Chapter 6

SHALLOW GEOTHERMAL SYSTEMS

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6.1 Introduction

Shallow geothermal systems harness the ground heat from the soil surface down to a depth of ca. 400-500 m, in areas without specific geothermal anomalies. Hence the temperature level of these systems is, depending upon the climatic conditions of the site, around 5-25 °C. With these temperatures, no direct heat use is possible. There are two methods to nevertheless bring shallow geothermal energy to good use:

- The low temperature in the ground can be increased to a useful temperature by using a heat pump, a device to transfer heat from a lower temperature level to a higher one by additional energy input.
- The temperature in the ground can also be changed artificially by storage of heat (e.g. from waster heat or solar heat) or cold, creating an Underground Thermal Energy Storage System (UTES for short)

The highest storage temperature achieved in UTES systems by now is ca. 90 °C, the lowest (for cooling purposes) ca. 5 °C. With heat pumps, the maximum delivery temperatures typically are in the order of 50-55 °C, with new developments looking for increased values, and in cooling mode ca. 6-7 °C.

Geothermal Heat Pumps (also called Ground Source Heat Pumps, GSHP for short) are systems with three main components:

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

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. This brochure is intended to show the advantages of Ground Source Heat Pumps, to help in understanding the design requirements, and to highlight some well done examples of this technology.

Ground Source 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, however, some other countries with a slow start in the same time now show good growth rates. As shown in fig. 6-1vas an example, the sales in Germany; achieved an annual increase in 2005 of 43.3 %.

6.2. Short History of Shallow Geothermal Energy

The earth offers a steady and incredibly large heat source, heat sink and heat storage medium for thermal energetic uses, like for the geothermal heat pump. A steady temperature in the underground first was scientifically proven in deep vaults beneath the Observatoire in Paris. The famous French chemist and physicist Lavoisier installed a mercury thermometer there at the

$$Length\,[m] = \frac{HP\ evaporator\ \ capacity\ \ \ [W]}{specific\ heat\ extraction\ rate\ \ [W/m]}$$

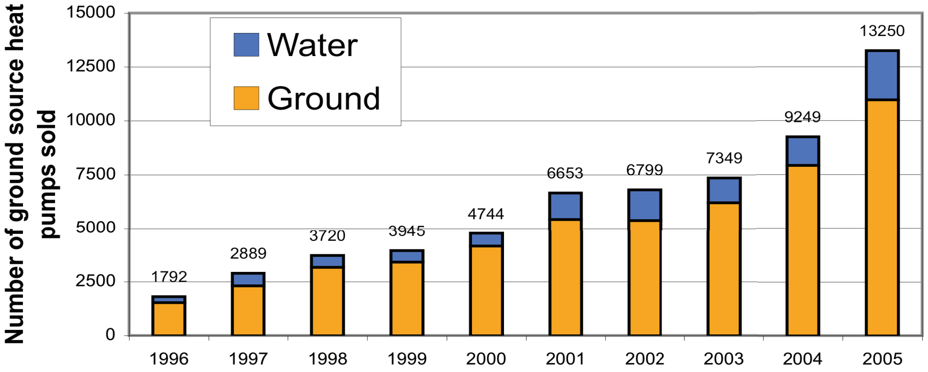


Fig. 6.1. Growth of Ground Source Heat Pump Sales, the example of Germany (after data from BWP)

end of the 17th century, at a depth of 27 m below street level. Buffon reported in 1778, that the temperature readings from this thermometer are constant throughout the year.

During his studies in Paris, Alexander von Humboldt noted (in 1799: "The average temperature supplied by the measurements since 1680 in this basement is 9.6 R“. This value, given in degree Reamur, equals 12 °C, and is said to have varied over the year by only ca. 0.04 °C.

In 1838, very exact measurements of temperature in the ground started at the Royal Edinburgh Observatory in Scotland (fig. 6.2):

It took until the mid of the 20th century, before this steady heat reservoir first was used by a ground-source heat pump. The first installation of that type was recorded to be operational in Indianapolis, USA, where a 2.2 kW compressor was hooked to a direct expansion ground coil system in trenches and supplied heat to a warm air heating system (Fig.6.3). The plant was monitored beginning Oct. 1, 1945.

In the following years, several proposals were made how to exploit best the earth as heat source and heat sink for heat pumps. An article in 1947 already showed virtually all methods in use until today, including ground water wells, horizontal coils with direct expansion as well as with brine circuit, vertical borehole heat exchangers in coaxial, U-pipe and spiral form (fig.6.4).

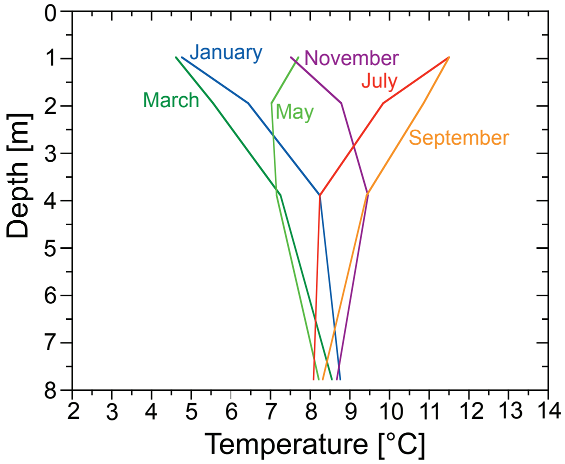


Fig.6.2. Underground temperatures at the Royal Edinburgh Observatory, average 1838-1854 (after data from Everett, 1860)

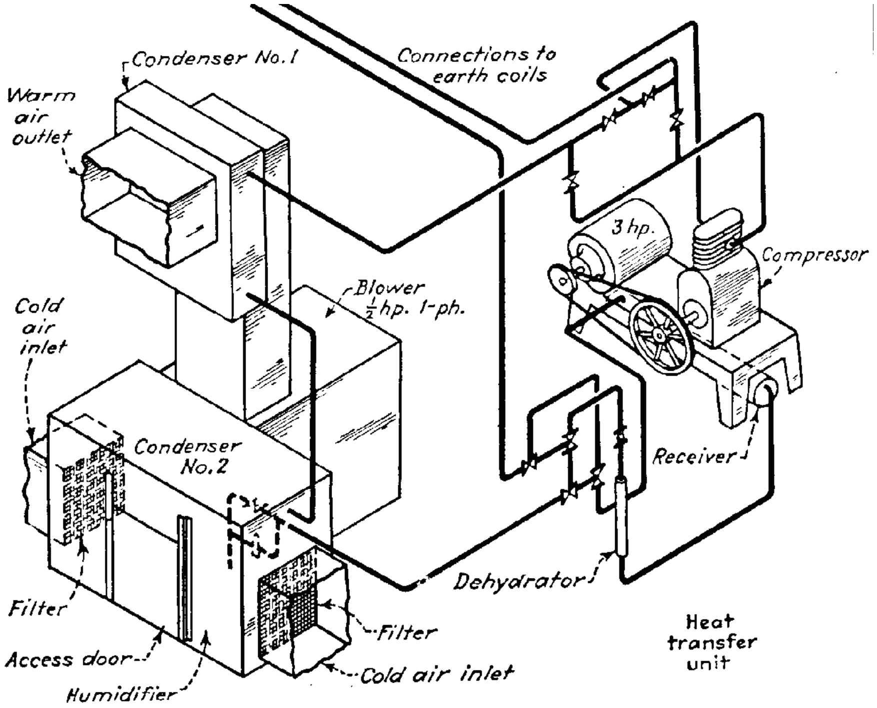


Fig. 6.3. Schematic of the first known geothermal heat pump, 1945 (from Crandall, 1946)

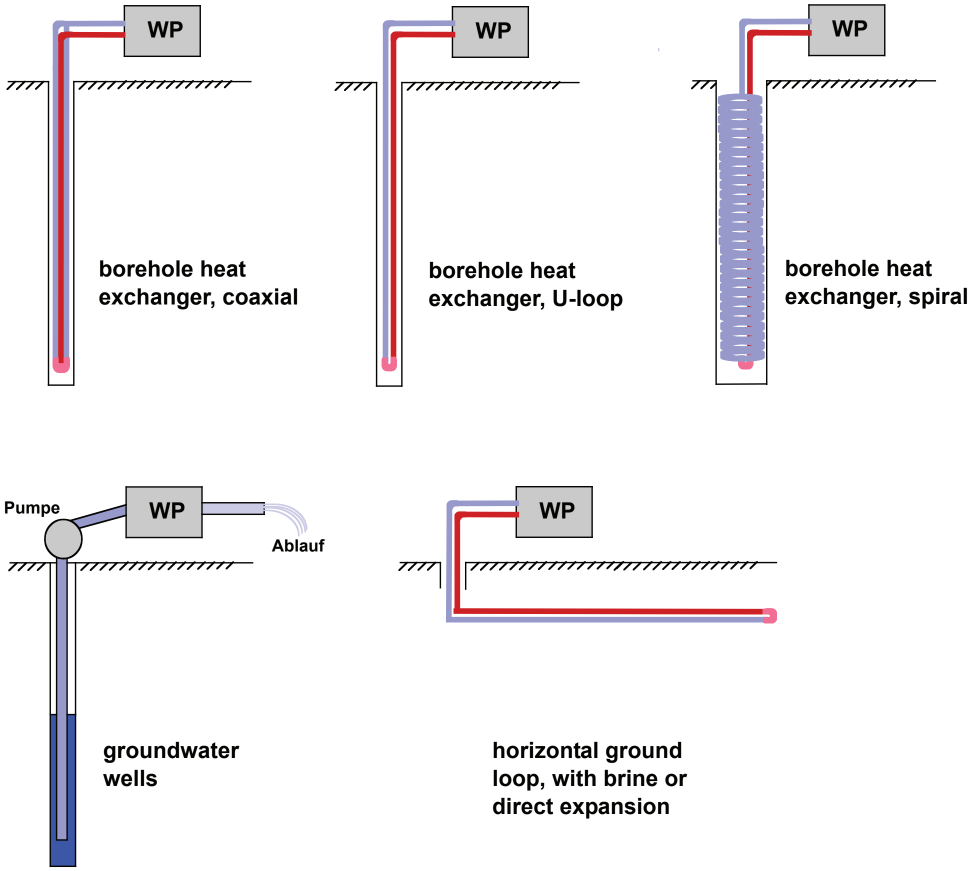


Fig. 6.4. GSHP-schematics, harmonised after Kemler (1947)

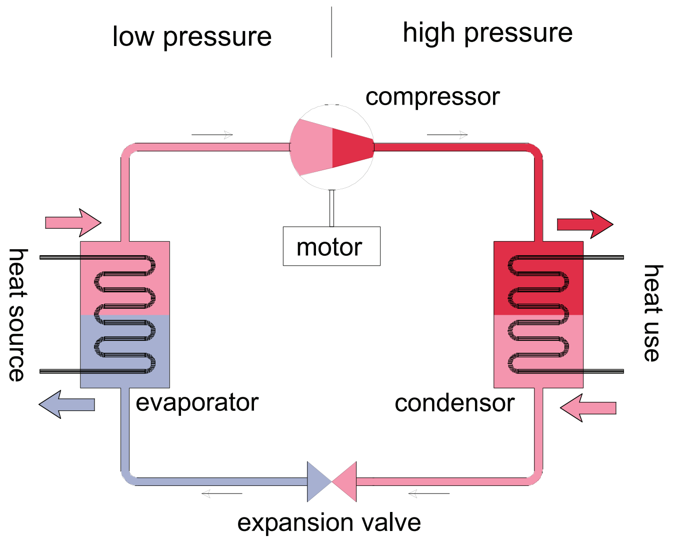


Fig.6.5. Schematic of a compression heat pump

6.3 Principle of a 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 6.5.

The thermodynamic principle behind a compression heat pump is the fact that a gas becomes warmer when it is compressed into a smaller volume. This effect is common experience e.g. for cyclists when adjusting air pressure in the tyres: The air pump gets warmer in the process.

In a heat pump, a medium with low boiling point ("refrigerant") is evaporated by the ground heat, the resulting vapour (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 vapour 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.

An alternative is the absorption heat pump, where heat at higher temperature (e.g. from a gas burner) 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:

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

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. 6.6).

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).

6.4. Systems and application

As could be seen in the previous chapter, the temperature levels in a heat pump system have a strong impact on the efficiency. A low efficiency would mean a higher

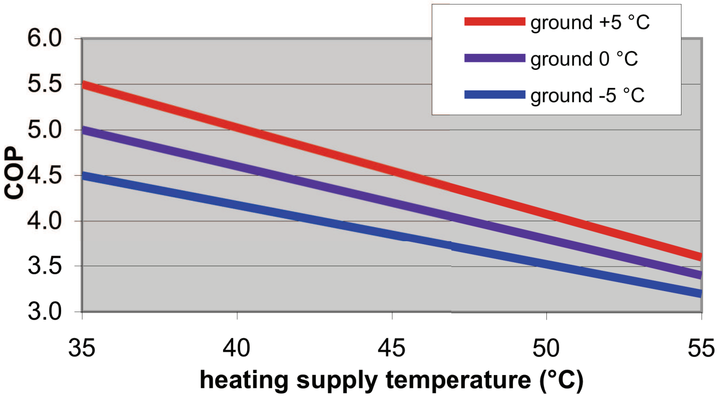


Fig. 6.6. Exemplary graph of COP versus heating supply temperature

demand for external energy, which has to be paid, and which decreases the savings in energy and emissions from the heat pump system.

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. 6-7.

A ground source heat pump system can not only be used for heating, but also for cooling purposes. There are typically three modi how such a system can be operated; they are shown in figure 6.8.

The exclusive heating mode has been the standard application in Western Europe since many years, while the reversible heat pump for heating and cooling made its successful way into the market in North America (also called “Geoexchange” system in the USA). The first system using direct cold from the ground with borehole heat exchangers was built in Germany in 1987 (fig. 6.9).

Direct cooling is only feasible if the cooling load is smaller than the heating load, and if the climate is not too humid. Otherwise the heat pump has to work as a chiller, or additional de-humidification is required.

Meanwhile GSHP systems with heating and cooling are a standard application also in Western Europe, in particular for commercial projects like offices, shops etc. The heat and cold distribution often is done through floor heating and/or cooling ceilings, which can be combined into one system using tubes in the concrete building parts to keep the whole building mass at an average, moderate temperature. An alternative is the use of fan-coil units.

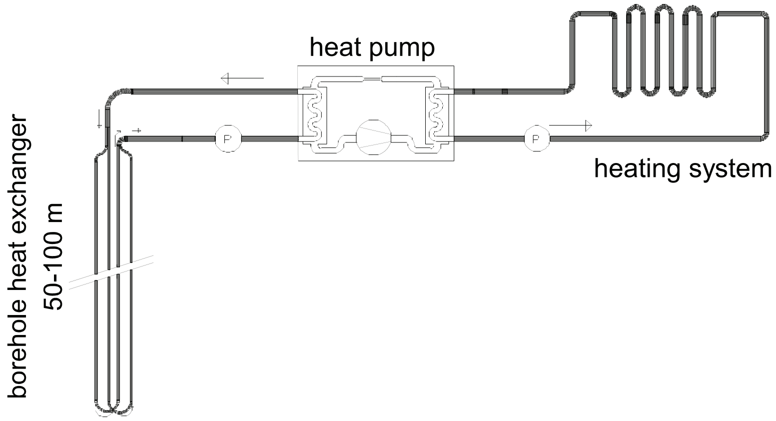


Fig. 6.7. Basic schematic of GSHP

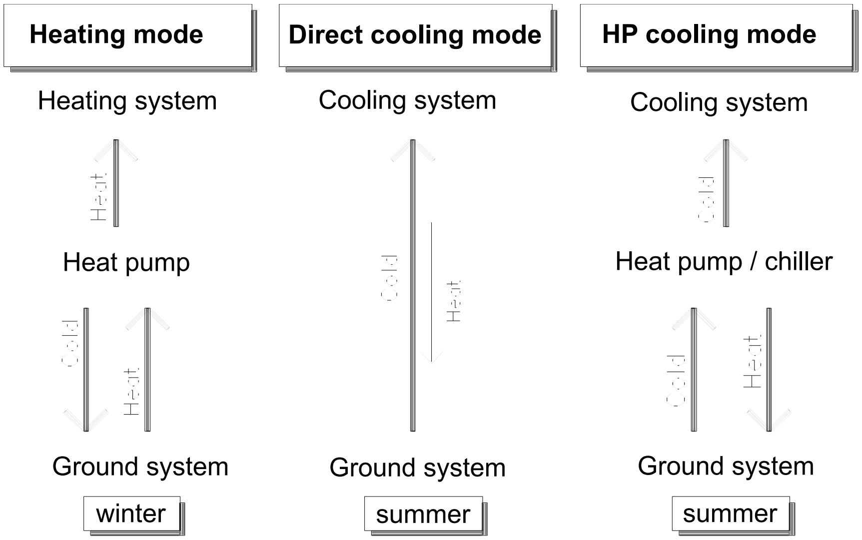


Fig. 6.8. Different GSHP operation modes

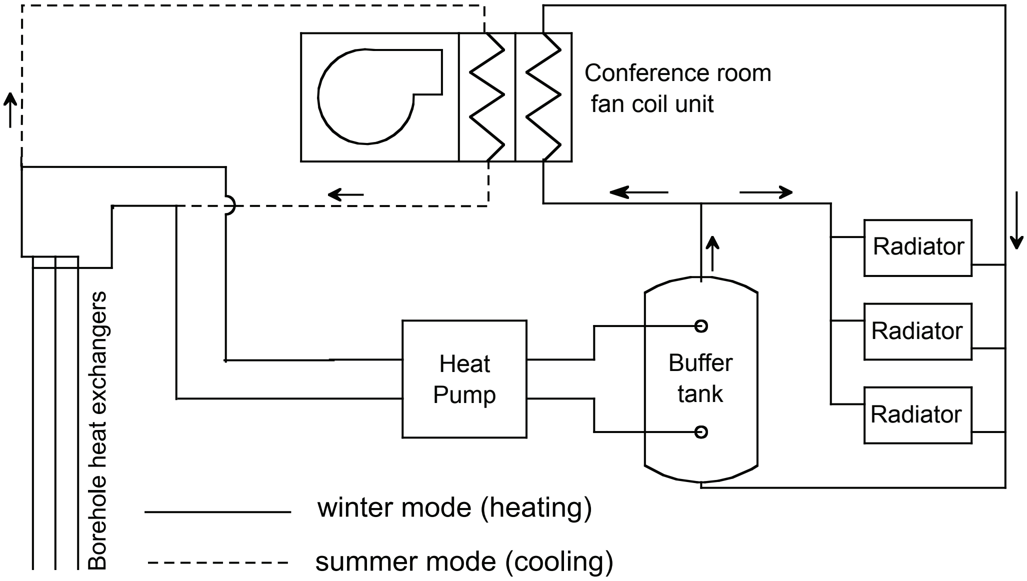


Fig. 6.9. System schematic of first GSHP plant with direct cooling in Wetzlar (after Sanner, 1990)

The range of application for ground source heat pumps (GSHP) is widely spanned, from small residential houses to large office complexes.

6.5 Ground system description

The ground system links the 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 individual types of ground systems are described in more detail on this and the following pages.

6.5.1 Open systems

This type is characterised by the fact that the main heat carrier, ground water, flows freely in the underground, and acts as both a heat source/sink and as a medium to exchange heat with the solid earth. Main technical part of open systems are groundwater wells, to extract or inject water from/to water bearing layers in the underground („aquifers"). In most cases, two wells are required („doublette"), one to extract the groundwater, and one to re-inject it into the same aquifer it was produced from (fig. 6.10).

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.

Open systems tend to be used for larger installations. The most powerful ground source heat pump system world-wide uses groundwater wells to supply ca. 10 MW of heat and cold to a hotel and offices in Louisville, Kentucky, USA.

6.5.2. Closed systems

a) horizontal

The closed system easiest to install is the horizontal ground heat exchanger (synonym: ground heat collector, horizontal loop, Fig.6.11). Due to restrictions in the area available, in Western and Central Europe the individual pipes are laid in a relatively dense pattern, connected either in series or in parallel.

For the ground heat collectors with dense pipe pattern, usually the top earth layer is removed completely, the pipes are laid, and the soil is distributed back over the pipes. In Northern Europe (and in North America), where land area is cheaper, a wide pattern („loop") with pipes laid in trenches is preferred. Trenching machines facilitate installation of pipes and backfilling.

To save surface area with ground heat collectors, some special ground heat exchangers have been developed. Exploiting a smaller area at the same volume, these collectors are best suited for heat pump systems for heating and cooling, where natural temperature recharge of the ground is not vital. Hence these collectors are widely used in Northern America, and one type only, the trench collector, achieved a certain distribution in Europe, mainly in Austria and Southern Germany.

For the trench collector (fig. 6.12), a

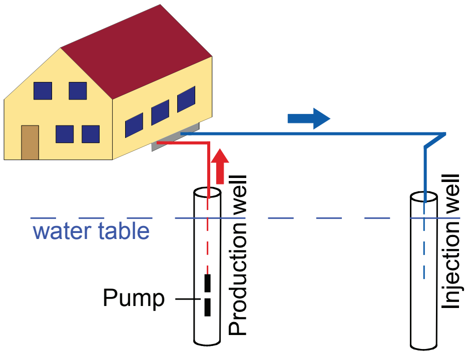


Fig. 6.10. Groundwater heat pump (doublette)

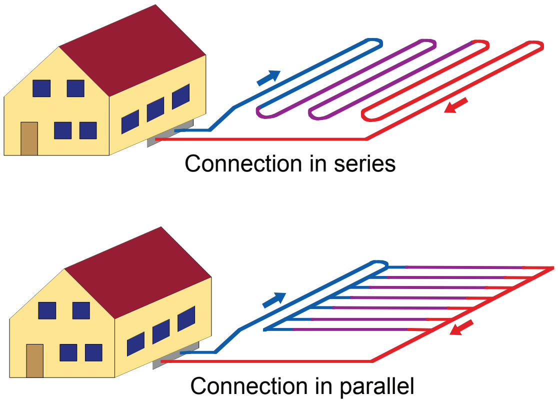


Fig. 6.11. Horizontal ground heat exchanger (European style)

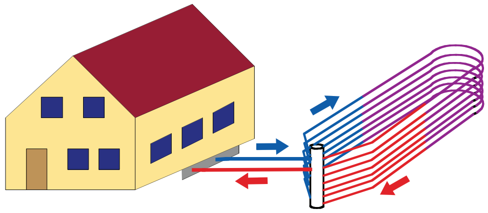


Fig. 6.12: Trench collector Fig.

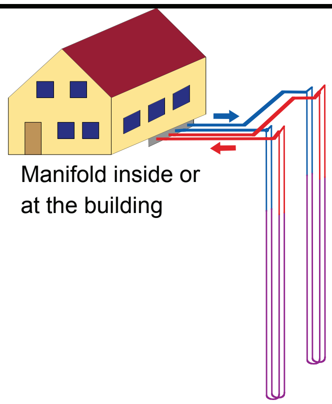


Fig.6.13: Borehole heat exchangers (double-U-pipe)

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.

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. In France and Austria, direct expansion also has been coupled to direct condensation in the floor heating system. Direct expansion requires good knowledge of the refrigeration cycle, and is restricted to smaller units.

b) vertical

As can be seen from measurements dating as far back as to the 17th century (see 6.2), the temperature below a certain depth („neutral zone“, at ca. 15-20 m depth) remains constant over the year. This fact, and the need to install sufficient heat exchange capacity under a confined surface area, favours vertical ground heat exchangers (borehole heat exchangers, fig. 6.13).

In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining room in the hole is filled (grouted) with a pumpable material. In Sweden, boreholes in hard, crystalline rock usually are kept open, and the groundwater serves for heat exchange between the pipes and the rock. If more than one borehole heat exchanger is required, the pipes should be connected in such a way that equal distribution of flow in the different channels is secured. Manifolds can be in or at the building, or the pipes can be connected in trenches in the field. Fig. 6.14 shows the relevant steps for installation of borehole heat exchangers.

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are (fig. 6.15):

- U-pipes, consisting of a pair of straight pipes, connected by a 180°-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.

An alternative to the aforementioned borehole heat exchangers filled with a liquid heat carrier, which is circulated by pumping, are heat pipes used as borehole heat exchangers. This concept can be used only in systems destined exclusively to heat extraction from the ground, as heat pipes cannot facilitate a heat transport downward. A fluid (e.g. CO_2) is evaporated inside the heat pipe by the ground heat, and releases that heat at the top of the heat pipe into the working cycle of the heat pump.

Fig. 6.14: Three steps of borehole heat exchanger installation: Drilling (upper left), inserting pipes (upper right), grouting (lower centre)

Ground source heat pump plants of every size have been realized with borehole heat exchangers, ranging from small houses with just one borehole to large buildings, requiring whole fields of borehole heat exchangers. One of the highest number of boreholes for a single plant in Europe have been installed for the head office of the German Air Traffic Control (Deutsche Flugsicherung), with 154 borehole heat exchangers each 70 m deep. The largest single plant in the world heats and cools the Richard Stockton College in New Jersey and comprises 400 boreholes each 130 m deep.

The heat source for thermal recovery of borehole heat exchangers is solar heat (in the upper part) and the geothermal heat flux (in the lower part), with some influence from flowing ground water or percolating water. However, the influence of groundwater in most cases is not very big, and the thermal conductivity of the ground is the main parameter.

The borehole filling and the heat exchanger walls account for a further drop in temperature, which can be summarised as borehole thermal resistance. Values for this parameter usually are on the order of 0.1 K/(W/m); for a heat extraction of 40 W/m, this means a temperature loss of 4 K inside the borehole. Thermally enhanced grouting (filling) materials have been developed to reduce this losses.

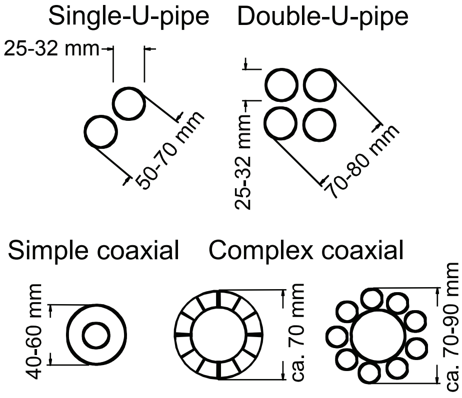


Fig. 6.15: Cross-sections of different types of borehole heat exchangers

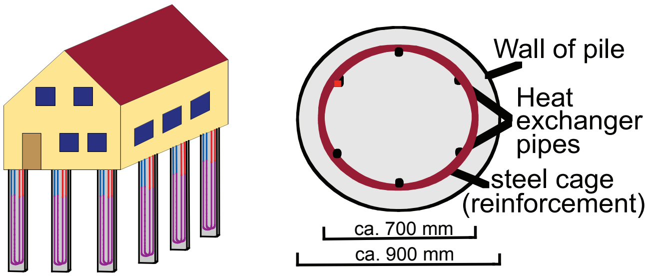


Fig. 6.16: Energy piles, cross-section of a pile with 3 loops

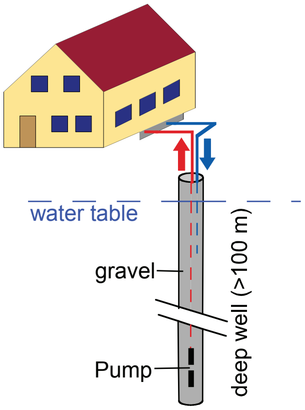


Fig. 6-17: Standing column well

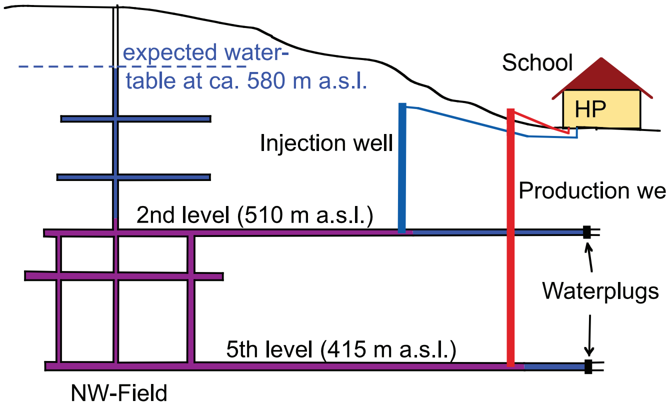


Fig. 6-18: Heat pump using mine water (example of Ehrenfriedersdorf, Germany, with abandoned tin mine)

A special case of vertical closed systems are „energy piles“, i.e. foundation piles equipped with heat exchanger pipes (fig. 6.16). All kind of piles can be used (prefabricated or cats on site), and diameters may vary from 40 cm to over 1 m.

6.5.3 Other systems

There is a number of ground systems neither to be categorized as open or closed.

In a standing column well (fig. 6.17), water is pumped from the bottom of the well and, after leaving the heat pump, percolated through gravel in the annulus of the well. Standing column wells need a certain depth to provide enough power without freezing of the water, and thus most plants have boreholes several hundred meter deep. Examples are known from Europe (Switzerland and Germany) and from USA. With the expensive borehole, the technology is not suited to small installations.

A very promising concept is the use of water from mines and tunnels. This water has a steady temperature the whole year over and is easily accessible. Examples with mine water use exist in Germany (Saxonia, fig. 6.18) and Canada. Tunnel water is used in the village of Oberwald at the Western entrance of the Furka rail tunnel in Switzerland and in Airolo, where water from the Gotthard road tunnel provide the heat source for a heat pump in the road maintenance facility. With the huge tunnel constructions ongoing in the Alps, new potential for this type of heat source is developing.

6.6 Design and planning

The design of borehole heat exchangers for small, individual applications can be done with tables, empirical values and guidelines (existing in Germany as VDI 4640, and Switzerland). A popular parameter to calculate the required length of borehole heat exchangers is the specific heat extraction, expressed in Watt per meter borehole length (fig. 6.19). Typical values range between 40-70 W/m, dependent upon geology (thermal conductivity), annual hours of heat pump operation, number of neighbouring boreholes, etc. With the known capacity of the heat pump evaporator, the required length can easily be calculated:

$$Length\,[m] = \frac{HP\ evaporator\ \ capacity\ \ \ [W]}{specific\ heat\ extraction\ \ rate\ \ [W/m]}$$

For larger borehole heat exchanger plants, for all cases with heating and cooling or with more than ca. 2000 h/a of heat pump operation, calculations have to be made to determine the required number and length of borehole heat exchangers. Programs for use on PC exist in USA and Europe, and for difficult cases, simulation with numerical models can be done. A standard software tool for design of borehole heat exchangers is the “Earth Energy Designer” EED, a Swedish-German development.

With a large number of small plants, a smaller distance between the boreholes makes deeper borehole heat exchangers necessary (Fig. 6.20).

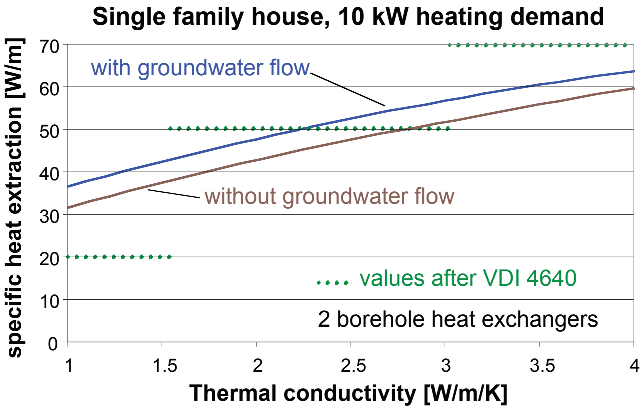


Fig. 6.19: Example of specific heat extraction values for a small ground source heat pump, no domestic hot water (heat pump run time 1800 h/a)

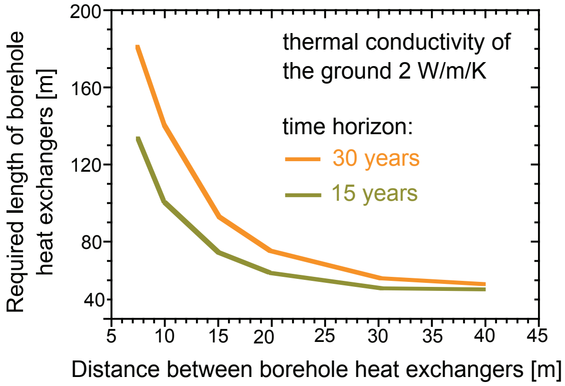


Fig. 6.20: Required borehole length in a field of 60 houses (7 kW heat load each) with 2 borehole heat exchangers for each house; no ground-water flow, no artificial thermal recharge

The main underground parameter for design of borehole heat exchanger plants is the thermal conductivity. This value can be estimated from the type of rock at a given site, but it can also be measured directly in situ. The relevant tool is called “Thermal Response Test” (fig. 6.21). A given, constant heat load is injected into a borehole heat exchanger, and the resulting rise of temperature is measured over at least 48 hours. The thermal conductivity then can be calculated using the slope of the temperature curve over logarithmic time.

6.7 Examples

6.7.1 Low-Energy Office near Aachen, Germany

Aachen in Western Germany is one of the cities closely linked to European history, the city of Charlemagne and located at central crossroads, where the Netherlands, Belgium and Germany meet. At the outskirts of the city, in short distance to Belgian ground, a new office building was erected in 2003 (fig. 6-22).

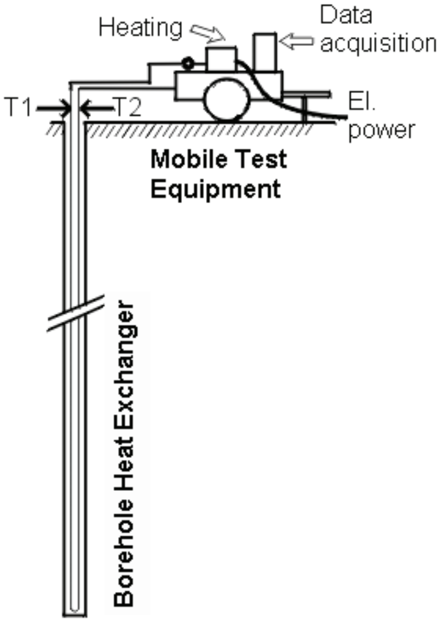


Fig. 6.21: Schematic of Thermal Response Test

Fig. 6.22: Office building “VIKA” in Aachen

Fig. 6.23. Geothermal Response Test equipment on site (in trailer)

For the heating and cooling of the building a geothermal system was intended. Because of the larger size of the project, a pilot well was drilled and a borehole heat exchanger installed. Then a Thermal Response Test was carried out (fig. 6.23) to determine the underground thermal conductivity, as input to the design calculations.

The building is designed as a low-energy-office, with high insulation standard. Most of the heat and cold is transferred to the rooms through pipes in the concrete building parts (fig. 6.24), with moderate temperatures both in heating and cooling season.

The borehole heat exchangers are only 43 m deep, as there is a big change in rock strength at that dept. The array of borehole heat exchangers (fig. 6.25) is located under the parking lot today. The performance of the system is highly satisfying. (photos and graph courtesy of EWS, Lichtenau).

Building data:

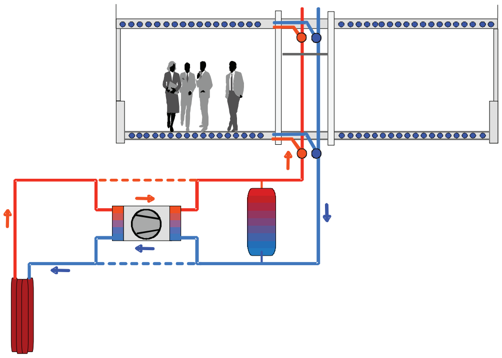


Fig. 6.24. Schematic of geothermal heating and cooling system in Aachen

- Floor area 2100 m^2
- Heating and cooling through BHE
- Heating with heat pump
- Direct cooling from borehole heat exchangers (BHE)
- 28 BHE each 43 m deep
- Annual heat and cold production 133 MWh with only 19 MWh electric power consumption
- On top of the BHE-field today a parking lot is located

6.7.2. Renewable Energy House in Brussels, Belgium

The installation built in 2005 is a classic ground-source heat pump with 4 BHE, supplying heat to the rear building of the REH; it also serves as a heat sink for solar absorption cooling during summer.

Some technical data:

- Heat demand: 25 kW

Borehole heat exchangers (BHE)

Fig. 6.25: Finished borehole heat exchangers, before connection

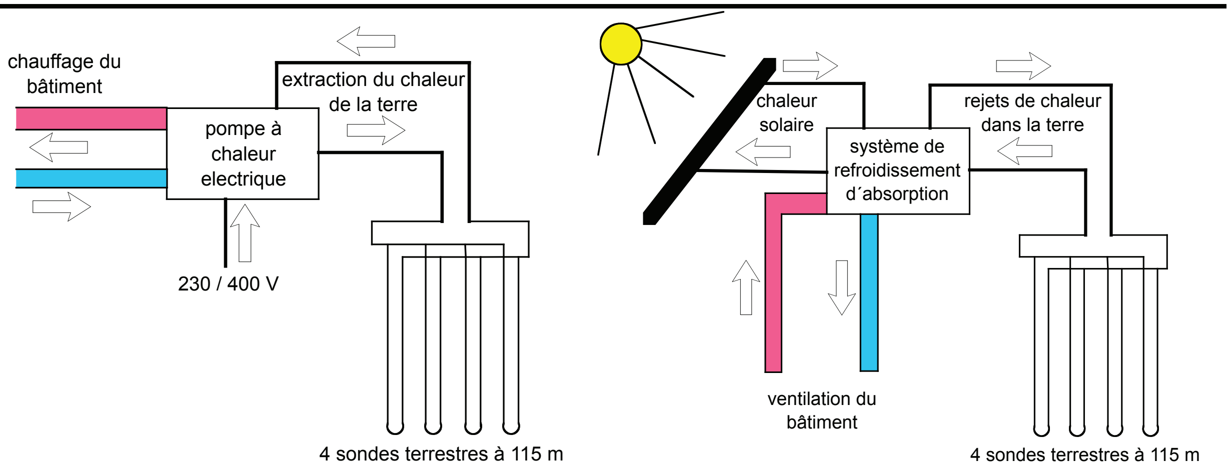


Fig. 6.26: Schematic of the geothermal heat pump system for the Renewable Energy House, to the left in winter operation (heating) and to the right in summer mode (cooling)

⇒ Geology: Quarternary and Tertiary sediments (marl, clay, sand)
⇒ Type : 4 double-U-type-BHE of 115 m length, tube diameter: 40 mm.
- Heating system (Fig. 6.26)
⇒ Antifreeze: propyleneglycol
⇒ Heat pump refrigerant : R407C
⇒ Heating water supply temperature: 40-50 °C
⇒ Radiator heating
- Summer operation (Fig. 6.26)
⇒ In summer, the ground system is used to act as a heat sink for a solar thermal absorption cooling machine (hence the large diameter of the BHE, in order to cover short but high heat peaks.

In the Renewable Energy House, geothermal energy is used in the form of a geothermal heat pump with 4 vertical borehole heat exchanger (BHE, “vertical loops”) each 115 m deep. The heat is used to heat the rear building with conference room in wintertime. The 4 BHE have been installed by drilling inside the interior courtyard (fig. 6-27), with the drilling rig passing the narrow doorway with only a few centimetres of clearance. The geothermal system is not only used for heating, but can act also as a heat sink for the condensor heat of the solar absorption cooling system in summertime (Fig. 6.26).

The design of the radiators in the back building shall secure a maximum supply temperature be in the order of 35-40 °C, and in any case below ca. 55 °C. The heat pump (generally a device which allows transport of heat from a lower temperature level to a higher one, by using external energy e.g. to drive a compressor) for the REH is from Ochsner company, Austria; it belongs to the “Golf” range of Ochsner heat pumps, is of the type GMSW 38, and has a heating output 28.3 kW.

Fig. 6.27. Drilling rig inside the courtyard in Rue d´Arlon

6.8. Underground Thermal Energy Storage (UTES)

While in GSHP-systems a heat pump is used to bring the temperature from the ground to a useful heating temperature, or to dump heat from space cooling into the ground, the ground itself is heated or cooled in a UTES system. Again, a distinction can be made between open and closed systems (Fig.6.29). The heat sources for heat storage can be various, however, waster heat or solar heat are typical. For cold storage, the cold ambient air in wintertime or during night is the cold source. The basic principle of an ATES can be seen in Fig.6.30.

Two examples are shown here to illustrate the principle. The technology is well established for cooling purposes, in particular in the Netherlands, but still some R&D has to be done to achieve reliable and economic UTES for heat storage at ele-vated temperatures. One example, of a real heat store with temperature up to 80 °C, is a BHE store in Neckarsulm, using solar energy (Fig.6.31 and table 1).

Fig.6.28: Plan of the commercial area in Hainburg to be heated and cooled by GSHP

Aquifer Storage (ATES)

Groundwater as heat carrier

- medium to high hydraulic conductivity and transmissivity
- high porosity
- low or none groundwater flow

Examples:
- Porous aquifers in sand, gravel eskers
- Fractured aquifers in limestone, sandstone, igneous or metamorphic rock

Borehole Storage (BTES)

Systems with boreholes and pipes

- high specific heat
- medium thermal conductivity
- no groundwater flow

Examples:
- Sediments like shale, marl, clay etc.; limestone, sandstone and others may also be suitable
- Igneous rocks like granite, gabbro, etc.; some metamorphic rocks like gneiss

Fig.6.29. Distinction of UTES-systems

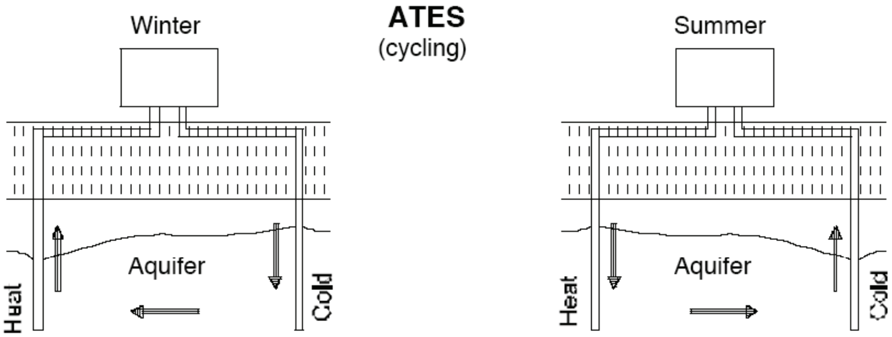


Fig.6.30: Operating principle of an ATES-system, with cycling operation ("warm" and "cold" wells)

6.8.1. BHE storage system in combination with solar heat in Neckarsulm

The store in Neckarsulm [15] is part of a solar assisted district heating system in a new building area with approximately 1300 flats and terraced houses in the final stage, to be realized within the next 5 years. A solar contribution of about 50 % to the total heat demand (space heating and domestic hot water) is planned. The BHE store is connected directly to the district heating network without a heat exchanger to avoid temperature drops. There is no heat pump in the system; peak load is covered by a gas boiler. Two buffer stores (each 100 m^3 water tank) help to cover short-time load peaks and solar collector production peaks.

One of the main advantages of the BHE-store is the possibility to extend the store by adding further boreholes in relation to the growth of the building area. A first experimental store with a volume of ca. 4300 m^3 was built in autumn 1997.

The store consisted of 36 double-U-pipes with a depth of 30 m and a borehole distance of 2 m. The borehole diameter was 115 mm. Each 6 boreholes were connected in series. This store was mainly used for charging and discharging experiments. The heat transfer capacity of the BHE used first was found to be not as good as estimated. Reasons for that are a closer than planned distance between the U-pipes (65 mm shank spacing) and a lower thermal conductivity of the grouting material. This effect decreased the performance of the overall system. In addition, the discharging of the store was reduced due to the network return temperature. Simulations showed that the heat transfer capacity of the BHE could be improved significantly by enlarging both the borehole diameter from 115 to 150 mm and the pipe shank spacing from 65 to 100 mm. Therefore the extension of the store from 4.300 m^3 to 20.000 m^3 with additional 132 boreholes was made with this new borehole geometry.

System operation started in January 1999. Besides the monitoring of the overall system (especially the interaction between the collectors and the store during charging and the effect of the network return temperatures on discharging), special attention will be paid on the combined heat and mass transfer inside the store .

If the ongoing project leads to successful results it is planned to extend the duct store stepwise according to the growth of the building area and simultanuosly increasing collector area. The extension will take place in eastern direction. At the final stage the total heat demand of the building area will amount to approximately 10'500 MWh/a and the available collector area to 15.000 m^3. According to present simulations a storage volume of about 150.000 m^3 will be necessary to achieve a solar fraction of 50%. The heat recovery factor of the store will reach 75 to 80 % depending on the depth of the store, i.e. on the surface/volume ratio. A quasi-steady- state operation will be reached after approximately 5 years.

6.8.2. Aquifer store for the Reichstag area in Berlin

The most prominent example for aquifer storage (ATES) in Germany has been built for heating and cooling of the Reichstag building in Berlin, now seat of the German Parliament (Bundestag). Fig.6.32 gives some details.

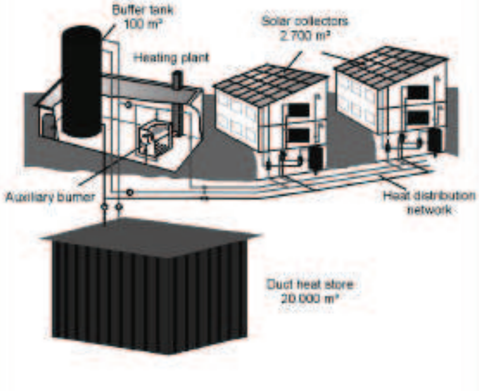
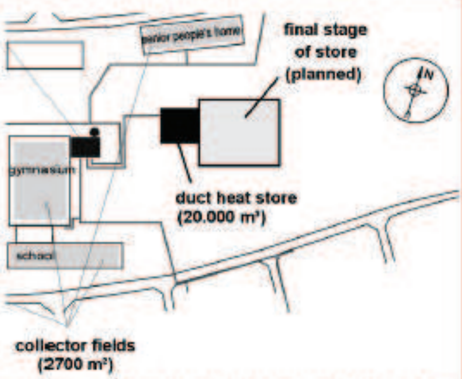
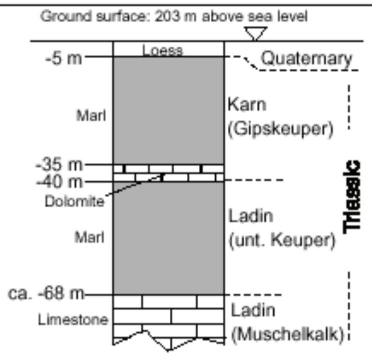
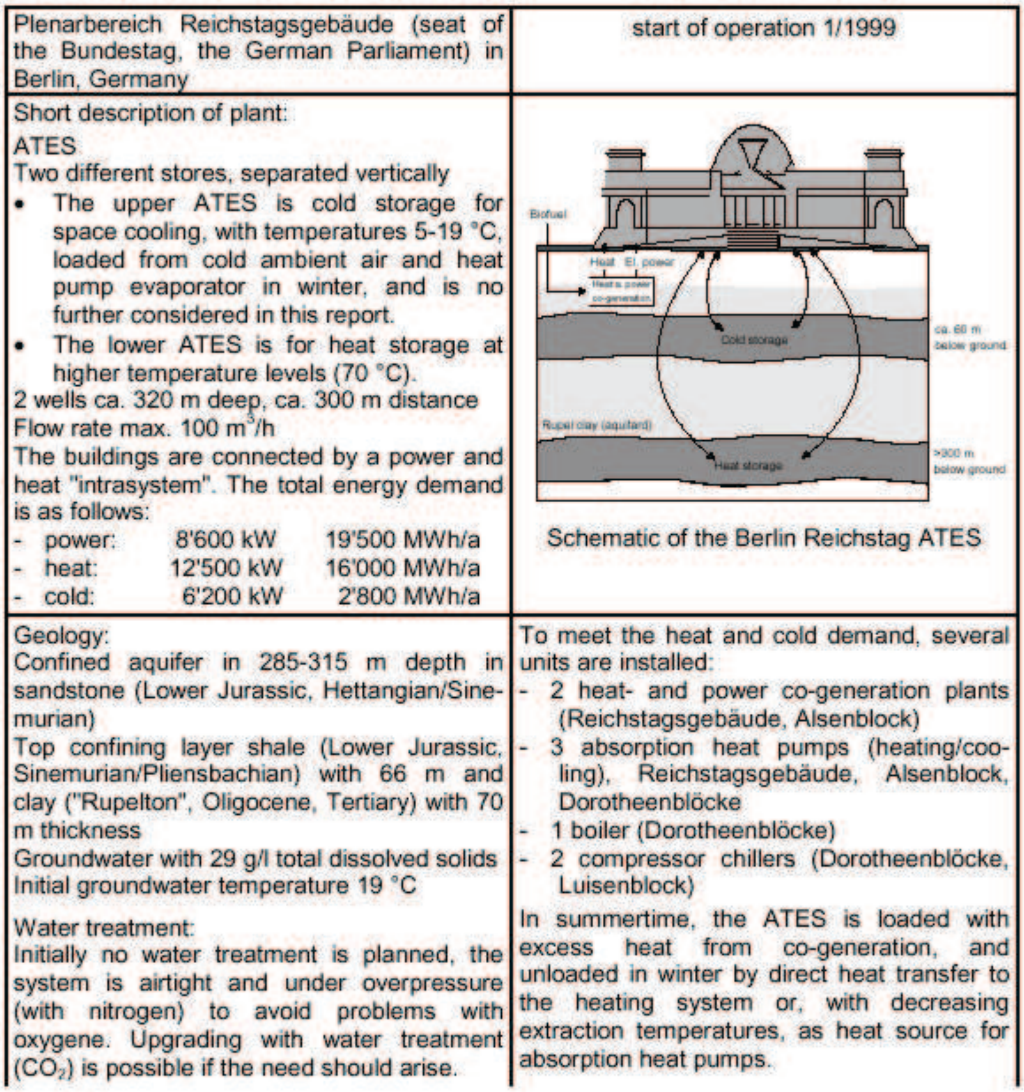
Subdivision Amorbach in Neckarsulm, Germany	start of operation 1/1999
Short description of plant: BTES >600 vertical BHE, depth 30 m Borehole spacing 2 m with a sqare drilling pattern (fig. 6) Polybuthene-double-U-pipes as BHE After the installation of the heat exchanger pipes the borehole is refilled with a suspension of bentonite, sand, cement and water Total storage volume about 20'000 m³ The store is insulated on top with 20 cm of extruded polystyrole, extending 4 m horizontally further out from the peripheral boreholes. The refilled ground above the store has a thickness of 2-3 m. 2'700 m² solar collector area	 Schematic of the Neckarsulm-Amorbach BTES
Geology s. table 2	Storage supply temperature up to 80 °C
BTES system in Neckarsulm.Amorbach, with chimneys of the peak boiler, two buffer storage tanks, and senior citizens home with solar collector roof in the background 	 Overview of the project site in Neckarsulm-Amorbach

Fig.6.31. Basic data for the BTES (BHE-store) in Neckarsulm

Table 1: Geological situation at Neckarsulm BTES

Mean underground thermal conductivity until 35 m depth	$\lambda = 2$ W/m/K
Mean volumetric heat capacity of the ground	$c_v = 3$ MJ/m³K
Groundwater level between 10 and 15 m below ground level	
Stratigraphy: • Overburden of Loess (silt) down to a depth of ca. 5 m • The subsequent layers consist of Upper Triassic sediments (Muschelkalk and Keuper, see right). • The layers with marls have very low hydraulic conductivity ($k_f \approx 5 \cdot 10^{-8}$ m/s).	 *Geological cross-section at the Neckarsulm BTES site*



Plenarbereich Reichstagsgebäude (seat of the Bundestag, the German Parliament) in Berlin, Germany	start of operation 1/1999
Short description of plant: ATES Two different stores, separated vertically • The upper ATES is cold storage for space cooling, with temperatures 5-19 °C, loaded from cold ambient air and heat pump evaporator in winter, and is no further considered in this report. • The lower ATES is for heat storage at higher temperature levels (70 °C). 2 wells ca. 320 m deep, ca. 300 m distance Flow rate max. 100 m^3/h The buildings are connected by a power and heat "intrasystem". The total energy demand is as follows: - power: 8'600 kW 19'500 MWh/a - heat: 12'500 kW 16'000 MWh/a - cold: 6'200 kW 2'800 MWh/a	 Schematic of the Berlin Reichstag ATES
Geology: Confined aquifer in 285-315 m depth in sandstone (Lower Jurassic, Hettangian/Sinemurian) Top confining layer shale (Lower Jurassic, Sinemurian/Pliensbachian) with 66 m and clay ("Rupelton", Oligocene, Tertiary) with 70 m thickness Groundwater with 29 g/l total dissolved solids Initial groundwater temperature 19 °C Water treatment: Initially no water treatment is planned, the system is airtight and under overpressure (with nitrogen) to avoid problems with oxygene. Upgrading with water treatment (CO_2) is possible if the need should arise.	To meet the heat and cold demand, several units are installed: - 2 heat- and power co-generation plants (Reichstagsgebäude, Alsenblock) - 3 absorption heat pumps (heating/cooling), Reichstagsgebäude, Alsenblock, Dorotheenblöcke - 1 boiler (Dorotheenblöcke) - 2 compressor chillers (Dorotheenblöcke, Luisenblock) In summertime, the ATES is loaded with excess heat from co-generation, and unloaded in winter by direct heat transfer to the heating system or, with decreasing extraction temperatures, as heat source for absorption heat pumps.

Fig.6.32 Aquifer storage for the German Parliament in Berlin

6.9. Market and Economy

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Fig. 6.33 gives some recent data for the number of installed units in the main European heat pump countries. The extremely high number for Sweden in 2001 is the result of a large number of exhaust-air and other air-to-air heat pumps; however, Sweden also has the highest number of GSHP in Europe (see 1998 values in Fig.6.33). In general it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland (Table 2). There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. In Germany, the trend is positive (Fig.6.33), with a share of GSHP (ground and water) of about 82 % in 2002.

6.10. Conclusions

GSHP are no longer exotic. Their number has increased steadily over the years, and the tech-nology is well understood. For residential houses, they begin to become a routine option when plan-ning the heating system.

The use of GSHP for commercial applications can yield economic and environmental advantages. In particular in cases were heating and cooling is required, the ground as heat source and sink can act as a

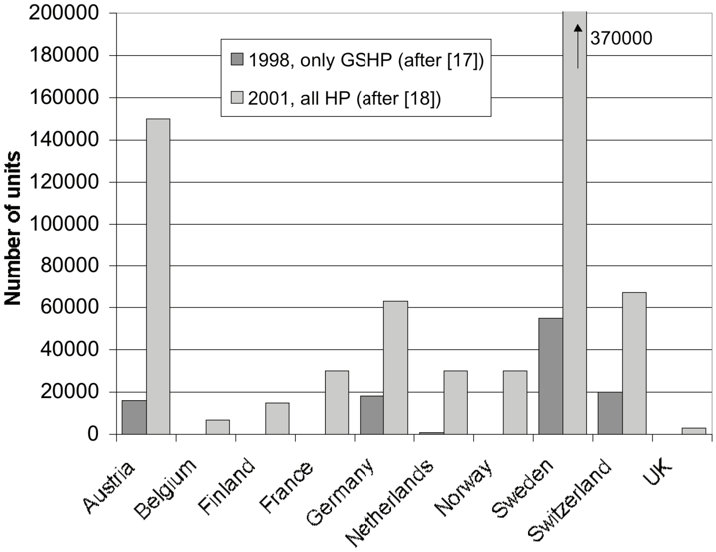


Fig.6.33: Number of installed heat pump units in some European countries (after data from [SANNER, B. (1999)] and [DONNERBAUER, R. (2003)])

Tab. 2: Share of ground coupled heat pumps in total residential heating market (after data from [VAN DE VEN, H. (1999)])

Country	%
Austria	0.38
Denmark	0.27
Germany	0.01
Norway	0.25
Sweden	1.09
Switzerland	0.96

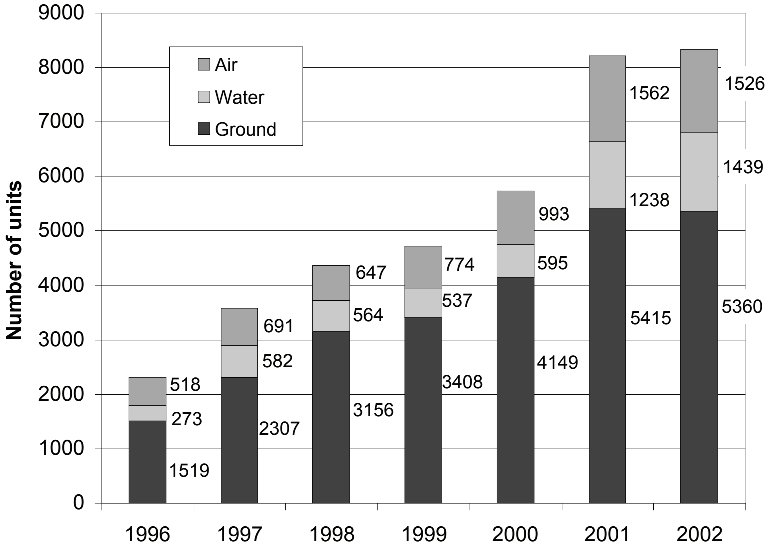


Fig.6.34. Number of annual heat pump sales in Germany, according to heat sources (after data from IZW e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included)

kind of seasonal buffer storage. In this paper only an overview of the development and the current use with some examples could be given. There are other plants and also other technologies, e.g. the use of larger diameter horizontal pipes buried in the ground for preheating and pre-cooling ventilation air directly. This technology is know in Germany as air-earth heat exchangers (L-EWT), and is used e.g. in a new office building in Frankfurt-Niederrad. Also the use of foundation piles as heat exchangers is becoming popular for those building that require a pile foundation [19]. These piles, equipped with plastic pipes, are known as “energy piles”, and some of the recent high buildings in Frankfurt use them. The main purpose here is to assist space cooling.

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