5. SHALLOW GEOTHERMAL SYSTEMS

Shallow geothermal resources (< 400 m depth by governmental definition in several countries) are omnipresent. Below 15 - 20 m depth everything is geothermal: the temperature field is governed by terrestrial heat flow and local ground thermal conductivity structure (± groundwater flow). The ubiquitous heat content of shallow resources can be made accessible by artificial circulation like the Borehole Heat Exchanger (BHE) system.

Shallow geothermal systems are mainly based on using low – moderate temperatures for heating and cooling. These temperatures are naturally found in the upper geological layers and will mostly be in the same order as the average out-doors temperature seen over a year. Using these temperatures in geothermal system is referred to a direct use, mainly for serving as a source of heat for heat pump applications. It may also be directly used for comfort and process cooling, especially in colder climate zones.

The distinction between shallow and deep geothermal is not fixed. Historically a depth of ca 400 m is used, going back to a Swiss support scheme from the 1980s. In general, shallow geothermal systems can be considered as those not pursuing the higher temperatures typically found only at greater depth, but applying technical solutions to make use of the relatively low temperatures offered in the uppermost 100 m or more of the Earth´s crust. In North America, shallow geothermal technology is also known under the term “geoexchange”.

For shallow geothermal, the undisturbed ground temperature that forms the basis of heat extraction or heat injection varies between < 2°C and > 20°C, depending upon the climatic condition of the region and the depth of the borehole.

To use the constant, low temperatures of the ground, there are two options:

- Increase or decrease the temperature of geothermal heat to a usable level using heat pumps (Ground Source Heat Pumps, GSHP)
- (Underground Thermal Energy Storage, UTES).

5.1. Introduction

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes analogous to oil in commercial oil reservoirs. This has recently changed with developments in the application of ground-source heat pumps using the earth as a heat source for heating or as a heat sink for cooling, depending on the season. This has made it possible for all countries to use the heat of the earth for heating and/or cooling, as appropriate. It should be stressed that the heat pumps can be used basically everywhere and are not as site-specific as conventional geothermal resources.

The geothermal heat pump doesn’t create electricity—but it greatly reduces consumption of it. If you would like to reduce the cost of heating and cooling your home, you might want to consider installing a geothermal heat pump, an economical and energy-efficient technology for space heating and cooling and water heating.

In winter, geothermal heat pump systems draw thermal energy from the ambient temperature of the shallow ground, which ranges between 10° and 21°C depending on latitude. In summer, the process is reversed to a cooling mode, using the ground as a sink for the heat contained within the building. The system does not convert electricity to heat; rather it uses electricity to move thermal energy between the building and the ground and condition it to a higher or lower temperature according to the heating or cooling requirements. Consumption of electricity is reduced 30% to 60% compared to traditional heating and cooling systems, allowing a payback of system installation in 2 to 10 years. And these low-maintenance systems have long lives of 30 years or more. Some systems are also capable of producing domestic hot water at no cost in summer and at small cost in winter.

Geothermal heat pumps use the earth as a heat source or sink by means of a circulating water loop. Since the heat pump supplies both heating and cooling, only one appliance is needed to satisfy both conditioning needs. No exterior equipment such as cooling towers or condensing units is needed, nor is heating plants. Each heat pump unit can heat or cool at any time, zoning is easy to accomplish and the part load performance is excellent. Maintenance is simple and less costly than conventional fossil fuel and cooling tower systems.

Geothermal heat pump (also culled Ground Source Heat Pumps, GSHP for short) are systems with three main components (Fig.5.1.1):

- the ground side to get heat out of or into the ground,
- the heat pump to convert the heat to a suitable temperature level, and
- the building side transferring the heat or cold into the room.

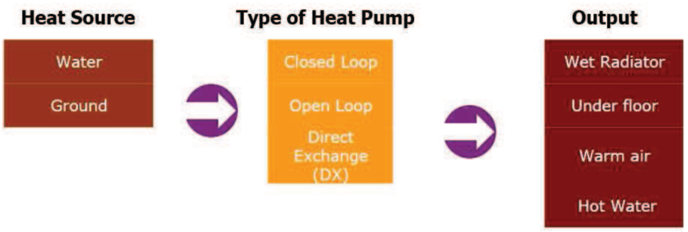

Fig.5.1.1 Sources, type and output of geothermal heat pump. [29]

A good design must take care of the whole system, matching the components in such a way that the most effective operation and the highest comfort can be achieved.

Ground sources heat pump have seen a tremendous market development in some European countries over the last years. Sweden and Switzerland are leading since the beginning in the 1980s, hover some other countries with a slow good growth rate.

Ground source heat pumps are space conditioning units that use the refrigeration cycle to heat or cool a medium (air or water), using the earth as a heat source or sink. The refrigeration cycle is reversible, so these units can be used to heat or cool.

5.2. Principle of a geothermal heat pump

A heat pump is a devise which allows transport of heat from a lower temperature level to a higher one, by using external energy (e.g. to drive a compressor). The most common type of heat pump is the compression heat pump as shown in figure 5.2.1.

As per the Second Law of Thermodynamics, heat will flow only from hotter to colder matter, but a heat pump will draw heat from the ground at, say, 5ºC and use it to warm a building to 21ºC. At certain times of the year, the temperature of the ground will be such that heat would flow in the desired direction anyway.

The thermodynamic principle behind a compression heat pump is the fact that a gas becomes warmer when it is compressed into a smaller volume.

In a heat pump, a medium with low boiling point (refrigerant) is evaporated by the ground heat, the resulting vapor (gas) is compressed (by using external energy, typically electric power) and thus heated, and then the hot gas can supply its heat to the heating system. Still being in the high pressure part, the vapor now condenses again to a liquid after the useful heat has been transferred. Finally, the fluid enters back into the low-pressure part through an expansion valve, gets very cold and can be evaporated again to continue the cycle.

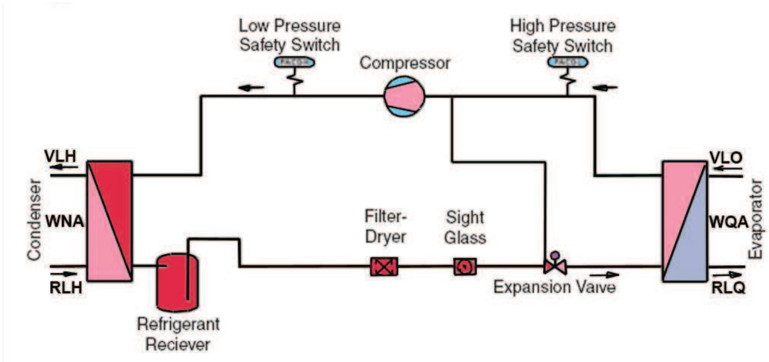

Fig.5.2.1 Refrigeration cycle of a compression heat pump. [33]
WNA-heat delivery system; **VLH**-heating supply; **RLH**-heating return; **WQA**-heat collection system; **VLO**-collector supply; **RLO**- collector return

An alternative is the absorption heat pump, where heat at higher temperature (e.g. from a gas burner, solar energy) is used to activate, by boiling a gas out of a liquid, a desorption-absorption cycle, which again offers a low-temperature side to take in heat from the ground, and a high temperature side to supply heat to the user,

In both cases, the amount of external energy input, be it electric power or heat, has to be kept as low as possible to make the heat pump ecologically and economically desirable. The measure for this efficiency is the COP (Coefficient of Performance). For an electric compression heat pump, it is defined as:

$$COP = \frac{useful\ heat}{electric\ power\ input}$$

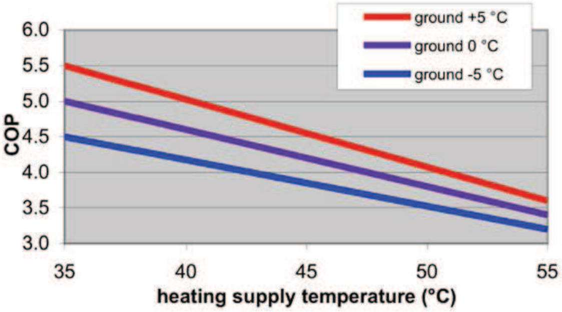

Fig.5.2.2 Exemplary graph of COP versus heating supply temperature [43]

The higher the COP, the lower the external energy input compared to the useful heat. COP is dependent on the heat pump itself (efficiency of heat exchangers, losses in compressor, etc) and on the temperature difference between the low-temperature (ground) side and the high-temperature (building) side (Fig. 5.2.2).

COP can be given for the heat pump under defined temperature conditions (e.g. 5 °C ground / 35 °C heating supply), or as an average annual COP in a given plant, also called SPF (Seasonal Performance Factor).

The COP of a water/brine-to-water heat pump varies with the temperature of the distribution system is given in the table 5.2.1.

Table 5.2.1

Heat distribution system	supply/return temperature	COP[1]
Conventional radiators	60/50°C	2.5
Floor or wall heating	35/30°C	4.0
Modern radiators	45/35°C	3.5
Hydronic convectors	48/38°C	3.5

[1] Heat source 5°C

In heating mode (Fig.5.2.1), the heat pump works as follows: heat from the earth connection arrives at an earth connection-to-refrigerant heat exchanger called the evaporator The refrigerant is colder than the temperature of the heat transfer fluid from the earth connection, so heat flows into the refrigerant. This heat causes the liquid refrigerant to evaporate; its temperature does not increase much. This gaseous, low pressure and low temperature refrigerant then passes into an electrically-driven compressor. This raises the refrigerant's pressure and, as a consequence, its temperature.

The high temperature, high pressure, gaseous output of the compressor is fed into a second heat exchanger, called the condenser. In water-to-air heat pumps, a fan blows air to be heated through this "air coil". In water-to-water heat pumps, water which will heat the building flows through the condenser. Since the refrigerant is hotter than the air or water, it transfers heat to it. As it loses heat, the refrigerant's temperature drops somewhat and it condenses.

This high temperature liquid refrigerant then passes through an expansion valve. The valve reduces the pressure of the refrigerant, and as a consequence, its temperature drops significantly. Now, this low temperature liquid flow to the evaporator and the cycle starts again. In this way, the heat from the water or other heat transfer fluid in the earth connection is transferred to the air or water in the building: hence the name "water-to-air heat pump" or "water-to-water heat pump".

For working fluid (refrigerant), suitable substances are those with large specific heat capacities and which evaporate at low temperatures. Today, only chlorine-free refrigerants are permitted. These are non-ozone depleting refrigerants (Ozone Depletion Potential, ODP = 0). R 134a, R 407C, R410A, R404A and propane fulfill these conditions. The most used refrigerants are R 134a and R 407C and other blends as they are both non-flammable and nontoxic.

5.3. Geothermal heat pump systems and application

As could be seen from figure 5.2.2, the temperature levels in a heat pump system have a strong impact on the efficiency. A low efficiency would mean a higher demand for external energy, which has to be paid, and which decreases the savings in energy and emissions from the heat pump system.

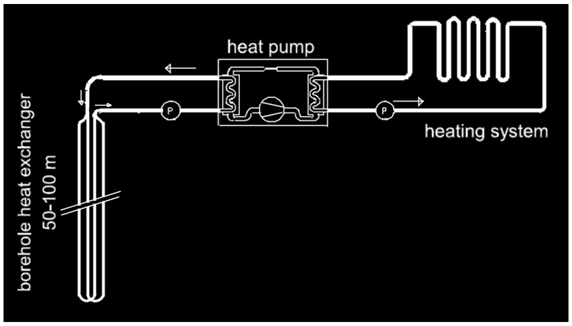

Fig.5.3.1 Basic schematic of water-to water GSHP system. [43]

A ground source heat pump (GSHP), also called geothermal heat pump, generally offers very good conditions for achieving high COP. To guarantee this, the temperature on the ground side has to be as high as possible (sufficient layout of the relevant geothermal system), and the temperature on the heating side has to be as low as possible, e.g. by using floor heating systems. The basic concept of a GSHP is shown in fig.5.3.1. A ground source heat pump system can not only be used for heating, but also for cooling purposes.

Geothermal heat pumps systems are configured as water-to-air, water-to-water, and split equipment.

The configurations manufactured are:

- **Water-to-air:** water from a ground source is circulated through the unit, and air ducted to and from the space to be conditioned is either heated or cooled.
- **Water-to-water:** water from a ground source is circulated through the unit and chilled or hot water is circulated to fan coil units for cooling, and to heating elements, radiant floor systems, or fan coils for heating.

- **Water to air split type.** Water from a ground source is circulated through the unit containing the compressor and condenser/evaporator section. Refrigerant piping connects this part with a remote direct expansion type air handler that heats or cools air ducted to and from the space to be conditioned.

Fan coil units and air handling units, as the larger sizes are called; distribute the conditioned air through ducted distribution systems. Each unit that requires ventilation air will need to be supplied by a ducted outside air distribution system, which should be filtered, but may not need to be conditioned.

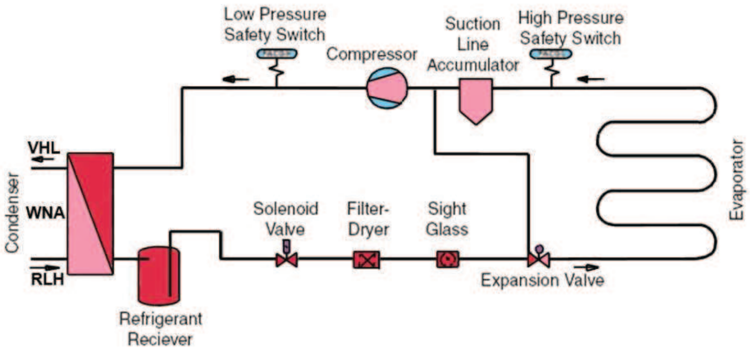

Fig.5.3.2 Refrigeration cycle –direct expansion. [33]
WNA-heat delivery system; **VLH**-heating supply; **RLH**-heating return

Direct expansion heat pumps do not have an intermediate heat exchanger on their source side. Instead, a loop of suitable pipe containing the refrigerant and lubricant is put in direct contact with the ground or water body. The compressor operation circulates the refrigerant directly around this loop – thus eliminating the heat transfer losses associated with the intermediate water/ DX heat exchanger found in conventional water source heat pumps. There is also no need for a source side circulation pump – the compressor undertakes this role. However, care has to be taken to ensure that the DX loops are totally sealed, corrosion resistant, and that the lubricant is adequately circulated to meet the needs of the compressor.

Environmental authorities in different countries are enforcing special standards on these systems depending on local concerns over increasing volumes of refrigerant being installed in vulnerable ground loop arrays. For example, there are double walled continuous ground loops and solenoid valves that are automatically closed when the compressor is not operating.

The water to water geothermal heat pumps are usually grouped together in a mechanical space, and can be treated as a conventional heater/chiller plant insofar as the distribution systems are concerned. The unit sizes range from 3 tons to 30 tons, but the market is in flux, with many new variations on this product being developed.

The most common type of heat pump used with GSHP systems is a “water-to-air” unit (Fig.5.3.3) ranging in size from 3.5 kW to 35 kW of cooling capacity. The water-to-air designation indicates that the fluid carrying heat to and from the earth connection is water or a water/antifreeze mix and that the heat distribution system inside the building relies on hot or cold air. All the components of this type of heat pump are in one enclosure: the compressor, an earth connection-to-refrigerant heat exchanger, controls, and an air distribution system containing the air handler, duct fan, filter, refrigerant-to-air heat exchanger, and condensate removal system for air conditioning.

Sizing the heat pump. The capacity (power) of a heating system is defined according to the maximum heat demand of a given building. The maximum heat demand, also called the heat load, is calculated for the building according to specific weather conditions and indoor air temperature.

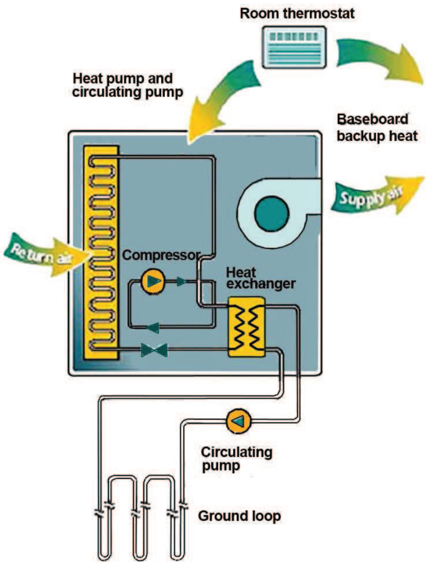

Fig.5.3.3 Basic schematic of water-to air GSHP system

In new buildings with a high level of insulation and using a low temperature heat distribution system, heat pumps can meet the whole heat load and heating requirement. For safety, a powerful immersion heater can be installed at the inlet of the heat distribution system.

Heat pumps should be sized in order to have the lowest initial cost and to be working as many hours as possible. The optimum economic size of the heat pump design capacity is normally in the range of 30 to 60% of the maximum heat load of the building. Such a heat pump can cover between 60 and 90% of the annual heat demand. The figure 5.2.6 shows schematically the relationship between the heat pump capacity and the building requirements.

As can be seen from figure 5.3.4, an auxiliary heater is used to supplement the heat pump during the colder part of the year. This combination, in which the heat pump is referred as bivalent, is particularly interesting in retrofit situations where the existing heating system can be kept to meet peak demand periods.

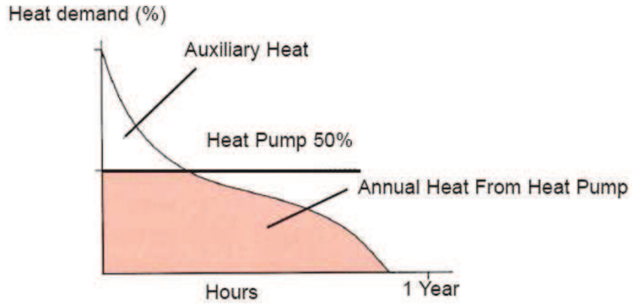

Fig.5.3.4 Heat pump capacity and building heat requirement in a heat duration diagram, the heat requirement of the building do not include domestic hot water

5.4. Overview of ground systems for geothermal heat pump

The ground system links the geothermal heat pump to the underground and allows for extraction of heat from the ground or injection of heat into the ground. These systems can be classified generally as open or closed systems, with a third category for those not truly belonging to one or the other.

To choose the right system for a specific installation, several factors have to be considered: Geology and hydrogeology of the underground (sufficient permeability is a must for open systems), area and utilization on the surface (horizontal closed systems require a certain area), existence of potential heat sources like mines, and the heating and cooling characteristics of the building(s).

In the design phase, more accurate data for the key parameters for the chosen technology are necessary; to size the ground system in such a way that optimum performance is achieved with minimum cost.

The design process must include a certified geothermal heat exchanger designer and a hydro geologist if ground water is to be used. These consultants should be integrated into the design process and design team in the same way the consulting engineers are.

Wells must be properly designed and developed, and periodic maintenance on the well and well pumps must be performed.

Depending on the development in different countries worldwide but also different research groups the nomenclature of the systems is somewhat different. The terms "open" and "closed loop" systems are originated from the USA, and may be looked upon as practical descriptions of systems with boreholes with plastic pipes (closed) and systems where groundwater is pumped from and injected through water wells (open). These terms are also used in Europe, but here some country specific terms are also contributing to the terminology as will be shown further down.

The various shallow geothermal systems to transfer heat out of or into the ground comprise:

– horizontal ground heat exchangers	1.2 - 2.0 m depth (horizontal loops)
– borehole heat exchangers	10 - 250 m depth (vertical loops)
– energy piles	5 - 45 m depth
– ground water wells	4 - >50 m depth
– water from mines and tunnels	

Systems using a heat exchanger inside the ground are also called "closed" systems; systems producing water from the ground and having a heat exchanger (e.g. the evaporator) above ground are called "open" systems.

5.4.1 Closed vertical loop

This system applied for single resident buildings consist of one or several boreholes in which borehole heat exchangers (BHE) are installed. The boreholes may commonly be up to 200 m deep and drilled into almost any type of soil and rock. The BHE is connected to a heat pump. By circulating a heat carrier fluid (water mixed with antifreeze), heat is extracted from the borehole surroundings and transferred to the heat pump from which heat at a higher temperature is distributed to the building.

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are (fig.5.4.1):

- U-pipes, consisting of a pair of straight pipes, connected by an 180^o -turn at the bottom. One, two or even three of such U-pipes are installed in one hole. The advantage of the U-pipe is low cost of the pipe material, resulting in double-U-pipes being the most frequently used borehole heat exchangers in Europe.
- Coaxial (concentric) pipes, either in a very simple way with two straight pipes of different diameter, or in complex configurations.

During the winter season the temperature of the fluid and the borehole surroundings will gradually get lower. The fluid will then often reach a temperature well below the freezing point. As a result the COP of the heat pump will gradually drop. However, in a correctly designed system the temperature will not be as low as making the heat pump to stop. This is as a matter in fact a great advantage of GSHP's compared to air as heat source.

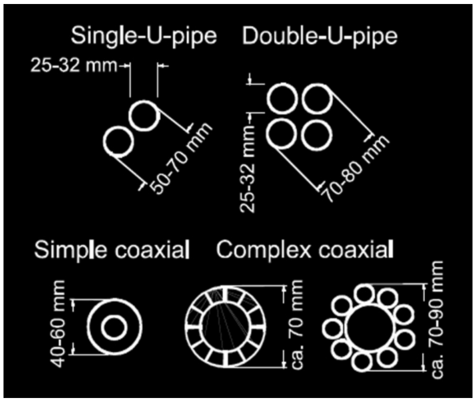

Fig.5.4.1 Cross-sections of different bypass of boreholes heat exchangers [43]

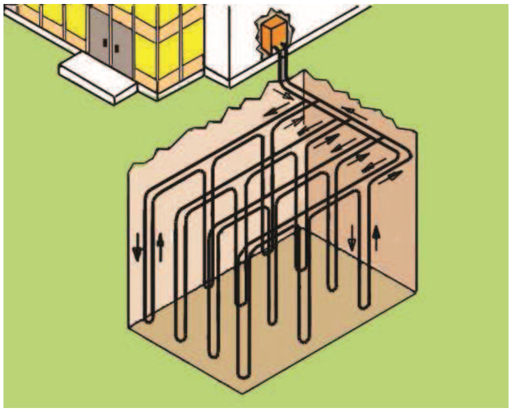

Fig.5.4.2 Closed vertical loop system [55]

In the summer, these systems may provide free cooling directly or the heat pump operates as a cooling machine and stores condenser heat in the ground. This is of cause a great advantage, especially in warmer climates. By definition, using the system also for cooling, transfer it into a BTES system, see next section.

If the system is used for heat extraction only, which is the most common practice in colder climates, a single borehole recover its normal temperature naturally during the summer season. If several boreholes are used it is of great importance that the boreholes are not too close to one each other. The holes are drilled at a distance of about 6 m and depth between (30 ÷ 120) m (Fig.5.4.2). If not, the natural recovery will not function properly and the temperature of the boreholes will gradually decrease over the years.

From a geological point of view, the best efficiency of vertical loops is obtained in crystalline rocks with a high content of silica, such as granites and gneisses. Among the sedimentary rocks the best efficiency is achieved in quartzite and dense sandstones with a low porosity. However, it is important to know that almost any types of rocks are technically feasible, as well as any types of soil. This makes the vertical loops having a very high potential regardless the geological conditions at site.

Vertical systems can also be used for direct cooling, especially for comfort cooling during the summer season. In these cases heat is disposed into the boreholes and the rock mass is then naturally regenerated during the winter season.

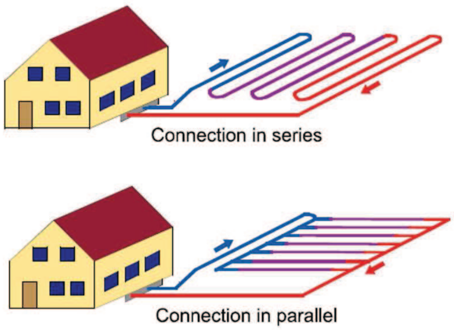

Fig.5.4.3. Closed horizontal ground heat exchanger (European style) [43]

5.4.2 Closed loop horizontal systems

The shallowest system is the horizontal loop. This consists of a plastic pipe that is typically ploughed or dug down in the garden of a residential house as shown in figure 5.4.3. Such a system may not be of interest for a driller, but may still be considered by an installer as an option to vertical loops.

Compared to vertical loops this system takes a less investment to construct. On the other hand it is somewhat less efficient due to a lower

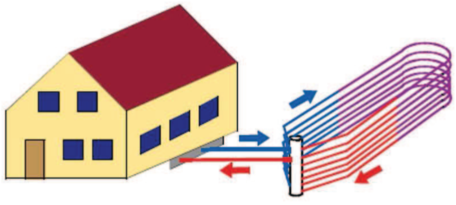

Fig.5.4.4. Trench ground heat exchanger (European style) [43]

working temperature of the fluid. This is partly due to the relatively less thermal conductivity of the soil compared to a rock. Furthermore, the technique is based on freezing the moisture in the soil that requires a rather low fluid temperature over a long part of the winter season. The freezing process will continuously draw water towards the pipe, hence creating ice scaling around the plastic pipes. The ice itself will have a positive effect on the thermal conductivity. Since the frost is melting rather quickly in spring, these systems are not suitable for any type of cooling.

Normally the pipes are placed approximately 1 m below the surface with a distance of 1 m between the pipes. The pipes can be connecting in series or parallel (Fig.5.4.3). For the trench collector (fig. 5.4.4), a number of pipes with small diameter are attached to the steeply inclined walls of a trench some meters deep.

The main thermal recharge for all horizontal systems is provided for mainly by the solar radiation to the earth's surface. It is important not to cover the surface above the ground heat collector, or to operate it as a heat store, if it has to be located e.g. under a building.

However, in later years a more compact system has been developed called “slinky”. These consist of coils of plastic pipes, that are placed vertical in dug ditches (Fig.5.4.5), one at each wall of the ditch.

A slinky configuration would flatten a spiral of piping at the bottom of a wide trench or large scraped area. The slinky loops could be placed adjacent to each other in a large excavated area and then backfilled to a depth of 1,8 to 2,5 m.

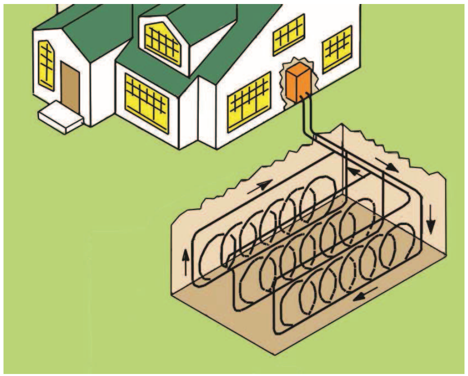

Fig.5.4.5 Closed horizontal-Slinky loop system [55]

- Typical systems require 90 m of two-foot-wide trench for two tons of peak block load.
- With 1,2 m spacing between trenches, a standard system would require 0,4 ha per 24 tons of peak block load.
- Typical slinky configurations require 45 m of three-foot-wide area per ton.
- A slinky configuration can require 0,4 ha per 90 tons of peak block load, but the entire area must be excavated or filled to a depth of 1,8 to 2,5 m.
- Ground loop heat exchanger installation costs can vary from $800 to $1,500 per ton depending primarily on the excavation cost.

The best efficiency of horizontal systems is obtained in fine grained types of soil with a high content of water, such as clay and silt, while dray gravel and sand should be avoided.

A variation of the horizontal ground source heat pump is direct expansion. In this case, the working medium of the heat pump (refrigerant) is circulating directly through the ground heat collector pipes (in other words, the heat pump evaporator is extended into the ground). The advantage of this technology is the omission of one heat exchange process, and thus a possibility for better system efficiency.

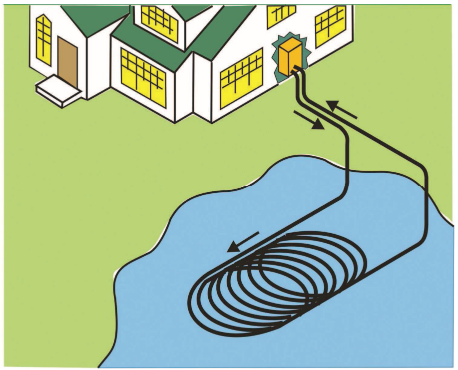

Fig.5.4.6 Closed loop system submerged in surface water [55]

5.4.3 *Closed loop systems submerged in surface water*

If near to the residential house there is surface water (pool, river, lake, etc.), it can be build the cheapest geothermal heat pipe system. The pipes go underground from the house and in the water they are consist of coils of plastic pipes (Fig.5.4.6). Coils should be fully soaked in water in the depth of at least 2,4 m below the surface, in order to avoid freezing of water which circulate in the loop, and to provide good condition for quality heat exchange.

5.4.4 *Open loop systems (groundwater systems)*

Ground water is a valuable natural source especially for drinking water. Still, using ground water for energy extraction is fairly common in many countries for both heating and cooling. The reason for this is that groundwater systems are more efficient than closed loop systems. This is based on the fact that the temperature of groundwater is practically constant all over the years (if pumped from a depth of 10 meter or more) and that water is the very best carrier of thermal energy (the highest heat capacity).

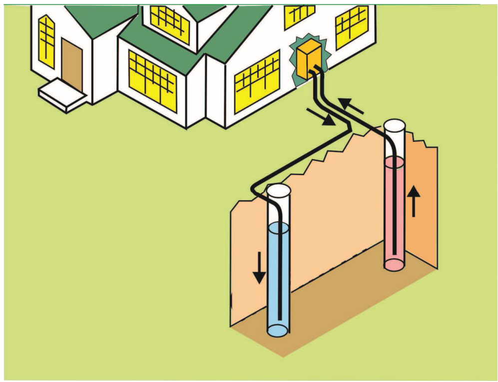

Fig.5.4.7 Open ground water loop system [55]

As illustrated in figure 5.4.7, the technology "normal" groundwater wells are used for energy extraction. However, to create a system with extraction and injection is more challenging. Such systems have to be circulated under pressure and under perfectly airtight conditions to avoid problems with clogging and corrosion induced by chemical processes. It is also common to use a heat exchanger to separate the groundwater loop from the heat pump loop. The term "open loop" system is therefore very misleading since the circulation of groundwater in such a system also has to be under "closed" conditions.

For small scaled applications (5-10 kW) on the country side, a single well or even a dug wells may be used. In these cases the chilled water is disposed to surface water or infiltrated by a buried stone bed.

For larger systems doublet wells have normally to be used, one or several for production and approximately an equal number of wells for reinjection of chilled water (environmental and legal issue each country).

The production well is equipped with a submersible pump with a riser pipe and a cable passing through a perfectly tight lid. The pump should be placed well below the lowest draw down level. For larger systems the pump may be frequency controlled. It is also an advantage to have a pressure recorder in the well to keep track of the drawdown.

The injection well is typically equipped with a pipe ending well below the ground water level. The lid should be perfectly tight and have a valve for ventilation.

The ground water loop has to be perfectly tight and preferably being put under pressure at all times (to decrease the potential for corrosion and clogging).

During winter the water is pumped either to a heat exchanger (recommended) or directly to the evaporator of HP (may cause corrosion and clogging problems). Typically the temperature is lowered with some 4-5°C.

The chilled water being injected may cause a thermal break through by time if the distance between the wells is not long enough. A thermal break through between narrow wells may be compensated by injection of heat during summer. However such measures will turn the system into an ATES system, see further down.

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, groundwater wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. The main requirements are:

- Sufficient permeability, to allow production of the desired amount of groundwater with little drawdown.
- Good groundwater chemistry, e.g. low iron content, to avoid problems with scaling, clogging and corrosion.

Groundwater can also be used for direct cooling. The efficiency of such cooling is normally very high and is therefore of great interest. The maximum temperature requirements would typically be some 10°C for comfort cooling and some 25°C for process cooling.

5.5. Limitation in the application of GSHP systems

The potential is in many ways related to local or site specific conditions, not only climate and geology, but also the sector of application. The latter may be family houses, commercial and institutional buildings, district heating and cooling systems, or even industrial facilities. These all represent very different size and load characteristics in the design of a geothermal system.

The limitations can be looked upon as the outer boundary conditions that lead to a go or a no-go for project concept. They can be physical, such as climate and geological circumstances, but may also be connected to other site conditions, for example ground availability or other interests for ground use. Country specific, there are also a lot of other potential limitations. These could be of a social, cultural or political nature, but more often economical or legal. However, these limitations are flexible and may disqualify one type of system, but allow another. It is of great importance that all potential limitations are considered early (at the feasibility stage) in any project.

5.5.1. Technical limitations

For systems using the underground for seasonal (or sometimes short-term) storage of heat and cold, the source of energy for storage may be different. Such a source is for example waste heat from industrial process cooling. Another may be waste cold from heat pump evaporators. These types of sources always have technical limitations such as load, duration, temperatures, availability, etc. that are site specific. These limits should of course be established in an early stage of a given project.

5.5.2. Geological limitations

In principle, one or several types of GSHP systems are technically feasible in any type of geology. It is more a matter of finding a proper construction method, related to the special geological conditions at the site for installation. Still, the geological requirements differ according to what type of system is to be installed, summarized in the following general statements.

- *Closed loop systems* are in general applicable in all types of geology. However, thermal properties and drilling problems may be a limiting factor.
- *Open systems* (based on pumping ground water) require a geology containing one or several aquifers. Still, aquifer geometry, hydraulic properties and water chemistry may be limiting factors on any site.

5.5.3. Hydro geological limitations

The hydro geological conditions would in practice govern the design of any open loop system. Inputs, such as type of aquifer, geometry, groundwater level and gradient, textural composition, hydraulic properties and boundaries are in fact essential for the design and realization of such systems. For closed loop systems these parameters are of less importance, but can in some cases constitute limiting conditions.

- *Closed loop systems* may be affected by flow of ground water. For systems with heat extraction, this is normally an advantage. For systems with storage of heat and cold (BTES), it may be a disadvantage for cold extraction. Furthermore, a low groundwater level will limit the extraction of heat and cold if no backfilling is used.

- *Aquifers used for open systems* may have a limited yield (well capacity) and/or an unfavorable chemical composition. It may also be that the size and geometry is not suitable. Furthermore, the aquifer may already be occupied by, for example, supply of drinking water. This will be a limiting factor that cannot be overcome. During such circumstances a closed loop system may or should be considered as an alternative.

5.5.4. Climate conditions

Climate plays an important role in the application of GSHP systems. There are many reasons for this, but one essential condition is that the ambient temperature of the ground is reflected by the average temperature in the air.

Another climate factor is the humidity. In hot climates with a high humidity, there will be temperature requirement for cooling that allows condensation. In practice this means that it is not possible to directly cool a building from the ground. However, in such a case there are other technical solutions.

5.5.5. Environmental limitations

GSHP energy systems will in general contribute to less global emission of carbon dioxide and other harmful environmental substances. However, country specific, and maybe also locally, there may be limiting concerns such as:

- Contamination of the ground and the ground water by boreholes connecting to the surface, boreholes shortcutting different aquifers and the usage of anti-freeze.
- Change of the underground temperature that may affect the chemistry and bacterial composition and growth in the underground.
- Emissions, damages and local disturbances (noise, etc.) caused by drilling and construction.
- Damage to buildings, fauna and flora operating the systems.

5.6. Benefit of GSHP systems

Geothermal source heat technology has several benefits, including:

- *Low operating cost* - The efficiency of the heat pumps operating under moderate loop temperatures provides the basis for high efficiency and low operating cost. The cost to move energy around the building is also low, as heat pumps are placed at each space. There is no need to circulate large amounts of air around the building to transport energy, nor is there a need to reheat air to maintain comfort in certain areas of a building.
- *Simplicity* – The distributed nature of the system makes it easy to understand. A heat pump located at each space will provide independent heating and cooling. The operation of one heat pump does not affect any other heat pump. Control simply requires turning the unit on or off in response to the area that needs heating or cooling.
- *Low maintenance* – The heat pump itself is a packaged unit no more complex than typical residential air conditioning equipment. The components are the same as those used for outdoor applications that have much wider operating ranges and exposure to the weather. Diagnosing problems has become easier due to the distributed nature of the system. Any problem is typically closely related to the equipment serving the particular space.
- *No supplemental heat required* – Heat pumps can meet all of the space loads, including ventilation loads. Ventilation air can be tempered by separate heat pumps and/or conditioned with heat recovery equipment.
- *Low cost integrated water heating* – Heat pumps can be dedicated to meet hot water loads. These heat pumps become particularly attractive when there is a large cooling load relative to the heating load. By extracting some of the heat from the ground loop for water heating, the ground heat exchanger size and cost can be reduced.
- *No required exposed outdoor equipment* – The ground heat exchanger is buried and the heat pumps are located inside the building. Vandalism, noise, and visual screen problems are eliminated. Designers do not have to supply space on the roof for equipment, making options such as standing seam metal roofs or large sloped roofs possible.
- *Low environmental impact* – No fossil fuels need to be consumed on site. Pollution can be best mitigated at a central power plant where electricity is produced. As the efficiency of electricity production or renewable power generation increases, so does the environmental efficiency of the heat pump system has low environmental impact.
- *Level seasonal electric demand* – With winter heat pump operation displacing fossil fuel use, and summer heat pump operation occurring at moderate, more efficient loop temperatures, the electric demand is more consistent throughout the year so the average price of electricity is reduced.
- *Longer life expectancy* - Both the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Electric Power Research Institute have concluded, based on independent research studies, that the appropriate service life value for ground source heat pump technology is 20 years or more. This benchmark is the current industry standard.