HEAT NETWORK PARTNERSHIP FOR SCOTLAND

District Heating Strategy Factsheet

Application of Heat Pumps in District Heating

Contents

1 Learning Objectives and Outcomes

1.1 Learning Objectives

At the end of this module, you will:

- Know how to carry out their own evaluations on the suitability of heat pumps in various applications; and
- Understand how to evaluate the financial viability of projects utilising this low carbon heating technology.

1.2 Learning Outcomes

On completion of this module, you will be able to:

- Describe the main heat pump technologies;
- Outline the benefits of heat pumps;
- Be able to assess site suitability for heat pumps; and
- Understand the key aspects in relation to heat pump projects when building a business case.

2 Why Install a Heat Pump?

The Scottish Government, through the Heat Policy Statement[1], has set a target of 11% of heat consumed in Scotland be generated by renewable sources by 2020. Heat pumps can play an important role in achieving that goal.

The Climate Change (Scotland) Act 2009[2] introduced ambitious targets and legislation to reduce Scotland's emissions by at least 80% by 2050. All public sector bodies in Scotland have duties under the Act to reduce carbon emissions in line with the emissions reduction targets. Heating accounts for a large element of the direct carbon emissions of many public sector bodies, so heat pumps can make a significant contribution to achievement of these targets.

There are several reasons why an organisation may consider installing a heat pump:

- Carbon reduction;
- Financial reasons;
- No space on site for fuel storage;
- Low maintenance needs;
- To provide heating and cooling.

2.1 Carbon Reduction

Correctly managed, heat pumps can deliver a significant reduction in net carbon emissions when compared with fossil fuels. The amount of carbon reduced will depend on the efficiency of the heat pump system.

There are financial rewards for saving carbon including:

- Reduction of the Climate Change Levy (CCL) which is charged on purchases of gas, LPG and electricity by public bodies[3];
- Reduction of payments under the Carbon Reduction Commitment Energy Efficiency scheme (CRC)[4]. The CRC scheme is a mandatory carbon emissions reporting and pricing scheme to cover all organisations in the UK using more than 6,000MWh per year of electricity. The scheme is managed, on behalf of the UK Government's Department of Energy & Climate Change (DECC) by the Scottish Environment Protection Agency; and
- Reduction in the quantity and cost of emission allowances purchase by very large energy users who are part of the EU Emissions Trading Scheme (EU-ETS)[5].

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[1] Please refer to www.gov.scot/Topics/Business-Industry/Energy/Energy-sources/19185/Heat/RHUpdate11 for more information [accessed 03/05/2017]

[2] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact for more information [accessed 03/05/2017]

[3] Please refer to www.gov.uk/green-taxes-and-reliefs/climate-change-levy for more information [accessed 03/05/2017]

[4] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/international-action/uk/CRC-1 for more information [accessed 03/05/2017]

[5] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/international-action/eu/EUETS for more information [accessed 03/05/2017]

2.2 Financial Reasons

There are financial rewards for carbon savings, including a reduction of the Climate Change Levy (CCL), reduction of payments under the Carbon Reduction Commitment Energy Efficiency scheme (CRC) and for some organisations a reduction in the quantity and cost of emission allowances purchase as part of the Emissions Trading Scheme (EU-ETS).

The market for heat pumps has been transformed by the introduction of the Renewable Heat Incentive (RHI). This is the world's first incentive scheme for renewable heat. For eligible installations the RHI offers a payment for each unit of eligible renewable heat.

The cost of heat from heat pumps can also be lower than the cost of heat produced by the current electricity, oil or LPG heating systems.

2.3 No Fuel Storage

Unlike biomass boilers, heat pumps do not require any fuel to be delivered, handled or stored. This avoids not only the space being required for a delivery lorry, large fuel store and the fuel handling equipment but it also eliminates the associated health and safety risks.

2.4 Low Maintenance

The basic mechanism for heat pumps is similar to a refrigerator, with few moving parts and few things that can go wrong. They also do not do not contain components exposed to high temperatures. Therefore heat pumps require very little maintenance and have an expected life span of 25 years.

In addition, there is no need for fuel deliveries. They do not require any fuel storage space, unlike oil and LPG which require large storage tanks, and biomass boilers which require wood/pellet storage.

2.5 Heating and Cooling

Heat pumps can be designed to deliver both heating and cooling very effectively. A heating and cooling heat pump can offer very significant cost, carbon and efficiency savings compared to a boiler and chiller.

3 Technology Overview

Simply put heat pump systems are considered to be renewable, sustainable and importantly, help save fuel costs.

The particular area in thermodynamics that is relevant to heat pumps is called the refrigeration cycle. The three most well-known cycles are called vapour compression cycle, sorption cycle and magnetic cooling.

The vapour compression cycle is used by refrigerators in our homes and used by air conditioning plant.

The sorption cycle uses heat generated from a process be it chemical, or as a by-product of another process. It can be by either absorption which is where a gas is dissolved in a liquid, compressed and then separated using heat is taken in or adsorption which is where liquid is absorbed into a solid and separated using heat. This cycle is generally used when applying cooling in a Combined Cooling, Heat and Power Plant (CCHP).

3.1 Vapour Compression Cycle

3.1.1 Fundamental Principle

Compressing a gas increases its temperature and expanding a gas reduces its temperature. This is why spraying an aerosol can makes it cold, or pumping up a bike tyre makes it warm.

Compressing a gas increases its temperature and expanding a gas reduces its temperature. This is why spraying an aerosol can makes it cold, or pumping up a bike tyre makes it warm.

If we fill the chamber of a piston with a gas and compress it, the temperature of the gas increases. We can then use this hot, compressed gas to do some heating by passing it through a heat exchanger.

Once we have done so, we expand the air again and it cools. Since we have taken some heat out, it returns colder than we started. We then heat it back up and start again.

To achieve a higher temperature, the set volume of gas must be compressed further, which takes more work. As we are using more energy to compress the same amount of gas it becomes a less efficient process. The efficiency of a heat pump depends upon how much compression must be done i.e. the difference between the inlet temperature and the outlet temperature.

In most heat pump systems the manufacturer will select a gas that will be just hot enough to be a vapour once they have compressed it. When it meets the cooler surfaces of the heat exchanger, it not only transfers heat to the colder substance but it also condenses. In doing so much more heat is transferred out.

Likewise once we have passed the liquid through the expansion nozzle, we warm it back up again at just the right temperature to evaporate it. This phase change from liquid to gas takes a lot more energy than simply heating a liquid or gas by the same temperature difference. For this reason, the heat exchanger we use to take heat into the heat pump is the evaporator, and the one we use to eject heat is known as the condenser.

The easiest way to think of this is boiling a pot of water: it takes a lot less time to take a pot of water from 10^{o}C to 100^{o}C than it does to boil the pot dry. If we were to put a thermometer in the pot, even the last drop of water would still be at 100^{o}C. The energy being put into the water by the cooker is used to change it from a liquid to a gas.

Heat pump efficiency is always dependent upon the temperature in and the temperature out. If we are cooling, we want to dump heat at as low a temperature as possible, if we are heating we want to absorb heat at as high a temperature as possible.

3.1.2 Refrigerants

Different gases not only store different amounts of heat but they also condense at different temperatures and pressures. For this reason there are specific fluids which have properties which are particularly useful for heat pumps. These are known as refrigerant gases.

There are many refrigerants that are used for different purposes. They all have the potential to harm the environment. The environment can be harmed in two ways: depletion of the ozone layer; and contribution to global warming.

Refrigerants with high ozone depleting potential (ODP) have now been banned; for example refrigerant containing CFC or, from 1st January 2014, Hydrochlorofluorocarbons (HCFCs).

Hydro fluorocarbon (HFC) based refrigerants are the most widely used refrigerant. These have low Ozone Depleting Potential however they can have a Global Warming Potential (GWP) thousands of times higher than Carbon Dioxide. This has meant that recently there is been a move to using carbon dioxide as a refrigerant, otherwise known as R744.

Other common refrigerants include:

- R407c is common for low temperature heating, limited to around 55°C;
- R134a is often used for hot water applications of more than 65°C; and
- R744 is generally used to provide better efficiency at high temperature differences (e.g. domestic hot water).

3.2 Sorption Heat Pumps

Another type of heat pump is known as a sorption heat pump – either absorption or adsorption. These heat pumps work very differently to the vapour compression cycle heat pump.

3.2.1 Absorption

Absorption heat pumps use two fluids, such as water and ammonia, which are heated together. This separates the ammonia from the water. The warm ammonia is used to provide heat to the heating system. It is expanded through an expansion nozzle and then passed through an evaporator to absorb heat, just as in a vapour compression heat pump. The ammonia vapour is then combined with the water again, which releases more heat. The solution is then pumped at a high pressure into the chamber to be heated and the process starts again.

Absorption heat pumps are more efficient but require a lot of maintenance and use hazardous chemicals which are difficult to dispose of.

3.2.2 Adsorption

Adsorption heat pumps use water as a refrigerant. These use solids such as silica gel to complete the process. The water evaporates as the silica gel absorbs water, causing a low vapour pressure. The silica gel is then heated to release the water. The warm water vapour condenses to release heat. The water is then re-used.

Adsorption heat pumps are much more straightforward to operate, require very little maintenance and use no hazardous chemicals, however they are less efficient.

3.3 Terminology

3.3.1 Coefficient of Performance (COP)

Coefficient of Performance (COP) is a measure of the efficiency of a heat pump. It is the ratio between the heat pump heat output and the energy input supplied by the electricity and/or gas driving the heat pump - a higher COP is better. The closer the temperatures of the heat source (the air around the evaporator) and the system that is being heated (hot water or indoor air at the condenser) the higher the COP.

A typical figure would be COP 4 which means that for every 1kW of electricity consumed by the heat pump it outputs 4kW of heat.

Manufacturers use sets of 'standard' temperatures when quoting COP - frequently 7°C outdoor temperature and 35°C heating temperature. This complies with part the electric heat pump test standard BS EN 14511. There can be a number of standards for each heat pump type so when comparing devices, you must know what input and outlet temperatures were used.

3.3.2 Seasonal Performance Factor (SPF)

A heat pump's efficiency measured across an entire season is expressed by the Seasonal Performance Factor - this either requires a measurement of the seasonal electricity/gas used and the heat produced at the outlet of the heat pump throughout the whole period or a prediction based on historic weather conditions. The higher your SPF value the more energy efficient your system is.

To be considered 'renewable' (under the Renewable Energy Directive[6]) heat pumps must have a SPF of at least 2.875, and this is the minimum performance that is eligible for the RHI. The term SCOP is sometimes used in place of SPF. SCOP is the Seasonal Coefficient of Performance.

3.3.3 Energy Efficiency Ratio

The Energy Efficiency Ratio (EER) is the cooling equivalent of COP. These are tested at different temperature operating conditions in accordance with British Standards. For example, a system that is rated in cooling at 6.5kW, with a rated power consumption of 1.8kW will have an EER of 3.61 or 361%.

The Seasonal Energy Efficiency Ratio (SEER) is the overall energy efficiency ratio of a heat pump, representative of the entire cooling season. It is calculated as the annual cooling demand divided by the annual consumption of electricity for cooling.

In general, the higher the SEER, the higher the overall cost of the system. However, the energy savings can return the higher initial investment several times during the heat pump's life. A new central heat pump (SEER=12) replacing a vintage unit (SEER=6) will use half the energy to provide the same amount of cooling, cutting costs in half. The most efficient heat pumps have SEERs of between 14 and 18.

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[6] Please refer to http://ec.europa.eu/energy/renewables/index_en.htm for more information [accessed 03/05/2017]

4 Technology Types

4.1 Air Source Heat Pumps

Air source heat pumps extract heat from the outside air. By extracting heat from the air, they cool it. When the air is humid, cooling it can cause the water in the air to condense into liquid water.

When the air outside is a few degrees above freezing, instead of the water vapour condensing, it freezes inside the heat pump. Specifically, it freezes onto the cold plates of the evaporator. This ice acts as an insulator, preventing the heat pump from efficiently extracting heat from the air passing through it. As such, heat pumps need to be able to remove this ice quickly and efficiently.

Most air source heat pumps, therefore, reverse the heat pump cycle to supply hot refrigerant gas to the evaporator and melt the ice. This means that instead of supplying heat to the heating system, it cools the heating system. To prevent it cooling too much, an electric element can provides some heat until the heat pump is defrosted.

How often this happens depends upon the design of the heat pump, heat pumps which have a higher air flow rate will cool the air less than those with a lower air flow rate, this means that the ice will form less quickly and it will not need to defrost itself as often.

The other way to reduce the energy required for defrosting is to use a buffer tank. A buffer tank is in simple terms, a tank that contains a certain amount of water. This water increases the volume of the heating distribution system. During the low load conditions, the extra volume of water would absorb any of the extra heat generated by the heat pump. By heating a buffer tank when in heating mode, the heat pump can store up some heat to use to defrost itself. The heat it stores in the tank will have been created at its operating SPF whereas the heat provided by the electric element is created at an SPF of 1.

Since Scotland often has high humidity levels and the temperature is often only a few degrees above freezing in winter, heat pumps have to defrost themselves more frequently. How efficiently a heat pump installation handles the defrost cycle will significantly influence running costs.

4.1.1 Air-to-Air Heat Pumps

Air-to-air heat pumps are designed to directly heat the air within the building. Heat is extracted from the external air via an externally located unit housing an evaporator. The internally located condenser heats the air where it is supplied to the building.

An air-to-air heat pump works when outside the property a fan blows air across a large heat exchanger. Cold refrigerant gases pass through the heat exchanger and are warmed by the passing air, up to the ambient temperature.

This refrigerant is then compressed by the compressor and hot refrigerant gas is sent though pipework to the indoor unit.

Inside the property, a fan blows air across a second heat exchanger and the air is warmed by the hot refrigerant gas passes passing through it where it condenses.

This liquid passes back to the outdoor unit through the refrigerant pipes where it is expanded through the expansion nozzle.

Some heat pumps can provide heating and cooling. In cooling mode, a valve rotates to reverse the direction of the refrigerant flow so that heat is being extracted by indoor unit, acting as the evaporator and the outdoor unit dumps heat outside by acting as the condenser.

4.1.2 Air-to-Water Heat Pump

In an air-to-water heat pump system, heat is extracted from the outside air in the same way as it is in air-to-air heat pumps. Instead of heating the inside air directly, air-to-water heat pumps transfer the heat to a wet heating system which may include radiators, fan convectors or under floor heating systems.

Unlike a boiler, the temperature the heat pump supplies heat needs to be considered. The inlet and output temperature have on the efficiency of an air-to-air heat pump. With an air-to-water heat pump system, there is no control over the inlet temperature; it is the same as the outside air temperature.

The outlet temperature of the heat pump will be the same as the temperature of the water we supply to the heating system, and we have some influence over that. This water temperature is dependent upon how the heating system was designed. To maximise the efficiency of an air-to-water heat pump radiators, underfloor heating or fan convectors need to be designed to heat the building using water that would be flowing at as low temperature as possible, ideally at 35^{0}C rather than conventional heating systems which run at 80^{0}C.

Figure 5.1 shows the effect of reducing the water temperature on the SPF of a heat pump system. If the flow temperature of a heat pump is reduced from 60^{O}C to 45^{O}C, then the SPF increases from 2.1 to 3.0.

The oversize factor describes how much larger the radiators need to be for a given flow temperature, compared to if they were sized for a boiler. This means that the radiators required to fully heat a room using water at 45^{O}C are more than three times the size that they would have to be for a standard boiler.

There are two ways this can be achieved:

- Reduce the heating requirement of a space by insulating it; or
- Install bigger radiators or fan coil units.

Figure 5.1 Effect of reducing the water temperature of the SPF of a heat pump

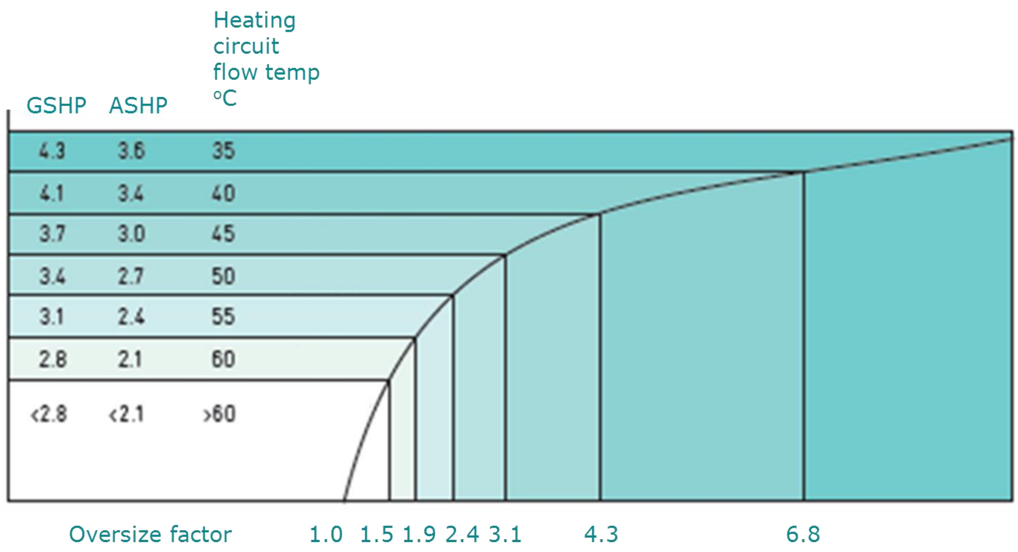


Table 5.1 shows the effect of changing the flow temperature of a heat pump on electricity consumption. Changing only the flow temperature from 60^{O}C to 50^{O}C reduces the amount of electricity used by 18%. Changing it to 40^{O}C will reduce consumption by 38% This effect is just as important on ground source heat pumps and water source heat pumps as it is on air source heat pumps.

Table 5.1 Effect of changing the flow temperature of a heat pump on electricity consumption

Units of heat	Flow temperature	SPF	Electricity	Renewable heat
252,000kWh	40	3.4	74,118kWh	177,882kWh
252,000kWh	50	2.7	93,333kWh	158,667kWh
252,000kWh	60	2.1	120,000kWh	132,000kWh

4.1.3 Summary

Air source heat pump systems are considerably easier to design than ground source or water source, as there is a constant supply of air.

The design of ground source heat pumps requires the total amount of heat to be extracted from the ground over the course of a year to be quantified. Operating a building for longer hours than it was designed. This is not the case for air source heat pumps, which could operate constantly all year without causing these problems.

Installing an air source heat pump involves installing fewer pipes and requires less ground drilling than other types of heat pump. This makes the installation easier and faster.

The down side of air source heat pumps is the efficiency. During winter, the ground temperatures are higher than the air so ground source heat pumps achieve a better efficiency. The external fan can generate up to 50 decibels of noise when running at full speed, similar to that of an air conditioning unit, and the compressor can generate up to 48 decibels of noise.

4.2 Ground Source Heat Pump

Ground source heat pumps use a network of pipes which are buried to extract heat from the ground. The ground stays at a constant temperature under the surface, so the heat pump can be used throughout the year – even in the middle of winter.

A ground source heat pump circulates a mixture of water and antifreeze, called brine. The reason antifreeze is used is that the mixture is returned to the ground at a temperature a few degrees below the ambient ground temperature, which is likely be very close or just below freezing.

Inside the heat pump, the refrigeration circuit is the same as that used for air source heat pumps but the evaporator is now a plate heat exchanger through which brine flows instead of air.

To ensure a system is designed as efficiently as possible, the temperature of the brine circuit will be important and there is more control over this temperature than the outside air temperature.

4.2.1 Ground Collectors

There are two types of ground collectors, vertical boreholes and horizontal trenches. Boreholes are usually 130mm to 150mm in diameter and 100m to 200m deep. Horizontal trenches are around 1m to 1.5m deep.

To work out how many boreholes or trenches, the peak load of the system and the total amount of heat to be extracted over a year as well as the thermal properties of the ground it is to be buried in must be known.

Calculating the peak load is usually straightforward but determining the total amount of heat that is to be used over a year can be challenging. In effect there is a limit on the amount of heat that can be delivered, which would limit the possibility for future expansion. The cost of installing spare capacity is usually prohibitive.

The cost of installing ground loops can be minimised by carrying out the work at the same time as installing foundations or other services.

Vertical Boreholes

It is rare in the UK for a borehole to be drilled in a single type of material all the way down. There are usually layers of material. The surface geology is anything from the surface to the bedrock. In the North West of Scotland this can be less than one metre, in other areas this can be 100m or more. The type of material can also be very different from one area to another. The amount of heat that can be extracted from the surface geology is usually a lot less than bedrock. Sites with a large amount of clay or silt are going to need a lot more boreholes than a site where the same bedrock is near the surface.

The exception is where sand or gravel is saturated with water. Water saturated sand or gravel have exceptionally high thermal outputs, however very little heat can be extracted from dry sand or gravel. The viability of a heat pump in these locations is completely dependent upon the water staying in place, if the water level drops significantly then the thermal properties of the ground changes and less heat can be extracted.

Once you know what is at the surface, the type of bedrock needs to be established. When bedrock is solid, its thermal conductivity determines the rate at which heat can be extracted. The higher the rate, the fewer metres of rocks the pipes will need to pass through to extract enough heat that the heat pump can to meet the peak load.

However, if there is a flow of ground water then the heat extracted by a heat pump will be replenished by this water meaning fewer boreholes will be required.

Conversely if the rock is fractured with air pockets then it will perform very poorly. This is because air acts as an insulator so the temperature change will be slower.

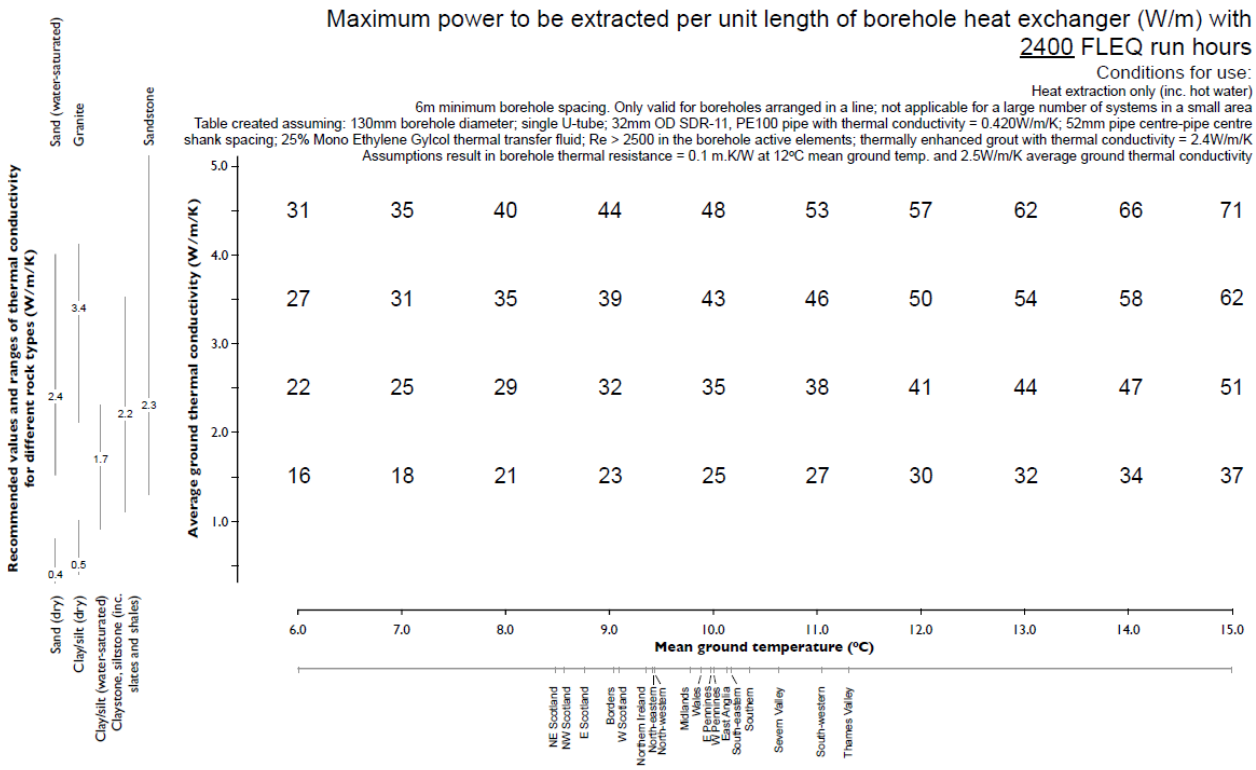
Table 4.2 outlines the design requirements for systems under 45kW. This is a guide for domestic properties but it is useful for us to get a sense of the numbers. For larger systems, detailed calculations are required. The information gives a sense of the difference that can be in place from one location to another.

The FLEQ running hours at the top refers to the Full Load Equivalent running hours. This is the total heat supplied over a year, in kilowatt hours, divided by the power of the heat pump in kilowatts. Separate tables are provided for sites with different full load equivalent running hours.

Table 5.2 describes the properties of bore holes on a site with an average ground temperature of 6 degrees centigrade (for example higher altitude sites in the Scottish Highlands), with clay/silt soil can expect to extract 16W/m but a site in Southern Scotland where the average ground temperature is 9C may be able to extract 39W/m.

Figure 5.2 – Ground outputs[7]

[7] Microgeneration Installation Standard: MIS 3005 (2011). Requirements for Contractors Undertaking the Supply, Design, Installation, Set to Work Commissioning and Handover of Microgeneration Heat Pump Systems. Issue 3



The British Geological Survey[8] provides free mapping which can be used to give an indication of the type of surface geology and bedrock likely to be encountered. It also provides a record of any boreholes drilled nearby. These borehole logs usually show the type and depth of each layer of rock and any water encountered and can be a valuable source of information.

In many parts of Scotland the geology changes rapidly from one location to another. There are often many layers of material, each very different from one another. The thickness of each layer and the type of materials can change across the same site as well as from location to location.

For this reason, it is important to gather as much information as possible on the ground types at the time of designing a system and then verify that this is correct when works start on site. The log of the first borehole should be checked against what was expected and the system re-designed if required.

It is important to note that permissions need to be sought and restrictions such as flood plains need to be taken into consideration.

Borehole Calculations

Once there is an understanding of the amount of heat needed and the surface geology, the number and depth of boreholes must be calculated.

This needs to be done using modelling software for all sites of over 45kW. A simulation is carried out for the design life of the heat pump system (e.g. 20 years). The software will specify how many boreholes are required, to what depth and in what layout, for the

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8 Please refer to www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html for more information [accessed 03/05/2017]

temperature coming out of the borehole to be sufficient for the desired heating requirements.

If the heat pump system is providing cooling then this can reduce the number of boreholes required.

Borehole Drilling

The cost of drilling depends upon geology – solid rock is cheaper to drill through than loose materials such as soil or sand. Loose material is slow to drill and requires casing to avoid the hole collapsing.

Borehole drillers will often supply a price based on a stated depth of casing, without good quality lining to the correct depth, boreholes can collapse. The final cost of the drilling will be affected by whether this assumption was correct. The difference in cost can be very substantial and different contractors can make different assumptions. It is important to be aware of the assumptions made and why the specific assumptions were made.

The lining of boreholes in clay/silt areas can be more problematic, thereby increasing the overall cost of installation.

Location of Boreholes

In terms of location of boreholes, they should be as far apart as possible to maximise heat recovery. They can be installed under tarmac, as solar gains and rainwater contribute very little to the heat recovery, geothermal energy is more important when considering boreholes. In the case of using boreholes for heating only applications, they should be installed no less than 6m apart from each other.

Installing boreholes in a line maximises heat recovery but requires a lot of space, whilst installing in a grid minimises the area required but reduces the amount of heat recovered. This means that slightly more boreholes may be required. The layout of the boreholes needs to be determined using modelling software.

Other Considerations

Some other factors to consider when considering boreholes are the locations of coal mines, caves or other existing underground services in the area.

There are coal seams under most of central Scotland, and often close to the surface. This has resulted in there being a lot of old mine workings, some of which are not recorded. It is important to carry out a search of mine workings prior to starting work.

If the site is in a location where coal is close to the surface it is important to consider the possibility of encountering mine workings. It is possible in some situations to drill a borehole through mine workings or other voids such as caves. However, not all drilling equipment is capable of doing so and it may be necessary notify the Scottish Environmental Protection Agency (SEPA) in case there is any contamination in a flooded mine which could contaminate other ground water in the drilling process.

When carrying out a ground assessment of the site, understand any existing underground services in the area and whether these may influence the boreholes layout.

Horizontal Trenches

Another method of using the heat within the ground is through trenches. Whereas boreholes recover heat from geothermal energy, almost no geothermal energy reaches the surface.

Trenches can be dug and filled with ground loops that recover the heat from the surface soil. Any heat removed from the ground near to the surface is replenished by solar gains or by rainwater.

The ground loops are a series of piping that is placed underground. As would be expected, the larger the geothermal system's equipment, the larger the ground loops must be. A larger loop field may mean the drill has to go deeper, the field has to be longer, or the pipes must be installed farther apart in order to move more heat to and from the ground.

For this reason it is very important that ground loops are not covered by anything which prevents water penetrating into the ground, such as tarmac.

Working out what area of ground you need for ground loops is similar to working out the number of boreholes. You need to know:

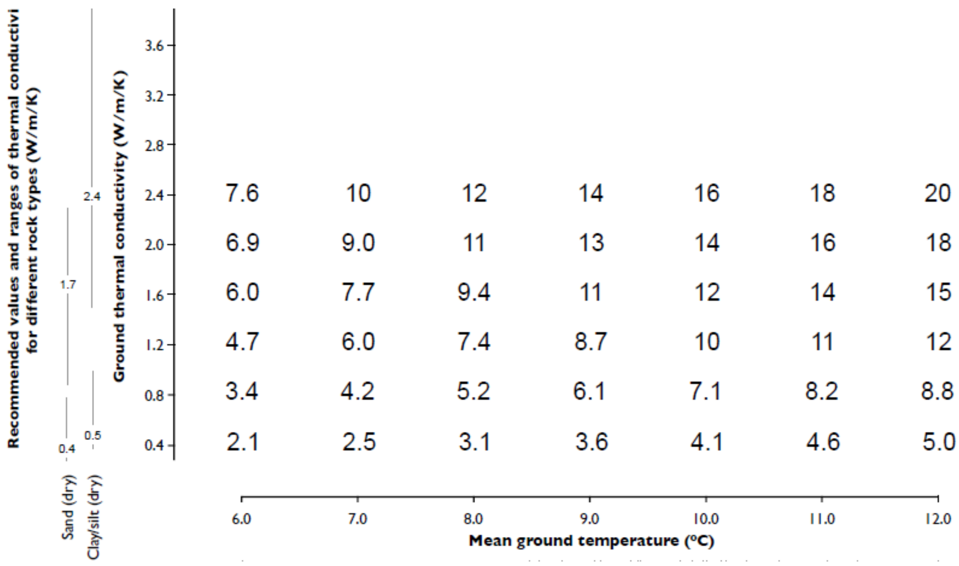
- The peak load of the heating system;
- The total amount of heat to be extracted in a year; and
- The thermal properties of the soil.

Soil type affects the necessary loop field size because different types of soil have different abilities to absorb energy. Soils which retain moisture, such as clay, have the ability to hold a great deal of heat, whereas soils which are well drained, such as sandy soils, require a larger loop field. As a general rule of thumb, the drier the ground the larger the loop field required.

Table 5.3 shows the outputs from ground at 2,400 Full Load Equivalent running hours. This assumes that the pipes are installed in straight lengths with 0.8m and 1.2m between them.

The outputs are a lot less than they were for boreholes; however a borehole has both the flow and return pipe in a small hole. In ground loops the flow will be 0.8m from the return.

Figure 5.3 – Ground outputs[9]



To get a gauge of the area, assume that the pipes are installed one metre apart. This would result in 1m of pipe needing 1m^2 of ground.

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[9] Microgeneration Installation Standard: MIS 3005 (2011). Requirements for Contractors Undertaking the Supply, Design, Installation, Set to Work Commissioning and Handover of Microgeneration Heat Pump Systems. Issue 3

If an insulated new house is being heated with a heating requirement of $40W/m^2$ using a heat pump with COP of 4 then 3 units of heat would be extracted the ground for every unit output. If we have moist clay in an area with a ground temperature between 8°C and 9°C then there is a heat output of about $10W/m^2$ which results a requirement of $3m^2$ of ground for every m^2 of building.

This is very much a best case scenario. If a system is to run for more hours, the building require more heat or the soil to be less than ideal, then the area of ground required will consequently be larger.

Installing Ground Loops

Installing ground loops involves excavating a trench, usually between 1.5-2m in depth, and about 1m wide. In reality the exact width of the trench will be the width of the digger bucket selected.

These trenches need to be around 1m apart. In the case of larger systems, it is often more practical to excavate a whole site down to the required depth, install the ground loops and then cover them all up again.

There are generally two types of ground loops:

- Straight ground loops, that are just straight loops of pipe; and
- Flat coils of pipe, often referred to as 'slinkies'.

Slinkies use more pipe per m^2 and therefore extract more heat from each m^2 of ground but require a greater distance between each loop to ensure that the temperature of the ground can recover.

Cooling and Heating

It is possible to use a ground source heat pump to do cooling as well as heating. In cooling mode the heat pump system reverses and it extracts heat from the building and heats the ground. This heat will contribute to recovering the ground temperature.

It is possible for a ground source heat pump to do heating and cooling at the same time. This is done by placing a heat exchanger in the ground loops. The cold water returning from the evaporator to the ground loops passes through this heat exchanger where it cools water for the chilled circuit. The heat exchanger can be by-passed when the system is only in heating or cooling mode. This configuration is particularly useful for buildings such as offices.

4.3 Water Source Heat Pump

The majority of heat pumps sold within the UK are either ground source or air source. Water is another source of energy which can sometimes be used for heat pumps. Water source heat pumps are heat pumps where the evaporator extracts heat from water.

Using water as an energy source has a number of advantages when compared to air or ground source:

- The heat transfer rate from water is far higher than that in the ground or air making them more effective than ground source heat pumps;
- The flow/circulation of the water source provides constant energy replacement. If using a water source heat pump with a moving body of water, the heat is constantly being replaced, as new warmer water replaces the cooler water that has had its heat extracted;
- The use of a water source removes the need of digging large trenches, often reducing the cost of installation compared to a ground source; and

- The return temperature to the heat pump is usually higher than either the ground or the winter average air temperature, increasing the CoP (coefficient of performance) of the heat pump.

For every 1kW of energy required to run a water source heat pump, 4-5kW of equivalent of heat energy is produced making them more efficient than both air and ground source heat pumps.

The systems are usually classed as either ‘open’ where water is extracted from the source, flowed around the heat pumps intermediate heat exchanger (or an open loop rated internal heat exchanger) and then discharged; or ‘closed’ loop where, similar to a ground source, pipes or heat exchange panels are placed within the water source and a water/antifreeze mixture is passed through the pipes/panels absorbing energy from the water.

Open Loop

An abstraction licence will generally be required from the SEPA, this must be done before work commences[10]. To give an example, a 45kW heat pump with a COP of 3 will require nearly 8,000 litres of water per hour, which is much higher than water extracted for drinking. A discharge consent is also required and it is important to consider what happens to the colder water after it has flowed through the heat pump.

As there is no ground heat exchanger i.e. coils of pipe that absorb the energy from the water, and hence no temperature drop across the pipe, open loop systems can be of a slightly higher efficiency than closed loop systems. However, care needs to be taken that this efficiency gain is not lost by any additional pumping costs if the water needs to be lifted higher by a pump, such as within a borehole.

There is a risk of freezing within the heat pump side exchanger. The outlet temperature must not be allowed to approach freezing point or ice will start to form. As a rule the source water needs to be reliably above 8°C for such systems to work well. If the heat exchanger freezes up, the heat pump stops working.

Water quality is also a concern with open loop systems as if the pH value of the water is not neutral, corrosion resistant pump, pipes and heat exchanger are required. In addition, maintenance requirements can be higher, due to requirements for filters and possible water treatment (to prevent algae deposits).

Closed Loop

Closed loop systems can be a slightly lower efficiency due to the ground heat exchanger and any temperature losses in transferring this heat from the water into the ‘closed’ loop.

However there is no corrosion risk, and because no lifting is occurring, pumping energy loss can be lower. No water is extracted so no licence is required and as the fluid in the closed loop contains anti-freeze there is almost no risk of freezing.

Care has to be taken in the placement of the pipes (generally coiled on mats and called pond mats) or panels to avoid any boat traffic or debris which might float past but once submerged (usually at least a meter deep) they would normally not require any further attention.

With all water source heat pumps it must be remembered that if the water source dries up then without water there is no heat. This is particularly important if open loop boreholes are

[10] Please refer to www.sepa.org.uk/regulations/water/abstractions for more information [accessed 03/05/2017]

used. If they have a low replenish rate then the energy source the heat pump utilises can be exhausted.

Water Source

Water sources can be lakes, ponds, rivers, springs, wells or boreholes.

Surface water from rivers and lochs can be used. Surface water can be significantly colder in winter, particularly on shallow bodies of water and the total heat extracted needs to be checked to prevent freezing. If a river is being used it is essential that there is enough water at all times of year. An assessment must be made of the seasonal changes to river levels and flow rates.

Seawater can be used if the correct permissions are sought including from Crown Estates.

It is important to consider the quality of the water when designing a system. Water quality analysis should be carried out on a sample from the proposed source. For ground water it is most often a concern that mineral deposits will develop inside the system. It is usually technically possible to include some water treatment in the system; however the cost of such a system can be considerable. It is often advisable to use a heat exchanger between the heat pump and the water source as a precaution. This ensures that a failure of the heat exchanger (the component most exposed to water quality issues) will not result in a failure of the heat pump system. It also allows much easier removal, inspection and cleaning of the heat exchanger than would be possible with the evaporator in the heat pump system. This is often referred to as a secondary plate heat exchanger.

Using a secondary plate heat exchanger reduces the efficiency of the heat pump system as there needs to be a slight temperature difference between one side and the other. However, it means that the temperature going into the heat pump is lower than it would be without the heat exchanger being present.

4.4 Planning Permission

In 2009 and 2010, the Scottish Government introduced a relaxation on planning controls, called “permitted development rights” on properties for many of the more common types of renewable technologies. This relaxed, and in some cases, removed the need for planning permission for many renewable systems[11].

Installing a ground or water source heat pump in the grounds of a non-domestic building is likely to be considered 'permitted development' with no need to apply to the Local Authority for planning permission. There are, however, important limits and conditions which must be met to benefit from the permitted development rights. In particular, the total area of excavation or total surface area covered by the heat pump (including any pipes) must not exceed 0.5 hectares.

Installation of air source heat pumps on non-domestic land is likely to require an application for planning permission to the local authority.

For a ground source or water source heat pump approval from SEPA will be required, particularly for the drilling of open wells or closed loop boreholes. In addition, the

[11] Please refer to www.scotland.gov.uk/Publications/2010/07/15092031/0 for more information [accessed 03/05/2017]

installation of a ground source or air source heat pump will have to comply with building regulations[12].

[12] Please refer to www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards for more information [accessed 03/05/2017]

5 Site Suitability

There are some simple steps that you can take to determine if heat pumps are a good option to consider. Table 4.4 provides a quick check list to determine the most appropriate heat pump.

A pre-requisite for heat pumps to operate efficiently is to have a low flow and return temperature. If a building is old, leaky and uninsulated then it is very likely to require a lot of heating and the first step should be to look at improving the fabric of the building and then start looking at technology solutions. If the building is listed and improvement would be limited then heat pumps are unlikely to be the most appropriate technology.

Conversely, this means heat pumps may be a good solution for a newer building. If a building is operating efficient heating or cooling flow temperatures, therefore lower heating fluid temperatures, and an elevated cooling fluid temperatures then all types of heat pumps could be effective.

If a building can have simultaneous heating and cooling demand it may be cost effective to apply a borehole heat pump solution in combination with a three-pipe solution.

Table 6.1 Heat Pump Checklist

Options	Air source heat pump	Ground source heat pump – ground loops	Ground source heat pump – bore holes
Old, uninsulated, leaky, building with very old radiators	X	X	X
New, insulated and air tight building with low loss radiators	✓	✓	✓
Cooling – at elevated temperatures	✓	✓	✓
Simultaneous heating and cooling demand	X	✓	✓
Low capital expenditure	✓	X	X
Low availability of naturally exposed land	✓	X	X
Urban area retrofit	✓	X	✓

7 Benefits of Heat Pumps

Table 7.1 and 7.2 demonstrate the impact that the efficiency of the heat pump system has on the financial viability. The costs here are for illustrative purposes only and are not designed to be a guide on costs.

Firstly, in both situations, a heat pump replacing electric heat sources will offer better payback than oil, which is better than gas. Therefore, sites which are not connected to the gas grid are more likely to be viable. Secondly, on gas sites, the change in efficiency is sufficient to make the system financially unattractive.

Table 7.1 Air source heat pump (SPF 2.5)

Existing Fuel	Current heat spend	Fuel cost (£/kWh)	Units of heat (kWh)	Electricity at SPF of 2.5 (kWh)	Heat pump electricity cost	Fuel saving	Renewable heat (kWh)	RHI income	Total saving	System cost	Payback (yrs)
Electricity	£30,240	0.120	252,000	100,800	£12,096	£18,144	151,200	£3,780	£21,924	£50,000	2.3
Oil	£14,616	0.058	252,000	100,800	£12,096	£2,520	151,200	£3,780	£6,300	£50,000	7.9
Natural Gas	£8,568	0.034	252,000	100,800	£12,096	-£3,528	151,200	£3,780	£252	£50,000	198.4

Table 7.2 Air source heat pump (SPF 4.0)

Existing Fuel	Current heat spend	Fuel cost (£/kWh)	Units of heat (kWh)	Electricity at SPF of 4 (kWh)	Heat pump electricity cost	Fuel saving	Renewable heat (kWh)	RHI income	Total saving	System cost	Payback (yrs)
Electricity	£30,240	0.120	252,000	63,000	£7,560	£22,680	189,000	£4,725	£27,405	£50,000	1.8
Oil	£14,616	0.058	252,000	63,000	£7,560	£7,056	189,000	£4,725	£11,781	£50,000	4.2
Natural Gas	£8,568	0.034	252,000	63,000	£7,560	£1,008	189,000	£4,725	£5,733	£50,000	8.7

Note: Renewable Heat Incentive rates are subject to review on a quarterly basis and are published by Ofgem at:

https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-non-domestic-rhi

6 Building the Business Case to Support Implementation

6.1 Renewable Heat Incentive

The Renewable Heat Incentive is a government scheme which makes a payment for generating heat from a renewable source. This table shows the amount of money paid for each unit of heat depending upon the boiler used, with the tariff correct as of 1st July 2014.

To be able to qualify for RHI, the units installed have to be sourced from the Energy Technology Product List or meet the efficiency requirements specified in the RHI regulations. The rate paid for heat produced from air source heat pumps or deep geothermal heat pumps (those where the boreholes are 500 metres or more) is a fixed tariff per unit of heat as shown in Table 9.1.

Heat generated from ground and water source heat pumps are paid a higher rate (see tier 1) for the first 1,314 full load equivalent running hours and a lower rate (see tier 2) for every unit thereafter.

Table 9.1 Renewable Heat Incentive
(Tariffs that apply for installations with an accreditation date on or after 1 April 2017)

Type	Tariff (p/kWh)	Tier
Ground and water source heat pumps	9.09 2.71	Tier 1 Tier 2
Air source heat pump (all capacities)	2.61	-
Deep geothermal (all capacities)	5.22	-

6.2 The Business Case

When building the business case it is important to not only quantify the income and expenditure from operating a system but also, be aware of the potential for each to vary. For example the RHI income depends upon the number of units of heat delivered. If a building is insulated further after a heat pump is installed then less heat will be required. While this will reduce the running costs, it will also reduce the RHI income. Conversely, if the heat pump provides more heat than anticipated then it may attract the lower, Tier 2, rate of RHI for these units of heat but the electricity usage will increase at the same rate.

Ground source heat pumps are particularly susceptible to changes in load, this is because the ground loop system, whether boreholes or trenches, will have been sized based on an anticipated heat load. The cost of installing additional ground loops is very substantial. It is unlikely that a heat pump system for an office will have been designed to allow the building to operate 24 hours per day if the building was specified to be operating from 08:00 to 18:00. Changing the use of the building without considering the heat pump system will result in the ground temperatures decreasing. This will lead to lower SPF and operating problems.

7 Further Useful Links and Documents

Title	Source	Description	Link
The Heat Pump Association		The HPA is a Trade Association representing manufacturers and distributors of heat pumps in the UK. It acts as a central focal point for the exchange of knowledge and information regarding heat pumps and liaises with Government departments to provide expert advice with regards to legislation, standards, guidance and financial incentives. Additionally, it informs the public and the wider HVAC industry, working with other trade associations and NGO's	www.heatpumps.org.uk
Renewable energy sources - Opportunities for businesses	The Carbon Trust	Provides an overview of the main sources of renewable energy and helps assess whether using renewable energy is a viable option for a business	www.carbontrust.com/media/7379/ctv010_-_renewable_energy_sources.pdf
Power play - Applying renewable energy technologies to existing buildings	The Carbon Trust	Provides details on applying renewable energy technologies to existing buildings	www.carbontrust.com/media/81373/ctg050-power-play-renewable-energy-technologies-existing-buildings.pdf
How to implement guide on ground source heat pumps	The Carbon Trust	Outlines the early stages of installing ground source heat pumps	www.carbontrust.com/media/147462/j8057_ctl150_how_to_implement_guide_on_ground_source_heat_pumps_aw__interactive.pdf
Down to earth - Lessons learned from putting ground source heat pumps	The Carbon Trust	Provides lessons learned from installing group source heat pumps	www.carbontrust.com/media/81349/ctg036-down-to-earth-ground-source-heat-pumps.pdf

into action in low carbon buildings			
How to implement guide on air source heat pumps	The Carbon Trust	Outlines the early stages of installing air source heat pumps	www.carbontrust.com/media/147466/j8058_ctl151_how_to_implement_guide_on_air_source_heat_pumps_aw.pdf
Easy guide to the Non-Domestic RHI - An introduction to the scheme	Ofgem	Guide to non-domestic RHI	www.ofgem.gov.uk/publications-and-updates/easy-guide-metering-requirements-non-domestic-rhi