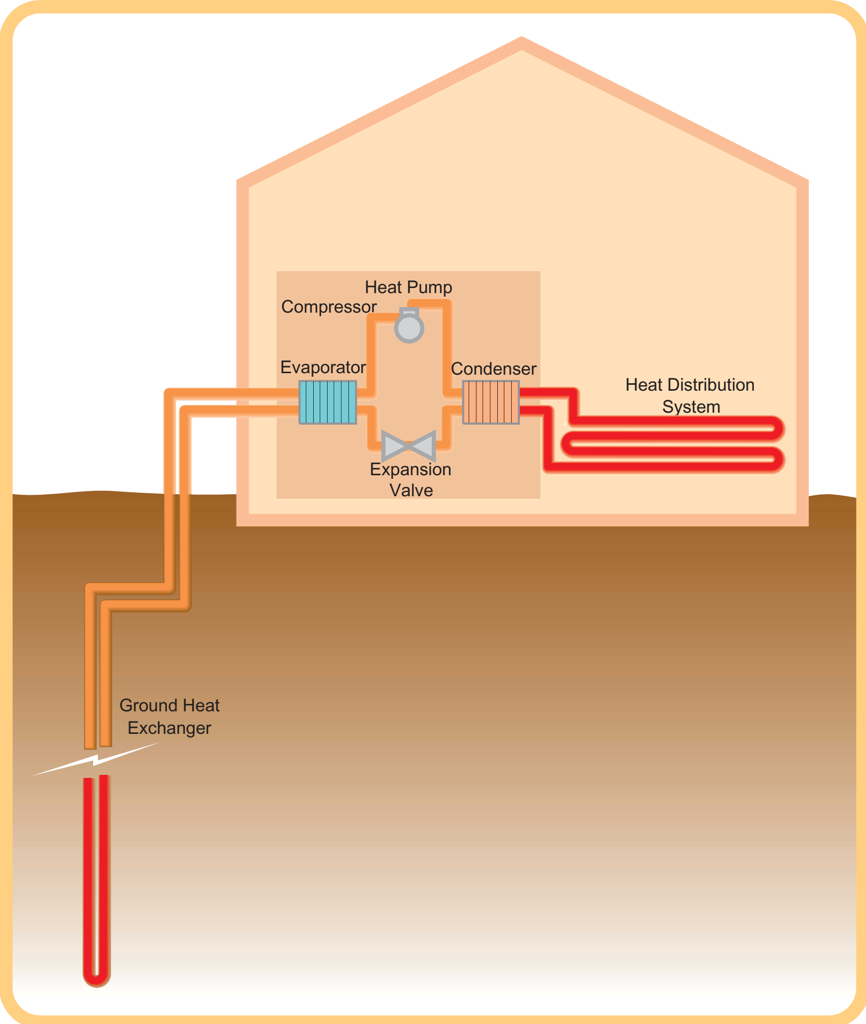
Energy Efficiency Best Practice in Housing

Domestic Ground Source Heat Pumps:

Design and installation of closed-loop systems



A Guide, for specifiers and their advisors as well as potential users, on:

- Types of systems
- How to achieve an integrated system design
- How to maximise efficiency
- Capital and running costs
- Do’s and Don’ts

ENERGY EFFICIENCY™ SAVE ENERGY MONEY ENVIRONMENT

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1 Introduction – systems and applications

A heat pump can take low temperature heat and upgrade it to a higher, more useful temperature. If this heat comes from an ambient source, for example outside air or the ground, the use of a heat pump can result in savings in fossil fuel consumption and thus a reduction in the emission of greenhouse gases and other pollutants. Ground Source Heat Pumps (GSHPs) in particular are receiving increasing interest in North America and Europe and the technology is now well established with over 550,000 units (80% of which are domestic) installed worldwide and over 66,000 installed annually.

Despite increasing use elsewhere, GSHPs are a relatively unfamiliar technology in the UK although the performance of systems is now such that, properly designed and installed, they represent a very carbon-efficient form of space heating. This document provides guidance notes on the design and installation of domestic closed-loop GSHP systems to help promote appropriate and effective use of this technology. It is aimed at both specifiers and their advisors but much of the information could be of interest to a more general reader. It provides outline rather than detailed guidance, focusing on the issues to be considered when selecting systems and components and estimating system performance.

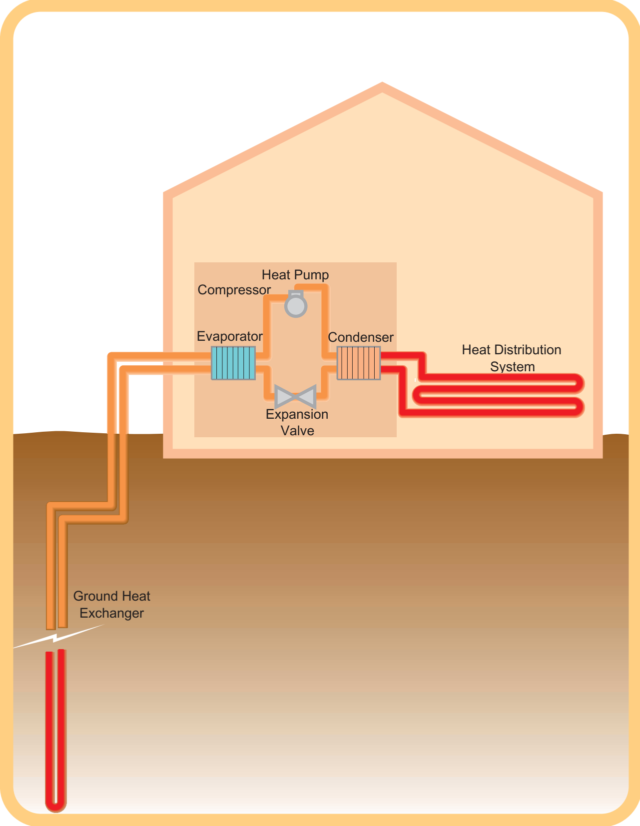


Figure 1: A typical GSHP system

A useful list of Do's and Don'ts can be found at the back of this document.

Types of system

A GSHP system consists of a ground heat exchanger, a water-to-water or water-to-air heat pump, and a heat distribution system. Figure 1 shows a typical system.

Until recently open-loop GSHP systems using groundwater were the most widely used type. Where a suitable source of groundwater is available this can be very cost effective because water can be delivered and returned using relatively inexpensive wells that require little ground area. However, the disadvantages are that water availability is limited, fouling and corrosion may be a problem depending on water quality and most importantly environmental regulations covering the use of groundwater are becoming 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. The refrigerant can be circulated directly through the ground heat exchanger in a direct expansion (DX) system but most commonly GSHPs are indirect systems, 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. Although more expensive than open-loop systems, closed-loop systems are more widely applicable. This guide will only consider closed-loop systems.

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. The provision of cooling, however, will result in increased energy consumption however efficiently it is supplied. 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. They can be particularly cost effective in areas where mains gas is not available or for developments where there is an advantage in simplifying the infrastructure provided.

This guide will concentrate 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.

Potential benefits

To maximise the efficiency of a heat pump when providing heating it is important, not only to have a low heating distribution temperature but also to have 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 than the mean air temperature in summer. The ground temperature also remains relatively stable allowing the heat pump to operate close to its optimal design point whereas air temperatures vary both throughout the day and seasonally and are lowest at times of peak heating demand. For heat pumps using ambient air as the source, the evaporator coil is also likely to need defrosting at low temperatures.

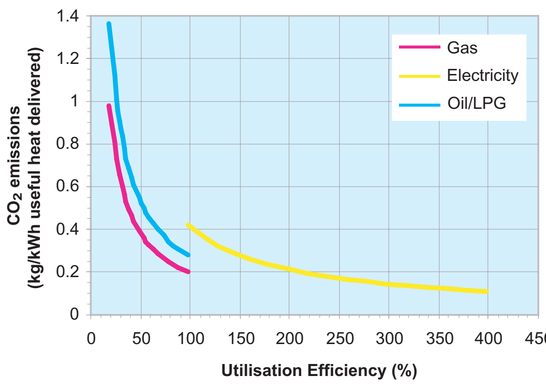
For GSHP systems, used to supply low temperature water based heating systems (eg underfloor heating), seasonal efficiencies of between 300% and 400% are common for indirect systems and can be higher (350% to 500%) for direct systems. By comparison the seasonal efficiency for an air source heat pump system is about 250%. 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 (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 0.414 kg/kWh, the use of a GSHP with a seasonal efficiency of 350% would result in the emission of 0.12 kg CO_2 for every kWh of useful heat provided. By comparison, a condensing gas boiler (assuming a CO_2 emission factor for gas of 0.194 kg/kWh) operating at a seasonal efficiency of 85% would result in 0.23 kgCO_2 for every kWh of useful heat supplied i.e. the CO_2 emissions would be almost double those from the GSHP. In practice the environmental impact of a heat pump will depend not only on the amount of electricity used but also on the demand profile. In periods of peak demand some electricity will have to be provided by less efficient power stations with emission factors as high as 0.8 kgCO_2/kWh.

As well as reducing purchased energy consumption and resulting in low CO_2 emissions, GSHP 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 and up to 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



Assumed CO_2 emission factors (SAP 2001):

Electricity = 0.414 kg/kWh delivered

Gas = 0.194 kg/kWh

Oil = 0.271 kg/kWh

Figure 2: CO_2 Emissions and fuel use efficiency

2 General design

The most important first step in the design of a GSHP installation is 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. This is particularly important because the capital cost of a GSHP system is generally higher than for alternative 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. Conversely 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 eg 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. Currently available heat pumps have an operating temperature limit of 50°C – 55°C in most applications and are not suitable for monovalent operation in combination with traditionally sized wet radiator distribution systems.

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 back page). 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:

- Risk of the underground pipes/boreholes creating undesirable hydraulic connections 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.

This picture illustrates a type of ground coil which is more fully explained in Section 3 page 6.

Trench and 'slinky' © GeoScience 2002

3 Ground heat exchanger

Types of ground heat exchanger

An indirect circulation system is the most common, where 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.

Alternatively the refrigerant can be circulated directly through a copper ground heat exchanger (this is called a direct expansion (DX) system). Good thermal contact with the ground, the elimination of a heat exchanger between the ground coil circulating fluid and the refrigerant and the fact that no circulation pump is required, means that direct circulation systems are more efficient than indirect systems. A shorter ground coil is required and the saving on installation cost helps to offset the higher material cost, but more refrigerant will be required and there is a greater potential risk of refrigerant leaks. DX systems are most suitable for smaller domestic applications. The majority of systems are indirect.

The ground heat exchanger is buried either horizontally in a shallow trench (at a depth of about 1m) or vertically in a borehole. The choice of horizontal or vertical system depends on the land area available, local ground conditions and excavation costs. The collector coil can also be laid under water, for instance in a pond, but system efficiencies are likely to be lower because of seasonal variations in the water temperature. 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. 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 SLINKYTM), 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% 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 100 mm to 150 mm diameter and between 15 m and 120 m deep. DX systems are only suitable for shallow vertical collectors (maximum depth 30 m). Vertical collectors are more expensive than horizontal ones but have high thermal efficiency and require less pipe and pumping energy. They are less likely to suffer damage after installation. Multiple boreholes may be needed for larger residential applications.

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 1.5 m 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 as, in general, it is more expensive and time consuming to drill through overburden than rock as the borehole has to be cased.

The temperature difference between the ground and the fluid in the ground heat exchanger drives the heat transfer so it is important to determine the ground temperature. At depths of less than 2 m the ground temperature will show marked seasonal variation above and below the annual average air temperature. 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 1.5 m the time-lag is approximately one month. Below 10 m the ground temperature remains effectively constant at approximately the annual average air temperature (ie between 10°C and 14°C in the UK depending on local geology and soil conditions). Figure 3, below, shows the annual variation in ground temperatures at a depth of 1.7 m compared to the daily average air temperature measured at a site in Falmouth. It also shows the ground temperature at a depth of 75 m.

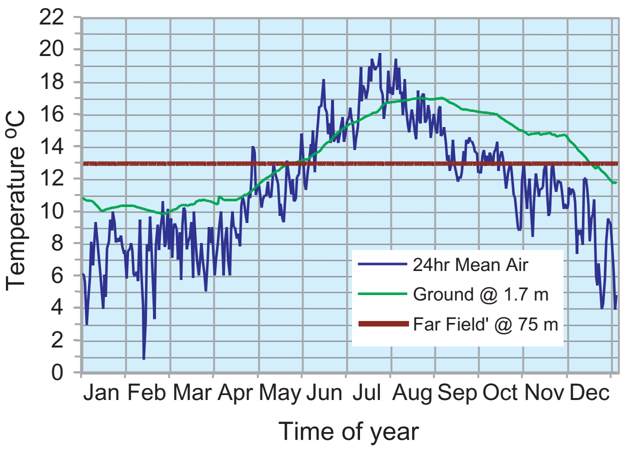


Figure 3: Air and ground temperatures, Falmouth 1994 (Source: Geoscience Limited)

In order to determine the length of heat exchanger needed to meet a given load the thermal properties of the ground will be needed. The most important difference is 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% 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 could result in a reduction in design loop length and easier loop installation. For large schemes where multiple boreholes are required, a trial borehole and/or a thermal properties field test may be appropriate.

Design issues

Sizing

The length of pipe required depends upon 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% of the total system costs, oversizing will be uneconomic. Conversely, undersizing, would lead to the ground loop running colder and could, at worst, result in ground temperatures not being able to recover and heat extraction from the ground being unsustainable ie the ground loop must be sized to meet the peak thermal power but also to deliver energy at no greater rate than the surrounding earth can collect energy over a twelve month period. If a system provides heating and cooling, energy transferred to the ground in summer can be stored and used in winter.

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

Figure 4 shows the variation in thermal power output for a single water filled 'indirect' vertical borehole in wet, medium density rock given a heat flux between the loop and ground of 5W/m (borehole) K. Typical heating only vertical collector systems would be designed assuming a mean ground loop fluid to far-field temperature difference of 10 K. For other ground conditions and loop types, the relationship would be similar but the gradient would be different from this particular example.

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 using specialised software programs the accuracy of which have been verified using monitored data. Software is available in the public domain or 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. Details of a variety of design tools are also given in their report number HPC-AR12 'Designing heat pump systems: Users' experience with software, guides and handbooks'.

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 approximately 1 m. Health and Safety Regulations do not allow personnel to enter unsupported trenches if they are more than 1.2 m deep. To reduce thermal interference multiple pipes laid in a single trench should be at least 0.3 m apart and to avoid interference between adjacent trenches there should be a minimum distance of 3 m between them. Vertical boreholes should be at least 3 m and preferably 5 m apart. Careful consideration should be given to the pipe layout in order to keep the dynamic hydraulic pressure drop across the ground heat exchanger as small as possible to minimise the pumping power needed.

Piping material

The piping material used affects life, maintenance costs, pumping energy, capital cost and heat pump performance. For 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 so as to ensure good heat transfer between the circulating fluid and the inside of the pipe wall. Pipe diameters between 20 mm and 40 mm are usual.

For direct expansion systems copper pipe (12 to 15 mm diameter) is usually used. Depending on soil conditions, a plastic coating may be necessary to prevent corrosion.

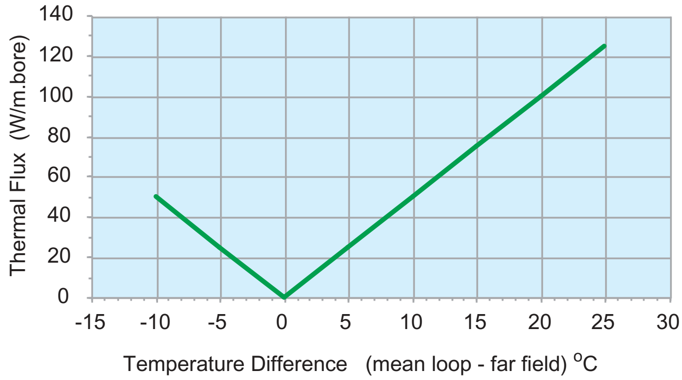


Figure 4: Thermal flux from a single U-tube closed-loop borehole

Circulating fluid

The freezing point of the circulating fluid should be at least 5°C below the mean temperature of the heat pump (ie the average of the inlet and outlet temperatures). As the mean operating temperature of the heat pump may be as low as –4°C it is usual to add antifreeze solution to prevent freezing to below –10°C. 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 viscous and need greater pumping power, reducing overall system efficiency.

The ground loop circulating pump

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

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 for installation depends on soil conditions, length of pipe, equipment required and weather conditions but typically installation of a vertical or horizontal ground coil can be completed in 1 to 2 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 straight forward 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 preferably have undergone training by manufacturers or other recognised authorities such as the International GSHP Association (IGSHPA).

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 150 mm 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, for instance high conductivity Bentonite grout, which is pumped from the bottom of the borehole. 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 connections in high density polyethylene pipe should be made using heat fusion techniques in accordance with relevant standards. For direct expansion systems the ground collector coil is usually delivered pre-charged with refrigerant.

External pipework must be insulated within 1.5 m 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 should still occur. 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 picture shows the trench accommodating the ground loop heat exchanger in relation to the house

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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 entering water temperatures can range from -5°C to +12°C for heat pumps delivering heat with maximum output temperatures, sometimes as high as 50/55°C.

The lower the heating output temperature and the higher the source input temperature the more efficiently the heat pump will operate.

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 manufacturer's data. This is the result of performance testing under standard test conditions such as those specified in BS EN 255-2:1997 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors – Heating mode. Part 2 Testing and requirements for marking for space heating units. The performance data should provide the coefficient of performance (COP), 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 (ie brine input temperature of 0°C and water output temperature of 50°C, etc).

Figure 5 shows coefficients of performance (COP) 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 and this should be kept as low as possible.

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.

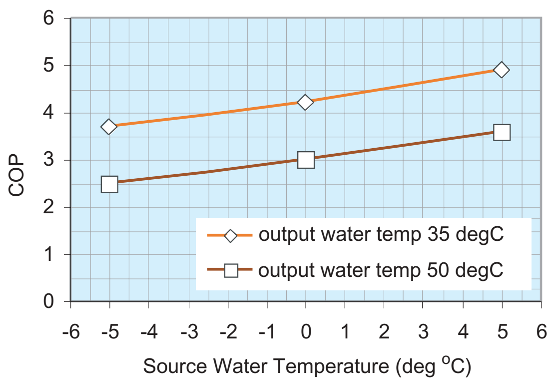

Figure 5: Coefficients of performance of typical small GSHP's

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 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. Detailed analysis of the building loads, energy consumption and cost effectiveness is required (design software is available). In general, a heat pump sized to meet 50% of the design heating load is likely to meet 80% to 85% of the annual heating energy requirement.

Electrical requirements
The heat pump is driven by an electric motor. This is an inductive load which 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 at 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/off shall 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 particular location because this may limit the size of heat pump that can be installed.

Ways to overcome this problem include using:

- heat pumps that incorporate soft start controls to limit starting currents
- heat pumps with compressors specially designed with low starting torque
- reducing the required heat pump capacity by using a direct acting electric flow boiler to supplement the heat pump at times of maximum heating demand
- multiple heat pumps, say one for the ground floor and one for the first floor
- obtaining a 3 phase supply and use of a 3 phase motor in the heat pump compressor

In most other European countries this is not a problem as a three phase electricity supply is generally available in houses, however it does mean that the majority of European made heat pumps are only available with three phase motors.

This picture illustrates an underfloor heating system. The tail of the trench for the ground coil can be seen in the upper half of the picture. More information on this topic is presented in Section 5 page 12.

Underfloor heating system © R Rawlings 1997

5 Distribution systems

The efficiency of a heat pump is a function of the difference between the temperature of the source and the output temperature of the heat pump (ie 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 if the distribution temperature required falls from 60°C to 40°C the COP can increase by more than 40%. It is therefore important to use the lowest possible temperature distribution system.

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

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

Table 1: Typical delivery temperatures for various heating distribution systems

GSHP systems may not be suitable for direct replacement of conventional water-based central heating systems because of the high distribution temperatures unless extensive measures are taken to improve the thermal insulation of the building. A wet radiator system usually operates at 60°C to 80°C and a drop in circulating temperature by 20°C would require an increase in emitter surface of 30% to 40% to maintain the same heat output. For an air system reducing the delivery temperature to 35°C would require increasing the air change rate by up to three times to maintain the same 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 most efficient type of 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.

Because of the higher output temperature, the seasonal performance of a low temperature radiator system will not be as high as that for an underfloor design. Fan convectors can be used but flow temperatures of around 50°C may be necessary to ensure high enough air temperatures which will also reduce the system 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 it, sufficient non-disconnectable thermal capacity to compensate for the loss of output during the delay restart period needs to be provided. 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 150 litres.

Domestic water heating
Water heating provides a year-round load and can improve the load factor for the heat pump. Hot water is usually required to be delivered from the tap at temperatures in the range 35°C to 45°C and 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 will be 55°C and the maximum water storage temperature achievable will be 50°C. An auxiliary electric immersion heater will be required to provide a 'boost' facility, and also to raise the water temperature so that it can be stored at 60°C in order to reduce the risk of Legionella. Because the efficiency of the heat pump falls as the output temperature rises it may be more economic to use the immersion heater to heat the stored water at temperatures above 45°C. The stored water volume should be sized so that virtually all the energy input could be supplied during the Economy 7 (or other reduced rate) electricity tariff period.

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% of the total heat pump power) but output temperatures up to about 70°C can be achieved. They are designed for use in situations where cooling loads dominate as they then act 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, so 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.

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.
This technology, however, is still in its infancy.

The heating needs of this house are supplied by a trench based GSHP system

6 Control strategies

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 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 so that as the outside temperature rises the output temperature is reduced. The heat pump thus never works at a higher temperature than necessary. In general an outside temperature sensor sends signals to a controller which 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 and GSHP systems are therefore designed to maintain a stable temperature rather than to be able to raise the temperature quickly immediately before occupation. Night setback is also unlikely to be appropriate. The main function of the timeclock is likely to be to try and maximise the use of any cheaper electricity tariffs.

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.

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 rather than a strap-on one should be used to sense the stored water temperature as it is more accurate.

7 Costs

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 generally will 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 the energy demands of the building and the ground conditions.

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 5 houses on a single site, the collector costs per house are likely to be between 10% and 15% lower than for an individual house.

System type	Ground coil costs (£/kW)	Heat pump costs (£/kW)	Total system costs (£/kW)
Horizontal	250 - 350	350 - 650	600 - 1000
Vertical indirect	450 - 600	350 - 650	800 - 1250

*costs include installation and commissioning but exclude the distribution system

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

The picture shows a typical drilling rig used for a vertical borehole based GSHP installation

A typical drilling rig © GeoScience 2002

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 to compare fuel costs with alternative heating systems is to use a method similar to that used to calculate 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%.

The best gas condensing boiler has a seasonal efficiency of approximately 85% compared with an efficiency of about 73% for a conventional boiler. Heat pump systems, however, can operate at seasonal efficiencies greater than 100% and an efficient GSHP will operate with a seasonal efficiency of at least 300%. Figure 6 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.

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 3 years.

The refrigerant circuit will be presealed and information about any requirements for maintenance concerning the refrigerant circuit and who should carry this out should be provided. The ground loop is expected to have a very long life (over thirty years for a copper ground coil providing the ground is non acidic and over 50 years for polyethylene pipe) and be virtually maintenance-free.

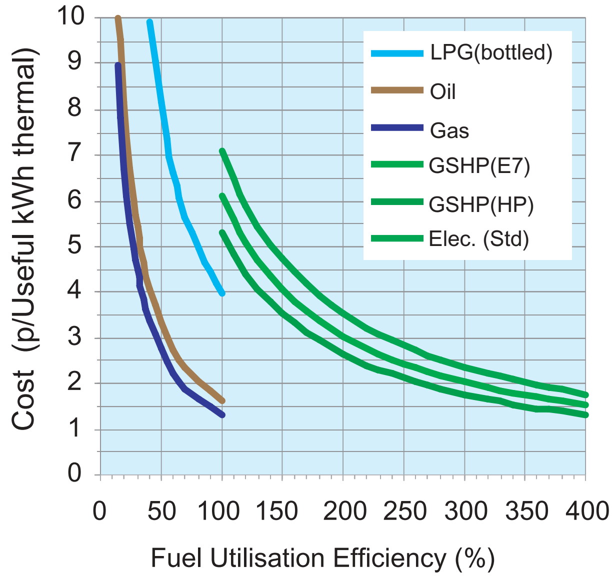

Figure 6: Domestic fuel costs versus fuel utilisation efficiency*

* *Fuel prices taken from SAP 2001 (Table 12 and Appendix F)*

Standing charges are not included

GSHP(E7) is a 7-hour off-peak tariff, GSHP(HP) is a special heat pump tariff

Copies of SAP 2001 are available from 01923 664258

Further guidance

Energy Efficiency Best Practice in Housing Publications
These publications can be obtained free of charge by telephoning the Helpline on: **0845 120 7799** or by visiting the website at: **www.est/org.uk/bestpractice**

GIR 72: Heat pumps in the UK – a monitoring report, 2000

Action Energy (formally The Energy Efficiency Best Practice Programme)

GIR 67: Heat pumps in the UK – Current status and activities

GIR 70: Heat pumps in the UK – Heat pump and heat pump-related R&D in UK universities

GSHPs – A Technology Review. R H D Rawlings, Technical Note TN 18/99, BSRIA, 1999

The Essentials – An introduction to heat pumps.
Future Energy Solutions
AEA Technology Plc
Harwell Business Centre
Didcot, Oxfordshire OX11 0QJ

UK heat pump equipment and services suppliers directory (Heat Pump Association or online from the UK Heat Pump Network website)

Closed-loop ground-coupled heat pumps. Informative Fact Sheet 2, IEA Heat Pump Centre, Sittard, 2002

Designing heat pump systems: Users' experience with software, guides and handbooks, Report Number HPC-AR12, IEA Heat Pump Centre, Sittard 2002.

Relevant 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 heat pumps. 1998

BS EN 255: Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors – heating mode (4 parts), BSI 1997

BS EN 814: Air conditioners and heat pumps with electrically driven compressors – cooling mode (3 parts), BSI 1997

BS EN 378: Specification for refrigerating systems and heat pumps – Safety and environmental requirements (4 parts), BSI 2000

Websites

UK Heat Pump Network
www.heatpumpnet.org.uk

Heat Pump Association
www.feta.co.uk
UK trade association representing the interests of organisations involved in the chain of supply of heat pumps

IEA Heat Pump Centre
www.heatpumpcentre.org
IEA is the information centre for the International Energy Agency Heat Pump Programme

European Heat Pump Association
www.ehpa.org

International GSHP Association
www.igshpa.okstate.edu
A centre for technical information and training in the US

Geothermal Heat Pump Consortium
www.ghpc.org
A US organisation for the promotion of GSHPs, includes a large number of case studies

Canadian Earth Energy Association
www.earthenergy.ca

The CADDET international energy efficiency information service
www.caddet-ee.org
Case studies on heat pumps

Groundswell
www.earthenergy.co.uk/eegrswel.html
A newsletter with brief details of activities relating to GSHPs in the UK, especially installations

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
  – running costs (fuel)
  – maintenance/servicing/inspection costs
  – lifetime costs

  Primary energy use

  Environmental impact – CO_2 emissions
- 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 eg digger/drilling rig.
- Contact the electricity distribution network operator (DNO) to find out the maximum load that can be connected to the electricity network.

Don't

- Expect initial capital costs to be lower than that for a conventional boiler.

Design Stage

Do

- 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).
- Take care over the design of the ground heat exchanger ie 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.

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 '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.

Don't

- Buy a collection of unmatched components from various suppliers and expect them to work efficiently.

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.
- 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 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.

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Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems

Useful contacts

British Standards Institution
389 Chiswick High Road, London W4 4AL.
Tel: 020 8996 9000, web: www.bsi.global.com

British Standards (BSI)
To order BSI standards telephone
020 8996 9001.

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E-mail: info@feta.co.uk

GHPC
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Tel: 202-508-5500
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Fax: +31-46-4510389
E-mail: hpc@heatpumpcentre.org

International GSHP Association
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499 Cordell South
Stillwater, OK 74078-8010
Toll-Free: 1-800-626-4747
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UK environment agencies

England and Wales
Environment Agency
Tel: 0845 933 3111

Scotland
Scottish Environment Protection Agency
Tel: 01786 457700

Northern Ireland
DOE, Environment and Heritage Service
Tel: 028 9025 4845

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Web: www.est.org.uk/bestpractice

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