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Heat Pumps

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Summary

- Performance depends on temperature of source, heat conductivity of source and temperature of outgoing water.
- Performance of a ground-source heat pump depends on sizing the ground array correctly
- Performance varies throughout the year.
- Return on investment is best where cheap electricity is available.
- Heat emitters must be considered at the design stage.

Introduction

Heat pumps are often described as fridges in reverse. In fact they are just fridges running in exactly the same way, the equipment on a fridge takes heat from the inside of the fridge and *moves* it to the outside of the fridge. In a heat pump it takes heat from a heat source, conventionally the air, the ground or water, and moves it to where you want it, a room, a hot water cylinder, a dryer a heat pad etc.. There are 2 basic types of heat pumps;

- Gas absorption heat pumps – these work like absorption chillers but in reverse. An ammonia solution is passed through an evaporator (heated by the low grade heat source) creating warm ammonia gas, this warm gas then dissolves in water and is heated to ammonia gas at useful temperatures by a gas burner, and this heat is then passed to the heating system. These tend to be less efficient than compressor based heat pumps, but as they can use gas as a heat source they will often have a lower carbon footprint compared to mains electric powered compressor systems (however a compressor system using renewable electricity would be better). Also if you have a building with a 500kW heat load, it can be fairly difficult to get the additional 200-300kW electrical supply required for a compressor based system but relatively simple to get a 250-350kW gas supply.
- Compressor based heat pumps – These are the most common ones found at the domestic and small commercial scale, and what we will be basing most of this technical note on.

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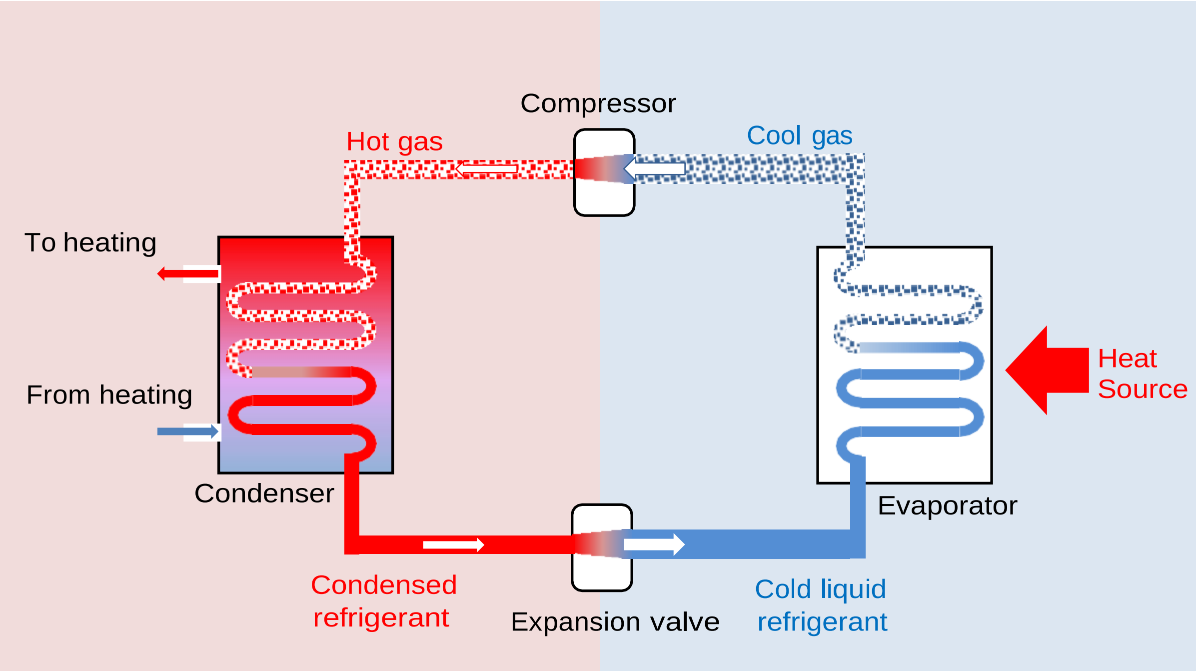

Figure 1: The principles of a compressor heat pump

What also differs is the source they extract heat from. They require a source of heat to take low grade heat and concentrate it to a higher temperature that can be used. Common sources of low grade heat are:

- Ground source (GSHP)
- Water source (WSHP)
- Air source (ASHP)

So for a heat pump to work all we need is a source of heat above about -15ºC, yes that's right minus 15ºC, and electricity to run the compressor. The amount of compression that needs to be done depends on the temperature of the heat source, the cooler the source the more compression it needs and therefore more electricity. Therefore at -15ºC you will only get out slightly more heat than electricity you put in, but once the temperature of the heat source is up towards +10ºC most heat pumps should easily deliver 3-4 times as much heat as electricity put in. This ratio of electricity in to heat out is known as the Coefficient of Performance (COP), in effect efficiency.

Heating and Cooling

As described above, heat pumps are very similar to refrigeration systems, with a hot side and a cold side, many of them are capable of both heating and cooling. You can both heat and cool the same space by simply diverting the cold liquid refrigerant into what was the "condenser" when it was in heating mode, the "condenser" then becomes the evaporator. This is often done when heat pumps are installed in poultry sheds, heat for the young, and cooling on warmer days as they grow. Also, it is possible to heat and cool at the same time in 2 different spaces. An example of this is cooling a potato or fruit store in the summer and pre-heating air for a dryer using the condenser. In this scenario there are significant operational financial savings to be made, as effectively it uses the heat that would have been wasted to the air, to heat the air coming into the dryer.

Performance

COP

All heat pumps use electricity to run the pumps and compressor, in almost all situations they will give out more heat than electricity used. However this varies depending on the temperature of the source of heat (warmer sources use less electricity) and the temperature required for the heating water (the cooler the water going to radiators the less electricity used). In the summer - when most users don't need much heat, an air source heat pump COP could be as high as 5, but in the winter as low as 1.5. Therefore it is best to consider the performance throughout the year, this is known as the Seasonal Performance Factor (SPF).

SPF

Seasonal Performance Factor (SPF), is a term used mainly for real installations, compared to the Coefficient of Performance, COP, which is evaluated in a controlled lab environment. A true SPF is calculated after installation by measuring the electricity used and the heat output over a year. However in order to evaluate the feasibility of heat pump project, we need to estimate it in advance. The most accurate is to use computer models with details of the heat pump, building, data about the ground properties in the case of GSHP's, local climatic data, number of occupants, and Domestic Hot Water (DHW) requirements. This is a very lengthy and complex calculation.

SCOP

In order to simplify things for designers and installers, various abbreviated methods are often used, the most common one today in the UK is the Microgeneration Certification Scheme (MCS) *Seasonal COP* (SCOP) method, for this method the installer or designer takes the manufacturers declared SCOP, and adapts it to the specific installation based on local climate and heat emitters, to give that system its own unique Seasonal Performance Factor (SPF).

Heat Emitter Design

The performance of all heat pumps is increased by keeping the temperature of the water going to the emitters - such as radiators, as low as possible. Below 35ºC is ideal, but anything up to 45ºC will give reasonable performance. However most UK emitters produce their design output at 75ºC-80ºC water temperature, at 45ºC the output is about 1/3 of its rated output, therefore in retrofit situations it could be that the existing emitters will not output sufficient heat.

However, before you go replacing all the emitters or installing underfloor heating, bear in mind the following;

- Most emitters are sized to get the room from cold to warm in about half an hour, if you keep the room at a constant temperature and accept a longer heat up period they may do the job at lower water temperatures
- Many emitters are over-sized, either due to the original installers' if-in-doubt-put-a-big-one-in approach or that size was the nearest one.
- Existing convection radiators (standard radiators) can increase output with a simple low-power fan unit which sits on top of the radiator.
- The water temperature of the heat pump can be increased on very cold days therefore only lowering the efficiency for short periods of colder weather. Some heat pumps have a function to automatically change the water temperature with outside temperature.
- If the heat pump is not able to provide enough heat on really cold periods, other heaters such as wood burning stoves can be used in living areas to top up the heat.

Therefore if you are thinking of installing a heat pump system it is important that a survey of the existing emitters is carried out to determine which (if any) emitters need changing for a target water temperature of about 40ºC.

Heat Sources

AIR SOURCE

Air source heat pumps, have the simplest and cheapest installation they typically sit outside and are very similar to an air conditioning unit.

Figure 2: Air source heat pump (courtesy of TheGreenAge)

There are 2 types of air source heat pumps;

- Air-to-air; these blow warmed air to heat a space
- Air-to-water; these heat water which in turn heats radiators or other water based heaters.

Air sourced heat pumps have the lowest performance (SPF) which can be as low as 2-2.5

GROUND SOURCE

Ground source heat pumps collect heat from the ground via a ground collector. This takes advantage of the ground not changing temperature greatly throughout the year, therefore providing good performance in the winter when heat is needed most. SPF of 4 are common.

WATER SOURCE

Water source heat pumps use a body of ground water such as a lake, river, well, borehole and so on. Water temperatures in the UK are more constant than the air but not quite as constant as the ground. However as water transfers heat best of all, usually water source heat pumps have the best performance of all. Water source heat pumps have a lower installation cost than ground source as there are no trenching costs.

HYBRID SOURCE

More recently, hybrid systems have been developed especially for sites with all year round use, which use the ground in winter and the air in summer, giving the best all round performance.

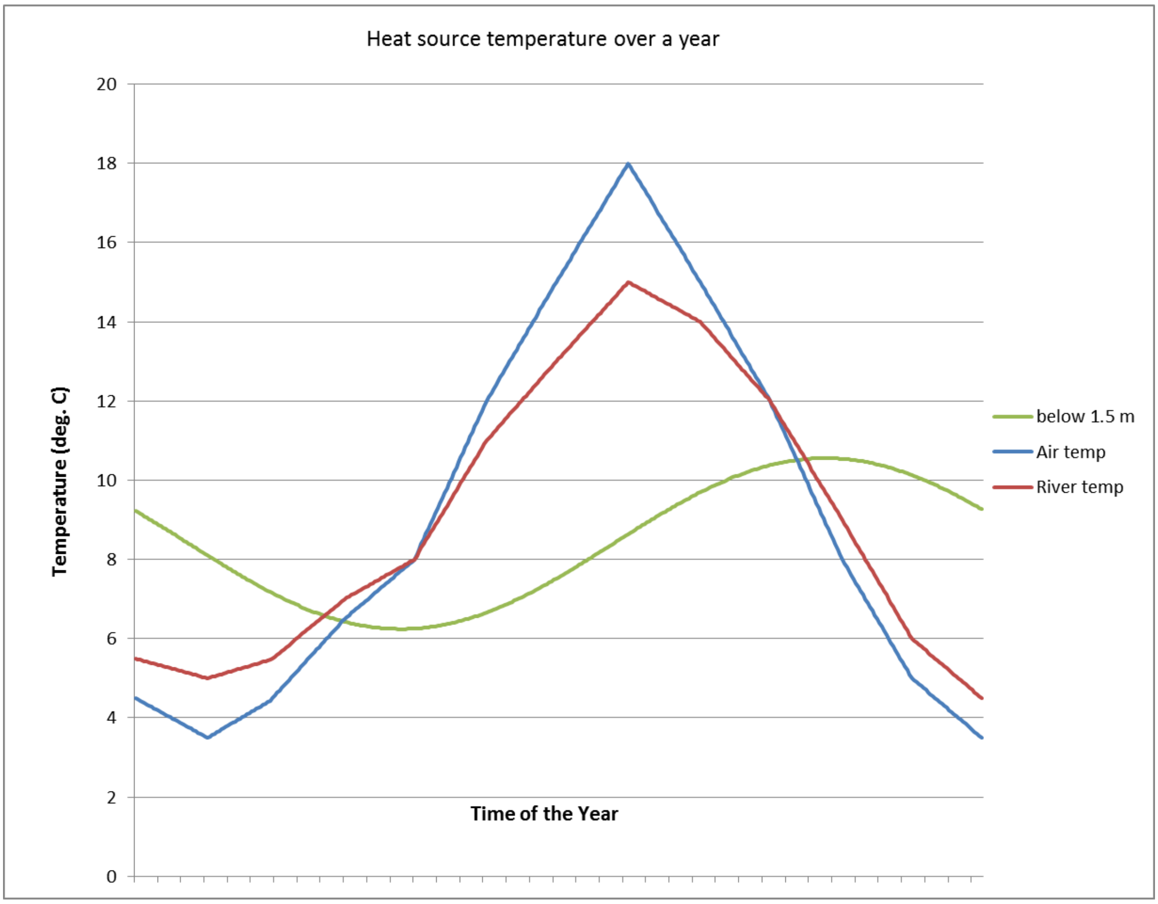

Figure 3; comparison of heat source temperatures over the year

Ground Source Heat Pumps - Details

Thermal Response Test

The amount of ground collector needed for each kWh of heat varies dramatically depending on the soil type and saturation. Whilst it is possible to extract very large quantities of heat from the ground for a short period of time, it will quickly cool and stop giving up heat. Therefore it is important that either the rate the heat is extracted is matched to the rate the heat is replaced from the surrounding ground (this rate is influence by the soil thermal conductivity), or an allowance is made for recharging the ground temperature in the warmer summer months, which is the common design approach for winter space heating loads. As the ground collector is a considerable part of the installation costs, it would be a good idea to get a Thermal Response Test (TRT) carried out which will exactly quantify the thermal capacity of your soil and hence inform the size of ground collector required. Without this it could be that the collector is oversized (wasted money) or undersized (cold house / high electricity bill).

Horizontal collector or borehole

With ground source heat pumps, there is a basic choice of a i) horizontal collector, either of coiled water pipes ("slinkies") or straight pipe in 1.5m deep trenches. (see Figure 4), or ii) vertical borehole(s).
Horizontal collectors are usually cheaper to install but require a large area which won't subsequently be disturbed below 1m depth. Boreholes have an unknown cost at the time of calculating the feasibility (borehole drilling is rarely fixed rate, if hard rock is discovered during the drill then the price can increase dramatically from about £80/m to over £150/m) but do not require large areas.

Figure 4; horizontal ground collector with "slinkies"

Horizontal collectors rely on heat from the sun stored in the ground and approximates to the monthly average air temperature. Output depends greatly on the thermal capacity of the soil, but based on the UK average soil thermal conductivity, with a 1.2m wide slinky collector and 5m trench spacing, gives a sustainable output of about 70-100kW per hectare.

Boreholes can be between 15m and 150m deep depending on the geology and heat load but typically over 80m deep. Most boreholes are sized to give about 3-5kW of heating capacity (the lower the thermal capacity of the ground the deeper the borehole) and needs to be spaced 6m apart, this gives an approximate sustainable output of over 600kW per hectare. The reason for the higher sustainable output is the fact that at these depths you are into solid rock and the permanent water table, both of which conduct heat far better than most soils. Also there is some effect from true geothermal (the earth's core temperature) warming which is approximately 3^{o}C every 100m of depth (see Figure 5).

The borehole system can be either "closed loop" - where pipes are placed in the borehole which is then backfilled with a high thermal conductivity grout, or "open loop" – for boreholes with good water infiltration the warm borehole water is directly extracted from one borehole goes through the heat pump, then put back into another borehole- sufficiently far away from the first to ensure no back-infiltration of cold water into the abstraction borehole. Some open loop systems require a consent to do the drilling into the groundwater and also an abstraction licence from SEPA if the net loss is over 10m3 per day.

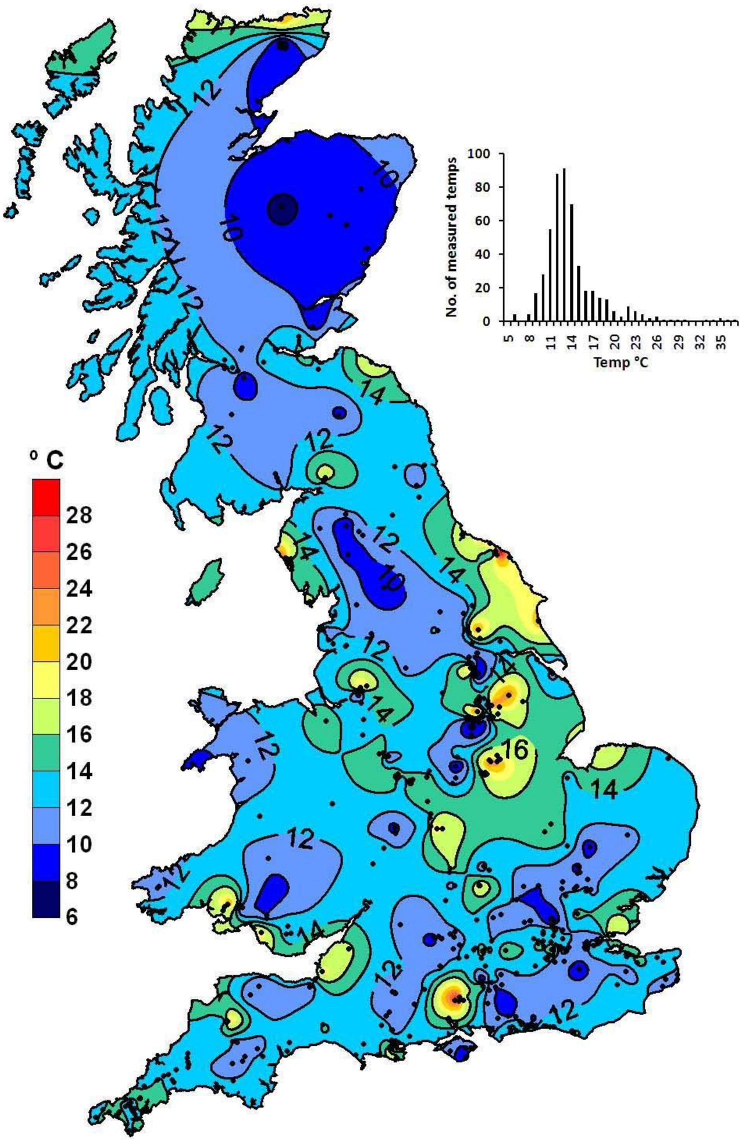

Figure 5; ground temps at 100m depth

Planning permission

For residential dwellings, ground and water source heat pumps are unlikely to require planning permission. However air source heat pumps may require it if it sticks out more than a metre from the wall, is on a visible frontage or in a conservation area or world heritage site.

For larger commercial ground source heat pump installations, if large horizontal collectors are required, as a farm business you need to consider this under agricultural permitted development, prior notification is required for more than 0.5 hectare of exposed trenching, this equates to about 3,000-4,000 meters or trenching for a 150-250kW heat pump.

Savings

Savings from a heat pump installation can be derived from the following sources;

- Savings on heating fuel.
- Savings on cooling costs if you have a cooling load at the same time as you have a heat load for the pump.

Savings are further enhanced, if cheap electricity is used, such as electricity from onsite renewable generations (wind, hydro, solar PV etc.) that would have been exported to the grid.
It should be noted that with the dramatic rise in electricity costs, depending on your current contract for electricity, grid electricity powered heat pump systems could be more expensive than running heating on heating oil or diesel. A general rule-of thumb would be that if your electricity is more than 2-3 times the cost of the alternative fuel, a very detailed feasibility study is recommended to ensure financial viability.

Budget costs

The cost of heat pumps has fallen in recent years. At the time of writing (2023) typical installation costs range from air source costing £800-£1,000/kW, water source only slightly higher at £900-£1,100/kW, ground source with the addition of trenching is about £1200-£2,000/kW. However most retrofit situations will also need modification of the heat emitters at additional cost.

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