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 (fig. 1), and with further depth temperatures are increasing according to the geothermal gradient (average 3 °C for each 100 m of depth).

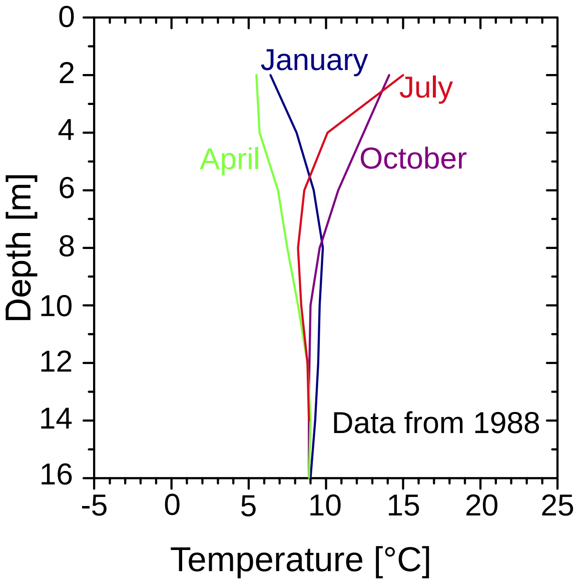

Fig 1: Underground temperatures from a borehole south of Wetzlar, not influenced by the heat pump operation

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 examples of successful realisations.

GROUND SOURCE HEAT PUMPS

The basic principle of a ground source heat pump is shown in fig. 2. Heat can be extracted from the ground at a relatively low temperature, temperature is increased through the heat pump and used in a heating system. For each kWh of heating output, only 0.25-0.3 kWh of electricity are required to operate the system (i.e. the seasonal performance factor is 3.3-4.0). For cooling in summertime, the system can be reversed, and heat from building cooling can be injected into the ground for a highly effective space cooling.

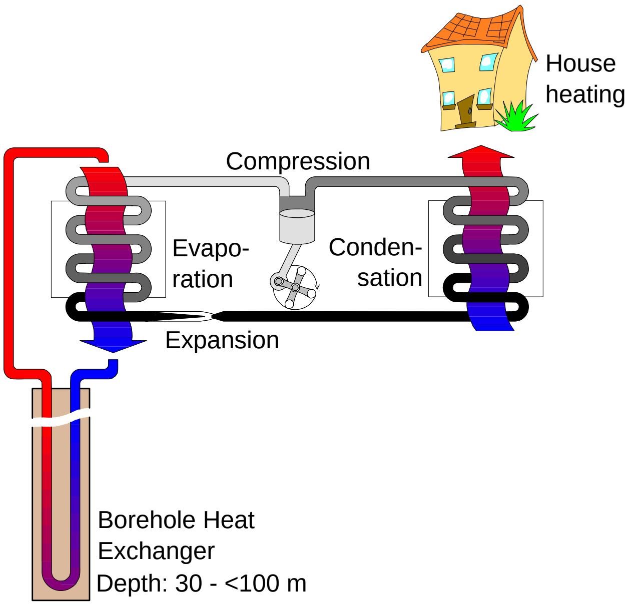

Fig 2.: Schematic of a ground source heat pump

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 circulated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa).

Not always the system can be attributed exactly to one of the above categories; standing column wells, mine water or tunnel water are examples.

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 utilisation 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

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“, fig. 3), one to extract the groundwater, and one to re-inject it into the same aquifer it was produced from.

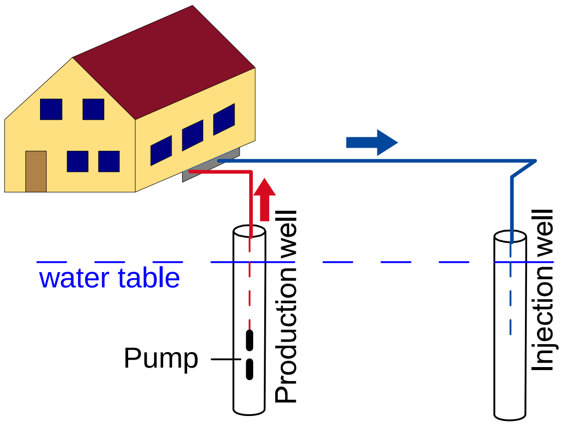

Fig. 3: Groundwater heat pump (doublette)

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

a) 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 (fig. 4).

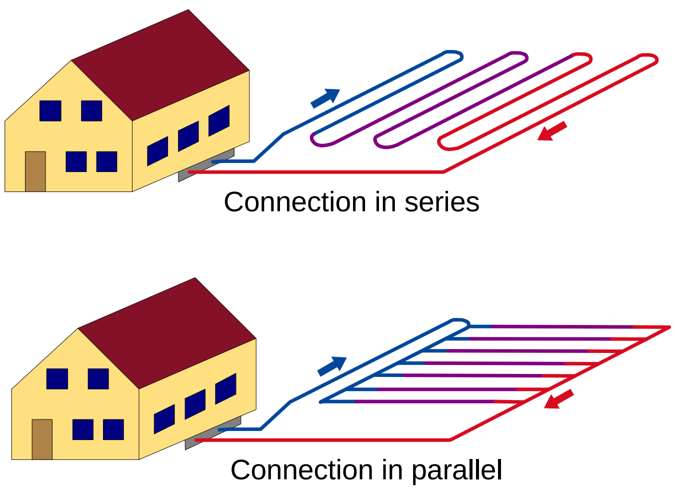

Fig. 4: Horizontal ground heat exchanger (European style)

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 (fig. 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).

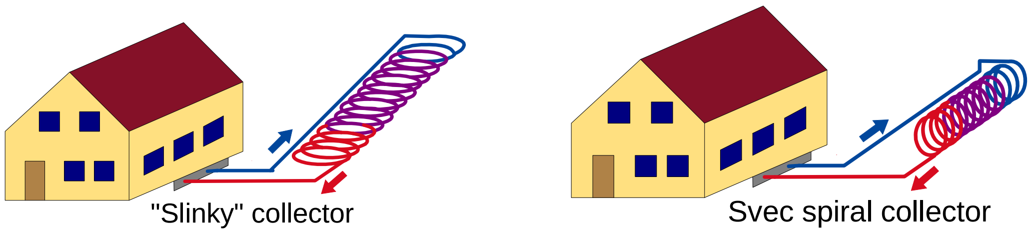

Fig. 5: Spiral-type ground heat exchangers (North America)

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.

<u>b) vertical</u>

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 favoured. 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.

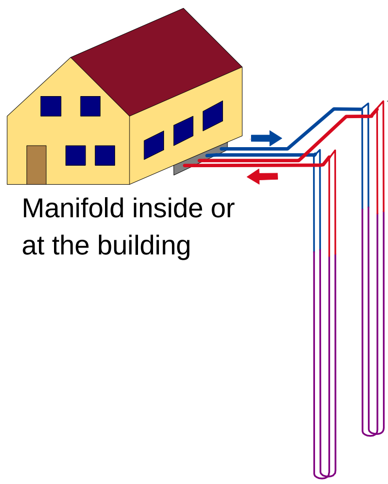

Fig. 6: Borehole heat exchangers (double-U-pipe)

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

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

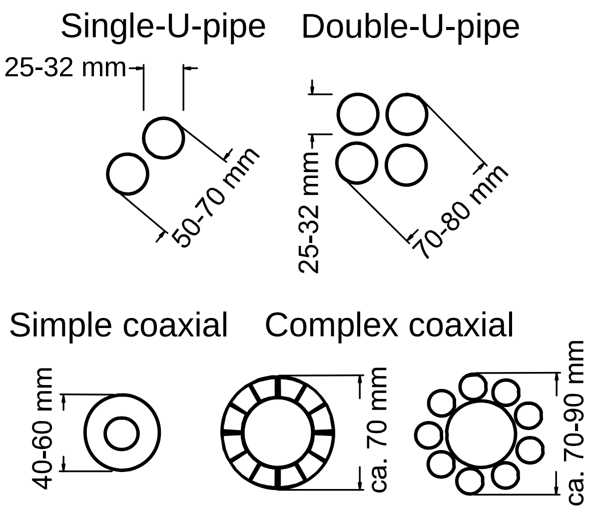

Fig. 7: Cross-sections of different types of borehole heat exchangers

Ground source heat pump plants of every size have been realised with borehole heat exchangers, ranging from small houses with just one borehole to large buildings, requiring whole fields 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 (fig 8.). 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.

Fig. 8: Construction Site of Deutsche Flugsicherung, Langen, with borehole heat exchangers

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, on an area of ca. 50'000 m^2 (fig. 9).

Fig. 9: Architect´s concept of the residential area „Am Fürstenhof" in Werne (Behr+Partner, Schwerte)

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 chain Philipps 66 in Prarie 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 (fig. 10). 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.

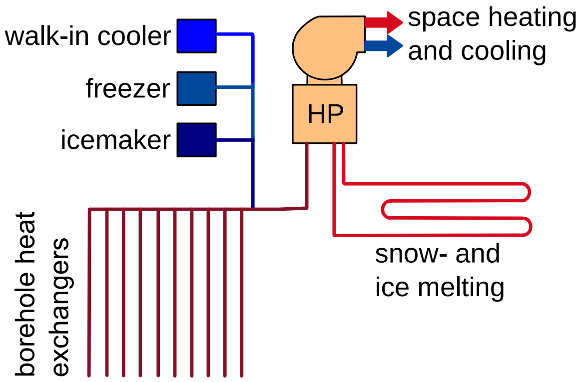

Fig. 10: Schematic of ground source system for filling station in USA

Further Philipps 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). 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. 11). Typical values range between 40-70 W/m, dependent upon geology (thermal conductivity), annual hours of heat pump operation, number of neighbouring boreholes, etc.

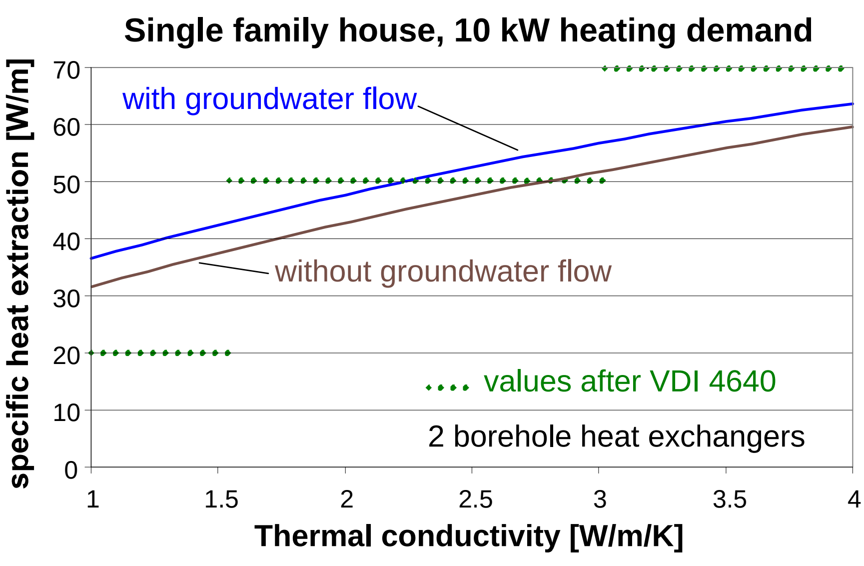

Fig. 11: Example of specific heat extraction values for a small ground source heat pump, no domestic hot water (heat pump run time 1800 h/a); VDI 4640 is a German guideline for ground source heat pumps

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. To get reliable input parameters for such calculations, the Thermal Response Test has been developed (fig. 12). This test allows determination of thermal parameters of the underground on site.

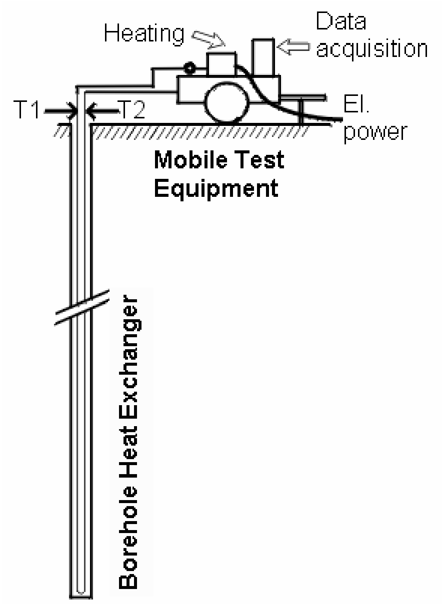

Fig. 12: Schematic of Thermal Response Test and the equipment on site

A special case of vertical closed systems are „energy piles", i.e. foundation piles equipped with heat exchanger pipes (fig. 13). All kind of piles can be used (pre-fabricated or cats on site), and diameters may vary from 40 cm to over 1 m.

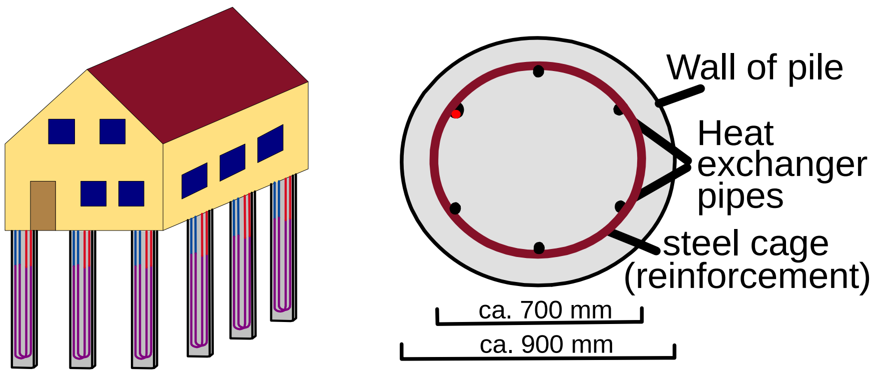

Fig. 13: Energy piles and cross-section of a pile with 3 loops

Umwelt Baugrund Geothermie Geotechnik

Other systems

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

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 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. 14) 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.

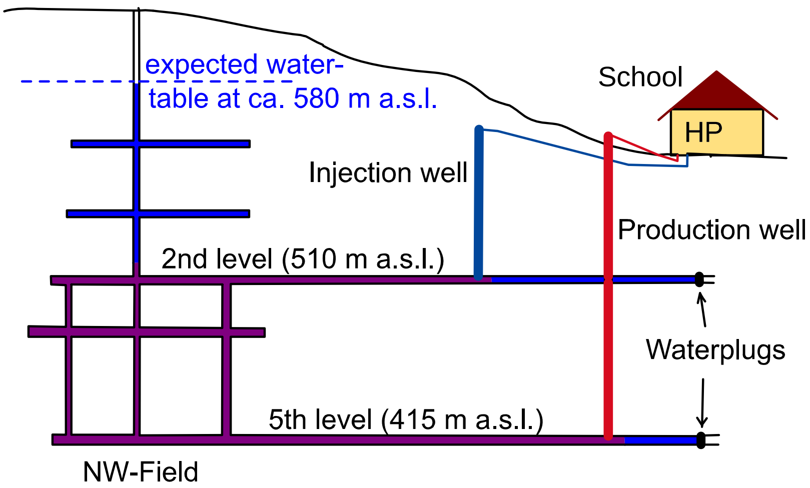

Fig. 14: Heat pump using mine water (example of Ehrenfriedersdorf, Germany, with abandoned tin mine)

UNDERGROUND THERMAL ENERGY STORAGE (UTES)

In UTES, heat, cold or both are stored in the underground. The methods of ground coupling (fig. 15) are essentially the same as for ground source heat pumps, with open systems (ATES) and closed systems (BTES).

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, sand-stone, 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. 15: Types of Underground Thermal Energy Storage and geological preferences

Cold storage is starting to become very popular, because cost for space cooling normally are rather high. They use cold air in winter to cool down the underground store and use this cold again in summer. In the 60s, China was a major pioneer in this field, with a number of plants in the Shanghai area (fig. 16).

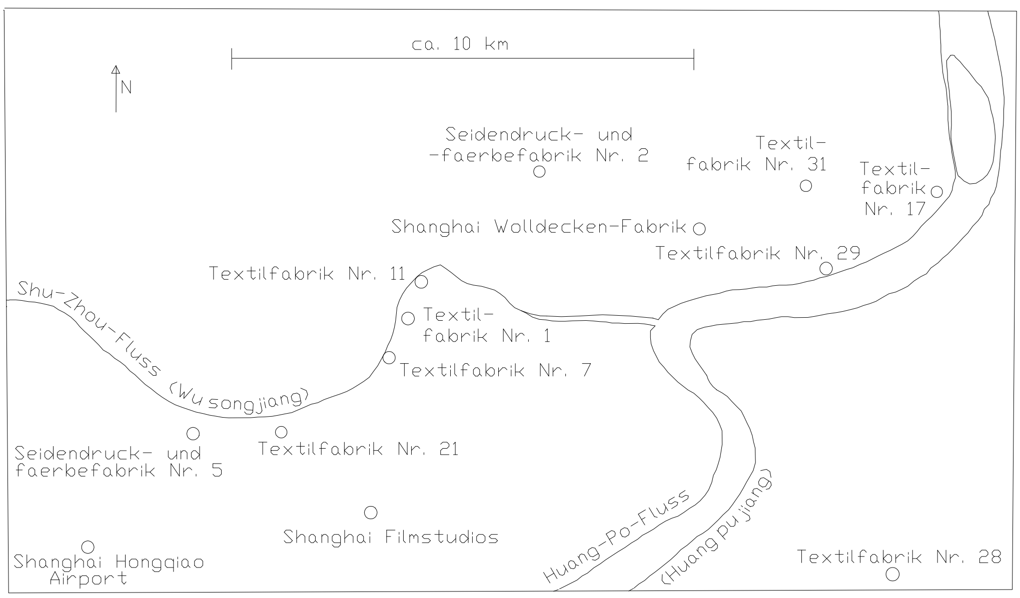

Fig. 16: Aquifer Cold Storage systems in Shanghai (status 1991)

A combination of heat and cold storage is the connection of road surfaces to an UTES (fig. 17). 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.

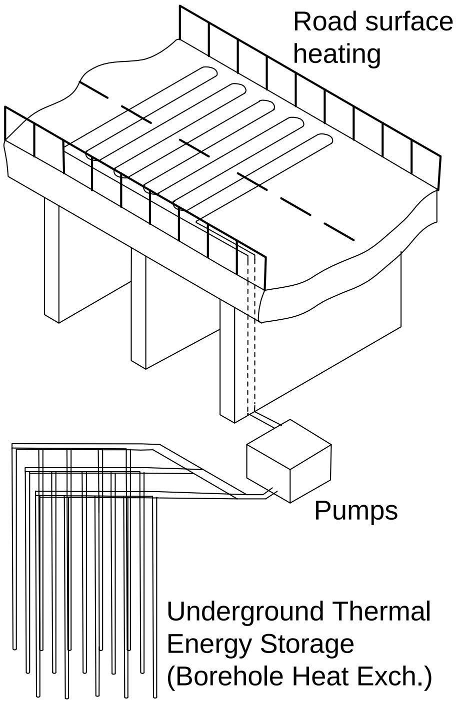

Fig. 17: UTES for de-icing of road surfaces

Heat Storage can make use of solar or waste heat in summertime to use it 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 (fig. 18). The Berlin plant supplies heat and cold to the German Parliament buildings (Reichstag buidling 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.

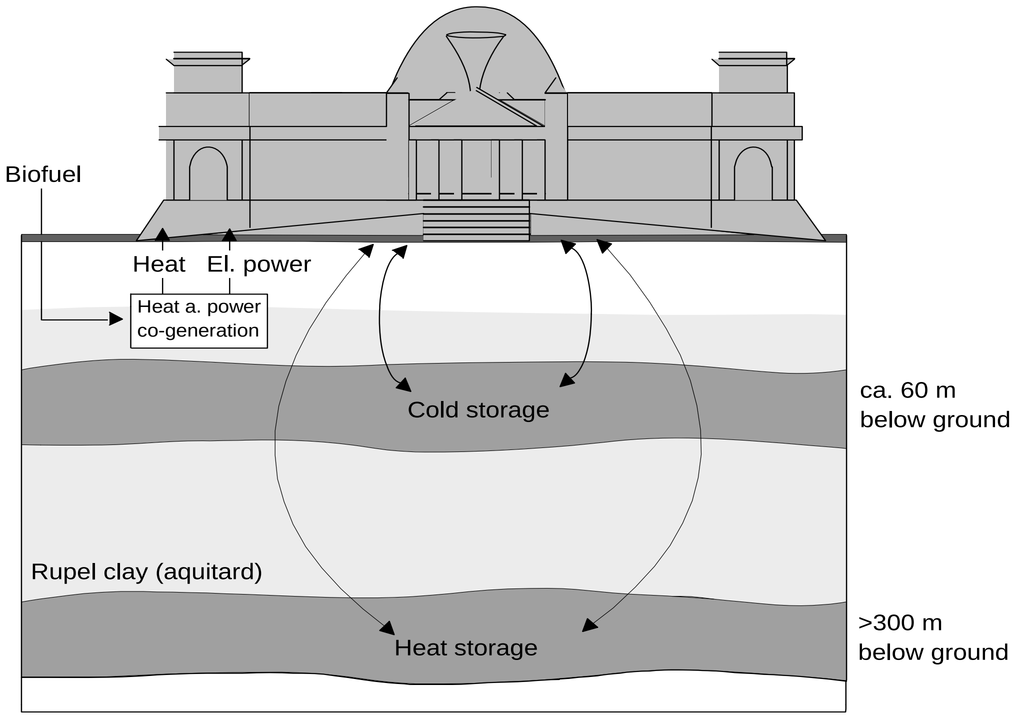

Fig. 18: Schematic of Berlin Reichstagsgebäude ATES (not to scale)

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. For China, good opportunities for use of this technology can be seen mainly in the commercial sector (offices, factories, department stores, etc.), where heating and cooling is required.