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1 Introduction – systems and applications

Our society has become increasingly dependent on fossil fuels such as oil, coal and natural gas. These are finite resources, having been created by natural processes over millions of years. Burning them to produce energy results in emissions of 'greenhouse gases', including carbon dioxide (CO_2). These gases trap solar radiation in the earth's atmosphere and cause undesirable changes in the climate.

Home energy use is responsible for over a quarter of UK CO_2 emissions which contribute to climate change. To help mitigate the effects of climate change, the Energy Saving Trust has a range of technical solutions to help UK housing professionals build to higher levels of energy efficiency.

The purpose of this guide is to give specifiers and advisors clear and concise information about ground source heat pumps (GSHPs) in dwellings. It covers the different types of system, and the benefits, limitations, costs and suitability of the various technologies. It can also help housing professionals to meet the energy efficiency requirements of the Code for Sustainable Homes.

Despite their increasing use elsewhere, GSHPs are a relatively unfamiliar technology in the UK. But their performance is now such that, if properly designed and installed, they represent a very carbon-efficient form of space heating. A useful list of do's and don'ts can be found on page 19.

1.1 Types of system

A GSHP system consists of three elements;

1. A ground heat exchanger, which collects heat from the ground.

2. A water-to-water or water-to-air heat pump, which raises the heat collected to a useful temperature and transfers it to the house.

3. A heat distribution system which provides the heat to the house for example underfloor heating.

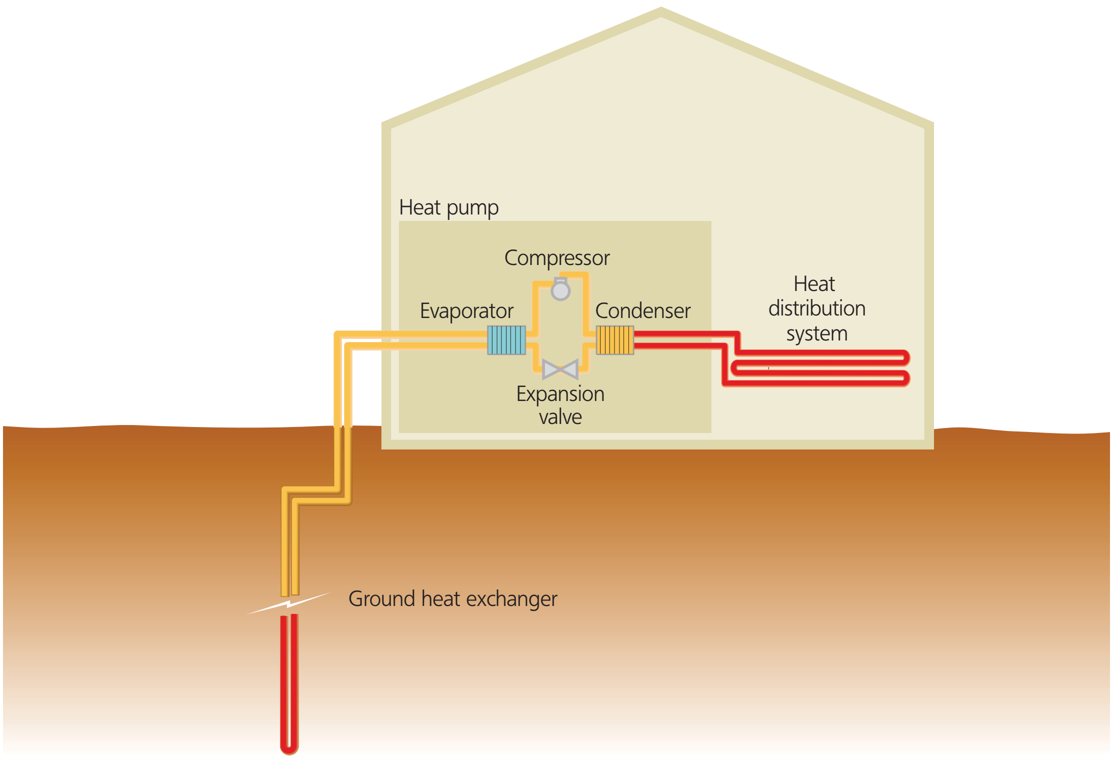


Figure 1: A typical GSHP system

Initially open-loop GSHP systems using groundwater as the heat source were most widely used. Where there is a suitable source of groundwater this can be cost effective, because the water can be delivered and returned using relatively inexpensive wells requiring little ground area. However, there are some disadvantages – water availability is limited, fouling and corrosion may cause problems depending on water quality and, most importantly, environmental regulations covering the use of groundwater are increasingly restrictive.

These limitations mean that interest is now focused on closed-loop or ground-coupled systems, where the ground heat exchanger consists of a sealed loop of pipe buried either horizontally or vertically in the ground. This guide only considers closed-loop systems as they are more widely applicable than open-loop systems.

Two types of closed-loop system are possible:

1 Direct expansion (DX) – where refrigerant is circulated directly through the ground loop

2 Indirect – where a water/antifreeze solution circulates through the ground loop and energy is transferred to or from the heat pump refrigerant circuit via a heat exchanger.

GSHPs are most commonly indirect systems.

1.2 Applications

GSHPs can be used to provide space and domestic water heating and, if required, space cooling to a wide range of building types and sizes. But the provision of cooling in addition to heating will result in increased energy consumption however efficiently it is supplied – see 'Reducing overheating - a designer's guide' (CE129) for further guidance.. GSHPs are particularly suitable for new build as the technology is most efficient when used to supply low temperature distribution systems, such as underfloor heating. They can also be used for retrofit, especially in conjunction with measures to reduce heat demand. GSHPs can be particularly cost effective in areas where mains gas is not available, or in developments where there is an advantage to simplifying the infrastructure provided.

This guide concentrates on the provision of space and water heating to individual dwellings, but the technology can also be applied to blocks of flats or groups of houses.

1.3 Potential benefits

To maximise the efficiency of a heat pump when providing heating, it is important to not only have a low heating distribution temperature, but also as high a source temperature as possible. Overall efficiencies for GSHPs are inherently higher than for air source heat pumps, because ground temperatures are higher than the mean air temperature in winter and lower in summer. The ground temperature also remains relatively stable, allowing the heat pump to operate close to its optimal design point. Air temperatures, however, vary both throughout the day and seasonally, and are lowest at times of peak heating demand. Air has a lower specific heat capacity than water, so to supply the same energy more air must be supplied to the heat pump, which in turn requires more energy. For heat pumps using ambient air as the source, the evaporator coil is also likely to need defrosting at low temperatures.

For well-designed GSHP systems, used to supply low temperature, water-based heating systems (e.g. underfloor heating), seasonal efficiencies of between 300 and 400 per cent are common for indirect systems, and can be higher (350 to 500 per cent) for direct expansion systems. By comparison the seasonal efficiency of an air source heat pump system is about 250 per cent, although there is technical potential to increase this. The seasonal efficiency is the ratio of the energy delivered from the heat pump to the total energy supplied to it, measured over a year or heating season (including energy demands for circulation, e.g. to circulate fluid round the ground heat exchanger).

The high seasonal efficiency of GSHP systems reduces the demand for purchased electricity, and the associated emissions of CO_2 and other pollutants. Figure 2 shows the relationship between utilisation efficiency and CO_2 emissions for different domestic fuels.

For example it can be seen that (assuming an average CO_2 emission factor for electricity of 0.422kg/kWh) using a GSHP with a seasonal efficiency of 350 per cent would result in the emission of 0.12kg of CO_2 for every kWh of useful heat provided. By comparison a condensing gas boiler (assuming a CO_2 emission factor for gas of 0.194kg/kWh), operating at a seasonal efficiency of 85 per cent, would result in 0.23kg CO_2 for every kWh of useful heat supplied – almost double the CO_2 emissions from the GSHP. The emission figure for electricity is an average for the UK generation mix. If the heat pump was supplied with energy from a renewable source, CO_2 emissions could be substantially reduced or eliminated.

As well as reducing purchased energy consumption and CO_2 emissions, GSHPs have a number of other environmental and operational advantages:

- High reliability (few moving parts, no exposure to weather).
- High security (no visible external components to be damaged or vandalised).
- Long life expectancy (typically 20 – 25 years for the heat pump and over 50 years for the ground coil).
- Low noise.
- Low maintenance costs (no regular servicing requirements).
- No boiler or fuel tank.
- No combustion or explosive gases within the building.
- No flue or ventilation requirements.
- No local pollution.

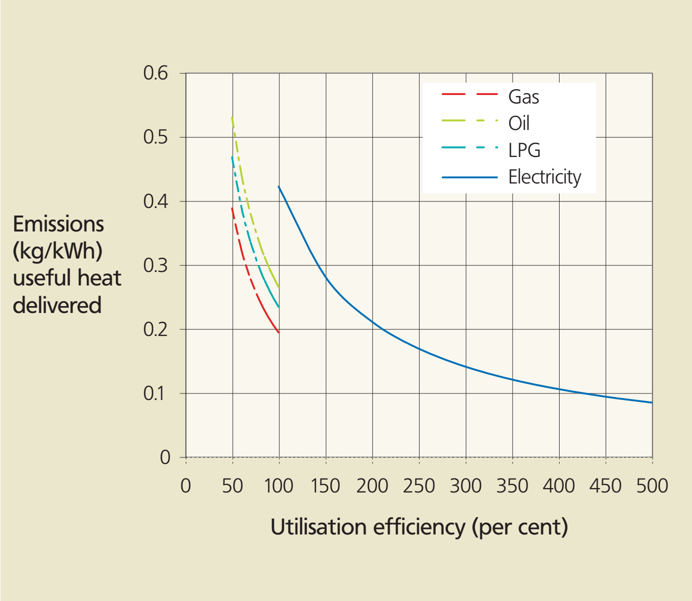


Figure 2: CO_2 emissions* and fuel use efficiency

*Assumed CO_2 emission factors (SAP 2005):
Electricity = 0.422kg/kWh delivered
Gas = 0.194kg/kWh
LPG = 0.234kg/kWh
Oil = 0.265kg/kWh

2 General design

Before considering a ground source heat pump, it is important to explore ways of minimising space heating and hot water demand by incorporating energy efficiency measures. (For possible measures see 'Domestic energy efficiency primer' (GPG171/CE101)).

The most important first step in the design of a GSHP installation is the accurate calculation of the building's heat loss, its related energy consumption profile and the domestic hot water requirements. This will allow accurate sizing of the heat pump system, which is particularly important because the capital cost of a GSHP system is generally higher than for conventional systems, and economies of scale are more limited.

Oversizing will significantly increase the installed cost for little operational saving, and will mean that the period of operation under part load is increased. Frequent cycling reduces equipment life and operating efficiency. If the system is undersized, design conditions may not be met and the use of top-up heating, usually direct acting electric heating, will reduce the overall system efficiency.

A GSHP system can be designed to provide all the required heat (a monovalent system). However, because of the relatively high capital cost, it may be economic to consider a bivalent system where the heat pump is designed to cover the base heating load, while an auxiliary system covers the additional peak demand (e.g. if the savings in capital cost offset any increase in running costs).

Reducing the output temperature required from the heat pump will increase its performance.

The majority of heat pumps have an operating temperature limit of 50°C – 55°C in most applications. These are not suitable for monovalent operation in combination with traditionally sized, high temperature wet radiator distribution systems, or for providing all the domestic water heating as they will not be able to raise the water temperature to that required (60°C) to avoid the risk of Legionella. A few heat pumps, however, can provide output temperatures of up to 65°C.

The performance of the heat pump depends on the performance of the ground loop and vice versa. It is therefore essential to design them together.

Closed-loop ground source heat pump systems will not normally require permissions/authorisations from the Environment Agency (see Useful contacts on page 22). However, the Agency can provide comment on proposed schemes with a view to reducing the risk of groundwater pollution or derogation that might result.

The main concerns are:

- The risk of the underground pipes/boreholes creating an undesirable pathway for water to flow between different water bearing strata.
- Undesirable temperature changes in the aquifer that may result from the operation of a GSHP.
- Pollution of groundwater that might occur from leakage of additive chemicals used in the system.

Where there is a risk of, or actual, releases of polluting matter to groundwater the agency can serve statutory notices to protect groundwater.

3 Ground heat exchanger

3.1 Types of ground heat exchanger

Indirect

In an indirect circulation system the ground heat exchanger consists of a sealed loop of high-density polyethylene pipe containing a circulating fluid (usually a water/antifreeze mixture), which is pumped round the loop. Energy is transferred indirectly via a heat exchanger to the heat pump refrigerant. The majority of systems are indirect.

Direct

Alternatively, the refrigerant can be circulated directly through a copper ground heat exchanger. This is called a direct expansion (DX) system. Direct circulation systems are more efficient than indirect systems because there is good thermal contact with the ground, the heat exchanger between the ground coil circulating fluid and the refrigerant is eliminated, and no circulation pump is required. This means that, for a given output, a shorter ground coil is required than for an indirect system, giving an installation cost saving that helps offset the higher material cost, but these systems require more refrigerant and there is a greater potential risk of refrigerant leaks. DX systems are most suitable for smaller domestic applications. They are uncommon in the UK.

Figure 3 Trench and SLINKY™ © GeoScience

Heat exchanger

The ground heat exchanger is buried either horizontally in a shallow trench (at a depth of 1.0m – 2.0m) or vertically in a borehole. The choice of horizontal or vertical system depends on the land area available, local ground conditions and excavation costs. As costs for trenching and drilling are generally higher than piping costs, it is important to maximise the heat extraction per unit length of trench/borehole.

Horizontal collectors require relatively large areas, free from hard rock or large boulders, and a minimum soil depth of 1.5m. They are particularly suitable in rural areas, where properties are larger, and for new construction. In urban areas the installation size may be limited by the land area available. Multiple pipes (up to six, placed either side-by-side or in an over/under configuration) can be laid in a single trench, but they should be at least 0.3m apart. The amount of trench required can also be reduced if the pipe is laid as a series of overlapping coils (sometimes referred to as a SLINKY™, see Figure 3), placed vertically in a narrow trench or horizontally at the bottom of a wider trench. The trench lengths are likely to be 20 to 30 per cent of those for a single pipe configuration, but pipe lengths may be double for the same thermal performance.

Vertical collectors are used where land area is limited and for larger installations. They are inserted as U-tubes into pre-drilled boreholes generally 100mm to 150mm in diameter and between 15m and 120m deep. DX systems are only suitable for shallow vertical collectors (maximum depth 30m). Vertical collectors are more expensive than horizontal ones but have high thermal efficiency and require less pipe and pumping energy. They are also less likely to suffer damage after installation. Multiple boreholes may be needed for larger residential applications.

The collector coil can also be laid under water, for instance in a pond. Seasonal variations in the water temperature are likely to be greater than in the ground, but heat transfer rates can be high so overall efficiencies can be higher than for collectors buried in the ground.

Figure 4 Typical drilling rig used for a vertical borehole based GSHP installation © R Curtis

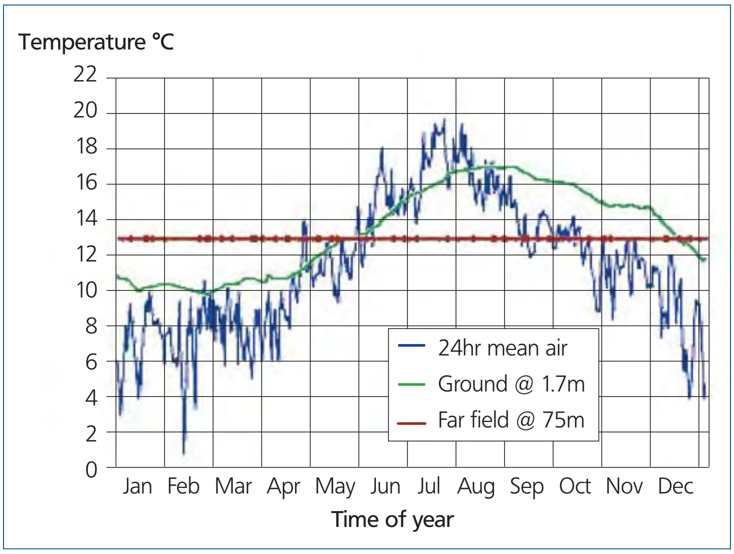


Figure 5 Air and ground temperatures, Falmouth 1994 (Source: GeoScience Limited)

3.2 Ground characteristics

It is important to determine the depth of soil cover, the type of soil or rock and the ground temperature.

The depth of soil cover may determine the possible configuration of the ground coil. If bedrock is within 1.5m of the surface, or there are large boulders, it may not be possible to install a horizontal ground loop. For a vertical borehole the depth of soil will influence the cost. It is generally more expensive and time consuming to drill through overburden than rock because the borehole has to be cased.

The ground temperature should be determined because the temperature difference between the ground and the fluid in the ground heat exchanger drives the heat transfer. At depths of less than 2m the ground temperature will follow the air temperature and will show marked seasonal variation. As the depth increases the seasonal swing in temperature is reduced, and the maximum and minimum soil temperatures begin to lag the temperature at the surface. At a depth of about 1.5m the time-lag is approximately one month. Below 10m the ground temperature remains effectively constant at approximately the annual average air temperature (i.e. between 10°C and 14°C in the UK depending on local geology and soil conditions).

Figure 5 shows the annual variation in ground temperatures at a depth of 1.7m, compared to the daily average air temperature measured at a site in Falmouth. It also shows the ground temperature at a depth of 75m.

Information on the thermal properties of the ground is needed for determining the length of heat exchanger required to meet a given energy load.. Most important is the difference between soil and rock, as rocks have significantly higher values for thermal conductivity. The moisture content of the soil also has a significant effect as dry, loose soil traps air and has a lower thermal conductivity than moist, packed soil. Low-conductivity soil may require as much as 50 per cent more collector loop than highly conductive soil. Water movement across a particular site will also have a significant impact on heat transfer through the ground, and can result in a smaller ground heat exchanger.

A geotechnical survey can be used to reduce the uncertainty associated with the ground thermal properties. More accurate information can result in a reduction in design loop length and easier loop installation. The British Geological Survey (see page 22) has an on-line service offering simple, or more detailed, GeoReports giving information on local ground conditions relevant for ground source heat pumps. (A basic GSHP report suitable for a domestic application currently costs £50 – and is available on-line.) For large schemes where multiple boreholes are required, a trial borehole and/or a thermal properties field test may be appropriate.

3.3 Sizing

The length of pipe required depends on the building heating load, soil conditions, loop configuration, local climate and landscaping. Sizing of the ground loop is critical. The more pipe used in the ground collector loop, the greater the output of the system. But as the costs associated with the ground coil typically form 30 to 50 per cent of the total system costs, oversizing is uneconomical.

Undersizing leads to the ground loop running colder and could, at worst, result in ground temperatures being unable to recover so that the annual energy that could be extracted from the ground would reduce over time. The ground loop must be sized to meet the peak thermal power load, but also to deliver energy at no greater rate than the surrounding earth can collect it over a twelve month period. If a system provides cooling as well as heating, energy transferred to the ground in summer will be stored and will be available to be extracted in winter.

Assuming that other conditions remain constant, the specific thermal power that a loop can extract (usually measured in: Watts/metre (W/m) pipe length for horizontal loops, W/m trench length for SLINKYs and W/m of borehole for vertical loops) will depend on the temperature difference between the circulating fluid and the 'far field' ground temperature (i.e. away from the influence of heat exchange with the collector coil).

The amount of energy that the ground loop can deliver is derived from the hours of use at particular temperature differences (and hence energy fluxes) over a given period. Sizing is complex and usually performed with specialised software programs, the accuracy of which have been verified using monitored data. Software is available in the public domain, and has been developed by manufacturers. An up-to-date list of design tools and suppliers is available from the IEA Heat Pump Centre's website (see page 22). Details of a variety of design tools are also given in their report, 'Designing heat pump systems: Users' experience with software, guides and handbooks' (HPC-AR12). Design of the ground heat exchanger will normally be the responsibility of the installer or the heat pump manufacturer.

3.4 Loop depth, spacing and layout

The deeper the loop the more stable the ground temperatures and the higher the collection efficiency, but the installation costs will go up. Horizontal loops are usually installed at a depth of between 1.0m and 2.0m.

Health and safety regulations do not allow personnel to enter unsupported trenches if they are more than 1.2m deep. To reduce thermal interference, multiple pipes laid in a single trench should be at least 0.3m apart.

To avoid interference between adjacent trenches there should be a minimum of 3m between them. Vertical boreholes should be at least 7m apart. Pipe layout should be carefully considered to keep the dynamic hydraulic pressure drop across the ground heat exchanger as small as possible, and so minimise the pumping power needed. For example, the maximum trench length for a single SLINKY loop is usually 50m. Multiple loops or boreholes should be connected to a manifold with individual isolating valves for each loop. This will allow individual loops to isolated when filling the ground collector or if a leak occurs.

3.5 Piping material

The piping material used affects service life, maintenance costs, pumping energy, capital cost and heat pump performance. It is important to use high quality materials for buried ground collectors. In indirect systems, high-density polyethylene is most commonly used. It is flexible and can be joined by heat fusion. The pipe diameter must be large enough to keep the pumping power small, but small enough to cause turbulent flow to ensure good heat transfer between the circulating fluid and the inside of the pipe wall. Pipe diameters between 20mm and 40mm are usual. For direct expansion systems, copper pipe (12mm – 15mm in diameter) is usually used. Depending on soil conditions, a plastic coating may be necessary to prevent corrosion.

3.6 Circulating fluid

The freezing point of the circulating fluid should be at least 5°C below the mean temperature of the heat pump (i.e. the average of the inlet and outlet temperatures on the source side). As the mean operating temperature of the heat pump may be as low as -4°C, it is usual to add an antifreeze solution to prevent freezing to below -10°C.

The specific antifreeze protection needed will depend on the design of the heat pump's heat exchanger, so it is important to comply with the manufacturer's specific recommendations for antifreeze concentration. The antifreeze should have good thermal performance. It is also important to make proper allowance for any change in properties of water/antifreeze mixtures as the loop temperature falls. For instance, below -10°C glycols (especially propylene glycol) become markedly more viscous and need greater pumping power, reducing overall system efficiency. If the flow ceases to be turbulent energy transfer will be significantly reduced.

3.7 The ground loop circulating pump

The circulating pump should have a low electrical load requirement, while still being adequate to ensure turbulent flow is maintained in the ground loop. In general the pumping power should not exceed 50W per kW (thermal) installed heat pump capacity. The pump must be suitable for the minimum design water temperature. Temperatures down to -10°C are possible so a pump that is suitable for use in chilled water circuits, and has its motor protected against the possibility of internal condensation, will be needed.

3.8 Installation and testing

Installation of the heat pump system, and especially the ground heat exchanger, needs to be carefully programmed so that it does not interfere with – or delay – any other construction activities. The time taken for installation depends on the soil conditions, length of pipe, equipment required and weather conditions. Typically, installation of a vertical or horizontal ground coil for domestic applications can be completed in one to two days. Prior to any excavation it is important to locate and protect any buried utilities, drainage pipes etc.

The GSHP manufacturer's procedures must be followed. The installation of horizontal heat exchangers is relatively straightforward, but vertical heat exchangers require highly specialist knowledge – not just by the drilling contractor, but also regarding pipe specification, joints, grouting etc. The ground heat exchanger should be installed by professionals who have preferably undergone training by manufacturers, or other recognised authorities such as the International GSHP Association (see page 22).

When installing the ground heat exchanger it is important to ensure good long-term thermal contact with the ground. Horizontal loops are usually laid on a bed of sand and then covered with a further 150mm layer of sand for protection. Care must be taken to avoid damage when backfilling, and the backfill material should be screened for rocks, stones etc.

For vertical heat exchangers, the space between the borehole wall and the inserted pipes is backfilled with a suitable grout material that is pumped from the bottom of the borehole. Low hydraulic permeability, high thermal conductivity grout (e.g. 'high solids' Bentonite), or a thermally enhanced, low permeability grout is used. Grouting over the full borehole length is required unless dispensation has been obtained from the Environment Agency. This not only provides good thermal contact but also prevents any vertical migration of groundwater.

It is recommended that the ground heat exchanger is made from a continuous loop of pipe. Any sub-surface connections in high density polyethylene pipe should be made using heat fusion techniques in accordance with relevant standards. For DX systems, work involving the refrigerant can only be carried out by personnel and companies certified to do this.

External pipework must be insulated within 1.5m of any wall, structure or water pipes, and sleeved where it enters the house. When the heat pump is delivering heat, the ground loop circuit will normally be operating below the building interior's dew point temperature.

Good quality insulation and vapour sealing of internal pipework and fittings in this circuit is therefore essential to minimise the risks, and the pipework should be configured so as to avoid potential damage if any condensation still occurs. A strainer, preferably a removable one, should be fitted. Also, it is good practice to fit a pressure gauge and pressure relief valve. Any arrangement for topping up the ground loop must not be permanently connected to the mains cold water supply. Warning tape should be installed over all buried pipes.

The ground loop should be pressure tested before installation in the ground (this may be done prior to delivery) and again after installation. The loop should be flushed and purged of all air before being charged with antifreeze, and pressurised ready for connection to the heat pump. The antifreeze must be pre-mixed with water before it is added – unless there is a single loop, or the configuration of multiple loops allows individual loops or boreholes to be valved off and filled separately.

Figure 6 Installation of a vertical SLINKY ground collector © Kensa Engineering

4 The heat pump

GSHPs are special versions of conventional water source heat pumps designed to operate over an extended range of entering water temperatures. Typical temperatures for the source water entering the heat pump range from -5°C to +12°C for heat pumps delivering heat with maximum output temperatures that are sometimes as high as 65°C.

The performance of heat pumps can vary widely so it is important to select an efficient unit. The heat pump output is a function of the rated efficiency of the unit and this should be quoted in the manufacturer's data. This is determined by performance testing under standard test conditions such as those specified in BS EN 14511-2 'Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. Part 2 Test conditions'.

The performance data should provide the coefficient of performance (COP). This is measured as the heat output (kWth) divided by the electrical input (kWel), at standard test conditions for brine/water heat pumps of B0W50, B0W35 and B5W35 (i.e. brine input temperature of 0°C and water output temperature of 50°C, etc). 'Brine' is used in the standard to denote any water/antifreeze solution. The higher the COP the more efficient the heat pump is.

Figure 7 shows coefficients of performance measured under test conditions for a typical GSHP. The efficiency for a specific installation will also be dependent on the power required by the ground loop circulating pump, which should be kept as low as possible.

A standard is being developed for calculating heat pump system efficiencies (EN 15316-4-2 'Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 4-2 Space heating generation system, heat pump systems'). This is currently available as a draft.

Figure 7 also shows that the lower the heating output temperature and the higher the source input temperature, the more efficiently the heat pump will operate.

Most heat pumps are designed to limit noise nuisance and vibration, for example by using anti-vibration mountings for the compressor and lining the heat pump casing with acoustic insulation. In addition flexible connections may be needed for the hydraulic connections from the heat pump. The heat pump should not be mounted close to sensitive areas such bedrooms.

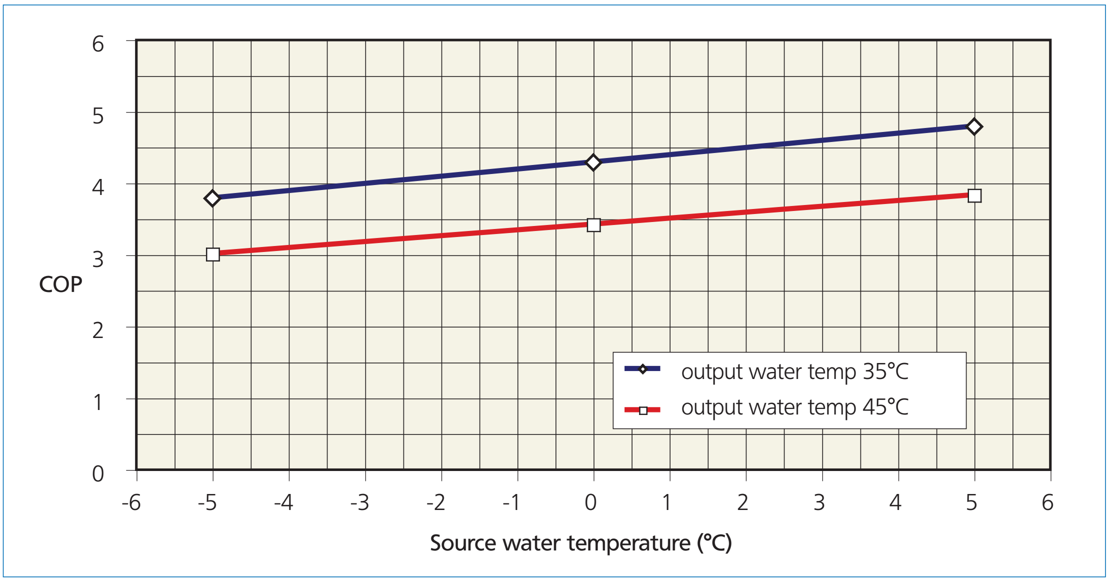


Figure 7 Coefficients of performance of typical small GSHPs

4.1 Heat pump sizing

The actual performance of the heat pump system is a function of the water temperature produced by the ground coil (which will depend on the ground temperature, pumping speed and the design of the ground coil) and the output temperature. It is essential that the heat pump and ground heat exchanger are designed together (see Section 3).

To size the system the design heat load must be known. An accurate assessment of the air infiltration rate is important, especially for highly insulated houses, and it is recommended that an air leakage pressure test is carried out to confirm that the design levels are met. It is also important to look at the load profile as the energy required to operate the system will depend on the operating conditions.

The heat pump system can be sized to meet the whole design load, but because of the relatively high capital cost it may be economic to size the system to meet only a proportion of the design load, in which case auxiliary heating (usually an in-line direct acting electric heater) is needed. As the efficiency of the auxiliary heating system will be lower than that of the heat pump, its use is likely to increase annual energy consumption. Detailed analysis of the building loads, energy consumption and cost effectiveness is required. In general, a heat pump sized to meet 60 per cent of the design heating load is likely to meet 85 per cent to 95 per cent of the annual heating energy requirement.

4.2 Electrical requirements

The heat pump is driven by an electric motor. This is an inductive load that can cause disturbances to the electricity distribution network because of high starting currents. It is a particular problem when using a single phase and can lead to flickering lights, voltage surges or 'spikes' (which can affect electronic equipment) and premature main fuse failure.

The Electricity Supply Regulations 1988, require that any particular consumer's installations do not interfere with the supplier's system, or the supply to other consumers. In particular, the variation in voltage caused by switching a load on and off must be within recognised limits. The actual voltage variation caused by a particular piece of equipment at a particular point on the network, will depend on the electrical impedance of the network at that point, as well as the actual size of the load connected. It is therefore essential to contact the distribution network operator (DNO) – formerly known as the Regional Electricity Company – at an early design stage to determine the maximum load that can be connected to the network at that location, because this may limit the size of heat pump that can be installed. Heat pumps with a heating output greater than 12kW are unlikely to be suitable for use with a single phase electrical supply.

Ways to overcome this problem include:

- Using heat pumps that incorporate soft start controls to limit starting currents.
- Reducing the required heat pump capacity by using an alternative heating system – for example a direct acting electric flow boiler to supplement the heat pump at times of maximum heating demand.
- Using multiple heat pumps, for example one for the ground floor and one for the first floor.
- Obtaining a three phase supply and using a three phase motor in the heat pump compressor (where there is a choice, a three phase supply is preferable to a single phase supply).

In most other European countries this is not a problem as a three phase electricity supply is generally available in houses.

Figure 8 illustrates an underfloor heating system. More information on this topic is presented in Section 5 page 14.

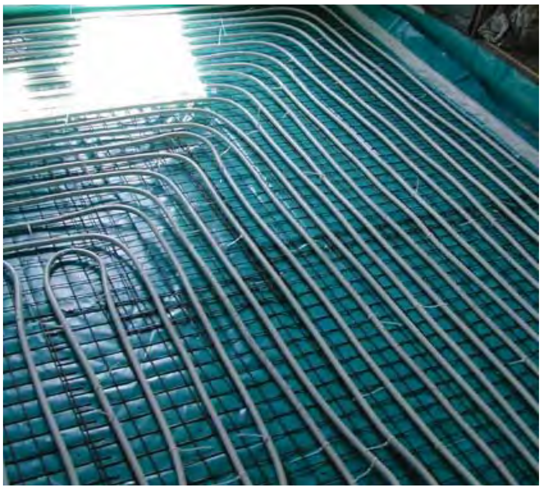


Figure 8 Underfloor heating system © J. Cantor

5 Distribution systems

As shown in Figure 7 the efficiency of a heat pump is a function of the difference between the temperature of the source and the output temperature of the water supplied to the heating system (i.e. the temperature of the distribution system). The smaller this temperature difference, the higher the coefficient of performance of the heat pump will be. For example the efficiency of a heat pump when supplying a distribution system at 35°C will be approximately 25 per cent higher than if it had to supply a distribution system at 45°C. It is therefore advantageous to use the lowest possible temperature distribution system.

5.1 Space heating

Table 1 shows the supply temperatures required for a range of domestic heating distribution systems.

Table 1: Typical delivery temperatures for various heating distribution systems

Distribution system	Delivery temperature (°C)
Underfloor heating	30 - 45
Low temperature radiators	45 - 55
Conventional radiators	60 – 90
Air	30 – 50

GSHP systems are not suitable for directly replacing conventional water-based central heating systems which have been designed to operate at 60°C to 90°C however if measures are taken to improve the thermal insulation of the building the reduced heating requirement may then be met using a reduced distribution temperature. Alternatively the radiator area can be increased. A drop in circulating temperature of 20°C would require an increase in emitter surface of 30 to 40 per cent to provide the same heat output.

For new housing where high insulation levels result in low heating demand, low temperature air distribution systems, low temperature water-based systems or underfloor heating are all possible options.

The seasonal performance of a low temperature radiator system will not be as high as that for an underfloor design because of the higher output temperature. Fan convectors can be used but flow temperatures of around 50°C may be necessary to ensure high enough air supply temperatures, which will also reduce the system's efficiency.

The thermal capacity of the distribution system is important. If it is too low the heat pump may suffer from artificially long off periods at times of light load. This effect is partly due to the presence of a restart delay (designed to reduce wear on the compressor by preventing rapid on/off cycling) in the heat pump.

To avoid this, sufficient non-disconnectable thermal capacity needs to be provided to compensate for the loss of output during the delay restart period. The heat pump manufacturer's guidance should be followed, but it may be necessary to install a 'buffer' tank in order to optimise the running time of the heat pump. The required capacity will depend on the system but is likely to be between 60 and 200 litres. Use of a buffer tank will allow more flexible individual room temperature control.

5.2 Domestic water heating

Water heating provides a year-round load and can improve the load factor for the heat pump. Hot water usually needs to be delivered from the tap at temperatures ranging from 35°C to 45°C. For domestic installations the thermal power output of the heat pump will be inadequate to deliver direct heating of incoming mains water to this level, so a storage system is required.

Heating is usually carried out via a primary coil or jacket to a storage cylinder. For most domestic heat pumps the maximum output temperature is 55°C, and the maximum water storage temperature achievable is 50°C. An auxiliary electric immersion heater is needed to provide a 'boost' facility, and also to raise the water temperature periodically to over 60°C to reduce the risk of Legionella. For full water heating the heat pump should be capable of supplying water in the range 60°C to 65°C.

The stored water volume should be sized so that virtually all the energy input can be supplied during a reduced rate electricity tariff period (such as Economy 7). Where auxiliary heating is provided by an efficient fossil-fuelled boiler it may be more economic to use the boiler to heat the stored water at temperatures above 45°C, because the efficiency of the heat pump falls as the output temperature rises.

Another option is to preheat the incoming cold water in a separate preheat tank, via an indirect coil, at whatever temperatures are being used to perform space heating.

Heat pumps, especially those for the US market, can be supplied with a desuperheater designed to provide partial domestic water heating. A desuperheater is a refrigerant hot gas-to-water heat exchanger that is installed between the compressor and the reversing valve of a space conditioning heat pump. It has a small thermal power output (about 10 per cent of the total heat pump power), but output temperatures up to about 70°C can be achieved. It is designed for use in situations where cooling loads dominate, as it then acts as a heat recovery system – whereas in heating mode the desuperheater leads to a small reduction in thermal power output.

The desuperheater only works when the heat pump is working. If the space heating need is satisfied (house up to temperature) the heat pump will be turned off and there will be no energy available at the desuperheater for hot water production, so an auxiliary immersion heater will still be required. The cost benefits of using a desuperheater need to be carefully assessed.

Where an unvented hot water cylinder is used it must meet all relevant UK regulations and be installed by a competent person.

5.3 Cooling

Most water-to-air heat pumps are reversible so a forced air distribution system can readily be adapted to provide cooling as well as heating.

A reversible water-to-water heat pump coupled to an underfloor distribution system can also be designed to supply space cooling in summer. Even with water-to-water heat pumps designed for heating only, a limited amount of 'passive' summer cooling can be provided by direct use of the ground loop, for example by by-passing the heat pump and circulating fluid from the ground coil through a fan convector. Protection against condensation should be provided especially for underfloor systems.

Figure 9 The heating needs of this house are supplied by a vertical collector GSHP system © Robin Curtis

6 Control strategies

6.1 Space heating

The first aim of the space heating control circuit is to operate the heat distribution system at the lowest temperature that will still meet the required comfort conditions. This will optimise the efficiency of the heat pump. The three main control options are:

Weather compensation

This is the most efficient form of control. The output temperature from the heat pump is adjusted according to the outside air temperature. As the outside temperature rises the output temperature is reduced, so the heat pump never works at a higher temperature than necessary. In general an outside temperature sensor sends signals to a controller. This automatically controls the output temperature according to a factory set curve defining the relationship between the outside air temperature and the heat pump output temperature. For water distribution systems the operation of the heat pump compressor is usually controlled in response to the return water temperature, so this is lowered as the outside air temperature rises.

Room sensor control

A room temperature sensor located centrally in the house can be used in conjunction with an outside air temperature sensor to influence the curve control function.

Fixed temperature

The heat pump is switched on and off by an in-built return temperature sensor and always operates up to its maximum working temperature. This method of control does not offer optimum savings from the heat pump.

Usually a single room temperature sensor is used to control the operation of the heat pump compressor. In addition the operation of the heat pump can be controlled by a timeclock, however, for water-based distribution systems there will not be the same potential for intermittent heating as there can be with conventional gas or oil fired heating systems. With output temperatures between 35°C and 55°C the response time of the heating system is long. GSHP systems are therefore designed to maintain a stable temperature rather than be able to raise the temperature quickly immediately before occupation. Night setback can be applicable but with a setback of 2°C to 4°C. The main function of the timeclock is likely to be to try and maximise the use of any cheaper electricity tariffs.

6.2 Domestic water heating

The heat pump is likely to be operating less efficiently when providing domestic water heating because higher output temperatures are required. Where the domestic hot water system includes a storage cylinder, it will be cost effective to make maximum use of any cheaper tariff periods for electricity. The basic control device is therefore a timeclock and a tank thermostat.

The auxiliary immersion heater should not be able to operate at the same time as the heat pump is supplying heat to the domestic hot water cylinder.

A tank immersion thermostat or sensor, rather than a strap-on one, should be used to sense the stored water temperature as it is more accurate.

7 Costs

7.1 Capital costs

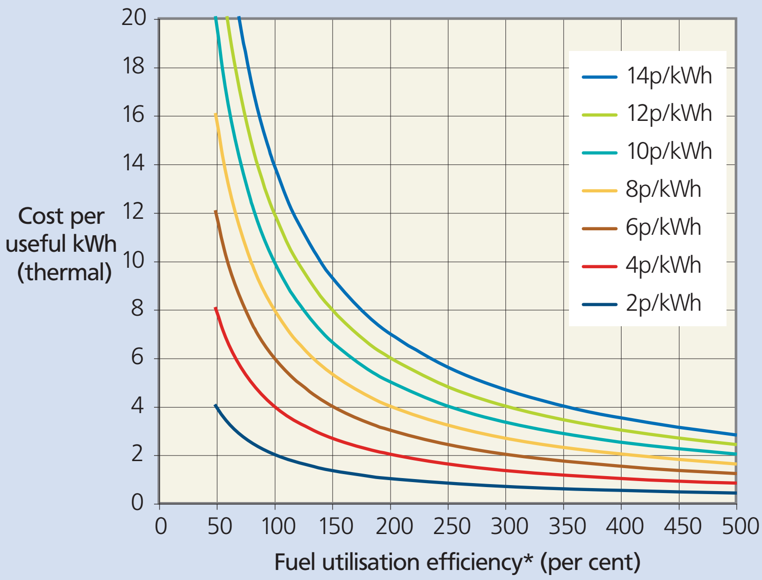
Table 2 provides an indication of the range of costs for GSHP systems using different types of ground heat exchangers. It is assumed that all the systems are ground to water, but the cost of the heat distribution system is not included..

Single or multiple pipe horizontal systems will generally be slightly more expensive than SLINKY systems because the cost of additional trenching will outweigh the reduction in the material cost for the piping. DX systems are also likely to be cheaper than the equivalent output indirect system as they require less ground coil. The actual costs for the ground heat exchanger will depend not only on the installed capacity of the heat pump, but also on the energy demands of the building and the ground conditions.

In general the smaller the system the higher the cost per kW output will be. For all types of ground collector, setting up costs (design, equipment mobilisation and commissioning) are a significant part of the total cost, therefore the capital cost measured in £/m of borehole or £/m of trench will fall as the collector size increases. For example, for a group of five houses on a single site, the collector costs per house are likely to be between 10 and 15 per cent lower than for an individual house. The capital cost of the heat pump measured in £/kW output also falls as the heat pump output gets larger.

Table 2 Indicative capital costs* for individual ground-to-water heat pump systems

System type	Ground coil costs (£/kW)	Heat pump costs (£/kW)	Total system costs (£/kW)
Horizontal	250-400	350-750	600-1150
Vertical	550-750	300-750	850-1500
*Costs include installation and commissioning of the heat pump and ground loop but exclude costs for the heat distribution system.			



*Fossil fuel (gas, LPG or oil) boilers have utilisation efficiencies (seasonal efficiencies) of 65-85 per cent

Direct electric heating has a utilisation efficiency of 100 per cent

GSHPs have utilisation efficiencies of 300-400 per cent

Figure 10 Domestic fuel costs (p/kWh of useful heat) versus fuel utilisation for a range of fuel prices.

7.2 Running costs

The running costs for a GSHP system are largely dependent on the associated fuel costs. The fuel used for the heat pump is electricity and usual tariff rates normally apply, although some suppliers offer a special heat pump tariff. Maximum advantage should be taken of any preferential tariffs (off-peak, Economy 7 etc) in order to keep annual costs as low as possible.

One way of comparing fuel costs with those of alternative heating systems is to use a method similar to that for calculating relative carbon dioxide emissions in Section 1 and shown in Figure 2. The delivered price for the alternative fuels is converted into the effective cost of 'useful' heat by the application of the fuel specific seasonal efficiency factor. For instance, fossil fuels are burnt in boilers with a wide range of seasonal efficiencies, none of them over 100 per cent. The best gas condensing boiler has a seasonal efficiency of approximately 85 per cent compared with an efficiency of about 73 per cent for a conventional boiler. Heat pump systems, however, can operate at seasonal efficiencies greater than 100 per cent, and an efficient GSHP will operate with a seasonal efficiency of at least 330 per cent.

Figure 10 shows the domestic fuel cost per useful kWh of heat provided, versus fuel utilisation efficiency. This graph can be useful at the early decision making stage.

Figures 11, 12 and 13 show an example of the annual energy consumption, and the CO_2 emissions and fuel costs predicted using figures 10 and 2 for different fuels providing 10,000kWh of useful heating.

Maintenance costs for GSHPs are minimal. There is no requirement for an annual safety inspection as there is for combustion equipment. There are few moving parts. The circulation pumps are likely to have the shortest lifetime and are unlikely to be guaranteed for more than one year. The system should be designed for easy replacement of the circulating pumps. The compressor is likely to have a life of up to 15 years (25 years for scroll compressors) and be guaranteed for up to three years.

Information about any requirements for maintenance concerning the refrigerant circuit, and who should carry this out, should be provided by the manufacturer. For indirect systems the refrigerant circuit will be pre-sealed, and if it contains less than 3kg of refrigerant little maintenance should be required. Hermetically sealed heat pumps containing more than 6kg of refrigerant (only very large heat pumps), or DX systems containing more than 3kg of refrigerant, will need to be regularly checked for leaks. Any maintenance or leakage checks have to be carried out by certified personnel. The ground loop is expected to have a very long life (over 30 years for a copper ground coil providing the ground is non-acidic and over 50 years for polyethylene pipe) and be virtually maintenance free.

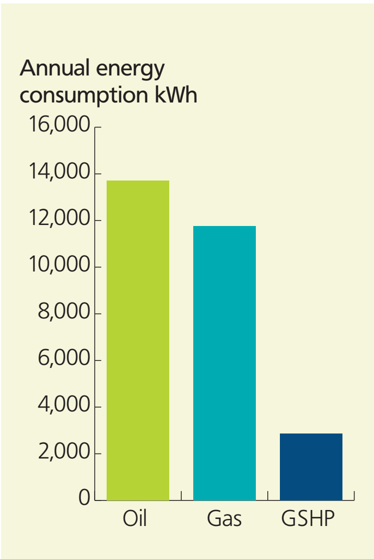


Figure 7 Annual energy consumption to provide 10,000kWh useful heat

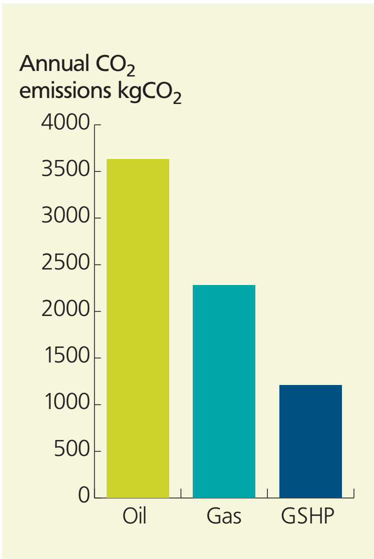


Figure 8 Annual CO_2 emissions to provide 10,000 kWh useful heat

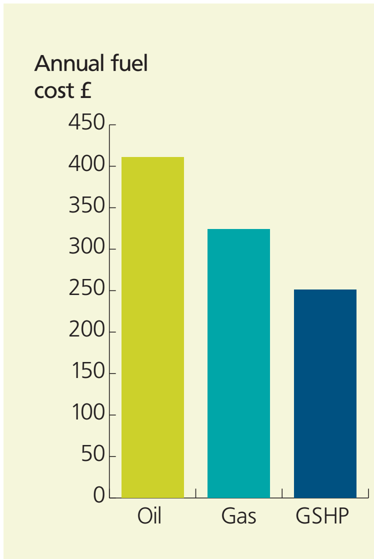


Figure 9 Annual cost to provide 10,000 kWh useful heat

Assumptions:
Oil – efficiency 73 per cent, 0.265kg CO_2/kWh, 3p/kWh
Gas – efficiency 85 per cent, 0.194kg CO_2/kWh, 2.75p/kWh
GSHP – efficiency 330 per cent, 0.422kg CO_2/kWh, 8.8p/kWh

Do's and don'ts

Concept stage

Do
Prioritise the reasons for considering a GSHP system (you can then rank the principal benefits which can be quantified during the design process). These could include:

- Costs
  - capital costs (see section 7.1)
  - running costs (see section 7.2)
  - maintenance/servicing/inspection costs (see section 7.2)
  - lifetime costs
- Primary energy use
- Environmental impact – CO_2 emissions (see section 1.3)
  - Check the suitability of the local soil and geology for an effective ground loop heat exchanger.
  - Check site access for equipment to install a ground heat exchanger, e.g. digger/drilling rig.
  - Contact the electricity distribution network operator (DNO) to find out the maximum load (and starting current) that can be connected to the electricity network. (See section 4.2)

Don't
Expect initial capital costs to be lower than that for a conventional boiler.

Design stage

Do

- Explore ways of minimising space heating and hot water demand by incorporating energy efficiency measures. For more information on the best way to achieve this see 'Domestic energy efficiency primer' (CE101).
- Recognise that a GSHP system needs to be sized, not just to meet the peak thermal power requirements, but also to deliver the annual energy requirements sustainably. Output is limited to the amount of renewable energy that the GSHP system can collect from the surrounding ground.
- Calculate building heat losses accurately (the accurate assessment of infiltration rate is particularly important).
- Assess monthly/annual useful energy requirements based on actual anticipated occupancy and use.
- Consider providing domestic hot water (DHW) – determine usage, loads and system type.
- Consider the need for space cooling (if any) and quantify.
- Decide on the need for supplementary heating/cooling (if any) and quantify.
- Consider the lowest temperature possible heat distribution system (the lower the heat pump output temperature the more efficient the operation of the GSHP system will be).
- Ensure that any underfloor heating system is designed for the lowest working temperatures. Be aware of the advantages of solid floors as opposed to timber and insulate adequately below.
- If the system does not include a buffer tank, ensure that there is adequate thermal capacity in the heating system such that run periods for the heat pump are not too short even if heating zones are switched off.
- Take care over the design of the ground heat exchanger, i.e. pipe length, diameter, configuration etc. Wrong ground heat exchanger pipe lengths and diameters are costly errors.
- Ensure that the ground heat exchanger and the heat pump are designed to operate efficiently together.
- Consider space for the spoil when planning trenches in a restricted area.

Don't

- Guess or use rules-of-thumb for heat loss calculations.
- Assume there will be sufficient space for a horizontal ground heat exchanger without calculating the length required.

Equipment selection

Do

- Correctly size equipment (do not add a large 'safety margin').
- Ensure that the ground heat exchanger circulating pump is suitable for use with the circulating fluid (for example water/antifreeze) and for the operating temperatures (for example suitable for chilled water applications).
- Take care using antifreeze for the ground heat exchanger (for example the viscosity of propylene glycol increases significantly at low temperatures).
- Use high density polyethylene (HDPE) pipe for vertical ground heat exchangers, and high or medium density polyethylene pipe for horizontal ground heat exchangers. Joints should be thermally fused to exacting standards, e.g. electrofusion.
- Make sure that any domestic hotwater cylinder used is suitable and has an adequately sized heat exchanger.

Don't

- Buy a collection of unmatched components from various suppliers and expect them to work efficiently.
- Use rule-of-thumb selection for pipework and pump sizes.

Installation

Do

- Discuss the implications of the GSHP system with the main building contractor so it can be included in site operations planning. Burying the ground heat exchanger is likely to be a novel activity for most builders.
- Use a reputable installation contractor (ask for and take up references, ask where the operatives were trained and how many installations they have done).
- Ensure that the ground heat exchanger is adequately pressure tested, both before and after it is inserted in the ground.
- Choose high thermal conductivity, low permeability grout for vertical borehole systems.
- Ensure that the ground heat exchanger is adequately protected from damage after installation and that its location is clearly marked.
- Use flexible connections for pipework connected to the heat pump to reduce noise transmission.
- Ensure internal ground heat exchanger pipework, fittings and pump are insulated (to chilled water specification) to limit the risk of condensation.
- Ensure the system is fully documented (including a detailed plan showing the location of the ground heat exchanger, details of the circulating fluid, pressure tests, warranties etc).
- Use a commissioning engineer accredited by the heat pump manufacturer.

Don't

- Use mechanical couplings on buried pipework.

Operation

Do

- Follow start-up instructions supplied with the heat pump.
- Improve efficiency by keeping the heat pump output temperature as low as possible (consistent with maintaining comfort).
- Read the electricity meter and record consumption at regular intervals. Once a pattern of normal use has been established any unexpected increases in consumption can provide warning of a potential problem.
- Check any fitted pressure gauges periodically to make sure there is no downward trend.

Further guidance and useful contacts

Standards

- ISO 13256-1: Water-source heat pumps – Testing and rating for performance – Part 1 Water-to-air and brine-to-air heat pumps, 1998
- ISO 13256-2: Water-source heat pumps – Testing and rating for performance – Part 2 Water-to-water and brine-to-water heatpumps, 1998
- BS EN 14511: Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling (4 parts), BSI 2004
- BS EN 378: Specification for refrigerating systems and heat pumps – Safety and environmental requirements (4 parts), BSI 2000
- EN 15316-4-2 Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 4-2 Space heating generation system, heat pump systems, 2005 (Draft)
- EN 15450:2006 (E) Heating systems in buildings – design of heat pump heating systems (Draft)

Useful contacts

British Geological Survey
Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG
Tel: 0115 936 324
www.bgs.ac.uk/georeports

British Standards Institution
To order BSI standards telephone 020 8996 9001 or order on-line at www.bsonline.bsi-global.com
389 Chiswick High Road, London W4 4AL.
Tel: 020 8996 9000,
www.bsi-global.com

EHPA
Secretary: Robert Garwood, BRE, Watford, Herts, WD25 9XX
Tel: 01923 664641
E-mail: garwoodr@bre.co.uk

European Heat Pump Association
www.ehpa.org

European Heat Pump Network
www.ehpn.de

Geothermal Heat Pump Consortium
A US organisation for the promotion of ground source heat pumps, includes a large number of case studies and information on design software.
www.geoexchange.org

Groundswell
A newsletter with brief details of activities relating to GSHPs in the UK, especially installations)
www.earthenergy.co.uk/groundswell/index.php/

Ground Source Heat Pump Association
Secretariat: National Energy Foundation, Davey Avenue, Knowhill, Milton Keynes, MK5 8NG
Tel: 01908 665555
www.nef.org.uk/gshp/

Heat Pump Association
UK trade association representing the interests of organisations involved in the chain of supply of heat pumps
2 Waltham Court, Milley Lane, Hare Hatch, Reading, Berks RG10 9TH
Tel: 0118 940 3416
E-mail: hpa@feta.co.uk
www.heatpumps.org.uk

Heating & Ventilating Contractors Association (HVAC)
www.hvca.org.uk

IEA Heat Pump Centre
Information centre for the International Energy Agency Heat Pump Programme
c/o SP Technical Research,
PO Box 857, SE-501 Bor_s, Sweden
Tel:+46 10516 5512
E-mail: hpc@heatpumpcentre.org
www.heatpumpcentre.org

International Ground Source Heat Pump Association
A centre for technical information and training in the US
Oklahoma State University
374 Cordell South, Stillwater, OK 74078 USA
Toll-Free: 1-800-626-4747
Tel: (405) 744-5178
E-mail: igshpa@okstate.edu
www.igshpa.okstate.edu/