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MARK THROWER MANAGING EDITOR

How to choose the correct heat pump

By Jamie Goth, managing director, Goth Energy Management Ltd

Heat pumps remove heat from one location and transfer it to another. In a conventional, vapour compression heat pump this is achieved by using pressurisation and phase change to effect heat transfer. When a liquid evaporates to gaseous phase, it takes heat from its immediate environment. Conversely, heat is lost when a pressurised gas condenses to liquid phase. The latent heat associated with these phase changes is significantly greater than the transfer of sensible heat that occurs without evaporation or condensation. The temperatures at which these phase changes occur are important parameters for practical application of this phenomenon to heating and cooling systems.

Substances selected for the suitability of their phase change temperatures, heat transfer and other properties to heating and cooling processes are termed refrigerants. They are the working fluids of refrigeration systems. The common domestic refrigerator is a simple example of an air source heat pump, whereby heat is removed from the air inside the fridge, which is typically maintained at 5˚C and rejected into the kitchen at around 20˚C. The heat it provides into the kitchen in winter may be welcome, but it is uncontrolled and can cause over-heating, particularly in small spaces in mild weather.

A commercial split air conditioning (or comfort cooling) unit is another example of an air source heat pump. The indoor unit (or evaporator) cools the conditioned space and the outdoor unit (or condenser) rejects the unwanted heat to the external environment. Reversible heat pumps are able to provide either heating or cooling into the conditioned space by simply reversing the role of the evaporator and condenser, depending upon indoor conditions and control set points.

Groups of heat pumps on common refrigerant distribution systems, such as variable refrigerant flow (VRF) systems are able to meet simultaneous heating and cooling demands in different parts of a building. However, the term heat pump is most commonly applied in the UK to systems that take heat from the external environment (i.e. the evaporator is outdoors) and emit it indoors (i.e. the indoor unit is the condenser). It is this definition of heat pumps that are the subject of this article.

Table 1: Heat Pump Categories

Heat Source	Heating Distribution Medium				
	Medium Type	Medium Temperature (°C) and Category*			
		Low	Medium	High	Very High
Air					
Water	Air or Water	35	45	55	>65
Ground					

*BS EN 14511-2013

Categorisation

Heat pumps can be broadly categorised by their heat source: air, water or ground source. Heat may be distributed either by air passing over the condenser into the heated space, or distributed by ductwork; or by water distributed via pipework to a heating system, as outlined in Table 1.

Efficiency

A key measure of the efficiency of a heat pump is its coefficient of performance (COP). The Building Regulations set minimum standards for the COP of a new electrically driven heat pump used for providing space heating in buildings of 2.5. Heat pumps operate at their greatest COP when the temperature difference between the heat source and the heating medium (temperature lift) is minimised. This can be achieved by maximising the heat source temperature and minimising the heating medium temperature. Systems with a low temperature heating medium will therefore have higher efficiencies than a high temperature heating medium for a given source temperature.

Heat pump manufacturers quote the COP of their heat pumps under a variety of conditions and it is not always easy to compare manufacturers' data, or to get an accurate correlation between manufacturers' COP claims and the conditions that will occur in a real installation. Reputable manufacturers will calculate the COP of their heat pumps using the British Standard BS EN 14511-2013. To meet this standard, COPs should be quoted at inlet and outlet temperatures of 0°C and 35°C, respectively. However, heat pumps are rarely operated under these temperature ranges in the UK. The charts 1 and 2 show the indicative trends of how COP varies with both inlet (heat source) and outlet temperatures. Note that the heating medium temperature will be less than the heat pump outlet temperature and this should be taken into account when interpreting the charts on page 26. The charts are for illustrative purposes only and should not be used for design or feasibility studies.

Chart 1 (page 26) shows COP rising as the source temperature rises, assuming a heat pump outlet temperature of 35°C. The high source temperature of 12°C would not typically be achievable in the UK without some form of heat recovery or heat storage to supplement ambient ground or outdoor air temperatures.

Chart 2 (page 26) shows COP falling as heat pump outlet temperature rises, assuming a heat pump inlet temperature of 0°C. The low outlet temperature of 35°C would not typically be achievable in the UK without high levels of insulation and other sources of heat gain, as the heating medium temperature would be below the 35°C heat pump outlet temperature, falling below the

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temperature at which low temperature heating systems can be effective.

Heating & cooling media

Heating systems that use a low temperature heating medium (such as underfloor heating (UFH) and low temperature radiant heating panels) have a good fit with heat pumps. They can operate down at 35°C to 50°C which are amongst the lowest temperature heating medium flow temperatures. This low temperature allows them to minimise temperature lift, optimising COP.

To avoid oversizing heat pumps and hence to optimise both their capital costs and operating efficiencies, it is worthwhile coupling them with a thermal store. This allows them to operate at full capacity for longer than with direct coupled systems. A thermal store also provides additional capacity at times of peak heating demand. The provision of domestic hot water is achievable with heat pumps. However, it is not ideally suited to heat pump applications, as it increases the temperature lift compared to UFH and radiant panels. To optimise heat pump efficiencies, alternative arrangements should be considered for domestic water heating.

Renewables

Interest in heat pumps is growing in the UK, as both air source and ground source heat pumps have been designated by the UK Government as low or zero carbon (LZC) technologies, eligible for subsidies, such as the Renewable Heat Incentive (RHI).

The source of heat could be naturally occurring, such as air, water or the ground sources. Typically the primary heat input into these three sources is from the sun, leading them to be regarded as at least partially renewable. However, the grid electricity or other fuel used to power the heat pump to extract the heat is not renewable, unless it is either supplied by a local renewable energy source, or purchased under a green tariff. Solar energy heats the atmosphere and the surface of the earth. Both air source heat pumps and ground source heat pumps can harvest this solar energy and hence both are considered to be renewable heat sources.

Air source heat pumps

Air-to-air heat pumps are the most common and well established form of heat pump. They use the heat available in external air as a heat source. The heat pump is usually directly coupled to the outside air. The second category of air source heat pump is one that distributes its heat via a hot water distribution system. This would typically be an underfloor heating system, or radiators oversized compared to traditional radiators to provide sufficient heat with a low heating flow temperature.

Chart 1: Indicative Trend of Variation in COP with Source Temperature

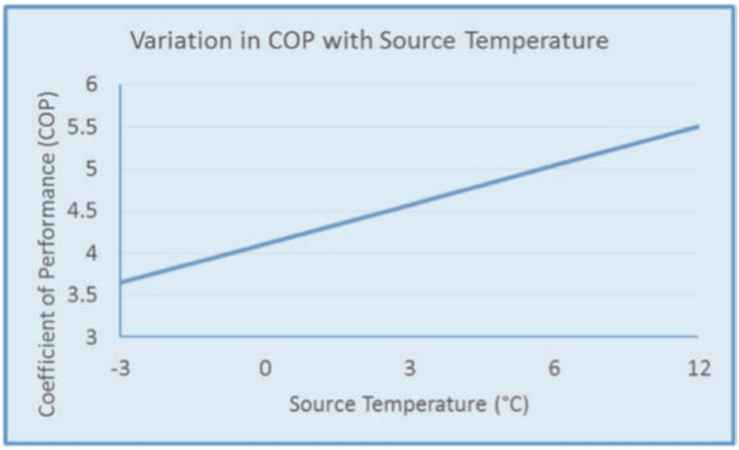
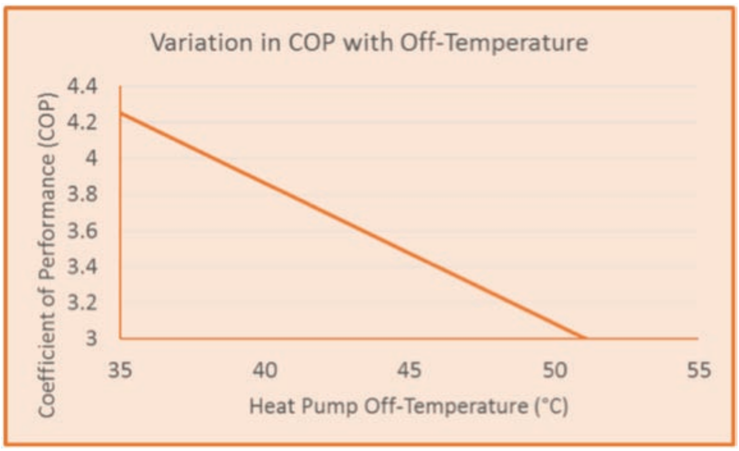


Chart 2: Indicative Trend of Variation in COP with Heat Pump Outlet Temperature



Ground source

Ground source (or ground coupled) heat pumps use the refrigeration cycle to transfer low-grade heat from the ground to high grade heat for heating systems. This is achieved by installing pipes in the ground through which a low-temperature water/anti-freeze mix is distributed. The cold water is heated by the ground by means of sensible heat transfer.

There are two configurations for the ground loop: borehole or trench. The boreholes will typically be of between 45m and 150m depth, enabling a high degree of consistency in ground temperature to be reached across all seasons. Ground coupling pipes are installed in the boreholes and connected via flow and return headers to the heat pump. Horizontal or trenched configurations are typically less costly to install than boreholes, particularly if the trenches are formed and refilled when excavation equipment is needed on site for other tasks, such as digging the foundations for new buildings and extensions. However, at 35 to 55m of pipe or 25m2 of trenched area required per installed kW of heating capacity, trench configurations require considerably more land than boreholes. For this reason they are suited to domestic and small commercial buildings, whereas boreholes are usually more practical for large installations, particularly in built-up areas. Ground coupled heat pumps can use as little as 25-30 per cent of the electricity used by conventional direct electric heating systems and 40-50 per cent of that of an air source heat pump on a cold winter's day.

Ground source heat pumps cost less to run than heating from LPG or oil and will usually be cheaper than gas, providing they are carefully designed, installed and operated and supply low-temperature heating systems, such as underfloor heating (UFH). The relative costs of gas and electricity also have a significant impact. Contemporaneous rising electricity prices and falling gas prices could reverse the relationship.

An important factor to take into account when considering GSHP is the geological and geothermal properties of the earth in the area where the project will be based2. The heat transfer from the earth to a GSHP loop is proportional to the conductivity of the materials in the ground. For example quartzite has a very high conductivity of 5.0 Wm-1K-1 and sand has a low value of 0.8 Wm-1K-1. The presence of ground water also has an impact. Where sand is saturated its conductivity could rise to 2.5 Wm-1K-1. This range of conductivities can directly affect the rate of heat transfer from the ground to the ground loop. A low thermal conductivity could reduce the temperature of water returning to the heat pump, reducing its COP, or increasing the number of boreholes required for a system. Conversely, for projects where waste heat is pumped into the ground in summer to be harvested during the heating season, low thermal conductivity and diffusivity could be an advantage.

Aquifer

Whereas ground source heat pumps use a closed loop underground, ground water heat pumps can use either open loop or closed loop systems. Under an open loop system a constant supply of water is extracted from an aquifer via a series of bore holes and is used as the heat transfer fluid between the ground water and the heat pump. After leaving the building, the water is pumped back into the aquifer via injection wells. Whilst open loop aquifer heat pumps can have great thermodynamic properties and be technically straight forward to operate, there is more preparation, investigation and planning required than with a GSHP. Consent is required from the Environment Agency in England and Wales or the Scottish Environment Protection Agency in Scotland.

Heat can also be extracted from surface water. Such installations are simpler than GSHPs and were commercially established before them. However, they are less universally applicable, as they are dependent upon the availability of abundant surface water, such as a lake or pond that is of sufficient depth, volume and with a source of heat replenishment.

The Energy Saving Trust (EST) published a report titled 'Heat Pumps: Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial' in May 2013. It provided comprehensive results from Phase II of a detailed monitoring study of domestic GSHP and ASHP installations. It found that

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the average measured space heating efficiency was 2.73 for ASHPs and 3.21 for GSHPs. Space heating efficiency is defined in the report as the ratio of heat output to total electricity input, taking into account the electricity consumption of the heat pump unit and the necessary fans and pumps etc. Monitoring showed that on average the electricity consumed by the compressor accounted for 82 per cent of the total electricity demand for each installation with the remaining 18 per cent for fans, pumps and auxiliary space and water heating. The report also showed that the energy consumed to defrost the evaporator coils of air source heat pumps could be significant and that minor modification to plant configurations and controls can result in significant improvements in seasonal COP.

Renewable Heat Incentive

The Renewable Heat Incentive (RHI) is a financial incentive scheme for LZC technologies, introduced for the non-domestic sector in November 2011. It provides a financial incentive for organisations to install and run selected low and zero carbon (LZC) heating technologies, including heat pumps. It offers quarterly 'tariff' payments over seven years for eligible technologies. Ground, water and air source heat pumps are eligible for the RHI, provided they meet a minimum standard seasonal COP. Air source heat pumps were not eligible when the non-domestic RHI was first launched, but air to water heat pumps were made eligible under recent changes to the scheme.

The RHI is set at different values for different technologies. The Tier values for ASHPs and GSHPs are 2.54 p/kWh and 8.84 p/kWh respectively for the first 1,314 hours of operation each year. The rates drop down to their Tier 2 values for systems that operate for more hours than this.

The RHI only applies to renewable heat sources. It does not apply to waste heat, such as warm air extracted from buildings, or heat rejected from cooling systems. Where heat pumps derive their heat from mixed sources, the proportion of renewable to recovered heat must be determined and the RHI will only apply to the renewable portion.

The Climate Change Levy (CCL) applies to electricity and gas used in the majority of non-domestic premises, including electricity for heat pumps and gas for boilers. The rates of CCL as of 1st April 2015 are 0.554 p/kWh for electricity and 0.193 p/kWh for gas. The Carbon Reduction Commitment Energy Efficiency Scheme (CRC) also sets a disincentive for using electricity and gas. It is set at £16.10/tCO2e this year, which, when taking electricity and gas emission factors into account, equates to additional costs per kWh of delivered fuels of 0.86 p/kWh and 0.30 p/kWh, respectively.

The impact of the RHI, CCL and CRC upon the cost of running heat pumps compared to the cost of running natural gas boilers is shown in table 2 (excluding maintenance and other costs of ownership).

Table 2 illustrates the impact of improving COP upon the financial case for heat pumps. It should be noted that the 'ideal' values are highest spot COP and boiler efficiency values quoted by one equipment manufacturer. They do not represent seasonal efficiencies and are not necessarily attainable throughout the winter under typical operating conditions. Under the 'Minimum' scenario applicable to Building Regulations, the minimum requirement for boilers is stricter than that for heat pumps, leading to ASHPs costing more to run than gas fired boilers under the price assumptions made. A small change in fuel unit cost assumptions would reverse this.

Enhanced Capital Allowance

A further incentive for private sector organisations is a reduction in corporation tax for companies purchasing heat pumps. The UK Government introduced the Enhanced Capital Allowance (ECA), a scheme that allows companies to depreciate their investment in energy efficiency and LZC technologies more quickly, reducing their tax burden. The allowance is only available for heat pumps that meet high performance criteria specified on the Energy Technology List (ETL). It is not applicable to public bodies or other not for profit entities.

Waste heat and heat recovery

Heat pumps can be used to recover heat from sources of waste heat, such as exhaust air. In principle this is similar to air source heat pumps. However, in the case of heat recovery from exhaust air, the heat pump evaporator would be situated in the exhaust air duct, rather than outside. This would considerably improve the heat pump's COP for a given supply medium temperature. There are many options for using the recovered heat, such as heating ducted air supplies in winter and heating swimming pool water throughout the year.

However, as the RHI only applies to renewable heat sources, the full benefit of the RHI does not apply to all heat delivered from a heat pump used in a heat recovery application. The RHI does not apply to the waste heat portion of the heat output. The proportion of renewable to recovered heat must be determined and the RHI will only apply to the renewable portion.

Key Advantages

Key advantages of heat pumps are their versatility, controllability, low maintenance, low energy costs and their suitability for integration with other renewable energy technologies. They are well proven technologies that are relatively inexpensive to maintain.

They must be treated differently to conventional heating systems and particular attention should be given to specific characteristics when specifying them, such as:

- the highest water output temperatures from heat pumps providing space heating are typically required in coldest external temperature, leading to the lowest COP in coldest weather;
- ground conditions should be carefully studied before committing investment to large GSHP arrays;
- heat pumps are not ideal for domestic hot water provision; and
- their use of refrigerants can lead to a risk of significant global warming potential if refrigerant leaks are not avoided and managed. This is a risk that does not apply to boilers and other non-refrigerant based systems. (The risk can be mitigated by selection of 'natural' refrigerants with low GWP). While heat pumps are capable of achieving significant cost and carbon savings compared to conventional heating systems, they are less forgiving and greater attention must be paid to design parameters and operating conditions to avoid significant system underperformance and inefficiencies.

Table 2: The impact of improving CoP on the financial case for heat pumps

Heat Source	Fuel	Heat Source Efficiency		Marginal Prices (p/kWh)						Saving per 100 MWh with RHI Compared to Gas
		Scenario	Value (%)	Fuel Input	CCL	CRC	RHI	Heat Output		
								Without RHI	With RHI	
Boiler	Gas	Minimum[4]	91%	-3.0	-0.19	-0.30	0.00	-3.84	-3.84	
Boiler	Oil		84%	-6.0	0.00	0.00	0.00	-7.14	-7.14	-£ 3,308
ASHP	Elec.		250%	-12.0	-0.55	-0.86	2.54	-5.36	-4.35	-£ 514
GSHP	Elec.		250%	-12.0	-0.55	-0.86	8.84	-5.36	-1.83	£ 2,006
Boiler	Gas	Typical[5]	82%	-3.0	-0.19	-0.30	0.00	-4.26	-4.26	
Boiler	Oil		82%	-6.0	0.00	0.00	0.00	-7.32	-7.32	-£ 3,061
ASHP	Elec.		273%	-12.0	-0.55	-0.86	2.54	-4.91	-3.98	£ 274
GSHP	Elec.		321%	-12.0	-0.55	-0.86	8.84	-4.18	-1.42	£ 2,832
Boiler	Gas	Ideal[3]	98%	-3.0	-0.19	-0.30	0.00	-3.56	-3.56	
Boiler	Oil		97%	-6.0	0.00	0.00	0.00	-6.19	-6.19	-£ 2,624
ASHP	Elec.		360%	-12.0	-0.55	-0.86	2.54	-3.73	-3.02	£ 541
GSHP	Elec.		460%	-12.0	-0.55	-0.86	8.84	-2.92	-0.99	£ 2,567

References

- Ground-Source Heat Pump Project Analysis, RETScreen International, Minister of Natural Resources, Canada 2001-2005; www.retscreen.net/download.php/ang/479/0/Textbook_GSHP.pdf
- Initial geological considerations before installing ground source heat pump systems, Jon Busby, Melinda Lewis, Helen Reeves, Russell Lawley, British Geological Survey
- Heat Pumps: Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial, Table 13, EST & DECC, May 2013. For Boilers: EST webpage, SAP 'D' rated boilers 78-82 per cent: http://www.energysavingtrust.org.uk/domestic/content/replacing-my-boiler
- Non-Domestic Building Services Compliance Guide 2013 (Single boilers < 2MW; Heat Pumps < 12 kW)
- Manufacturers' Data: Viessmann's Gas Boiler Vitoden 200; Oil Boiler Vitoradial 200-T; ASHP: Vitocal 350-G (2°C and 35°C) & GSHP: Vitocal 350-G (0°C and 35°C)

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CPD ENTRY FORM

HEAT PUMPS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. 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 in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. What does a domestic fridge have in common with an ASHP?

☐ They both have a primary objective of providing useful heat
☐ They both transfer heat up the temperature gradient from a cold to a warmer space
☐ They are a similar size
☐ They both have a primary objective of providing cooling

2. How does COP vary with heat pump outlet temperature for a fixed inlet temperature?

☐ As outlet temperature rises, COP rises
☐ As outlet temperature falls, COP falls
☐ As outlet temperature rises, COP falls
☐ As outlet temperature falls, COP is unaffected

3. How does COP vary with heat pump inlet temperature for a fixed outlet temperature?

☐ As inlet temperature rises, COP rises
☐ As inlet temperature falls, COP falls
☐ As inlet temperature rises, COP falls
☐ As inlet temperature falls, COP is unaffected

4. What is the minimum COP that must be achieved by a GSHP under the Building Regulations?

☐ 1.0 ☐ 91%
☐ 84% ☐ 2.5

5. What is the standard for heat pump manufacturers' to determine and report COP?

☐ IS014001 ☐ ISO50001
☐ BS EN 14511 ☐ QS9001

6. To meet the above standard, what outlet temperature should COP be quoted at?

☐ 0°C ☐ 12°C
☐ 35°C ☐ 82°C

7. At what frequency and duration is the RHI paid?

☐ Weekly for a Year
☐ Monthly for five years
☐ Quarterly for seven years
☐ Annually for a decade

8. If the electricity unit price dropped by 1 p/kWh, which would cost more under the 'Minimum' scenario in Table 2, the gas-fired boiler or the ASHP?

☐ ASHP
☐ Gas-Fired Boiler
☐ They would be equal
☐ GSHP

9. If the gas unit price rose by 1 p/kWh, which would cost more under the 'Minimum' scenario in Table 2, the gas-fired boiler or the ASHP?

☐ ASHP
☐ Gas-Fired Boiler
☐ They would be equal
☐ GSHP

10. Sort the following in order of value for GSHPs: RHI, CRC, CCL

☐ RHI, CRC, CCL
☐ CCL, RHI, CRC
☐ CRC, CCL, RHI
☐ CCL, CRC, RHI

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