SHALLOW GEOTHERMAL ENERGY

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The underground in the first approx. 100 m is well suited for supply and storage of thermal energy. The climatic temperature change over the seasons is reduced to a steady temperature at 10-20 m depth (Figure 1), and with further depth temperatures are increasing according to the geothermal gradient (average 3°C for each 100 m of depth).

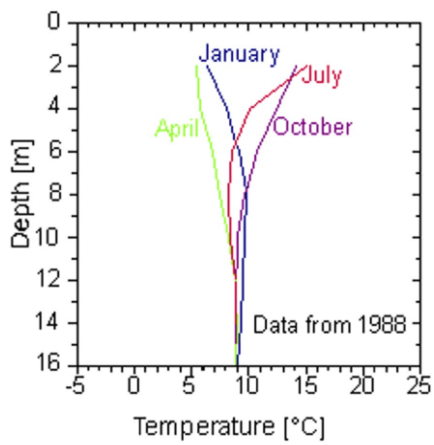

Figure 1. ***Underground temperatures from a borehole south of Wetzlar, not influenced by the heat pump operation.***

The main methods to make use of this energy are:

- Ground-Source Heat Pumps (a.k.a. Geothermal Heat Pumps)
- Underground Thermal Energy Storage (UTES)

This presentation will give an overview of these methods, possible application and systems, and some successful examples.

GROUND-SOURCE HEAT PUMPS

The basic principle of a ground-source heat pump is shown in Figure 2. Heat can be extracted from the ground at a relatively low temperature the temperature is then increased through the heat pump and used in a heating system. For each kWh of heating output, only 0.22-0.30 kWh of electricity are required to operate the system (i.e., the seasonal performance factor is 3.3-4.5). For cooling in summertime, the system can be reversed, and heat from building cooling can be injected into the ground for highly effective space cooling.

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:

- **Open systems:** Groundwater is used as a heat carrier, and is brought directly to the heat pump.
- **Closed systems:** Heat exchangers are located in the underground (either in a horizontal, vertical or oblique fashion), and a heat carrier medium is circu-lated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa).

The system cannot always be attributed exactly to one of the above categories. Examples of exceptions are use of standing column wells, mine water or tunnel water.

To choose the right system for a specific installation, several factors have to be considered: geology and hydro-geology 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.

Open Systems

The 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")(Figure 3), one to extract the groundwater, and one to reinject it into the same aquifer from which it was produced.

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.

Closed Systems

Horizontal

The closed system easiest to install is the horizontal ground heat exchanger (synonym: ground heat collector, horizontal loop). 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 (Figure 4).

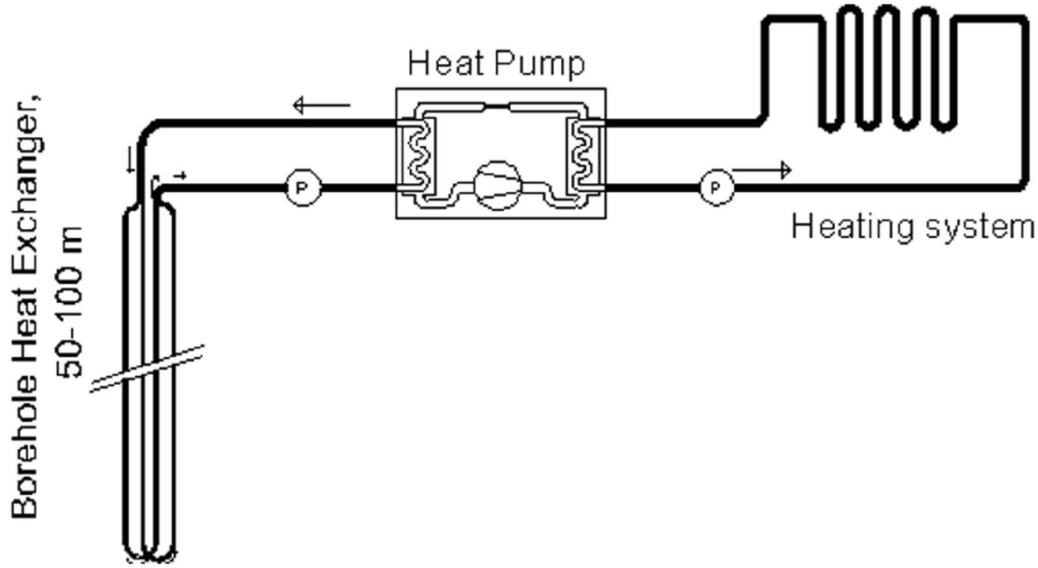

Figure 2. Schematic of a ground-source heat pump.

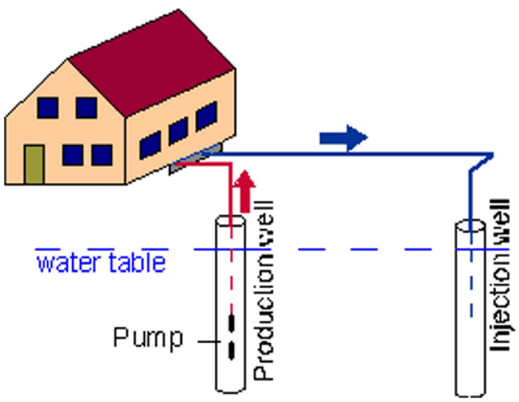

Figure 3. Groundwater heat pump (doublette).

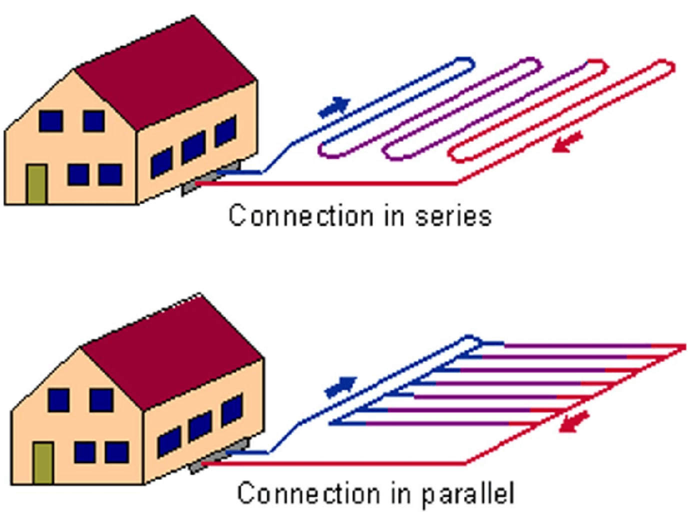

Figure 4. Horizontal ground heat exchanger (European style).

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. Spiral forms (Figure 5) are popular in USA, mainly in the form of the so-called "slinky" collectors (placed horizontally in a wide trench like in the figure, or vertically in a narrow trench).

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.

Vertical

Because the temperature below a certain depth (ca. 15-20 m) remains constant over the year, and because of the need to install sufficient heat exchange capacity under a confined surface area, vertical ground heat exchangers (borehole heat exchangers) are widely favored. 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.

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are (Figure 7):

- 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.

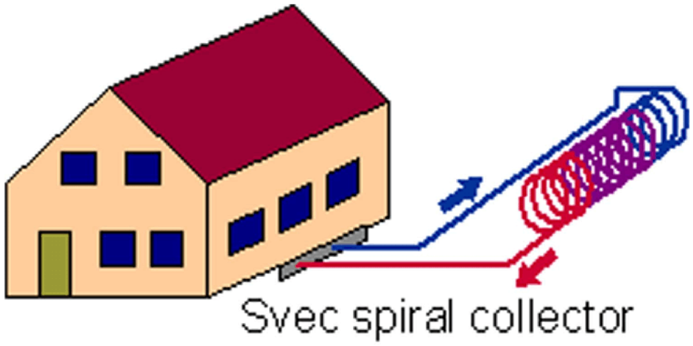

Figure 5. Spiral-type ground heat exchangers (North America).

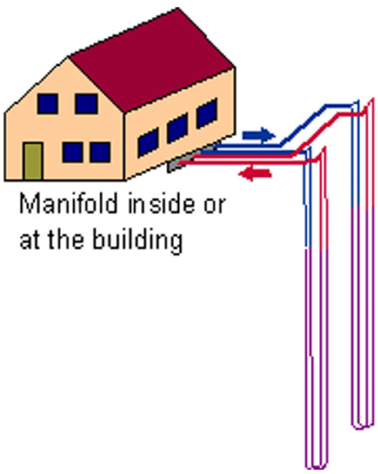

Figure 6. Borehole heat exchangers (double U-pipe).

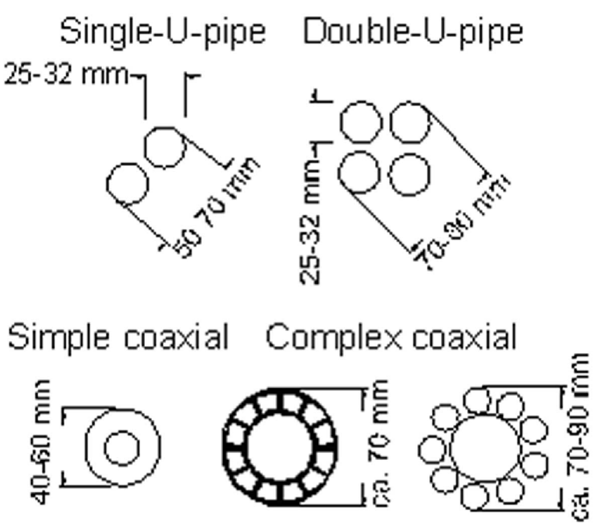

Figure 7. Cross-sections of different types of borehole heat exchangers.

The borehole filling and the heat exchanger walls account for a drop in temperature, which can be summarized as borehole thermal resistance. Thermally enhanced grouting (filling) materials have been developed to reduce this losses.

Ground-source heat pump plants of every size have been used with borehole heat exchangers, ranging from small houses with just one borehole to large buildings, requiring a whole field of borehole heat exchangers. The highest number of boreholes for a single plant in Europe may be 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.

Another trend are residential areas with heat supply from ground source heat pumps; an example with ca. 130 houses with individual ground source heat pumps and one or two borehole heat exchangers for each house can be found in Werne, Germany, over an area of ca. 50,000 m^2 (Figure 8).

A perfect example for the total integration of ground source heat pump systems is the use for filling stations. The first plant was installed for the Philips 66 chain in Prairie Village, Kansas. The heat pump used for space heating and cooling is coupled to ten borehole heat exchangers each 99 m deep. The convenience store appliances (14 kW walk-in cooler, freezer and icemaker) have their own separate water-cooled compressors, and waste heat from the appliances is discharged into the same ground loops used by the space conditioning system (Figure 8). This installation has reduced electricity consumption by 40% compared to air-cooled equipment of the same size. For the wintertime car wash operations, the ground-source heat pump is coupled to radiant floor heating in the car wash bays and below the concrete at the car wash entrances and exits.

Further Philips 66 stations use ground source heat pumps in Colorado, Oklahoma and Texas, and another example is Conoco's "Skunk Creek" Service Station in Sandstone, Minnesota. Similar systems have been tested for fast food chains (e.g., McDonalds).

The design of borehole heat exchangers for **small, individual applications** can be done with tables, empirical values and guidelines (existing in Germany and Switzerland). The most important guideline currently in use is issued by the German Association of Engineers (Verein Deutscher Ingenieure, VDI) with the title "VDI 4640: Thermal Use of the Underground." This guideline consists of four parts (the first three published by the date of the EGS), dealing with:

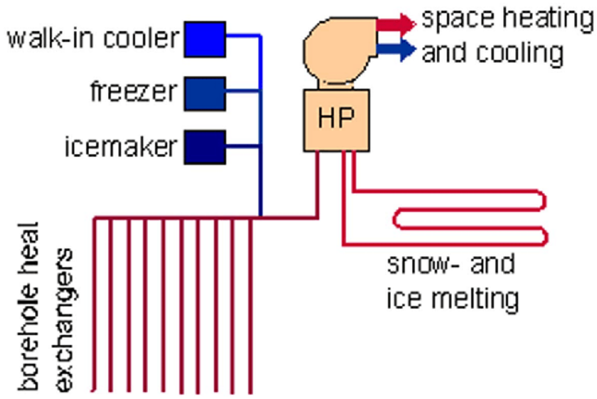

Figure 8. ***Schematic of ground-source system for filling station in USA.***

- Fundamentals, environmental aspects, licensing
- Ground-source heat pumps
- Underground thermal energy storage
- Other uses, direct uses

A popular parameter to calculate the required length of borehole heat exchangers is the specific heat extraction, expressed in watts per meter of borehole length (Figure 9). Typical values range between 40-70 W/m, dependent upon geology (thermal conductivity), annual hours of heat pump operation, number of neighboring boreholes, etc.

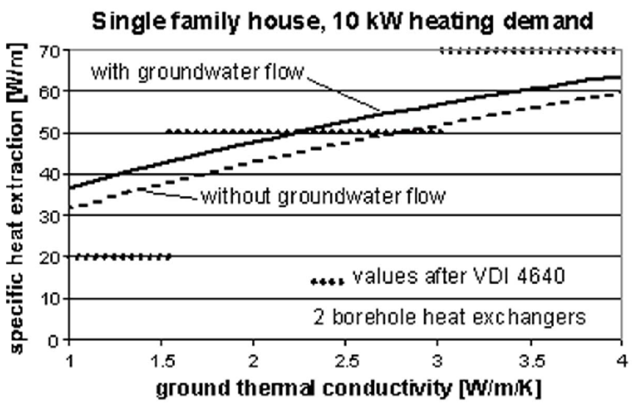

Figure 9. ***Example of specific heat extraction values for a small ground-source heat pump, no domestic hot water (heat pump operation time 1800 h/a).***

For **larger borehole heat exchanger plants**, 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. The design tool mostly used in Europe is the "Earth Energy Designer" (EED), developed by the universities of Lund, Sweden, and Giessen, Germany. A demo version of the program and further information can be found on the website of Lund University under:

http://www.buildingphysics.com (goto "Software")

Numerical simulation can help to solve even the most difficult design problems, in particular if the influence of groundwater flow has to be considered. An example of the temperature development around three borehole heat exchangers is shown in Figure 10, modeled with the code TRADIKON-3D developed in Giessen.

To get reliable input parameters for such calculations, the Thermal Response Test has been developed (Figure 11). This test allows determination of thermal parameters of the underground on site.

A special case of vertical closed systems are "energy piles" (i.e., foundation piles equipped with heat exchanger pipes) (Figure 12). All kind of piles can be used (pre-fabricated or cast on site), and diameters may vary from 40 cm to over 1 m.

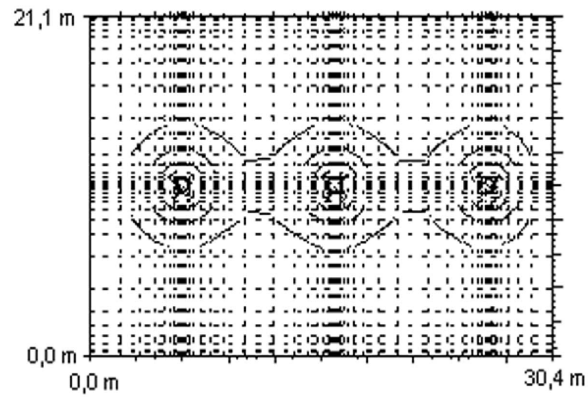

Figure 10. ***Isotherms around 3 borehole heat exchangers, calculated with TRADIKON-3D.***

Other Systems

There is a number of ground systems which are not categorized as open or closed.

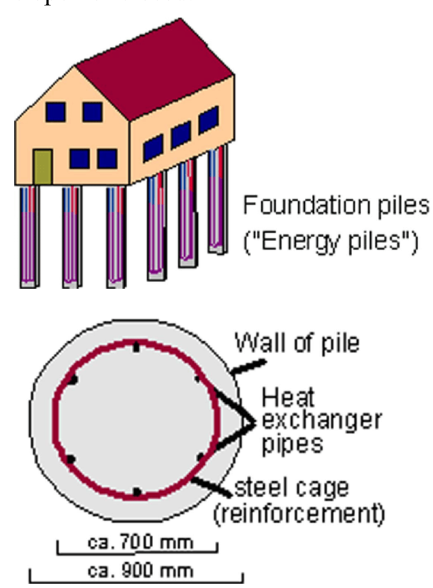

Figure 12. ***Energy piles and cross-section of a pile with three loops.***

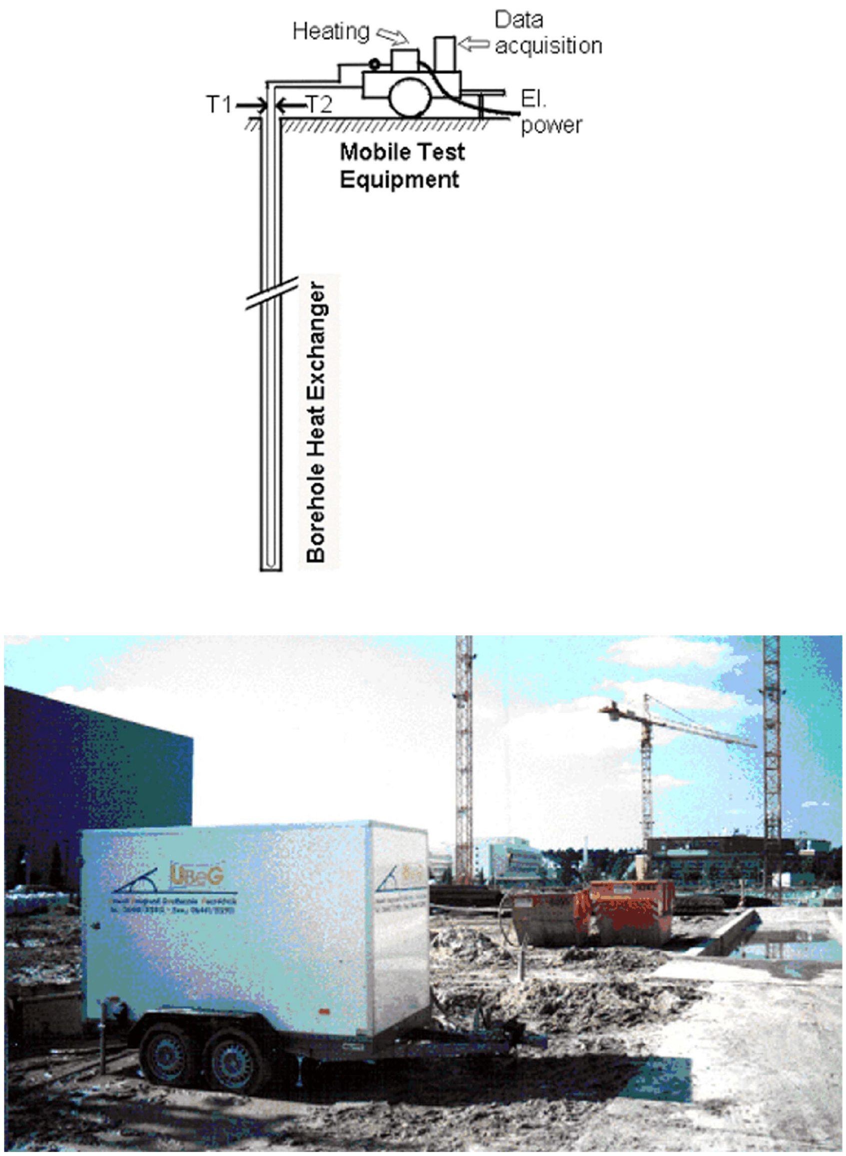

Figure 11. Schematic of Thermal Response Test and the equipment on site.

In a standing column well, 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 the water, and thus most plants have boreholes several hundred meters 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 around and is easily accessible. Examples with mine water use exist in Germany (Saxonia, Figure 13) 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.

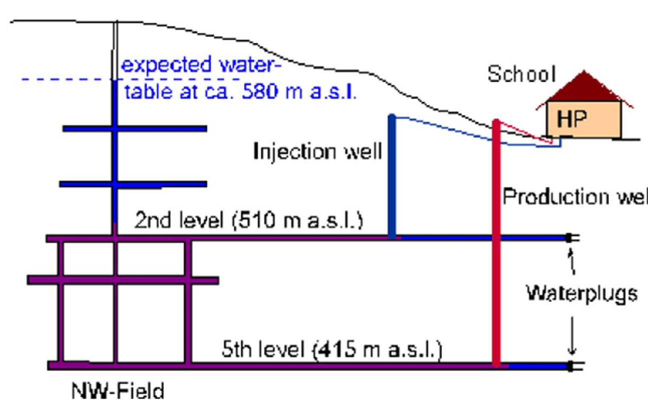

Figure 13. Heat pump using mine water (example of Ehrenfriedersdort, Germany, with abandoned tin mine).

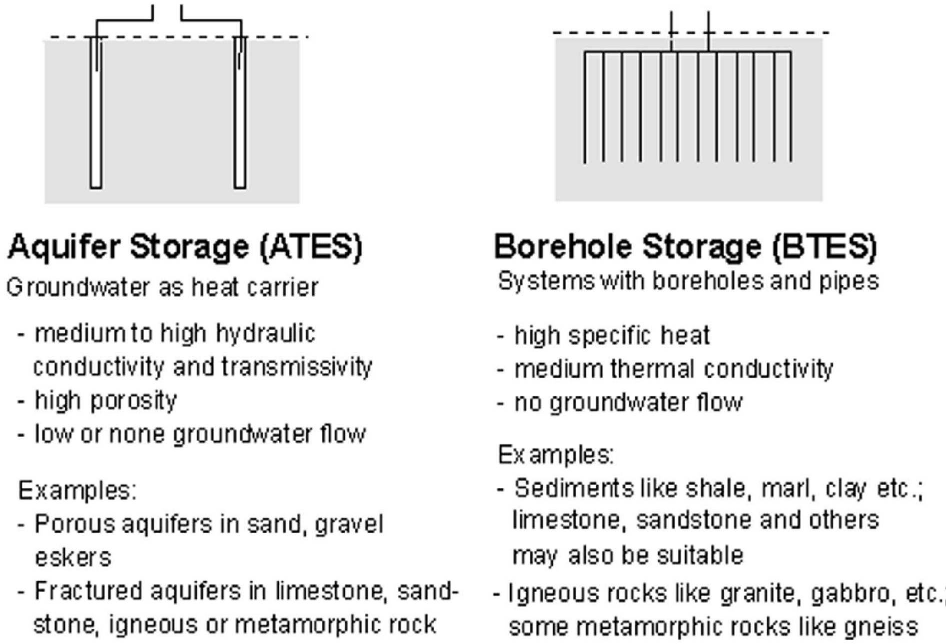

Figure 14. Types of underground thermal energy storage and geological preferences.

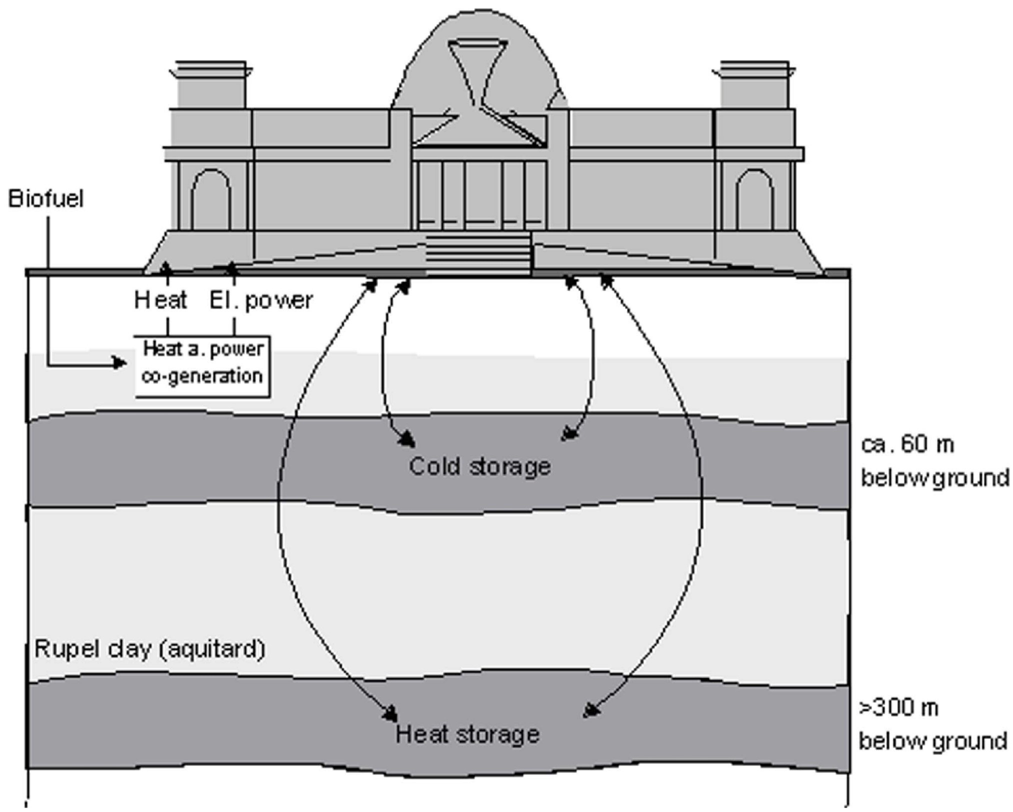

Figure 16. Schematic of Berlin Reichstagsgebäude ATES (not to scale).

UNDERGROUND THERMAL ENERGY STORAGE (UTES)

In UTES, heat, cold or both are stored underground. The methods of ground coupling (Figure 14) are essentially the same as for ground source heat pumps, with open systems (ATES) and closed systems (BTES).

Cold storage is starting to become very popular, because the cost for space cooling normally is rather high. Cold air in winter is used to cool down the underground store and this cold is used again in summer. In the 60s, China was a major pioneer in this field, with a number of plants in the Shanghai area. Today, the main activity on seasonal cold storage is in Belgium, the Netherlands, and Southern Sweden.

A combination of heat and cold storage UTES is used for road surfaces (Figure 15). Heat from solar radiation on the surface can be stored and used in winter for de-icing and snow melting on that surface. The system is used mainly on bridges, but can also be applied to any other road surface, airport runway, etc.

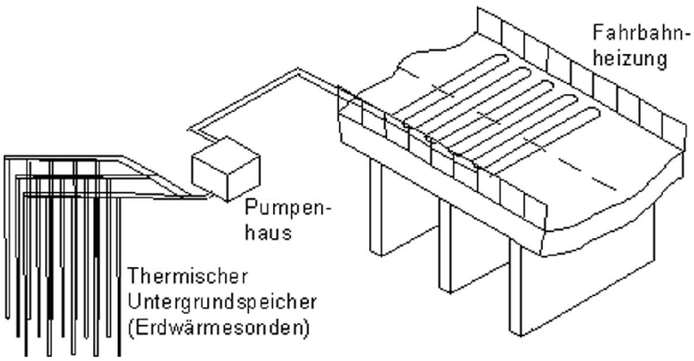

Figure 15. UTES for de-icing of road surfaces.

Heat Storage can make use of solar or waste heat in summertime for heating in winter. Major plants in Germany are at Neckarsulm, were a BTES system is charged with heat from solar collectors and heats a housing district, or in Berlin, were waste heat from heat-and-power-co-generation in summer is stored in an ATES for heating in winter (Figure 16). The Berlin plant supplies heat and cold to the German Parliament buildings (Reichstag building and surrounding offices), and for the first time incorporates two ATES systems at different levels, the upper for cold storage, and the lower for heat storage (up to 70°C). System parameters are:

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

To meet the heat and cold demand, several units are installed within the Reichstag building and the surrounding buildings:

- 2 heat- and power co-generation plants
- 3 absorption heat pumps (heating/cooling)
- 1 boiler (for peak heating)
- 2 compressor chillers (for peak cooling)

All excess heat from power generation is stored in the lower ATES system, and a big part of the cooling is provided from the upper ATES.

CONCLUSION

Shallow geothermal energy applications can be used in a variety of sectors, from house heating to process cooling and road de-icing. Design and construction is well understood and done routinely, however, skill and knowledge is required to guarantee successful installations. Ground-source heat pumps in some of the countries have a wide application in simple cases of heating a residential house (Table 1). In the future, further good opportunities for use of this technology can be seen within Europe mainly in the commercial sector (offices, factories, department stores, etc.), where heating and cooling is required.

Table 1. Estimation of GSHP-Numbers in Europe by the End of 1998, Using Published Information (with year) and Extrapolation According to Published Rates of Increase

	Number of GSHP-plants	Remarks
Austria (1996)	ca. 13000	annual increase ca. 1600
Germany (1995)	14 000-22 000	240-450 MW thermal capacity, annual increase ca. 2000
Netherlands (1997)	ca. 900	market development is about to begin
Sweden (1998)	more than 60 000	ca. 330 MW thermal capacity
Switzerland (1998)	more than 20 000	ca. 300 MW thermal capacity, annual increase ca. 10%
France (1999)	10 000 - 20 000	mainly horizontal GSHP heating capacity < 15 kW
Rest of Europe	NA	Growing market in Great Britain
Total Europe (extrapolated to end of 1998)	110 000-140 000	almost 1,300 MW thermal capacity, ca. 1,950 kWh heat per year