and run as efficiently as possible.

[2] Next steps for UK heat policy, Committee on Climate Change, October 2016

Before considering a heat pump system to improve the efficiency of heating your site, first ensure that your building is thermally insulated to appropriate levels to minimise the demand for heating.

Who is this publication for?

This heat pumps overview outlines the main technologies and applications relevant to small and medium sized businesses. It will be useful for facilities managers, business managers and others looking to understand the opportunities available. Further specialist advice will be required prior to design and investment.

Heat pump principles

This guide will explore the most common types of heat pump system, and provide guidance on how to ensure effective implementation.

Heat pumps can often provide both heating and cooling and are commonly found in commercial and residential settings. They can be both gas and electrically driven, but most commonly use electricity. Where a domestic fridge extracts heat from inside the fridge and rejects it outside, heat pumps work in reverse to transfer energy from a low temperature source such as ambient air, water, ground or waste heat and raise it to a higher useful temperature. This is made possible using a thermodynamic refrigeration cycle. What makes a heat pump so efficient is that the quantity of thermal energy transferred is often much greater than the external energy used to drive the refrigeration cycle. The cycle is reversed where cooling is required.

The ratio of heat transferred into the building versus energy used to drive the refrigeration process is known as the Coefficient of Performance, or COP. Meaning that a standard space heating system with a COP of 3.0 is capable of providing 3kW of heat for every 1kW of supplied electricity.

Heat pumps are not zero carbon, as they require some electricity to drive the refrigeration cycle and raise heat to useful temperatures. However, the energy extracted from the external environment is considered to be renewable.

Although there are a wide array of configurations for different types of heat pump, in its most basic form a heat pump system will be composed of four components:

- An evaporator to collect energy from the cooler heat source (outside air, underground etc.)
- A compressor to drive up the pressure and temperature of the thermal fluid (greatest energy consumer)
- A condenser to deposit the thermal energy into the building (internal air, water etc.)
- An expansion valve to lower the pressure and temperature of the thermal fluid (minimal energy consumer)

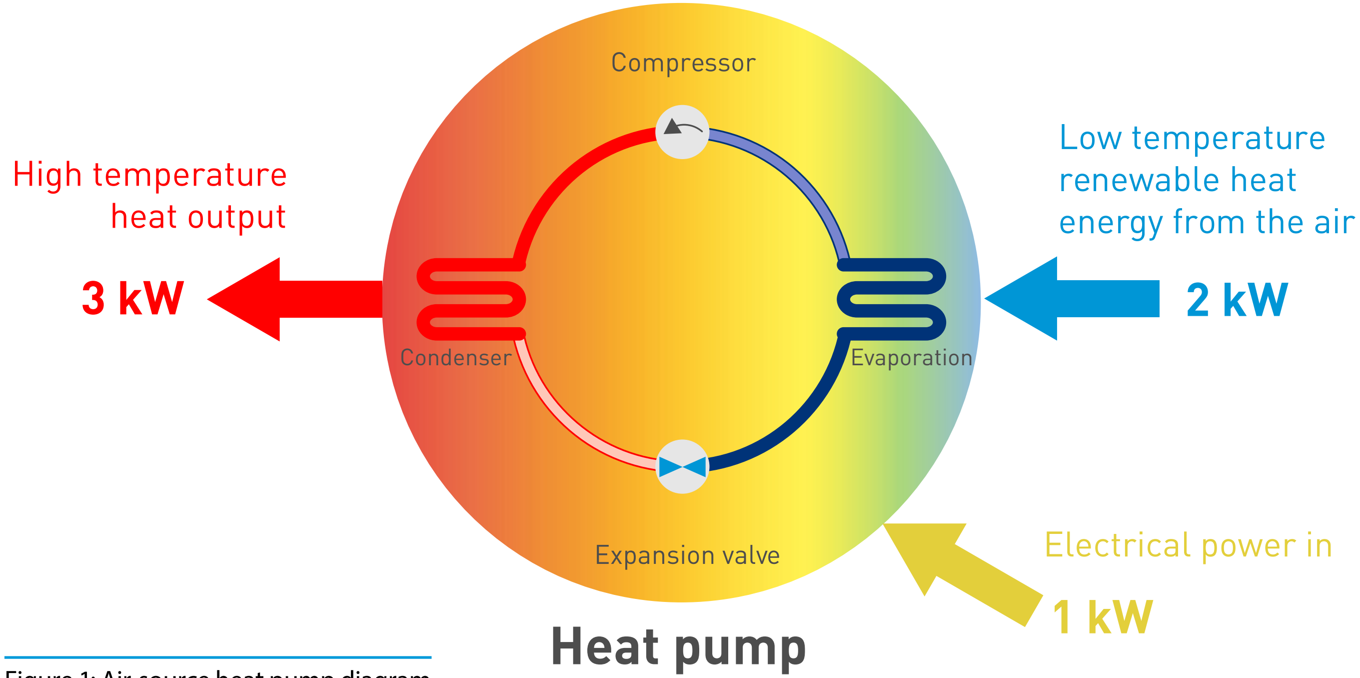


Figure 1: Air-source heat pump diagram

Air-source heat pumps

Air-source heat pumps (ASHPs) take low-level heat occurring naturally in the air, and convert it to high-grade heat by using an electrically driven or gas-powered pump.

Such systems typically use an air-source collector, which is located outside the building. The heat collected from the outside air is stored in the refrigerant fluid and can be transferred inside to provide space heating or domestic hot water. ASHPs can also be driven in reverse to provide comfort cooling, collecting heat from inside and expelling it outside.

System components

External

Air-source collectors or evaporators are much like external air conditioning units, but working in reverse. These are typically self-contained wall or floor mounted units located external to the building containing single or multiple fans drawing ambient air over a pipework coil containing refrigerant. Even at external temperatures as low as -15°C, thermal energy in the air will be collected by the refrigerant (causing it to evaporate, hence external units being referred to as evaporators) for the compressor to convert to higher grade heat for use in the building.

Internal

The method for delivering collected heat into a building depends on the type of air source heat pump being used. There are two common classifications of air source heat pump, these are:

- Air-to-Air – internal units for this type of system are often wall mounted and operate like a typical small air conditioning systems (only providing heating rather than comfort cooling). A fan blows air over pipework containing the heated refrigerant, which acts to cool and condense the refrigerant and transfer the heat into the building.
- Air-to-Water – refrigerant containing thermal energy from external air is passed through a heat exchanger to transfer this heat to water. A simple low temperature system will raise water to around 40°C where it is at an ideal temperature for use with underfloor heating systems. Water can also be raised to higher temperatures using direct electric heaters or second stage refrigeration cycles to provide water temperatures over 60°C for hot water and standard wet radiator heating.

Fact:

Heat pumps used for heating can offer carbon emission savings of around 30% when compared to conventional natural gas boilers

Site suitability

Installation of an ASHP involves siting an external unit and may involve drilling holes through the building wall. This may require planning permission. Good airflow is essential for the external unit to interact effectively with ambient air; therefore, it should be sited away from any potential obstructions. The fan will also generate a small amount of noise, so this should be considered when selecting a location.

Cold climate performance

The performance of an ASHP varies dramatically with the external air temperature. In colder temperatures, the heat pump system will be less efficient at drawing heat from external air as the compressor has to work harder to raise the temperature of the refrigerant for use in the building, this can significantly reduce the COP of the system. In mild climates, such as that in the UK, frost can also accumulate on the system's evaporator in the temperature range 0-6°C, leading to reduced capacity and performance of the system.

Costs and payback periods

Air-source heat pumps offer good energy, cost and carbon savings when compared to standard electric heating (see example business case right). When compared to conventional gas fired heating systems the potential payback periods for ASHPs improve dramatically when the current boiler heating system is due for replacement and installation of an ASHP is considered as part of this process. Some ASHP systems are also eligible for Renewable Heat Incentive (RHI) payments (currently only air-to-water systems) which can significantly improve project economics. The expected life of an ASHP is between 10 and 15 years and when used for heating typically offer carbon emission savings of around 30% when compared to conventional natural gas boilers.

Case study

Electric ASHP example business case

A small ASHP installation (air-to-air) can cost between £4,000 and £7,000. Larger installations can cost much more depending on the system size and application.

For example replacing the electric heating system in a building with an annual heat demand of 18,000kWh with an ASHP will save 12,000kWh per year, assuming a coefficient of performance of 3.0. This gives an annual carbon saving of more than 6.5 tCO_2e. At a unit price of 9p/kWh for electricity, this would save £1,080 per year and assuming a typical installation cost of £5,500, you'd recoup your costs in about five years. The paybacks associated with replacing natural gas or fuel oil based heating systems will be considerably longer than this.

Maintenance of an air-source heat pump

Air-source heat pumps require relatively little on-going maintenance, though each manufacturer will have their recommended requirements concerning annual or seasonal maintenance. An annual service prior to the heating season is recommended to ensure the system functions optimally. There are also checks that heat pump owners can perform to ensure the unit operates as intended, these include:

- Check thermostat and controller set points regularly to make sure they are optimised
- Clean or change dirty filters
- Ensure air flow is not impeded by dirt or debris (e.g. leaves or dirt on external units)
- Check insulation for damage
- Power off the unit and check/clean fan blades

A well maintained system will potentially be 10-25% more efficient than a poorly maintained equivalent.

Gas-fired air-source heat pumps

Gas-fired (or absorption) systems function in a very similar way to standard AHSPs, however rather than using electricity to power a motor to drive the refrigeration compressor, gas-fired heat pumps use a gas burner.

Typical COP for a gas system is around 1.3-1.5 (so for 1kW input, 1.3kW of heat is produced). This doesn't sound particularly strong when compared to the COP of electric heat pumps, but when the lower unit costs and carbon intensity of natural gas are taken into consideration, gas-fired systems can offer strong performance over their lifetime, particularly when compared to gas boiler systems (see example business case below).

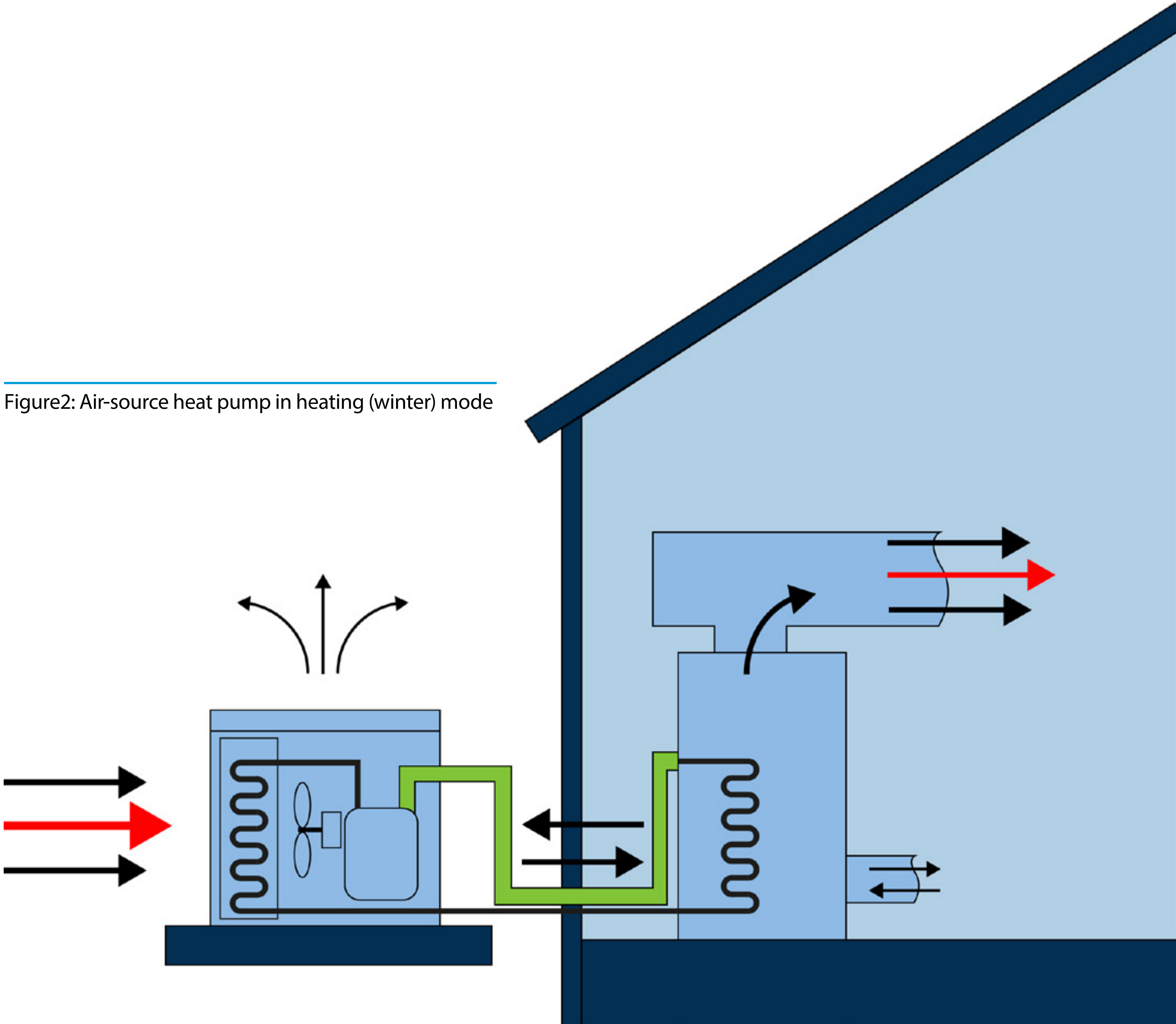
Case study

Gas-fired ASHP example business case

For an office with annual heating thermal load of 180,000 kWh, a typical condensing boiler with efficiency of 90% would use 200,000 kWh of gas per year, costing £6,000 (based on a gas unit rate of 3p/kWh).

A gas-fired ASHP with COP of 1.3 could achieve the same thermal output using 31% less natural gas, saving approximately £1,850 per annum.

Figure2: Air-source heat pump in heating (winter) mode



Ground-source heat pumps

Due to relatively stable below ground temperatures, GSHPs can offer better year round efficiency than ASHPs.

The temperature below ground typically remains between 8-12 °C throughout the year. Ground-source heat pumps (GSHPs) exploit the stable temperature of the ground or groundwater beneath a site and use it as a source of heating and/or cooling.

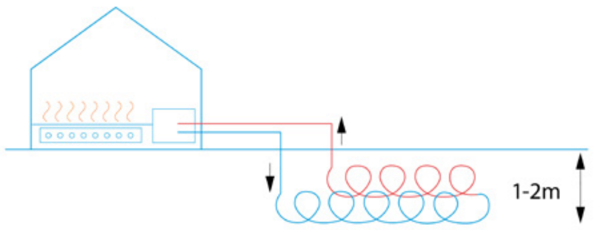
As with an ASHP, GSHPs use electricity to raise or lower the temperature of the heat exchange fluid, COPs typically range from 3.5 to 4.5.

External system components

There are three common types of GSHP:

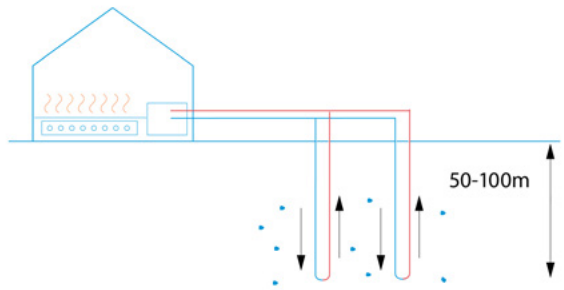
Closed loop horizontal system

- A heat exchange fluid is circulated through pipes laid horizontally in trenches in the ground
- A large area of ground is required – larger than vertical systems.



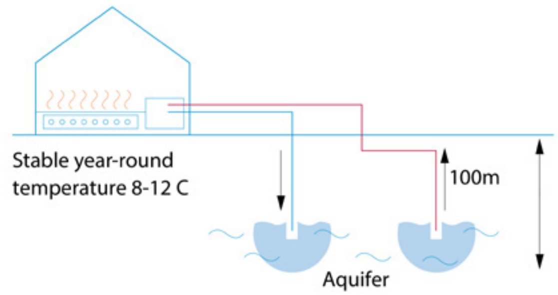
Closed loop vertical system

- A heat exchange fluid (often a water/antifreeze mix) is circulated through pipes laid vertically in boreholes in the ground
- Can be used in most ground types in the earth or in ground water
- Output is fairly predictable
- Less efficient than an open loop system so more boreholes are required (often by a factor of around 40)
- Generally less cost effective than open loop systems – but up-front investigation costs less.



Open loop system

- Groundwater or surface water is extracted from and returned to a suitable body of water (aquifer below the site for groundwater, river or lake for surface water)
- Output is dependent on how much water can be extracted
- More efficient than closed loop systems, so fewer boreholes are needed
- Generally more cost effective than a closed loop system
- Can use cooling effect of groundwater without running a heat pump in the summer.



Internal

Similar to ASHPs, GSHPs can be used to heat air in a building, or to heat water. By far the most common way of using heat from GSHPs is by heating water via a heat exchanger. Output temperatures from the GSHP are typically in the between 30-55°C, so the technology is well suited for supporting underfloor heating installations. Higher temperature systems are available that are capable of supporting domestic hot water and standard radiator heating without additional thermal support.

Site suitability

The success of GSHPs depends on ground conditions, which are highly variable. It is important to research site feasibility and technology choices.

Open loop boreholes require aquifers below the site, or suitable nearby bodies of water that are able to support sufficient water extraction to meet the heating/cooling demands of the building. Suitability can only be determined by local surveys and site testing, with some larger systems requiring a license for abstraction/discharge.

Closed loop vertical systems require sufficient floor area to accommodate an array of boreholes (approximately 3-6kW heating per borehole depending on depth) spaced at approximately 7-10m centres. Below ground conditions must be able to accommodate borehole drilling to 120m in depth and the site must be able to accommodate large drilling rigs.

Closed loop horizontal systems are typically buried 1-2m deep but require a very large open area in order to accommodate sufficient ground loops. This can be up to 85m^2 of open ground per kW of heating.

Cold climate performance

Due to the relatively consistent temperature below ground (particularly for deeper boreholes), GSHPs maintain high levels of efficiency all year round.

Maintenance of a ground-source heat pump

As with air-source heat pumps, each manufacturer will have a recommended regime of maintenance for their given ground-source heat pump system. An annual service by a suitably qualified technician is typically recommended to ensure the system is operating within the manufacturer's tolerances. Energy efficiency and performance losses of up to 25% are possible for poorly maintained systems. Maintenance checks will typically include reviews of the control equipment, water pumps, compressors, above ground pipework, levels of coolant fluid in the ground array as well as checks on the internal heating system.

Case study

Stoke Local Service Centre

A GSHP was installed to provide 100% of the heating requirements for a new extension to an existing building at the Centre. The GSHP had a heating capacity of 90kW, with a closed loop borehole array consisting of 16 boreholes, spaced at 7 metre centres.

The installation cost was £149,000 and provided carbon savings of around 30% when compared to a conventional gas boiler heating system.

Source: Carbon Trust Down to earth GSHP guide

Costs and payback periods

GSHP can offer the benefits of reduced energy bills, carbon savings and reduced maintenance costs. These will eventually offset the up-front capital investment.The additional costs of installing the external ground loop pipework can mean that GSHP systems are significantly more expensive to implement than ASHPs or boilers. Open loop systems require fewer boreholes and are therefore less expensive to install, but an allowance should be made for site investigations regarding the impacts to local source aquifers. The cost associated with drilling deep boreholes or excavating large areas of land for closed loop systems can mean that the ground array will account for a majority of the system installation costs. Because conditions and solutions can vary from site to site, cost ranges can be broad.

Early involvement and upfront planning with experienced contractors is essential to ensure a successful project that delivers efficient heat to the building with effective cost management.

GSHP systems are also eligible for renewable heat incentive (RHI) payments, which can help improve project economics.

Type of system	Cost per kW of heat output
ASHP (air to air and air to water)	£250 to £1,500
GSHP (open loop)	£1,000 to £2,000
GSHP (closed loop)	£1,500 to £3,500
LPHW boiler	£70 to £150

Typical cost per kW of heat output
Source: Carbon Trust proprietary data

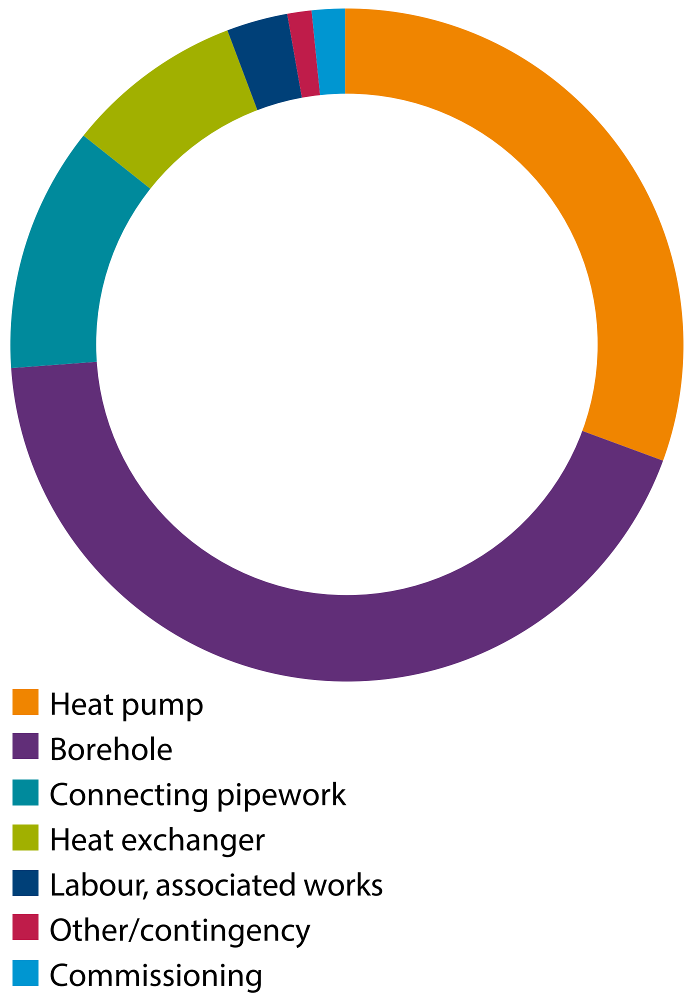


Figure3: GSHP example cost breakdown

Example cost breakdown. Source: Carbon Trust Down to earth GSHP guide

Waste heat recovery heat pumps

In many manufacturing processes, significant amounts of heat are often wasted, while a simultaneous demand for thermal energy exists on site. By taking this waste heat and boosting the temperature to a useful level, heat pumps can be a highly effective way of optimising the efficiency of site processes.

Before considering heat recovery, businesses should first look to reduce the amount of waste heat from a process. Examine ways to optimise the temperature and time that is required in the manufacture of the product to ensure that, as much as possible, any heat going in is fully utilised in the manufacture of the product.

When considering heat recovery it is important to understand the type of waste heat available (e.g. temperature, exhaust air or water), and then what thermal demands are required on site that could potentially be met by the waste heat.

Conventional means of heat recovery are available for recovering high-grade heat via direct heat exchangers such as condensing gas to water economisers for boilers that can improve net thermal efficiencies of boilers by up to 15%. However, when waste heat is of a much lower grade (say 30-50°C), the temperature often needs to be elevated to make it usable.

Heat pumps are an efficient way of raising the temperature of recovered low-grade heat, with COPs of between 3.5 and 5.0 typically achievable. Depending on the scale of the system, investment costs can be high. Simple paybacks of 3-5 years are therefore typical for a heat pump heat recovery system.

Almost all sites will have different sources and uses for heat, so there is unlikely to be a 'one size fits all' off-the-shelf solution. It is therefore recommended that technology specialists are consulted before considering a heat recovery heat pump solution.

Heat sources

- Air
- Water
- Process heating
- Process cooling
- Oil cooling
- De-superheating
- Condensing

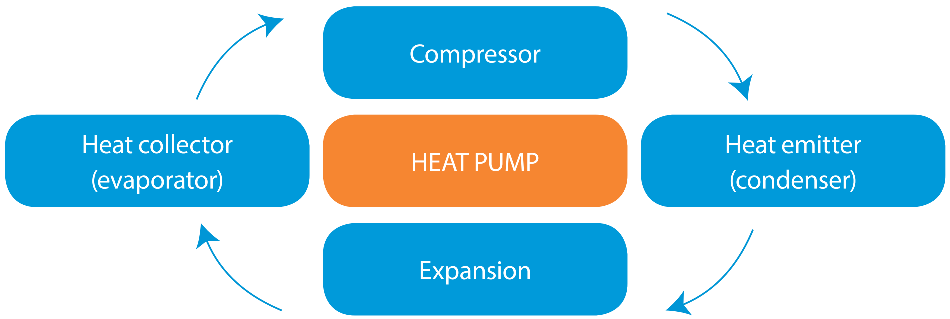


Figure4: Waste heat recovery solutions

Potential applications

- Domestic hot water
- Boiler pre-heat
- Process drying
- HVAC systems
- Food production
- Sanitation
- Washing
- Brewing
- Pasteurisation
- much more...

F-gas regulations – future proof your heat pump:

Heat pumps typically use refrigerants which can be natural (CO_2 or ammonia) or synthetic (mostly hydrofluorocarbons or HFCs such as R134A and R410A). F-gas regulations are imposing a gradual phase out of harmful HFCs with high Global Warming Potential (GWP). From 2020, all HFCs with GWP greater than 2,500 (such as R404A) will be banned from all but a few very low temperature refrigeration systems. By 2030, only 20% of the quantity of HFCs that were sold in 2015 will be available as over the next 12 years end users and manufacturers will have to move to using refrigerants with lower GWP.

Using a low GWP refrigerant is essential when considering an investment in a heat pump system with a potential lifetime of 10-15 years.

Examples of common refrigerant GWP

Refrigerant	GWP
R404a	3,922
R410a	2,088
R407c	1,770
R32	675
R1234yf	4
R1233zd	4
R290	6.3
R717 (Ammonia)	0
CO_2	1

More information on F-gas regulations is available on government websites
https://www.gov.uk/government/collections/eu-f-gas-regulation-guidance-for-users-producers-and-traders

Seasonal Efficiency

Seasonal efficiency is a measure of the true energy efficiency of heating and cooling systems across a whole year. This new method of rating energy efficiency is driven by the EU's Energy Related Products (ErP) directive, which specifies the minimum eco-design requirements for heating and cooling products. There are two seasonal efficiency measures:

- The Seasonal Energy Efficiency Ratio (SEER) value in cooling
- The Seasonal Coefficient of Performance (SCOP) value in heating

The higher the value of SEER or SCOP, the more efficient the cooling or heating system respectively.

Checklist

Before undertaking a heat pump project, the first step should be to undertake the following checks to ensure that a heat pump is the appropriate solution for your site

<table>
<tr><th>Check</th><th>Comments</th></tr>
<tr><td>1. What are the heating requirements of the site? Is there a need for space heating and hot water, or space heating only?</td><td>Select the most appropriate type of heat pump system for the site. As a guide:
<table>
<tr><th>Site type</th><th>Typical heat pump application</th></tr>
<tr><td>Office, retail</td><td>Air to air</td></tr>
<tr><td>Hotel, leisure centres, swimming pools, education, healthcare</td><td>Air/ground to water</td></tr>
<tr><td>Industrial</td><td>Waste heat recovery</td></tr>
</table>
If hot water is required, additional heating input may be required to raise temperatures to required levels.

For retrofit installations, ensure the system selected will work with any existing heating system otherwise higher costs would be incurred.</td></tr>
<tr><td>2. Is there an area of open land/body of water/aquifer located close to/below the site? If not, can higher costs/longer paybacks be considered for drilling vertical boreholes?</td><td>Though often a higher cost option than air source heat pumps, ground/water source heat pump systems typically offer better year round efficiency than air source heat pumps as the thermal source (ground or water) is at a more constant year round temperature than external air.</td></tr>
<tr><td>3. Is there a suitable external location to position external condensing units?</td><td>An air-source heat pump requires a secure location with good airflow to the external condenser to allow effective rejection of heat.

Understand the noise level of the air source heat pump in decibels and consider suitable locations for external units.</td></tr>
<tr><td>4. Is the system less energy/carbon intensive than an equivalent gas-fired system?</td><td>This step may require the assistance of a qualified heating engineer who can undertake the necessary calculations.</td></tr>
<tr><td>5. Do I have enough electrical capacity to install a suitably sized system?</td><td>Investigate the available electrical capacity in the building.</td></tr>
<tr><td>6. Will this technology save costs?</td><td>Engage at least two competent (MCS accredited installers, Green Business Directory listed) heat pump installers to provide detailed feasibility studies, quotations and business cases for the most suitable heat pump solution for the site.

Full life cycle costs analysis should be provided to fully understand the financial performance of the system.

Costs should include all investigatory works required assess the viability of the solution (particularly for ground/water source heat pumps).

Equipment used in proposals should include those listed on the governments ETL (Energy Technology List) to enable the purchaser to benefit from ECAs (Enhanced Capital Allowances) for all high efficiency technology supplied.

Proposals should also detail any financial incentives available for the proposed solution (e.g. RHI payments for air to water, ground/water source heat pumps)</td></tr>
<tr><td>7. What are the ongoing maintenance requirements of the proposed system?</td><td>Supplier proposals should include details of ongoing maintenance requirements, and can include training of inhouse staff at handover.</td></tr>
</table>

Your next steps

Before undertaking a heat pump project, start with the following easy low and no-cost options to help save money and improve the energy performance of your site.

Step 1: Understand your energy use

Look at the site and identify the major areas of energy consumption. Check the condition and operation of equipment and monitor power consumption over one week to obtain a base figure against which energy improvements can be measured. Also monitor relevant variables that affect energy consumption.

Step 2: Identify your opportunities

Compile an energy checklist. Walk round the site and complete the checklist at different times of day (including after hours) to identify where energy savings can be made.

Step 3: Prioritise your actions

Draw up an action plan detailing a schedule of improvements that need to be made and when, along with who will be responsible for them.

Step 4: Seek specialist help

It may be possible to implement some energy saving measures in-house, but others may require specialist help. Discuss the more complex or expensive options with a qualified technician.

Step 5: Make the changes and measure the savings

Implement your energy saving actions and measure against original consumption figures. Take the variables and driving factors into account when you come to verify savings. This will assist future management decisions regarding your energy priorities.

Step 6: Continue to manage your site's energy use

Enforce policies, systems and procedures to ensure the site operates efficiently and that savings are maintained in the future.

Further Resources

For further information, the following organisations and Carbon Trust guides may be useful

Heat pump associations

- https://www.feta.co.uk/associations/hpa
- https://www.ehpa.org/about/news/article/optimising-heat-recovery-from-industrial-processes-with-heat-pumps/

Ofgem

- https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi
- https://www.ofgem.gov.uk/system/files/docs/2018/05/easy_guide_to_heat_pumps.pdf

Energy Saving Trust

- https://www.energysavingtrust.org.uk/renewable-energy/heat/air-source-heat-pumps

Carbon Trust Guides

Find other Carbon Trust Guides on our website and for heat pumps in particular:

- Renewable Energy Sources (CTV010v3)
- How to implement air source heat pumps (CTL151)
- How to implement ground source heat pumps (CTL150)
- Down to earth: ground source heat pumps (CTG036)

Go online for more information

The Carbon Trust provides a range of tools, services and information to help you implement energy and carbon saving measures, no matter what your level of experience.

Website – Visit us at www.carbontrust.com for our full range of advice and services.

www.carbontrust.com

Tools, guides and reports – We have a library of publications detailing energy saving techniques for a range of sectors and technologies.

www.carbontrust.com/resources

Events and workshops – We offer a variety of events, workshops and webinars ranging from a high level introductions to our services through, to technical energy efficiency training.

www.carbontrust.com/events

Small Business Support – We have collated all of our small business support in one place on our website.

www.carbontrust.com/small-to-medium-enterprises/

Our client case studies – Our case studies show that it's often easier and less expensive than you might think to bring about real change.

www.carbontrust.com/our-clients

The Carbon Trust Green Business Fund – is an energy efficiency support service for small and medium-sized companies in England, Wales and Scotland. It provides direct funded support through energy assessments, training workshops, and equipment procurement support.

www.carbontrust.com/greenbusinessfund

SME Network - Join a community of over 2000 small and medium-sized businesses to discuss your strategy and challenges to reducing carbon emissions and improving resource efficiency. Sign up for free to share knowledge, exchange useful resources and find out about the support and funding available in your area, including the details of your local energy efficiency workshops.

www.carbontrust.com/resources/tools/sme-carbon-network

The Carbon Trust is an independent company with a mission to accelerate the move to a sustainable, low-carbon economy. The Carbon Trust:

- advises businesses, governments and the public sector on opportunities in a sustainable, low-carbon world;
- measures and certifies the environmental footprint of organisations, products and services;
- helps develop and deploy low-carbon technologies and solutions, from energy efficiency to renewable power

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