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The heat pump potential

CPD module sponsored by LG

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Although the theory underpinning the heat pump dates back to 1824 the first practical heat pump was built by Peter von Rittinger in 1856. In 1945, John Sumner, City Electrical Engineer for Norwich, installed an experimental water-source heat pump fed central heating system, using a neighbouring river to heat new council administrative buildings. Then in 1951 along came the first large-scale installation in the UK at The Royal Festival Hall in London. This featured a town's gas-powered reversible water-source heat pump, utilising the River Thames, for both winter heating and summer cooling needs.

The 1950s also saw the advent of the package air-conditioning unit, which is the basis of the modern air source heat pump. The domestic heat pump entered the marketplace in the 1970s but it was not until the 1990s that the heat pump as we know it today became a mass market product. There were often issues with early heat pump installations – typically because of poor implementation.

Many people see the heat pump as a key technology for low-carbon heating. For this reason, it is worth reviewing heating as part of the UK's greenhouse gas emissions. In 2016, heating accounted for about 37 per cent of emissions. This comprised 17 per cent for space heating; 4 per cent for hot water; 2 per cent for cooking and 14 per cent for industrial processes. It is suggested that 85-90 per cent of the UK's heating comes from gas boilers. For 2018 it is estimated that the UK installed 1.7m new gas boilers but only 27,000 heat pumps.

Overall, natural gas is thought to account for 70 per cent of the heat used in the UK. Green gas (bio-methane or hydrogen) is a possibility but there are significant challenges in its implementation as it requires significant infrastructure work. A recent Carbon Trust report suggests that, for London, the overall efficiency of heat pumps would be higher than that of a hydrogen-based system.

According to the International Energy Agency, heat pumps could satisfy 90 per cent of the global heating needs with a lower carbon footprint than gas-fired condensing boilers.

Low-carbon heating solution

Heat pumps provide an alternative, low-carbon heating solution that can be delivered unit by unit – without new infrastructure. However, to be a true low-carbon solution heat pumps are relying on the decarbonisation of the electricity grid – or running on renewable electricity.

Heat pumps work by transferring energy from a low-temperature source (for example, ambient air, water, ground or waste heat) and raise it to a higher, useful temperature. The renewable nature of the heat source makes a heat pump a low-carbon solution – the extent of this dependent on the energy used to drive the heat pump. The most common form of the heat pump is based on the vapour compression system with an electric motor. There are also gas-fired absorption systems.

One way of looking at a heat pump is to see it as a refrigeration system working in reverse. The objective of a refrigeration system is to make the controlled space cooler and reject the heat. With the heat pump we are making the controlled space warmer.

The key components of a basic heat pump are:

- an evaporator to collect the heat from the source (e.g. outside air);
- a compressor to raise the pressure and temperature of the refrigerant;
- a condenser to deliver the thermal energy into the building/process; and
- an expansion valve to lower the pressure and temperature of the refrigerant.

Input energy is required for the compressor (the largest energy use of the system) but also for fans and pumps that are part of the heat pump system. The more efficient these components the better the overall performance of the system. The performance improvements in heat pumps are closely related to those for other refrigeration systems, for example, more efficient compressors, variable speed derives, etc.

When selecting a heat pump the choice of refrigerant is important. Ideally, the chosen refrigerant should have the lowest possible Global Warming Potential (GWP).

An important difference between heat pumps and conventional forms of heating is that heat pumps are more efficient when supplying heat at lower temperatures. This suits underfloor heating, warm air systems and fan coil units.

Heat pumps are normally described by the heat source they utilise:
- air source heat pumps (ASHP) – typically ambient air;
- ground source heat pumps (GSHP) – soil and aquifers;
- water source heat pumps (WSHP) – lakes, ponds, rivers, etc; and
- waste heat recovery heat pump (WHRHP) – could be air or water.

Air source heat pumps are the most common type of heat pump. Typically, it is ambient air to warm air. In commercial applications it is not uncommon to combine summer cooling and winter heating with a 'reversible' heat pump unit. Where heating is required in addition to cooling this is a better option than direct electric heating. A key aspect is the location of the outdoor unit. As with the outdoor unit for an AC unit there should be free air flow around the unit. Poor air flow and coil fouling can lead to a significant decline in performance.

Ground source heat pumps can be effective as the temperature at around 2m below ground remains between 8-12°C providing a stable year-round heat source.

GSHPs can be further classified by the heat collection system. These can be:
- closed loop, horizontal systems. A heat exchange fluid is circulated through pipes laid horizontally at a depth of 1-2m. The collector system requires a large area of ground, up to 85m^2 per kW of heating. Looked at another way, the system needs between 10 and 50m of pipe per kW – so a 20kW unit could require up to 1km of piping. The actual length will depend on the specific installation. Research is currently being undertaken on the use of flat plat collectors for GSHPs.
- closed loop, vertical. As with the horizontal system, heat exchange fluid is circulated, but in this case through pipes laid in boreholes that range in depth between 50-100m. Each borehole would support about 3-6kW of heating, with a spacing of 7-10 metres. Site access for the drilling rig needs to be considered.
- Open loop. This system takes advantage of ground water extracted from and returned to a suitable underground body of water. Can also provide cooling in summer. More efficient than closed loop systems – but extensive site investigation required and not suitable for all sites. Environment Agency approval may be required.

Waste heat recovery heat pumps can be used to recover waste heat in manufacturing/process industries. This can be attractive where the waste heat is 'low grade'. In these situations the waste heat can provide a 'stable' source of heat. Solutions could be: air to air; water to water; water to air.

It is essential that the process producing the waste heat is fully optimised before considering the heat pump. It is unlikely there is a stock heat pump solution for waste heat recovery and a specialist provider will need to be involved from the early stages.

The dual source heat pump (DSHP) takes advantage of either air or ground heat sources, depending on operating and climatic conditions. It can select the most favourable heat source or heat sink (for heating or cooling, respectively). In winter it can provide hot water for heating buildings, using either the air or the ground as heat sources. Alternatively, in summer, it uses the air or round as a heat sink to provide cooling. The unit can also provide domestic hot water, which in summer it can generate by using the system's condensing waste heat.

A hybrid system is a combination of a heat pump matched with a gas-fired boiler. A hybrid system can supply heat at a higher temperature and as such is a possible candidate for retrofit systems. However, as the system does use gas its carbon benefit will be less than a 'pure' heat pump.

For an idea of the uptake of heat pumps we can review the data from the Renewable Heat Incentive (RHI). While this is not a full picture it provides a good indication.

Domination of global sales

In terms of units installed the most significant market sector is the domestic ASHP. Air to air heat pumps also dominate global sales.

When looking at boilers we rate the performance in terms of efficiency i.e. the ratio of heat output to heat input e.g. 95 per cent efficient. However, when we look at heat pumps the input (purchased) energy is significantly less than the output energy. Accordingly, performance is expressed using the Coefficient of Performance (COP). For example, a heat pump that delivers 6kW of heat with an electricity input of 2kW would have a COP of 3.0.

The theoretical maximum COP of a system operating between two temperatures Ts (the temperature of the heat source) and Th (the heating supply temperature) is given by:

Theoretical Coefficient of Performance =

$$\frac{Th}{Th - Ts}$$

Where Th and Ts are measured in degrees Kelvin

In practice, the measured COP might only be 60 per cent of the theoretical COP. But what this

Accredited Applications for the Renewable Heat incentive (RHI)

Domestic RHI April 2014 to August 2020	
ASHP	48,407
GSHP	11,208

Non-domestic RHI November 2011 to August 2020	
ASHP	642
GSHP/WSHP >100kW	380
GSHP/WSHP – <100kW	1,166

Note: Above data is from the date of the introduction of the incentive.

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It is for this reason that heat pumps work best with 'low temperature' heating systems. For example, warm air, underfloor heating, fan coil systems. Standard heat pumps operate most efficiently in the range 35-55ºC (gas-fired heating systems typically operate at 60-80ºC). Therefore, heat pumps should not be seen as a direct replacement for gas boilers. Domestic hot water systems ideally need to achieve a temperature of 60ºC for legionella control – this could be achieved with an additional direct electric boost.

With boilers we also consider seasonal efficiency. For heat pumps we use the seasonal coefficient of performance (SCOP) for heating and the seasonal energy efficiency ratio (SEER) for cooling. These methodologies derive from the EU Energy Related Products Directive (ErP). Under EU labelling there is the familiar rating system – which currently runs from D to A+++.

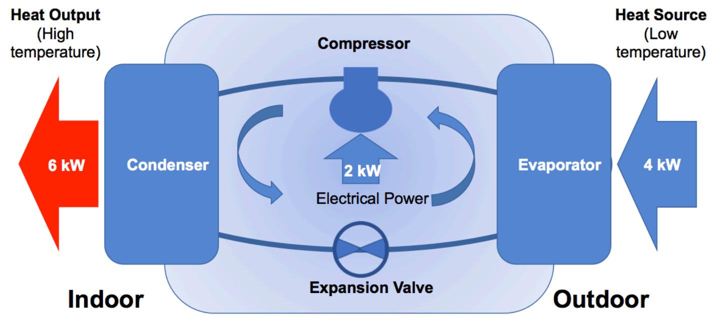
For a typical air source heat pump (ASHP) system delivering water at 35ºC water the COP could range from 2.0 at minus 15ºC rising to 5.5 at plus 15ºC. In contrast, if it were delivering water at 55ºC the range COP would range from 1.8 to 3.0.

High temperature heat pumps are defined as pumps capable of delivering output temperatures over 55ºC. Higher temperatures are possible and can be achieved by some specialist heat pumps. One approach is a cascade heat pump system which is in effect one heat pump coupled to another through a heat exchanger. Absorption heat pumps (gas-fired) can also reach the higher temperatures, but the carbon benefits are compromised by using natural gas. The typical COP for a gas-fired heat pump is around 1.3 to 1.5.

The relevant standard for heat pump testing is:

BS EN 14825:2018 - Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling. Testing and rating at part load conditions and calculation of seasonal performance.

The cost of an installation will depend on site specifics and the system selected. However, it is useful to have a rule of thumb guide for initial appraisal purposes.



Heat Pump – Air to Air

Similar maintenance costs

Maintenance cost – studies suggest that the cost of maintaining a heat pump are similar to those for an equivalent gas or oil boiler. The Carbon Trust notes that a well-maintained system will potentially be 10-25 per cent more efficient than a poorly maintained equivalent. The expected life of an ASHP is between 10 and 15 years – arguably a little less than a boiler system.

Where heat pumps are being used for space heating it is important to reduce the heating requirement as much as possible before considering the heat pump. This makes sense as it not only reduces the running costs but may also reduce the capital cost.

With electricity typically costing three times the cost of natural gas, a COP of 3.0 is needed for running cost parity. (This is a simplified view and does not take account of incentives or seasonal efficiency). The seasonal performance indicator for heat pumps has steadily increased since 2010 to nearly 4.0 for most space heating applications which suggest there are running cost benefits in most cases.

As a retrofit technology heat pump technology works best where the heat pump is replacing a high-cost existing heating system, such as direct electricity, and a low temperature heating system can be used.

The payback of an ASHP, as a boiler replacement, is improved where the existing boiler is at the end of its life. Under current tariffs and incentives paybacks of more than five years would be common for a heat pump replacement of gas boiler before the end of its life. This is potentially a major barrier implementation unless carbon reduction is a strategic policy that can be used to override the extended payback.

If an organisation is committed to net zero carbon and purchasing carbon offsets it might be appropriate to factor in the cost of the offsets in the payback calculation.

New build provides the ideal opportunity to optimise both building and systems. When looking at new build in the domestic sector it is suggested that upgrading to Passivhaus standards would add between 5 and 10 per cent to the build cost but deliver a 75 per cent reduction in heating demand (Source Energy Saving Trust).

Underfloor heating is ideal for heat pump technology as it is typically operated at a maximum of 35ºC. Warm air is also suitable – while quite common in the commercial and industrial sectors it is not commonly used in the UK residential sector.

Future regulation (e.g. zero carbon buildings) may positively impact on the uptake of heat pumps.

Heat pumps can qualify under the Renewable Heat Incentive (RHI). The non-domestic RHI closes to new applications on 31 March 2021 with the domestic RHI closing on 31 March 2022. Payments under the non-domestic scheme are for 20 years, while those under the domestic are for seven years. Systems under 45kW thermal require MCS certification. The details of the RHI are not covered here, so check with Ofgem for full details.

The heat pump is a key technology in the provision of decarbonised heating. It is a proven technology that also benefits from the developments in refrigeration and air conditioning. The most effective deployment of heat pumps is in new build as all systems can be optimised to maximise the impact of the technology. The next cost-effective level is the replacement of high-cost heating systems – such as direct electric. Replacement of good condition, efficient gas-fired systems will give extended paybacks but can deliver carbon savings. When specifying heat pumps it is important to take a whole system view that also includes the building/process that the heat is required for.

Comparative cost of installation of heat pump systems

System Type	Cost per kW heating output
ASHP	£250 to £1,500
GSHP – open loop	£1,000 to £2,000
GSHP – closed loop	£1,500 to £3,500
Gas boiler	£70 to £150

Source CTV 072, Carbon Trust 2018

Further reading

1) Heat Pumps CTV072, Carbon Trust, 2018.
2) Domestic Heat Pumps – A Best Practice Guide, MCS, 2018.
3) Heat pump retrofit in London, August 2020, Carbon Trust.
4) Options appraisals for heat pump retrofit in 15 London buildings A Carbon Trust report for the Greater London Authority (GLA), August 2020.
5) UK Literature Review for International Energy Agency (IEA) Annex 36 on investigating the effect of quality of installation and maintenance on heat pump performance. Report prepared by The National Energy Foundation (NEF), 2013.

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SERIES **18** | MODULE **05** | NOV/DEC **2020**

CPD ENTRY FORM

HEAT PUMPS

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet, return it to the address below. Photocopies are acceptable.

QUESTIONS

1) In 2016 what percentage of UK GHGs were related to heating?
- ☐ 14 per cent
- ☐ 30 per cent
- ☐ 37 per cent
- ☐ 45 per cent

2) According to the IEA what percentage of global heating could be met with heat pumps?
- ☐ 70 per cent
- ☐ 80 per cent
- ☐ 90 per cent
- ☐ 100 per cent

3) Heat pumps cannot be used as a direct replacement for a gas boiler because:
- ☐ They cannot maintain the flow rate
- ☐ The temperature of the heat supplied is too high
- ☐ They operate most efficiently at lower temperatures
- ☐ They cannot be controlled in the same way

4) The year-round temperature of the ground at 2m below the surface is typically:
- ☐ 2-5°C
- ☐ 6-8°C
- ☐ 8-12°C
- ☐ 12-15°C

5) What percentage of the theoretical COP is most likely in practice?
- ☐ 90 per cent
- ☐ 80 per cent
- ☐ 70 per cent
- ☐ 60 per cent

6) When delivering water at 35°C from a source at 15°C what COP could be expected?
- ☐ 2.0
- ☐ 3.0
- ☐ 4.0
- ☐ 5.0

7) What would be the indicative cost per kW (heating) for an ASHP?
- ☐ £70 to £150
- ☐ £250 to £1,500
- ☐ £1,000 to 2,000
- ☐ 1,500 to £3,500

8) Which heat pump retrofit would be the least cost effective?
- ☐ Replacing a 2-year-old condensing gas boiler
- ☐ Replacing a direct electric heating installation
- ☐ Replacing a 30-year-old gas boiler
- ☐ Replacing an end-of life heat pump

9) Which heating technology is least suited to heat pumps?
- ☐ LTHW radiators
- ☐ Underfloor heating
- ☐ Warm air systems
- ☐ Fan-coil units

10) For a closed loop horizontal GSHP system the area required per kW is:
- ☐ 25m²
- ☐ 55 m²
- ☐ 85m²
- ☐ 20m²

Please complete your details below in block capitals

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CPD fundamentals

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This is the fifth module in the eighteenth series and focuses on **Heat Pumps**. It is accompanied by a set of multiple-choice questions.

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