A Guide to Ground Source Heating

Ground Source heating and cooling is one of the easiest forms of renewable energy to install in buildings and in doing so enables a substantial reduction in greenhouse gas emissions. It is suitable for any residential, commercial, retail and public building.

1.0 An Introduction to Ground Source

From about 2m below ground level, the naturally occurring temperature of rocks, soils and groundwater in the earths crust stays at a fairly stable, albeit low level.

The heat energy stored at shallow depths in the earths crust is in fact stored solar energy and is therefore continuously renewed from the sun's solar radiation and is therefore true renewable energy.

This 'Ground Source' heat energy can be exploited to heat (or cool) buildings using a ground source heat pump (GSHP).

If designed correctly GSHP systems can provide a sustainable energy source at a lower cost than traditional energy sources.

Ground source heat should not be confused with true Geothermal Energy which comes from hot water and rocks much deeper in the earths crust.

1.1 The Earth as a Heat Source

Solar radiation is absorbed by the earths surface with seasonal variations affecting the upper 15m or so, the variation is most pronounced in the top two metres. Deeper rocks and soils stay fairly uniform in temperature throughout the year, roughly equating to the average air temperature of the location.

When heat is extracted from the ground it is regenerated by solar radiation, rainfall and the temperature gradient of the ground. As depth increases there is a reasonably constant increase in temperature of around 2-3°C every 100m, this is the Earths true geothermal gradient. In the UK the temperature at 100m depth is usually around 7-15°C, dependant on local geology and soil conditions.

1.2 'Closed Loop' Ground Source Systems

The system circulates a water based fluid through a series of horizontal collector loops or though collector loops installed in drilled boreholes. The circulating fluid is warmed by the heat energy in the ground before being collected by header pipes and then passed through heat pump.

The heat pump uses a refrigerant and a compressor to extract this low temperature heat energy and increase it to a figure that is suitable for heating buildings. Removing the heat from the circulating fluid reduces its temperature back to about 0°C and it is then re-circulated through the collector or borehole loops to be reheated (Fig 1).

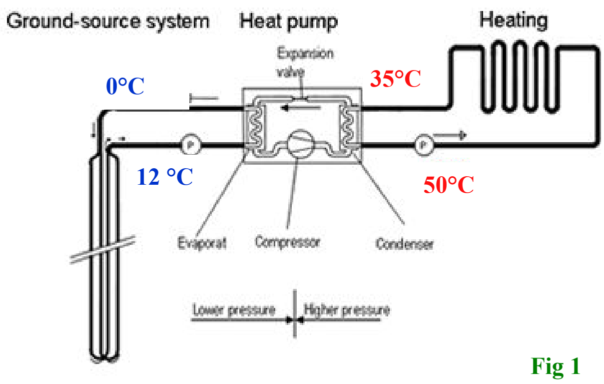

Fig 1

The heat pump unit contains two heat exchangers. The first is the 'evaporator' and it contains an evaporant to extract the heat from the circulating fluid. The evaporant is then compressed to increase it's temperature to between 45°C and 65°C before interfacing with the building's heating system water in a second heat exchanger, called the condenser, which heats the water. The heated water is circulated through the building and returned to the heat pump at about 35°C. The evaporant is passed through an

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expansion valve where it returns to its original pressure and temperature.

In addition to building heating, the system will heat the domestic hot water in the same way.

The energy needed to run a heat pump is significantly less than that needed to heat a dwelling.

GSHP systems can also be 'reversed' by using a reverse cycle heat pump to provide building cooling solutions during summer months. In this configuration heat is extracted from the building and put back in the ground. This assists the temperature re-charge of the ground around the loops and ensures the heat energy status quo of the system is maintained.

The efficiency of GSHP systems is optimised by ensuring heating and cooling loads are compatible with heat pump selection and loop design and that the ground loops or boreholes are properly installed.

1.3 Open Loop Ground Source Systems

Open loop systems can be installed in larger diameter boreholes where permeable strata and high groundwater flows exist, such as an aquifer, or in a large water body such as a water filled mineshaft. Groundwater from the 'well' is extracted by suitably sized borehole pump and passed through the heat pump. The cooled water is re-circulated back to the water source via a separate recharge well which will sited some way from the abstraction point.

The groundwater inflow to the abstraction borehole must be several times greater than the proposed abstraction volume to ensure there is no significant drawdown during operation and to ensure sufficient groundwater flow is available to cater for the removal of required heat energy. Open Loop systems require regulatory approval from the Environment Agency as they involve 'abstraction' of water.

1.4 Applications

Ground source systems are suitable for heating and cooling as well as provision of domestic hot water for any public, industrial, commercial and residential buildings and can also be applied to a number of industrial processes.

Heating and cooling arrangements will be designed to suit the design of the building services and M&E installation but may consist of radiators (convection), ducted air or underfloor systems.

A dual heating and cooling GSHP installation powered by a renewable energy source would be a fully sustainable system.

2.0 Design of Closed Loop Systems —Introduction

The majority of systems installed are closed loop arrangements.

Collector pipe arrays are normally placed in shallow trenches of up to 2m depth. A reasonably large area open land is required to provide the necessary area of installation taking into account the spacing of feed and return loops.

Some collector pipe systems are installed as coils or 'slinky's' in trenches although these installations are not as efficient as separated feed and return loops.

Borehole based systems are generally installed up to 150m depth and most commonly at 100—120m and may consist of one or several hundred boreholes depending on the size of the building which, for example, may range from individual houses to large public buildings such as hospitals.

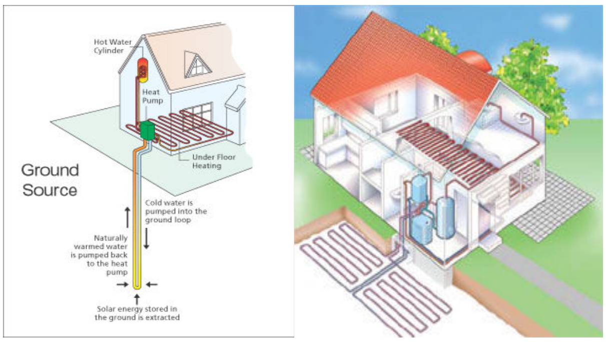

Fig 2—Borehole and Collector GSHP Systems

At a depth of 100m the temperature is about 12°C increasing to about 15°C at 200m. The thermal conductivity of different soils and rocks, however, ranges from about 1 to 3 W/mK and a ground source heating system cannot be operated for long periods at high extraction rates without allowing the zones surrounding the ground loops or boreholes to have a temperature re-charge. This is normally allowed for in a design by assuming a reduced loading in summer months when only domestic hot water is being heated, allowing thermal recharge from the surrounding ground, or by design a cooling system to operate during summer months which will provide direct recharge to the ground surrounding the loops.

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In the design of a GSHP system there are a number of controlling factors that will determine the type of system chosen and sizing the of GSHP;

- The heating or cooling load and which is the dominant design factor - it is often the case that in modern, well insulated buildings that the cooling load is significantly higher than the heating load
- The efficiency of the heating and cooling arrangements in the building—radiators, ducted air, underfloor etc which may be different if the installation is retrofit or new
- Heat pump capacity
- Annual operating hours and full load hours
- The likely peak load on the system
- The geology and hydrology of the site
- The ambient ground temperature
- The thermal conductivity of the soils and rocks and the resultant heat energy availability over time
- The available space for installation of collector loops or boreholes
- Possible future extensions to the buildings or facilities
- Access for maintenance

Note: Standardised thermal properties of the soils with a suitable factor of safety will be used unless a site specific 'thermal response' test has been carried out to verify site conditions.

Installing Ground Source Loop in 100m deep Borehole

The analysis of the above factors will determine the heat pump capacity but will also lead to a decision on whether;

- Horizontal ground collector loops
- Borehole collector loop systems or
- An open loop system—is used

2.1 Design and sizing of Collector Loops

Sizing the collector loop arrangement i.e. diameter, depth, length and area coverage is one of the most important aspect of the design of a GSHP system and is crucial to achieving good performance. If the loop arrangement is undersized it will result in poor efficiency from the outset.

An undersized system will try and draw more heat energy from the ground than it can sustain. Temperature recovery is not achieved between heating seasons and ground temperatures will gradually decrease year on year. A long term effect can also be that return fluid is below freezing and sections of the ground near surface can become frozen.
Heat pump designs need to balance long term issues such as heat build up or depletion, while also catering for short term peak loads (during which temperatures can increase between 5°C and 10°C in 1 to 2 hours). With an undersized collector loop arrangement there is considerable risk of not being able to meet the required building heating (or cooling) load.

Conversely, if the collector loop system is oversized, the installation costs of the GSHP system will increase and may make overall project costs unacceptable. A bigger ground heat exchanger will result in increased system capacity,

To optimise the size and length of the collector loops all design parameters should be known and this is where the information from a site specific thermal response test can be invaluable in order to understand the thermal gradient and temperature of the ground and the thermal conductivity of the strata which will determine the availability of the heat energy to the collector loops for the particular geological conditions of the site. The moisture content/saturation of the ground will further affect design considerations as this alters thermal conductivity.

If these thermal properties are not properly measured and understood, standard values must be used but they should be used with caution and should include factors of safety.

These risks on system sizing can be partially offset by installing heat pump systems that offer both heating and cooling since heat is returned to the ground

during summer cooling and therefore aids thermal recovery of the ground.

Climatic conditions can significantly affect the performance of near surface collector loop systems as up to 2m depth there can be a significant seasonal variation in ground temperature The climate determines the temperature of the heat source and the extent of thermal recovery after heat extraction has taken place.

The collector loops themselves are subject to a number of different factors which must also be taken into account during design and these include; pipe material, loop configuration, number of boreholes and spacing of feed/return pipes.

In addition the materials and methods used for backfilling around loops in trenches or grouting the annulus around loops in boreholes will all affect the efficiency and performance of the system and the resulting sizing/number of loops and boreholes required.

In order to calculate the total length of collector loops required it is essential that the building loads are known which requires an accurate calculation of the building heat loss, its related energy consumption profile, the cooling load and the domestic hot water requirements. This detail should include the peak loads for heating and cooling which will be the coldest winter period hottest summer months respectively.

Heat gain should also be considered and the system's 'balance point' determined. Since net heating and cooling of the ground depends on the heat load or cooling load of the building, design should be based on loads for the whole year and not just peak heat/ cooling times. Therefore the total annual heating/ cooling energy requirement and monthly profile are also needed. Calculating these loads requires information on the planned indoor conditions (i.e. room temperatures), the input temperature needed to achieve these and the normal weather conditions.

Operating characteristics of the heat pump itself also need to be known including the minimum and maximum entering temperatures and the required flow rate of refrigerant inside the unit..

2.2 Design Methods

On small installations, empirical guidelines covering power extraction and operating hours can be used together with a factor of safety. These guidelines are generally conservative and satisfactory for installations up to 50kW.

For larger schemes site investigation boreholes to at least the proposed loop installation depth will provide accurate information on the soils, rocks and groundwater present at the site however standard thermal properties of these materials would have to be used and a factor of safety allowed in the design for potential variations.

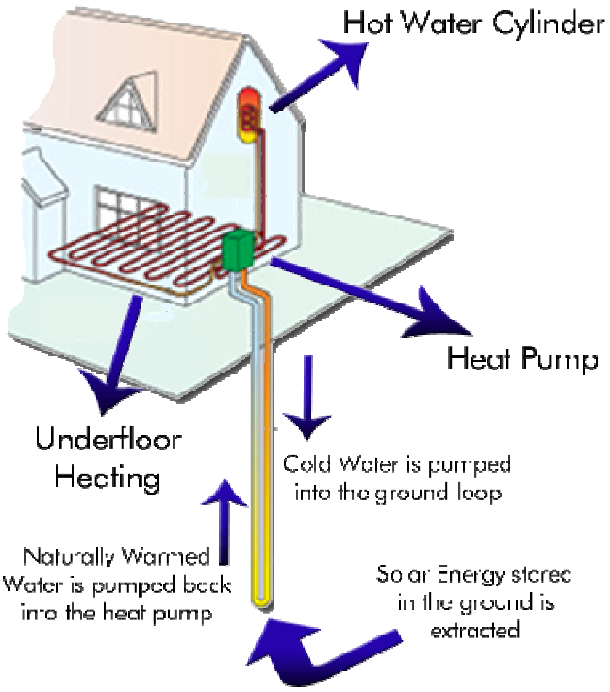
A more precise way of obtaining the correct data is to undertake a **Thermal Response Test (TRT).**

Undertaking a Thermal Response Test (TRT)

Closed loop, ground source heat pump systems operate by the thermal conduction of heat from the surrounding ground. Measuring the average, in-situ, thermal conductivity of the ground over the full length of a borehole is therefore the ideal way of optimising the design of a ground loop array to produce an efficient system.

The performance of borehole based systems is also affected by a combination of the thermal resistance and thermal conductivity of the constituent parts of the borehole which includes the borehole wall interface, the grout surround to the borehole loops and loop itself. The thermal response test is carried out on a borehole loop that is installed and grouted to the designed depth and specification and so will account for these factors in the measured data.

Generally, a TRT involves injecting heat at a constant rate into a trial borehole while measuring the change in inlet and outlet water temperatures over time. This trial borehole must be representative of those planned on site, same depth, diameter, grout etc, and can be used as one of the boreholes in the final borehole field.



A Typical Borehole Heat Pump System

The test should be carried out for sufficient time, possibly 5 to 10 days to achieve a steady state and to overcome the effects of any latent thermal resistance effects in the borehole. Once the steady state is achieved the temperature rise/drop is governed by the average thermal conductivity of the ground around the borehole only.

Once this figure has been established it can be used together with the building's heating and cooling profile to calculate the overall number of boreholes required in the 'field' i.e. the overall length of collector loop. Software packages are available to assist design engineers model the heat transfer between the heat transfer fluid (brine/antifreeze) and the surrounding ground.

The overall length of the collector loops will be linked to the optimum circulation flow rate and the specified range of fluid temperatures entering the heat pump. For a system used primarily for heating, the minimum fluid temperature limit may well depend on the freezing point of the working fluid.

3.0 The Heat Pump

Typical GSHPs' input water temperatures can range from -5°c to +12°C for pumps delivering heat. Maximum output temperatures can be as high as 65°C.

3.1 Heat Pump Sizing

To size the system, the design heat load must be known. It is also important to look at the load profile as the energy required to operate the system will depend on the operating conditions. Detailed analysis of the building loads, energy consumption and cost effectiveness is required. Design software is available for this analysis.

4.0 Building Heating Systems

The efficiency of a heat pump is a function of the difference between the temperature of the source i.e. the ground and the output i.e. the temperature of the building heat distribution system. The smaller this temperature difference the higher the coefficient of performance (COP) of the pump will be. For example, if the distribution temperature falls from 60°C to 40°C, the COP can increase by more than 40%. It is therefore important to design the building heat distribution system with as low a temperature difference as possible.

4.1 Space Heating

The table below shows the delivery temperatures required for a range of domestic heat distribution systems.

Distribution system	Delivery Temperature °C
Underfloor heating	30-45
Low temperature radiators	45-55
Conventional radiators	60 to 90
Air	30 to 50

For new buildings where high insulation levels result in low heating demand, heat distribution options include low temperature ducted air systems, low temperature water based systems or underfloor heating.

The most efficient type of building space heating to use with a GSHP system is underfloor heating. Ideally the system should be designed to give floor surface temperatures no higher than 26°C and should be sized using a water temperature difference of about 5°C.

4.2 Building Cooling

Most water-to-air heat pumps are reversible, so ducted air heat distribution systems can readily be

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adapted to provide cooling as well as heating. A reversible water-to-water heat pump coupled to an underfloor system can also be designed to provide building space cooling in summer.

5.0 Installation of the Ground Collector Loops

The ground collector loops (sometimes referred to as the 'ground heat exchanger' must be installed correctly to work efficiently, this is especially important for borehole based systems.

Installing a Collector Loop in a Borehole

In Borehole systems the key to producing an effective and cost effective GSHP system which meets design parameters is to ensure that there is a continuous thermal conductivity medium between the ground and the water circulation loops to allow effective heat transfer.

In boreholes, which may be 150m deep, this is often difficult to achieve due to the nature of the strata and the problems of hole degradation and blocking both during drilling, loop installation and hole grouting. This can result in incomplete holes, holes not drilled to the design depth, inability to install loops to the correct depth due to hole collapse or in hole debris and the inability to achieve a fully grouted surround to the loops. Heating installations based on such risks will be inefficient and unable to meet design outputs.

Once installed, the borehole loop cannot be replaced or repaired and a new hole must be drilled if failure occurs.

It is essential, therefore, when considering borehole based solutions that the correct drilling methods are used to ensure properly installed and efficient systems.

5.1 Grouting

Ground collector loops installed in boreholes must be fully grout surrounded to ensure that they are in full thermal contact with the rock/soil in which they are placed. The grout must have a similar thermal conductivity to the surrounding medium so that the ground heat is conducted to the loops efficiently. The grout has to be injected via a grout pipe from the base of the borehole up, so as to push out all the water, air or silt that is present in the bore.

The grout, as with the loop material, must be capable of lasting the design life of the system. It must also have limited shrinkage during curing otherwise an annulus may be formed around the ground loops reducing the thermal conductivity from the grout to the coils.

Why use Forkers

Forkers are able to provide a complete 'turnkey' installation service for ground source heating systems, from drilling deep boreholes to a complete heating system installation service.

We operate a number of multi-functional Casagrande C6 and M9 'dual head' rotary drilling rigs which allow holes to be simultaneously cased (or lined) to depths of up to 150m. The dual head facility enables one-pass, steel cased borehole drilling through all types of strata including voids, broken ground, unstable or loose ground to provide a 'clean hole' for installation of the water circulation loops. These rigs are equipped with bespoke cuttings collection systems mounted below the lower drill head allowing collection of wet or dry cuttings to either dust collector or sealed skip thus enabling clean drilling in any location.

As an alternative to fully cased holes we also use bio-degradable polymer drilling fluids to provide hole support and flushing in deep holes.

The fully cased hole or polymer drill fluid methods both provide a clean open hole allowing the ground collector loops and grout injection tubes to be easily inserted to the base of the boreholes and the holes grouted from the bottom up, thus ensuring fully grout surrounded loops with a thermally conductive grout such as a silica sand rich grout, for the full hole depth.

With our compliance monitoring and validation of loop installation and grout injection the quality of the installation can therefore be assured.

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Ground Source Heating

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Installing Borehole Collector Loops for New School

A residential property where we have installed 5 test borehole collector loops to varying depths for a ongoing long term data collection programme

Overview

The most significant direct benefits of GSHP systems are the reduced energy requirement and the use of a sustainable energy source.

If the system is designed appropriately, the mode of operation can be reversed to cool the building and replace the heat energy previously taken from the ground.

Indirect benefits of GSHP systems also include:

- low environmental impact with a significantly reduced carbon footprint
- Improved Standard Assessment Procedure (SAP) calculating ratings for assessing energy performance for dwellings (2007)
- Improved Eco-homes and Code for sustainable Homes ratings for new builds
- Zero visual impact.

To warrant the energy efficiency and reliability of ground source installations, it is important to ensure that clients ensure;

- Installations are installed to current best practice standards published by EA, GSHPA and BDA and are certified to MIS 3005 to be in scope for RHI payments
- Engage an experienced building services or M&E designer
- Use good quality, durable materials
- Employ reputable contractors for both the borehole ground collector loops, the heat pump and the building heating/cooling system
- Operate a rigorous inspection, testing and validation regime during installation and commissioning

The Future

The UK faces considerable challenges to meet the government targets set for low-carbon construction. Government spending cuts and the recession have affected the construction industry and may have lowered the focus on carbon reduction, but the drive to reduce carbon emissions will not go away.

The renewables industry together with designers and architects need to lobby clients in promoting the construction of efficient and sustainable buildings. The implementation of the Carbon Reduction Commitment (CRC) means that the next 40 years will be a period of considerable change.

At Forkers we view this as an opportunity not a problem. If a building is worth heating, it is worth installing renewable energy and it is worth considering Ground Source Heating. The annual energy and cost savings potential together with long life-span and low maintenance is another significant attraction for this technology.

That is why we make sure that the most expensive item and hardest-to-change component - the borehole collector loops are properly installed to ensure we hand over an efficient long lasting system for the end user.

GSHP association

British Drilling Association

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Meeting Renewable Heat Goals In The UK

At present about two-thirds of the oil and gas burnt in the UK is used for industrial and domestic heating. This situation cannot continue indefinitely. The governments National Renewable Energy Plan estimates that the share of UK heat demand met by renewable resources needs to increase from today's 1% to around 15% in 2020 to help the country meet its overall target on renewable energy for that year. Ground source heating and cooling (GSHC) schemes play an important part in the mix of technologies that will be needed to meet the 2020 target.

There are some 12,000 heat-pump installations in the UK today and the EA forecast that there could be over 300,000 ground source heating installations by 2020.

The Government estimates that ground source heating and cooling systems have the potential to provide up to 29 per cent of total UK built environment heat demand by 2050.

GSHP association

British Drilling Association

New guidance published by the Environment Agency, the GSHPA and the BDA will support this energy revolution in homes and businesses whilst also helping to ensure high standards of installation and protection of the environment.

Whether or not we agree with all of the assumptions used in government forecasts there is a clear need for massive investment and uptake of the technology for this sort of growth to be achieved.

For further details on Forkers Renewable Energy Services please contact

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