Ground source heat pumps

++Energy from the ground

Each day, our planet absorbs solar energy which is stored up in the ground as warmth. With a little effort we can exploit this constantly refilled reserve of heat. It is **inexhaustible and free.**

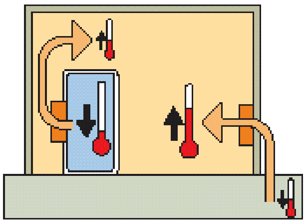
Collecting this thermal energy, transforming it to make it usable, and making use of it to heat buildings, is possible thanks to a machine called **the Ground Source Heat Pump.**

This equipment is powered by electricity however it performs a remarkable role. For every one kilowatt-hour (unit) of electricity consumed, it harvests three to four kilowatt-hours of heat for your house. A good part of your heating can thus be delivered in the form of free, renewable and non-polluting energy taken from the ground. Even more remarkably systems can also run in reverse and provide cooling in the summer at far better energy efficiencies than traditional air conditioning systems.

In 2004, around 70,000 heat pumps were sold in the EU. In the UK during this period, there were more than 1,000,000 boilers sold, of which more than 100,000 were oil fired. So, the entire EU heat pump market is dwarfed just by oil boilers in the UK. 60,000 of these 70,000 heat pumps have a British made compressor.

So, heat pumps are very much a "British" technology

++ A refrigerator in reverse



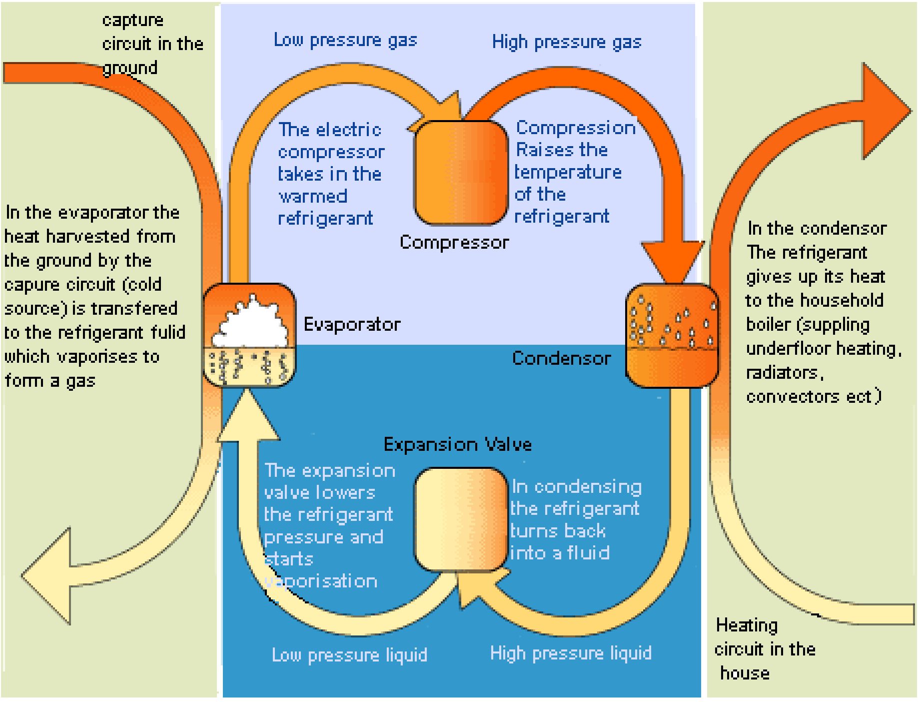
The thermodynamic system in a refrigerator or freezer draws heat out from the inside, lowering the inside temperature. The heat is pumped out and warms the air in your kitchen. If you feel the back of the fridge it is actually quite warm as the heat pumped out from inside is released!

A grounds source heat pump (GSHP), works in exactly the same way except it draws heat in from the ground outside and releases it inside your building to warm it up.

++Technical principals

Basically, the heat pump takes a little heat from a large area like your garden or car park and turns it into a lot of heat in a smaller area like a radiator or convector. The heat pump concentrates the heat it collects.

More technically the heat pump is a thermodynamic machine, whose main component is a closed loop, in which a refrigerant circulates. The refrigerant is changed between liquid state and gas state according to the components of the system that it crosses. There are four components that all act on the refrigerant: The evaporator, the compressor, the condenser, and the expansion valve. The heat pump connects to a separate collection circuit or ground heat exchanger to harvest low level heat from the ground and a delivery circuit or heat distribution system to deliver concentrated heat to the building.



Refrigerant

The only reason that we can create thermodynamic machines (refrigerators, heat pumps) is because of the properties of the refrigerants that flow around inside them. It is the capacity of these man-made fluids to vaporize and condense at room temperature that makes the whole process possible.

Until recent years, the most popular refrigerant was called R22, a CFC based refrigerant. Unfortunately R22 contains Chlorofluorocarbons (CFCs) whose destructive effects on the ozone layer are now well-known. Also R22 is a powerful greenhouse gas.

R22 is gradually being replaced by other refrigerant fluids, such HFCs or Hydroflourocarbons (R407C, R410A and R417A). These new compounds do not damage the ozone layer and most are not such potent greenhouse gasses. When old fridges and freezers are disposed of they now need to have the dangerous CFCs removed so it is important to take them to a specialist waste recycling centre.

++Heating but also…..

If a heat pump is a refrigerator working in reverse; a heat pump working in reverse... is a refrigerator! Logically, this is called a **reversible heat pump.**

Ground source heat pumps have mainly been used to supply **space heating systems;** however they are now increasingly used to fill the dual purpose of **heating and cooling**.

For very little extra cost a heat pump can be equipped with a device making it possible to reverse the cycle of the refrigerant. The condenser becomes the evaporator, the evaporator becomes condenser: the heat pump then draws heat from the house and releases it outside (in the buried heat exchanger). 80% of installations in Canada are solely for air conditioning systems. Combined systems replacing electric air conditioning can dramatically reduce fuel bills in large buildings and offices.

Cooling and air conditioning systems are usually powered by electricity. Global warming is increasing average temperatures, and electricity costs are increasing as fossil fuels run low.

As the world gets hotter due to global warming there will be a greater and greater need for summer cooling in buildings, especially workplaces and those housing people more in danger of heat related ill health.

More buildings now require air conditioning to keep people cool and that air conditioning is costing more to run. On top of this, because the air is hotter due to climate change, these systems have to work harder to cool it.

Using traditional air conditioning is getting more expensive, highly efficient GSHP systems that can cool as well as heat are a great energy efficient alternative.

Cooling and condensation

If your heat pump feeds under floor heating/cooling, the temperature of this should not be allowed to drop too low compared to the ambient air temperature. If this happens condensation can build up on the floor. To avoid this it is important to have suitable temperature regulation systems in place. Most cooling systems are for large building and are linked to convection systems or blowers.

Production of domestic hot water

With certain models of GSHP it is possible **to heat water** in the hot water tank for baths and showers etc. This is achieved by simply attaching the heat pump to a heat exchanger in the hot water tank.
In these applications, the hot-water tank must be equipped with an alternate heat source to bring water up to a temperature higher than 60 °C at least once per day. GSHPs generally only heat water up to a maximum of 50-55oC. This heat cycling is essential to kill off bacteria and remove any risk of legionnaire's disease.

Performance and electricity consumption

The compressor in the GSHP heat pump is powered by an electric motor.

Even though the pump requires power to run, it is power well invested. For every **1 kWh (kilowatt hour) of electricity consumed**, the house receives the equivalent of **3 to 4 kWh of heat**.

The space required for a heat pump and its hot-water tank are similar to those of a traditional installed heating system with a boiler

However, this does not take account of the electricity required to power auxiliary components (ventilators for convectors, circulating pump for the under floor heating or radiators, and if required a pump to circulate water in the external collection circuit). Generally these components would still be necessary in a conventional system.

The ground source heat pump is one of the most efficient heating or cooling systems available. The cost per kWh for heat is less than a gas condensing boiler. The cost per kWh for heat removal with a good system is generally significantly lower than traditional cooling systems. Heat pumps are at their most efficient when powering under floor heating due to their typical low operating temperature, however modern blower or convector systems for large buildings are highly efficient.

What is COP?

The energy performance of a heat pump is calculated by the relationship between the quantity of heat produced or removed and the amount of electricity consumed by the compressor. This ratio is called the coefficient of performance (COP) of the heat pump. A COP figure can be given for heating and cooling, COPs for cooling are generally higher. In heating 1 kWh of electricity yielding 4 kWhrs of heat is a COP of 4. In cooling 1kWh of electricity removing 5kWhs of heat is a COP of 5.

++ The different types of geothermal heat pump

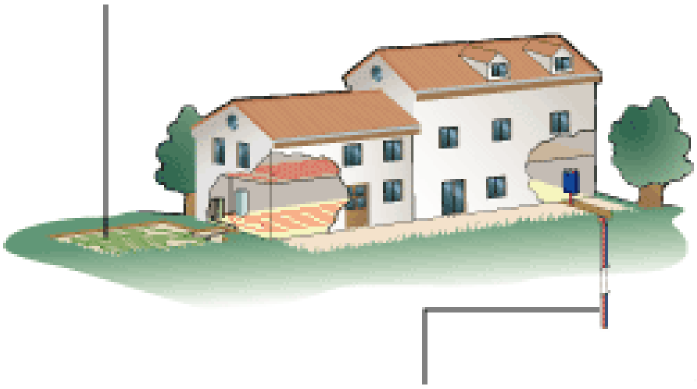
Out of all varieties the heat pumps, GSHPs offer the best energy yield. The systems are well developed, robust and reliable. This is an already established and viable technology. The technology can be used on a small or a large scale.

Collecting the energy

The ground heat exchanger or collector can be placed in a horizontal or vertical configuration. Either laid out just under the surface or descending many metres into a borehole.

Horizontal ground heat exchangers are tubes of sheathed polyethylene or copper. They are installed in loops buried horizontally at shallow depth (a 1-1.5m).

These loops form a closed circuit containing water with antifreeze or the heat pump refrigerant (according to technology employed)

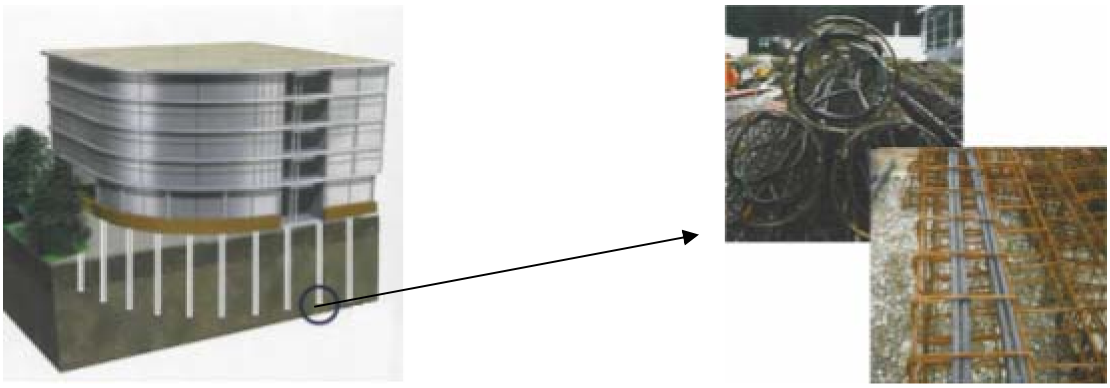


Vertical ground heat exchangers consist of a loop of polyethylene tubing forming a U, installed in a borehole (up to 15-120m deep) filled in with cement. Once built, water with antifreeze circulates in the loop.

Large scale

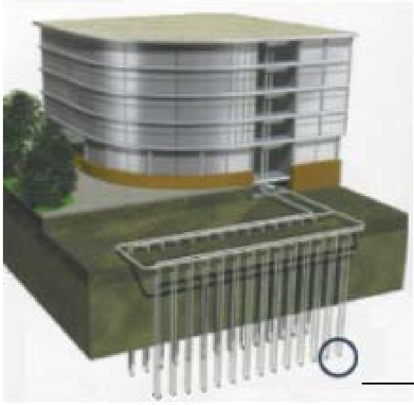
The collectors can be scaled up for larger installations

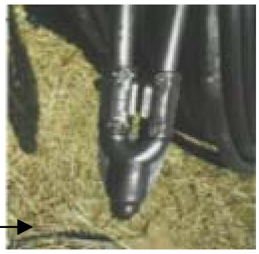
Some larger buildings need to be built with deep concrete foundation piles. These piles are often prefabricated in a factory; it is possible to equip the piles with ground heat exchangers (polyethylene tubes encased in the pile) as they are manufactured. The collection system is then connected to a heat pump when the building is constructed. More than 300 buildings in Europe are now equipped with such systems.



Picture courtesy of Mitsubishi electric
Air conditioning systems

Collectors can also be installed in the same way as domestic sites, as closed loops of high density polyethylene pipe.





Picture courtesy of Mitsubishi electric
Air conditioning systems

Sizing the system

The heat pump is sized to meet the full space heating losses from your building - no larger, and no smaller. The better insulated your building, the smaller the Heat Pump you will require - and the less money it will cost. There are a range of sizes available. It is recommend that you ask your building service professional (builder, architect etc.) what the heat losses are for your buliding, and be prepared to ask them to substantiate their answers if the figure appears too high.

Be aware that boilers are always substantially oversized - because they are cheap - often by a factor of two; the actual heating requirement for most UK homes is around 6 to 8 kW. You can perform this calculation yourself by calculating the ground floor area of your house and asking your local authority Building Regulations staff to what insulation standard your home was built to, likely to be in the region 70 to 100 watts per square metre.

Sadly, the UK housing stock is a very good example of what happens when a country obtains a glut of very cheap energy - in our case North Sea oil - that means there has been no interest in energy efficiency. Any building which obtained building regulations approval after April 1st 2002 will be a bit better than the usual UK fare of dismal insulation that was allowed before, and you could allow a figure of 50 watts per square metre of peak heating requirement to give you an estimate of the size of system that you will need, (i.e 160 sq m @ 50 watts per sq m = 8kW). However, this is just a "rule of thumb" which ought to be calculated more accurately by building services professional.

You may find that it is cheaper to better insulate your building and have a smaller heat pump system. UK buildings use well over half the country's energy requirements just for heating and cooling - and are therefore the biggest polluters.

How much space will I need for the collectors?

Normally the harvest area covered by the collector needs to be **1.5 to 2 times the floor area of the building**. For a building of 150 m2, a horizontal collector will need between 225 and 300 m2 of collectors. The actual land area needed can be considerably reduced with various orientations of collector.

Horizontal collector pipes can be laid in various orientations. These are examples in domestic installations.

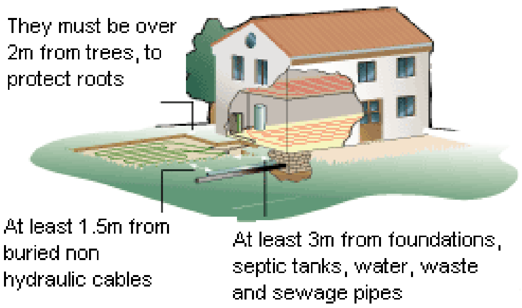
There may be several hundred metres of tubing in a **horizontal collector**. The tubes are folded up into loops of at least 40 cm (often called a slinky) to avoid a taking too much heat from the ground. If this was not done there would be risk of freezing the soil.

For **vertical collectors**, two **50 depth m heat exchangers** are generally sufficient to heat a building of 120 m2 usable area.

The disruption of the surface and land area needed is tiny compared to horizontal collectors, vertical collectors can even be incorporated into a buildings foundations or under a car park

Taking some precautions

Horizontal collectors must follow certain installation guidelines



Lawns, flower beds and bushes all cohabit happily with buried horizontal collectors.

The surface above the collector must be permeable (not paved or tarmac) and must not be crossed by water supply networks (risk of freezing). The ground should not be too steep and rocky ground is less suitable than an area with good thick topsoil.

Boreholes are a more difficult to site. Drilling boreholes is a job for a specialist contractor.

++Planning

Planning and regulation in the UK has still to catch up with GSHP technology. It is not yet necessary to get planning permission for a borehole. For most applications such as water abstraction or mining exploration it is necessary to notify British Geological Survey who keep a record of boreholes in the UK, this is not currently necessary for GSHP boreholes, though this may change. If drilling to extract water, as is required in some heat pump applications, the environment agency will need to be notified if you intend to take more than 20m3/day.

If digging a trench for a horizontal collector you may require a specialist contractor especially for trenches over 1.5m deep, where support and shuttering will be required for safe working.

To choose a configuration

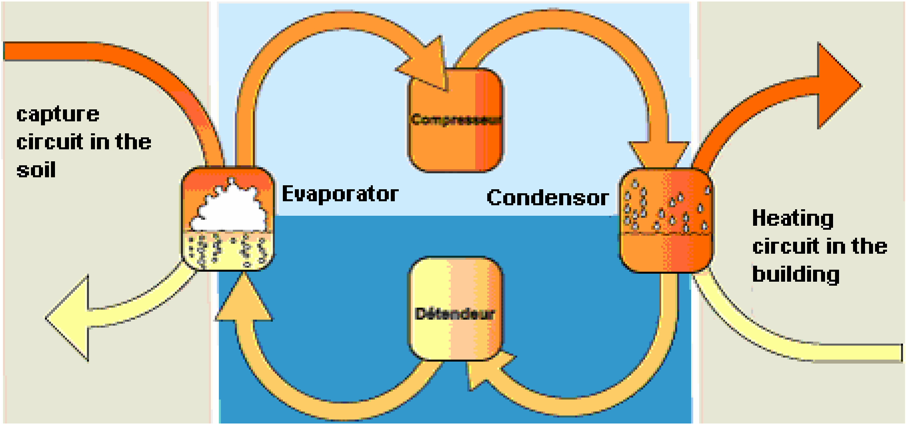
Currently, horizontal collectors are the most widely installed. These systems are **the least expensive,** but require you to have **a sufficient ground area for the collector**.

Vertical configurations are increasingly popular especially in built up areas and large scale systems. These systems are **more expensive** but can have a greater yield. **The disruption caused by excavations and ground works is definitely reduced**. It is possible to install vertical systems below car parks or paved surfaces. These sorts of systems can thus be appropriate to heat houses, but also small groups of properties and office buildings which have limited surrounding grounds.

++Types of heat pump

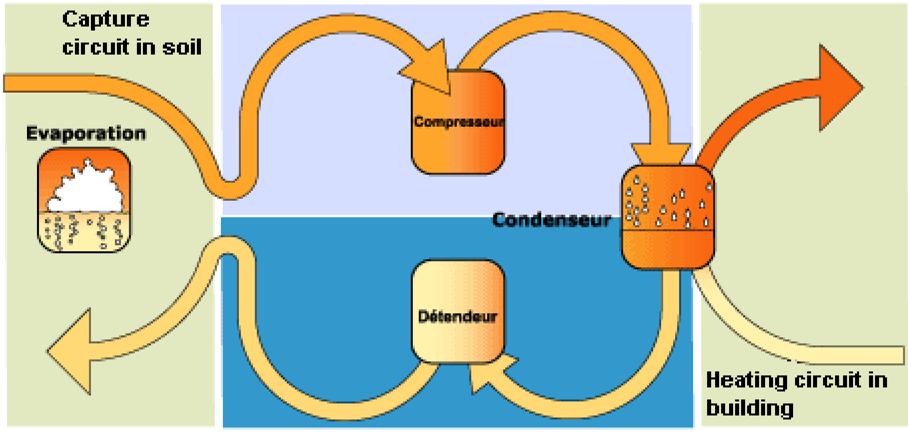
Manufacturers have developed various types of heat pumps. The differences between the systems are normally due to the nature of the fluids circulating in the collectors and the heat distribution system. The second type of variation is whether the circulations in the ground heat exchanger, the heat pump and the heat distribution system are 3 separate closed circulations or not. Only the indirect circulation systems are generally approved by funders in the UK, due to the perceived potential for environmentally damaging refrigerant leaks in other systems. It is however worth briefly mentioning and comparing these different systems, which are still legal and may still be offered for sale by companies

The Indirect circulation system



Also called a ground to water system. This is the most common system type and is the only type recognised in installations for funding by the DTI clear skies grant programme. Water with added antifreeze is pumped around the collector circuit and water also circulates in the separate heat distribution system (usually under floor heating). The refrigerant remains confined in a 3rd closed circuit in the heat pump. The system works with either of horizontal or vertical collectors.

The direct expansion system



Also called a ground to ground or DX system. The refrigerant circulates in the collector and the under floor heating. Good thermal contact with the ground, the elimination of a heat exchanger between the collector and the heat pump and the fact that no circulation pump is required means that the direct circulation system is more efficient than indirect systems. No condenser or evaporator are required as these functions are performed by the heat distribution system and the ground heat exchanger.

A shorter collection circuit is required and the savings on installation cost helps offset the higher materials cost. In these systems however more refrigerant is required and there is a greater risk of refrigerant leaks. This process is usable only with horizontal heat exchangers and is most suitable for smaller domestic applications.

++At a glance,

GSHP with indirect circulation	
Auxiliary heating	not necessary
Domestic hot water	Possible production (independent of the GSHP or not) A secondary boiler will be required.
Cooling	Possible and easy to control. If cooling replaces electric air conditioning, significant energy and cost savings are made
Pros and cons of horizontal collector	• Cheap and simple to install • Efficiency varies seasonally with ground temperature • large area of flattish, exposed earthy ground needed.
Pros and cons of vertical collector	• Little disruption to install • less space needed. • More expensive and difficult to install • No seasonal efficiency variation; deep soil temperature constant 13 oC
Costs quoted for heating systems -Cooling systems require an increase in capital cost of £400-800 for buildings up to 600m2 When GSHPs are used for heating and cooling, in larger buildings, major savings can be made on energy use as cooling systems are usually electric.	**• Capital investment:** **Systems with horizontal collector** £800-1000 inc VAT per kW domestic (heating only) not including installation costs or heat distribution system. **Systems with vertical collector** £1000-1200 per kW bore hole drilling costs push the installation costs up A typical 8kW system costs £6,400-£9,600 plus the price of the heat distribution system. This can vary with property and location. **• Operation costs:** Assuming COP of 3-4 and 8.5p per unit (kWh) electricity cost: from 2.8-2.1 p per kWh of heat inc VAT. The equivalent cost of heat from an efficient gas condensing boiler (the cheapest traditional source) is currently 2.7p per kWh. If economy 7 or a renewable energy source powers the pump costs may be lower than gas.
Heat distribution	In all GSHP installations a heat distribution system must also be bought. This cost is not usually included in quoted prices. **Convectors** • Work best for cooling • Work well for instant heating • Uses more electricity • Easy to retrofit, usually ceiling mounted • Relatively expensive units **Under floor heating** • Under floor heating is ideal for heating • Works for cooling, but not ideal for domestic use, requires control system to prevent condensation. • More energy efficient than convectors. • Under floor heating is easiest and cheeper to install on new builds.

++ Installation and maintenance, a job for the specialists

GSHP systems are a well established but rather sophisticated technology. Their design, sizing and installation require some technical know-how.

You must be sure that you are confident in the **quality of the equipment** that you chose and in the **competence of the professionals** whom you use:

• You should ensure that the equipment complies with BSI standards and the installers are appropriately accredited professionals. For the installation to be partially funded by the DTI the equipment and installers must also be accredited by them.

• You should ensure that the manufacturer, installer and system designer are experienced or supervised by experienced installers, and that they recommend a system suitable to meet the requirements of your property. Do not forget to ask about essential **maintenance and their after-sales service.**

Maintenance

Regular maintenance (with a maintenance contract) ensures your system remains in perfect working order and guarantees optimum performance. In particular, the pressure control in the circuits needs regular, infrequent, monitoring to detect escapes of refrigerant.

Releases of refrigerant are harmful to the environment. Even though the current generation of refrigerants does not damage the ozone layer, they are greenhouse gases and contribute to climate change if released into the atmosphere.

Generally Ground Source Heat Pumps are a low maintenance technology even compared to other heat pump technologies.

At the end of systems life the refrigerant fluid need to be recovered by a specialist, then recycled or destroyed.

The old heat pumps contain fluids whose use is now prohibited. **A suitably registered waste recovery company must be employed to recover, treat or destroy the refrigerant**.

++ Other types of heat pumps

Water source heat pumps

These also form part of the family of heat pump technologies. Heat contained in water from shallow water tables (less than 100 m) can be collected by drilling. Heat can also be harvested from lakes or reservoirs.

In **single borehole systems**, the extracted water is released into a river, pond or a rain water harvesting system after the heat has been harvested.

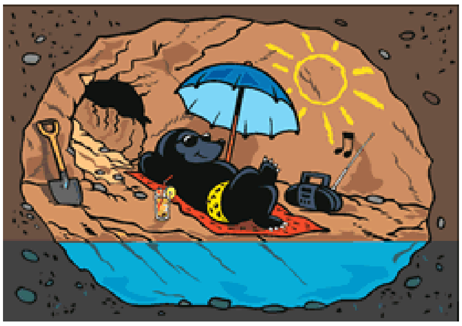
A **double borehole system** is more expensive, but more generally used as it avoids the release of extracted groundwater on the surface. The second drilling is used to return the used water in the aquifer.

Lake or reservoir systems. As is suggested by the name these use a lake or reservoir as the heat source. Horizontal collectors weighed down with ballast are used.

In general, these sorts of heat pump systems are more appropriate for large buildings

Air source heat pumps

The principle



These are typical in standard air conditioning systems. The energy needed to heat a building is drawn from **the surrounding air**. This heat source is easily exploitable; the system is cheep to install and doesn't require major collectors or any special planning permission or permits.

The heat is carried out either by an air to air heat pump, or by the means of a refrigerant circulation system feeding under floor heating, radiators or convectors (an air to water heat pump).

These heat pumps are **reversible** and can also cool a house in summer.

Use

Unlike the ground temperature, which remains stable between 10 and 15 °C throughout the year, air temperature fluctuates, and can become very low.

The performance of a heat pump is directly proportional to the difference between the temperature where the heat is harvested and the temperature where the heat is released. The higher this difference the worse the systems performance. For this reason air source heat pumps are less effective than ground or water source equivalents. Air source pumps are usually only suitable in **temperate climate zones**, e.g. coastal areas.

When the weather is cold, the evaporator, in contact with the surrounding air can ice up. Icing up also decreases also the effectiveness of the heat pump. For this reason air source pumps are generally fitted with a regulator which periodically briefly reverses the heating circuit to ensure the de-icing of the evaporator.

In locations with a harsh climate, it is essential to have **an auxiliary heating system** to replace the heat pump, when the outside temperature becomes too low.

Air-source and water-source heat pump systems have maintenance costs comparable to most conventional HVAC systems, but ground-source systems appear to have significantly lower maintenance costs.

++ financial assistance

There are several sources of financial assistance for individuals, charitable or not for profit groups or businesses

Grants
The government Clear skies fund will contribute to the cost of heat pumps solely used for heating (not cooling) the grant is £1200 regardless of system size for domestic installations and 50% of the installed cost for community projects. This fund is due to end in April 2006 and will be replaced by the Low Carbon Buildings Programme which is likely to continue funding in a similar way though with more emphasis on energy efficiency and possibly also funding cooling applications for heat pumps. www.clear-skies.org, 08702 430 930.

In Scotland householders can access capital funding of 30 per cent of the installed cost, up to a limit of £4,000 from the Scottish Community and Householder Renewables Initiative (SCHRI). Call the SCHRI Hotline on 0800 138 8858.

VAT rated at 5.5%
For domestic installations, heat pumps are classed as a carbon reducing technology and if fitted and installed by a trained installer the whole project cost can be rated at 5.5% for VAT

Enhanced Capital Allowance (ECA) scheme
GSHP systems installed by businesses attract 2 potential support schemes. Firstly the full capital depreciation can be claimed back in the first year rather than just 7.5%. Thus 30% of the installed cost is rebated if the appropriate boxes are ticked on the tax and the invoice is submitted return. 0800 085 2005

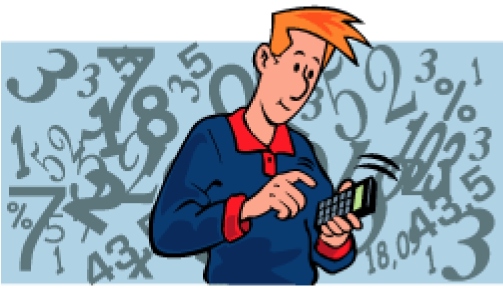
There are also and 0% loans for a term of 1-4 years available from the Carbon trust to assist in the purchase energy efficiency technologies. www.thecarbontrust.co.uk; 0800 0852005

In both cases the specific system must be registered on www.eca.gov.uk Energy Technology List.

Others
For community, not for profit and school installations there are many other funding sources. Including power company green funds, grant making trusts, local industry corporate social responsibility schemes and European money, usually via a regional body. There is a good if slightly out of data guide available from the DTI mainly aimed at schools www.dti.gov.uk/publications/ you could also contact your local community renewable initiative team www.countryside.gov.uk/NewEnterprise/Economies/CRI.asp; local council energy or environment team or Energy efficiency advice centre www.est.org.uk

Powergen heat plant

Powergen also offer a programme, specifically for social housing, whereby they carry out the whole project from assessment to installation. The consumer is given a carbon credit cash-back of up to £1000 on project completion depending on the type of fuel replaced. For further information contact Andy Blower on 0115 906 2090. The Metropolitan housing trust in Nottingham installed 10 systems through this scheme in 2003.



The roadmap for success

Here are a few tips to ensure maximum benefits from a heat pump project:

For the system designer:

- Incorporate it right at the beginning of the building construction or refurbishment project
- Carefully determine the building requirements for heating, ventilation and air-conditioning(HVAC)
- Take into consideration the variety of needs and constraints of the different areas of the building as well as its different users
- Size the heat pump and associated HVAC system to match the building requirements accurately. Accurate sizing of the heat pump and design of the HVAC system will ensure lower capital and operating costs, best comfort and total security.
- Take full advantage of the versatility of heat pump systems to ensure a high level of comfort for the building occupants, while minimising energy consumption by balancing cooling and heating needs simultaneously.

For the project developer:

- Integrate the heat pump project into a "sustainable" energy strategy for the building whereby its energy requirements are minimised by high insulation, natural ventilation, passive solar design,
- Require an official and independent certificate, or quality label, for the heat pump from the supplier ensuring minimal performance and compliance with quality standards.
- Require proof of qualification and experience of the installer of the heat pump to ensure proper installation.

- Require adequate warranty of equipment and make provision for its maintenance. Make sure that the heat pump operators are properly trained.

In short

- The ground stores energy which is constantly replenished.
- Ground Source Heat Pumps are machines which make it possible to exploit this energy, to collect it to heat a building.
- Space heating is the main use of the energy, but it is also possible to produce domestic hot water and cool air in summer, GSHPs have multiple applications. The more functions carried out by a single heat pump the better the payback time.
- All heat pumps are based on the same basic principles, there are many alternatives. If they are well installed, they can combine comfort and the economy.

Example costing for a large scale office system.

A heat pump system to be used to heat and cool a 200m2 office. The example uses the prices for the Mitsubishi electric VRF R410A range for GSHP with vertical collectors and boreholes and the Mitsubishi City multi range for air to air. Both systems qualify for Enhanced capital allowances and reduced VAT, only the GSHP system qualifies for Clear skies funding.

GSHP system		**Modern air source system**	
Component	**cost**	**Component**	Cost
Heat pump and collector rated at 28kW heat and 31.5kW cooling	£6,670	Roof mounted air con rated at 33kW heat and 31.5 for cooling	£5,695
5 wall mounted Convectors	5x £650=£3,250	5 wall mounted Convectors	5x £650=£3,250
1 heat reclaim controller (optional)	£1,610	1 heat reclaim controller (optional)	£1,610
Installation cost (0.6X capital)	£6,918	Estimated Installation cost	£5,000
Subtotal	£18,448.00	subtotal	£15,555
Vat at 5.5%	£1,014.64	VAT at 5.5%	£855.53
Total	£19,462.64		£16,410.53

Resource	Per kW cost for heat	Per kW for cooling	Cost of 30,000 kW-annual heating load	Cost of 20,000kW annual cooling	Annual CO2 released (heating only)
Gas-with condensing boiler (87.8% efficient)	2.7p	n/a	£810	n/a	6492
Gas standard boiler (65% efficient)	3.65p	n/a	£1095	n/a	8769
GSHP COP of 3.5 heat/6 cooling	2.42p	1.41	£726	£282	3673
Air con unit COP of 3 heat/ 4.5 cooling	2.82p	1.89	£846	£378	4279

Electricity at 8.5ppkW and gas at 2.37ppkW

Useful further sources

The Heat Pump Centre of the International Energy Agency:
www.heatpumpcentre.org

CADDET, Energy Efficiency Information of the International Energy Agency:
www.caddet.org (including database with case studies)

The European Heat Pump Network:
www.ehpa.org

Centre for Alternative Technology:
www.cat.org.uk

UK Heat Pump Network:
www.heatpumpnet.org.uk

The Geothermal Heat Pump Consortium (USA):
www.geoexchange.org

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):
www.ashrae.org

British geological survey
http://www.bgs.ac.uk/boreholes/

Renewable Energy Information Office, Irish Energy Centre
www.sei.ie/reio.htm

Commercial

Kensa engineering ltd
The only UK heat pump manufacturer.
http://www.kensaengineering.com

Mitsubishi air conditioning
http://www.mitsubishi-aircon.co.uk

Total concept solutions
www.totalconceptsolutions.com

Geoscience ltd
http://www.earthenergy.co.uk/