GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

IGC2003 - Short Course
September 2003

Integrated use of geothermal and other renewable energy sources - heat pumps, solar thermal, combined heat and power

Burkhard Sanner
Institute of Applied Geosciences, Justus-Liebig-University
Giessen, Diezstrasse 15, D-35390 Giessen, Germany
email: burkhard.sanner@geolo.uni-giessen.de

1 Introduction

Geothermal energy is per definition in Germany "the heat stored beneath the surface of the solid earth". So all systems, independent of their depth and of the origin of the heat, here are considered as geothermal. This is consistent with other definitions. Coal originally was considered solar energy (through photosynthesis), but is now considered fossil fuel. With this broad range in depth and, in consequence, temperature, several usage characteristics in the heating sector can be distinguished:

- Deep geothermal plants (mainly hydrogeothermal) with temperature high enough for direct heating.
- Deep geothermal plants with lower temperature and heat pumps.
- Deep geothermal plants in combination with other heat sources (other than peak boilers, which are common in any system).
- Deep geothermal plants with storage of heat to increase production temperature.
- Deep geothermal plants with heat and power co-generation, with temperatures of ca. 100°C and more.
- Shallow geothermal plants with heat pumps for heating (and cooling).
- Shallow geothermal plants for storage of solar or waste heat.

This manuscript shows realized examples of the aforementioned system concepts.

2 Geothermal district heating

2.1 Hydrogeothermal projects for heating only

Geothermal district heating is a rather well-known technology. In most cases a doublet system is used (Figure 1), allowing for re-injecting the thermal water. This may be necessary to keep the aquifer pressure, but also to get rid of saline water which would be a pollutant at the surface. The heat is extracted through heat exchangers and, if higher energy yield is desired, with heat pumps.

A plant that makes as much use of the geothermal source as possible is located in Riehen in Switzerland. The site is to the northeast of Basel, directly at the German border; two wells ca. 2,000 m deep exploit an aquifer in fractured Triassic limestone (Muschelkalk). The system schematic is given in Figure 2; the geothermal loop is kept as short as possible, and the following heat usage steps exist in Riehen:

- Direct heat exchanger.
- 2 electric compression heat pumps, powered by heat-and-power-co-generation (CHP).
- Small air-to-water heat pump to retrieve the heat from the motor room.

The plant in Riehen meanwhile not only supplies heat to the district heating of the town, but also to the Stetten area of the city of Lörrach, across the border in Germany.

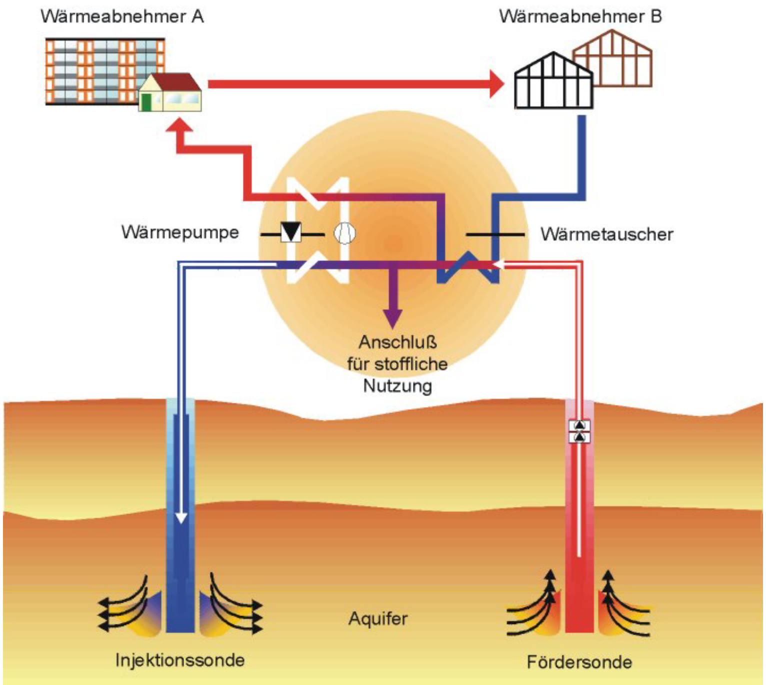

Figure 1: Generic scheme of a hydrogeothermal doublet (source: GTN, Neubrandenburg).

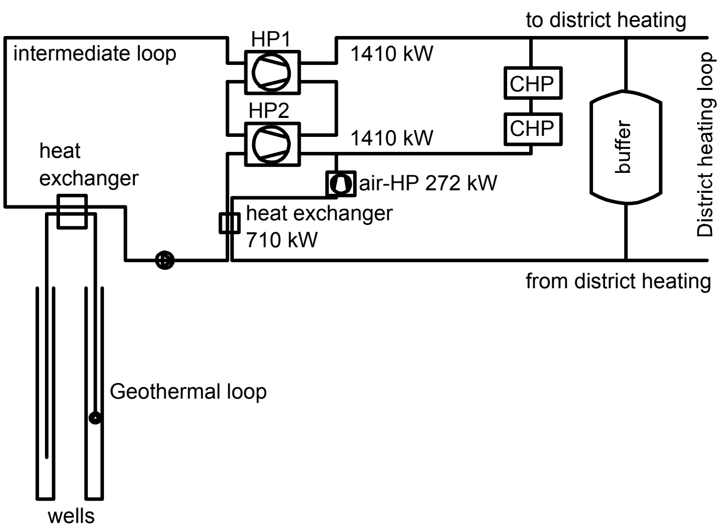

Figure 2: Schematic of Riehen geothermal district heating, Switzerland.

Another cross-border geothermal district heating system exists in the cities of Simbach (Germany) and Braunau (Austria). Here, the wellheads are on the German side, with a deviated well reaching beneath Austrian ground (Figure 3). The district heating connects both cities, with a pipeline over river Inn.

Many more plants for geothermal district heating exist in Europe, mainly in the Aquitaine and Paris basins of France, the North German – Polish basin, the Molasse basins to the North and South of the Alps, and the Pannonian basin with Hungary and the neighbouring countries. A substantial number of geothermal district heating plants also exist in Turkey.

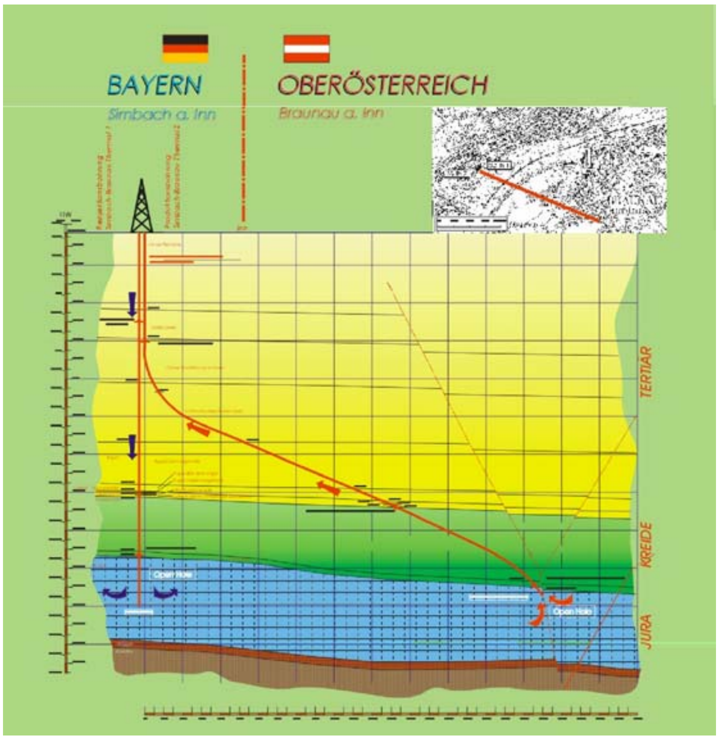

Figure 3: Geological cross-section of the Simbach-Braunau geothermal district heating system (source: Geoteam, Gleisdorf; altered).

2.2 Example of geothermal district heating combined with waste incineration

A combination of this type has been operational in Italy since 1990, in the city of Ferrara in the Po-plain. A well intended for oil exploration in the Molasse basin south of the Alps already yielded water of about 100°C from depths between 1,000-2,000 m in 1956. However, not before the oil price crisis in the 1970s, the thermal energy contained in that water was considered useful. The old well Casaglia 1 was opened again, and a new well (Casaglia 2) was drilled down to 2 km to re-inject the saline water.

In 1983, the city of Ferrara could start the construction of a district heating network, supported by the Italian state, and in 1990 the first geothermal heat could be supplied to the customers. To achieve sufficient yield, a third well (Casaglia 3) was drilled, and a combined production of ca. 400 t/h could be achieved from two wells (Figure 4). The heat is transfered to the district heating circuit via plate heat exchangers made from titanium (Figure 5). An insulated pipeline transports the district heating water to and from the heating plant at the outskirts of the city, over a distance of about 2 km.

The heating plant is located beside a waste incineration station of the Ferrara city utility with a thermal output of about 9.3 MW. In total, there are 3 heat sources that together cover the demand of the district heating:

- Geothermal heat ca. 60 %
- Waste incineration ca. 20 %
- Peak boilers fuelled by natural gas ca. 20 %

Four large tanks (2 for hot supply and 2 for cooler return water) are needed to balance the different suppliers and the varying demand. The supply temperature is 95°C, with 60°C return. A total of 58,000-64,000 MWh of heat are supplied per year to the district heating. A project supported by the European Union is destined to optimize the operation strategy and the control system of the network, to allow for higher efficiency and even higher geothermal share.

The heating network covers a large area alongside the central axis of the city, including the parts of the medieval city centre. The system contributes largely to a reduction of emissions, avoiding in 1997 about 28 tons of NO_x and ca. 42 tons of SO_2, while saving at the same time 6.5 million.m^3 of natural gas and 3,500 tons of fuel oil.


Figure 4: Ferrara geothermal district heating, Italy. Left: Castello d´Este in the city centre, a symbol of Ferrara. Right: Head of one of the production wells (photos: O. Joswig).


Figure 5: Ferrara geothermal district heating, Italy. Left: Plate heat exchanger. Right: Hot-water storage tanks beside the waste incineration station (photos: O. Joswig).

2.3 Geothermal district heating linked to CHP

The combination of a geothermal district heating with a large plant for heat and power co-generation (CHP) is under completion in the city of Neubrandenburg in the northeastern part of Germany. After study and design started in 1997, the reconstruction of the plant began in 2002, with completion scheduled for late summer 2003.

The project has been built around the basis of the thermal water circuit of the geothermal heating plant Neubrandenburg, which from 1987 until 1998 supplied heat to the quarters

„Rostocker Straße“ and to a school for disabled persons, using a large heat pump to increase temperature from the thermal water level to the heating circuit level (see Figure 6). Of the original 4 wells with about 1,400 m depth, for the new design only 2 wells at 1,300 m distance are kept, with the depth reduced to 1,200 m and 1,300 m deep, respectively, and a flow rate of max. 100 t/h.

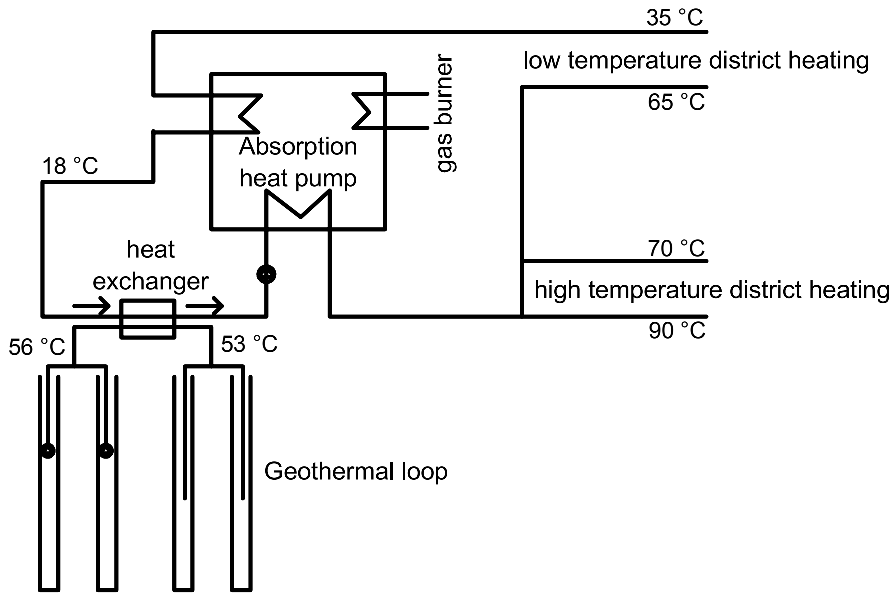

Figure 6: Schematic of the geothermal district heating plant in Neubrandenburg, Germany, before re-building into a deep thermal storage plant in 2002/03.

In the new scheme, the system is coupled to the CHP plant to store surplus heat during summer operation with a storage loading temperature of about 80°C, thus increasing the geothermal production temperature. The CHP plant has gas and steam turbines and an electrical output of 77 MW_{el}. The goal is to retrieve, for heating purposes in wintertime, about 8,800 MWh of the 12,000 MWh of waste heat stored during summer (storage efficiency 73 %). The underground thermal energy storage will cover the basic load of a district heating system with 12 MW; the design temperatures are 80°C supply and 45°C return.

2.4 Geothermal heat and drinking water supply

Two geothermal district heating systems have been built in such a way that the thermal water can be used as drinking water, after having given the thermal energy to the district heating. A condition for this is a good fresh water quality, and hygienic design and construction of the thermal water circuit. The plant in Erding, Germany, with water of ca. 55°C, uses an absorption heat pump to cool the water to ca. 20°C. It then can be mixed with other water and supplied to customers. The Erding plant is constructed that way, but has mainly been run for heating only, because the water utility refrained mostly from using this source. A similar system exists in Mszczonow in Poland, with 45°C water temperature and ca. 2 MW thermal output.

Seawater de-salination is a means of water supply on some islands and coastal areas in arid climates. A pilot plant is in the design and field study phase on the Greek island of Milos; Figure 7 shows the principle.

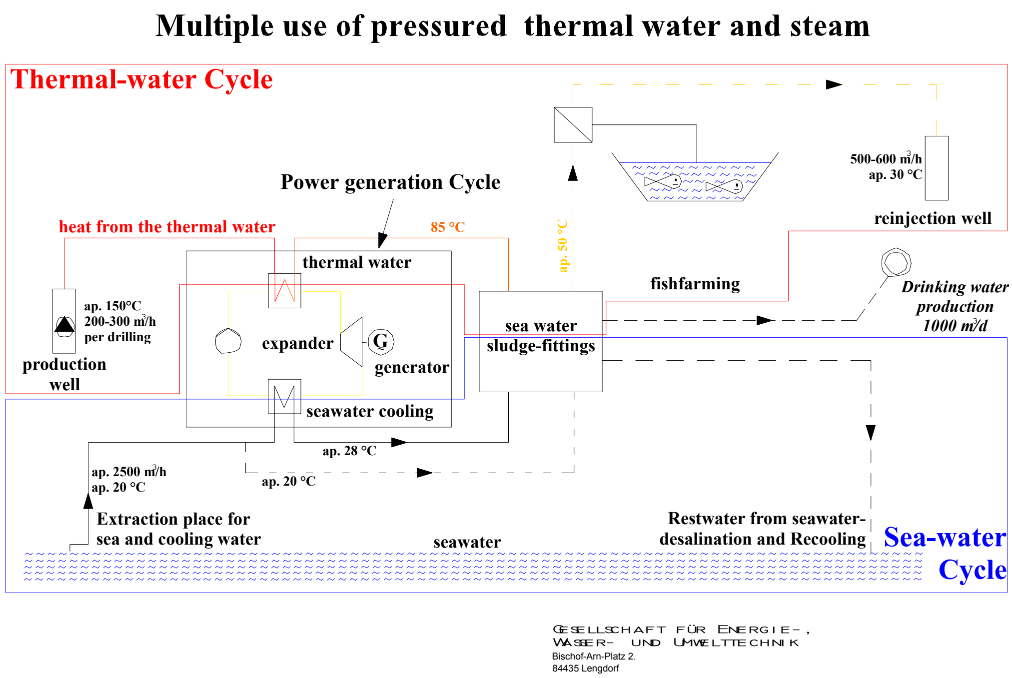

Figure 7: Schematic of an integrated geothermal plant for power generation and seawater-desalination (source: Terrawat, Lengdorf; altered).

3 Ground source heat pumps

Geothermal Heat Pumps, or Ground Source Heat Pumps (GSHP), are systems combining a heat pump with a ground heat exchanger (closed loop systems), or fed by ground water from a well (open loop systems). They use the earth as a heat source when operating in heating mode, with a fluid (usually water or a water-antifreeze-mixture) as the media transferring the heat from the earth to the evaporator of the heat pump, utilising that way geothermal energy. In cooling mode, they use the earth as a heat sink. BHE geothermal heat pumps can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. More than 20 years of R&D focusing on BHE in Europe resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. Recent developments are the Thermal Response Test, which allows in-situ determination of ground thermal properties for design purposes, and thermally enhanced grouting materials to reduce borehole thermal resistance.

For cooling purposes, but also for the storage of solar or waste heat, the concept of underground thermal energy storage (UTES) could be proven successful. Systems can be either open (aquifer storage) or can use BHE (borehole storage). While cold storage meanwhile is established on the market, heat storage, and in particular high temperature heat storage (>50°C) still is in the demonstration phase.

Despite the use of geothermal heat pumps for over 50 years now (first in USA), market penetration of this technology is still in its infancy, with fossil fuels dominating the market of heating of buildings, and air-to-air heat pumps dominating the market of cooling of buildings. In some countries, namely Germany, Switzerland, Austria, Sweden, Denmark, Norway, France and the USA, already larger numbers of geothermal heat pumps are operational. In these countries meanwhile, installation guidelines, quality control and contractor certification become major issues.

The climatic conditions in Central and Northern Europe, where most of the market development took place, are such that by far the most demand is for space heating; air conditioning is rarely required. Therefore, unlike the “geothermal heat pumps” in the USA, the heat pumps usually operate mainly in the heating mode. Only in very recent years are the installations of GSHP in Southern Europe, in particular in Greece and Western Turkey, on the way to exceed demonstration status, with the first pilot plant for GSHP with BHE in Greece, installed with Swiss technical support, dating from around 1993. With the inclusion of larger commercial applications, requiring cooling, and the ongoing proliferation of the technology into Southern Europe, the double use for heating and cooling will become of greater importance in the future.

3.1 GSHP technology status

Ground Source Heat Pumps (GSHP), or Geothermal Heat Pumps, are systems combining a heat pump with a system to exchange heat with the ground (Figure 1). The systems can be divided basically into those with a ground heat exchanger (closed loop systems), or those fed by ground water from a well (open loop systems). The means to tap the ground as a shallow heat source comprise:

- Groundwater wells ("open" systems).
- Borehole heat exchangers (BHE).
- Horizontal heat exchanger pipes (incl. compact systems with trenches, spirals etc.).
- “Geostructures” (foundation piles equipped with heat exchangers).

Experimental and theoretical investigations (field measurement campaigns and numerical model simulations) have been conducted over several years to elaborate a solid base for the design, and for performance evaluations of BHE systems. While in the 1980s, theoretical thermal analysis of BHE-systems prevailed in Sweden, monitoring and simulation were done in Switzerland, and measurements of ground heat transport were made on a test site in Germany.

A typical BHE-installation uses the earth as a heat source when operating in heating mode, with a fluid (usually water or a water-antifreeze-mixture) as the media transferring the heat from the earth to the evaporator of the heat pump, utilising in that way geothermal energy. In the cooling mode, they use the earth as a heat sink. For each kWh of heating or cooling output, they currently require 0.22 – 0.35 kWh electricity, which is 30%-50% less than the seasonal power consumption of air-to-air heat pumps, which use the atmosphere as a heat source/sink.

The ratio of useful energy over electricity consumption of a heat pump at given operating conditions is defined as the “Coefficient of Performance” or the COP. The COP depends on the temperature of the input water from the ground circuit, which depends on geological conditions (thermal and hydraulic parameters of the underground, climatic setting) and technical parameters (length and type of ground heat exchanger, material, type and quality of grouting, etc.). Other factors that affect the COP of a heat pump are the heating/cooling load, the type of the building heating/cooling system, and the relevant supply temperatures. Since at depths below ca. 10 meters, the ground temperature is constant throughout the year (depending upon prevailing weather conditions or ambient temperature), and increases slightly with depth beneath the ground surface, BHE show better performance and energy efficiency than horizontal ground heat exchangers.

In the USA, the Water-Source Heat Pump Engineering Committee conducted laboratory tests comparing efficiency ratings under the different standards for a variety of models. These results, which correspond to units with rated power less than 40 kW, indicate the existing ARI standards specify minimum COP for ground loop heat pumps: 2.5 for heating and 2.9 for cooling. The Committee’s recommended adjustment to the minimum efficiency requirements proposed for water-source heat pumps under ASHRAE 90.1 as of 2001 are 3.1 for heating and 3.9 for cooling for ground loop systems. Values from similar measurements in Europe, mainly in the Swiss heat pump test centre in Töss, already show substantially higher ratings. For a source temperature of 0°C, values close to COP = 5 can be achieved for 35°C heating supply temperature, and still values around COP = 3.5 for 55°C supply temperature (see Figure 8).

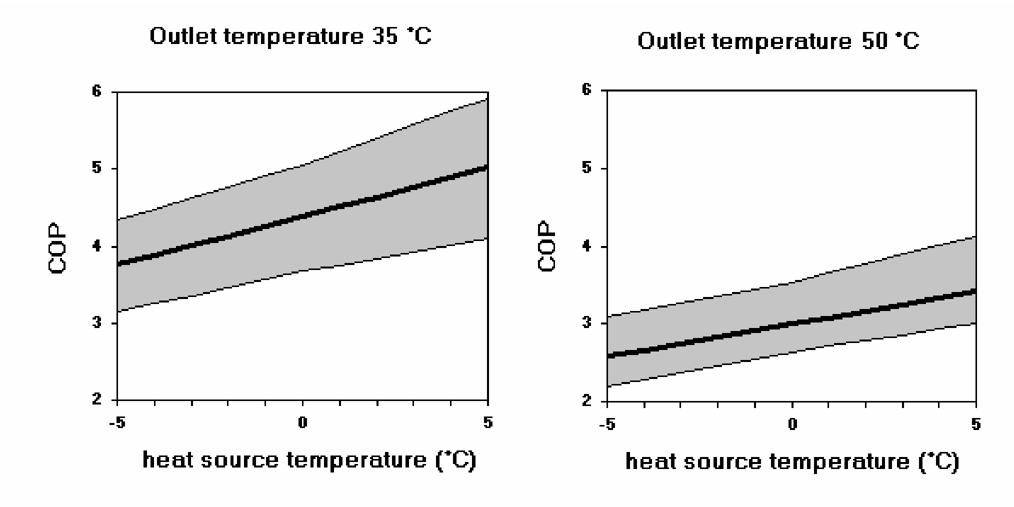

Figure 8: Values of COP for brine/water heat pumps (as used typically in geothermal heat pump systems), measured in the Heat Pump Test Centre Toess (extract from http://www.wpz.ch/).

Although the maximum COP of existing ground source heat pumps is around 4.5, their mean COP during operation is lower. This mean COP, usually called "Seasonal Performance Factor" (SPF), is defined as the mean COP during operation and varies at around SPF=3.0-3.8. In cases where high quality standards for all components of a geothermal heat pump system are applied, and also an optimum building heating system exists, values of SPF=4.0 can be achieved; in these cases usually no domestic hot water can be provided by the heat pump.

When using BHE, the required length for a given power output is highly dependent upon soil characteristics including temperature, moisture content, particle size and shape, and heat transfer coefficients. Correct sizing of the BHE continues to be a cause for continued design concern, and special attention should be placed on minimising interference between neighbouring BHE. Key points are building load, borehole spacing, borehole fill material, and site characterisation. Due to the high capital costs involved, over-sizing carries a much higher penalty than in conventional applications.

Two important technical developments of recent years should be mentioned in this respect:

- Thermal Response Test to determine the thermal parameters of the underground in-situ.
- Grouting material with enhanced thermal conductivity.

For a thermal response test, basically a defined heat load is put into the BHE and the resulting temperature changes of the circulating fluid are measured (Figure 9). Since mid 1999, this technology now also is in use in Central Europe for the design of larger plants with BHE, allowing sizing of the boreholes based upon reliable underground data. Thermal response tests were first developed in Sweden and the USA in 1995, and are now used in many countries world-wide, including Turkey. Together with reliable design software, BHE can be made a sound and safe technology even for larger applications.

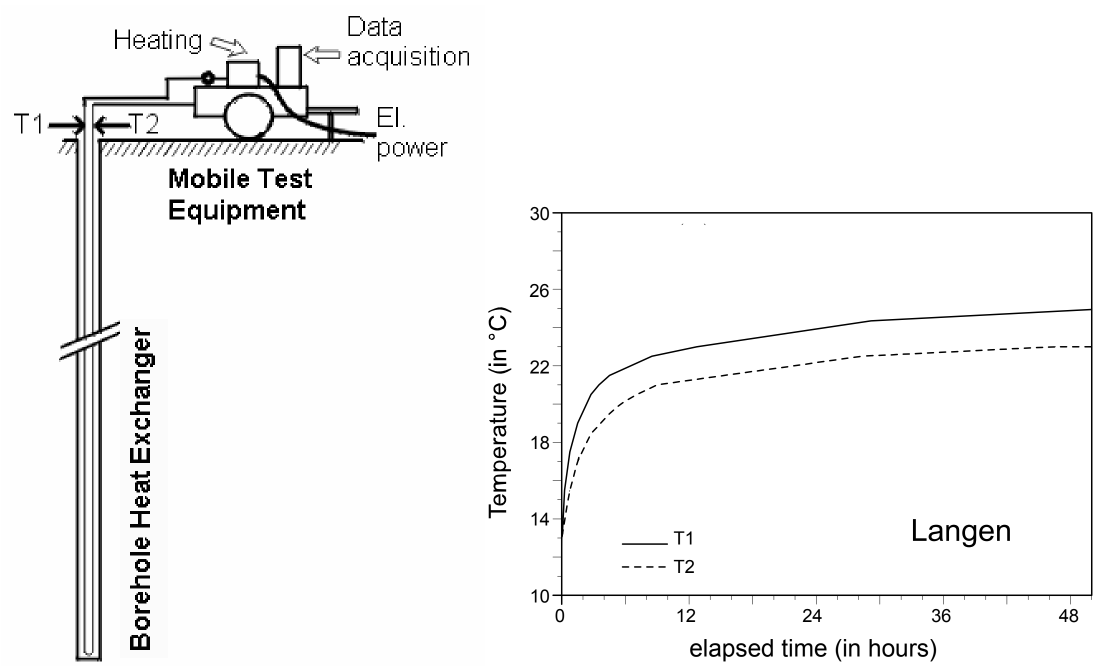

Figure 9: Left: Schematic of a Thermal Response Test. Right: Example of measured data from a Thermal Response Test.

Thermally-enhanced grouting material has been available in the USA for about 10 years. Meanwhile, also in Europe such material can be purchased. The advantage of its use is a significant reduction in the borehole thermal resistance (Figure 10), which governs the temperature losses between the undisturbed ground and the fluid inside the BHE pipes. The table in Figure 10 gives some values for typical BHE; the effect could meanwhile also be demonstrated in-situ, using the Thermal Response Test on BHE with different grouting materials.

Type of BHE	λ grout	r_b
single-U, PE	0.8 W/m/K 1.6 W/m/K	0.196 K/(W/m) 0.112 K/(W/m)
double-U, PE	0.8 W/m/K 1.6 W/m/K	0.134 K/(W/m) 0.075 K/(W/m)

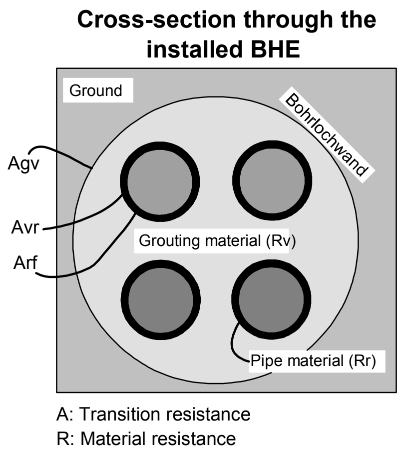

Figure 10: Left: Table with data for r_b for different grouting materials. Right: schematic of the concept of borehole thermal resistance r_b.

3.2 GSHP market opportunities and barriers

Problems often encountered with BHE design include inadequate address of flow, pressure drop and control parameters, leaks associated with corrosion of fittings, poor workmanship, as well as with the selection of pipe material and of the circulated heat transfer fluid. All of the above require the need for both a specialised engineer and a specialised contractor for the installation of ground source heat pumps, which is a significant barrier to their market penetration. In countries with higher sales numbers of geothermal heat pumps (e.g. Sweden, Switzerland or Germany), measures like technical guidelines, certification of contractors, quality awards etc. are beginning to be set into force to protect the industry and the consumers against poor quality and insufficient longevity of geothermal heat pump systems.

Existing geothermal heat pump features make them only suitable for their operation with low-temperature heating systems, which limits their application mainly to new buildings, and they are not designed to meet the high supply temperature demands of older heating systems already installed in many existing buildings all over Europe. The heat pumps which provide hot water feeding fan-coils, floor heating or low-temperature radiators, usually heat a water flow from 40°C to 45°C which circulates within the heating system of the buildings, with a max. temperature of 50°C. The higher the temperature of the supply water, the lower the COP of the heat pumps. Standard and maximum testing temperature values for liquid entering the indoor side in water-to-water systems are 40°C and 50°C, respectively as per ISO 13256-2, and a maximum of 55°C in some European guidelines.

The upper temperature limits encountered in commercially available heat pumps limit their application to low-temperature heating systems, such as fan-coils, low-temperature radiators or floor heating. However, traditional heating systems already installed in many buildings all over Europe, comprise a fossil fuel boiler and standard radiators, i.e. a high-temperature heating system. These systems with radiators have been designed in order to use hot water of 80-90°C with a temperature drop of 10-20°C. As commercially available heat pumps are designed to provide water up to 50°C or 60°C with a temperature drop of 5-6°C, their installation in existing buildings implies the complete replacement of the high-temperature heating system, namely the replacement of both radiators by fan coils or other advanced systems, and piping of the buildings by pipes of larger diameter. In recent times, the development of a heat pump capable of delivering 65°C water has been announced in Switzerland (SATAG/Viessmann; http://www.satagthermotechnik.ch/english/aktuell.htm); this can be regarded as an initial step towards addressing the retrofit market for older buildings.

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Figure 11 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 Figure 11). In general, it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland (Table 1). There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. The Swiss example with a real boom of installed capacity (Figure 12) may encourage others. Also, in Germany the trend is positive (Figure 13), with a share of GSHP (ground and water) of about 82% in 2002.

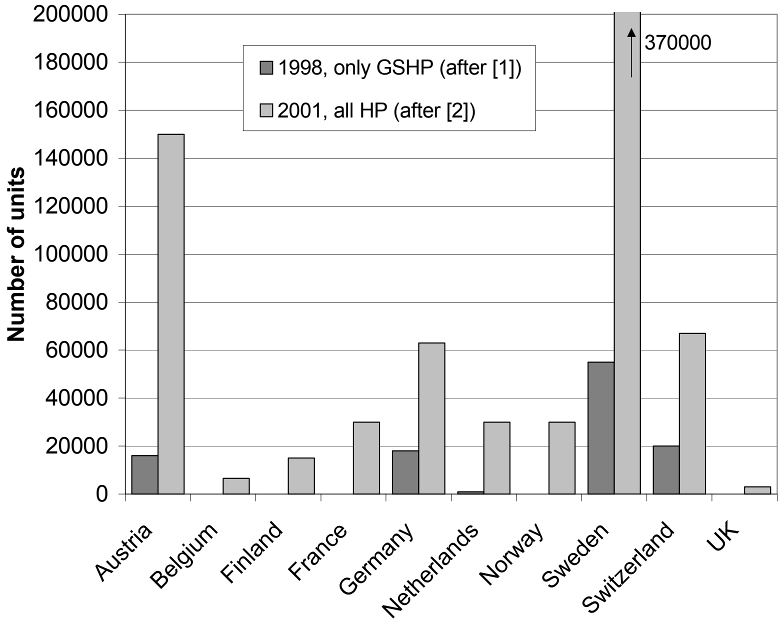

Figure 11: Number of installed heat pump units in some European countries, after data from Sanner, 1999 [1]; and Donnerbauer, 2003 [2].

Table 1: Share of ground-coupled heat pumps in total residential heating market in 1999, after data from IEA Heat Pump Centre (Van den Ven, 1999).

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

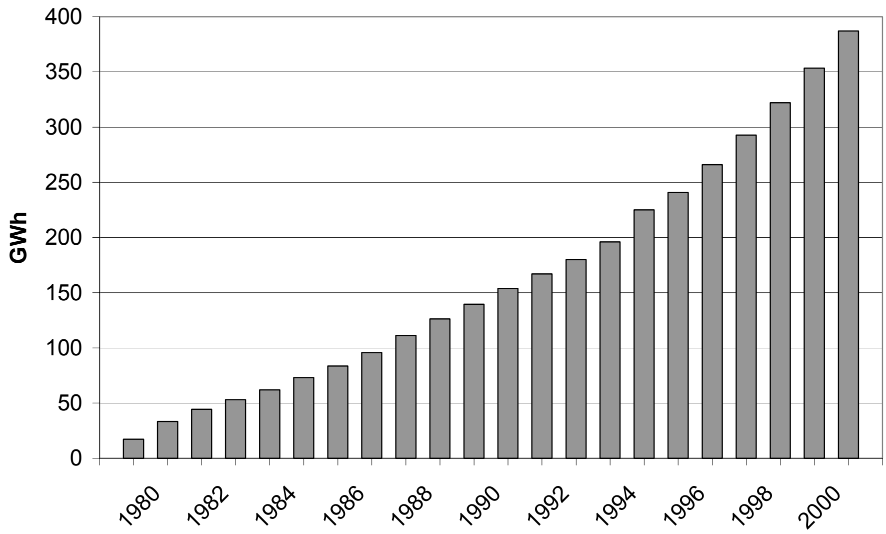

Figure 12: Compilation of geothermal heat production (before the heat pump) by BHE systems in Switzerland. The values are based on AWP sales statistics (AWP = Arbeitsgemeinschaft Wärmepumpen Schweiz). The compilation was commissioned by the Swiss Federal Office of Energy, Bern (Wilhelm and Rybach, 1999).

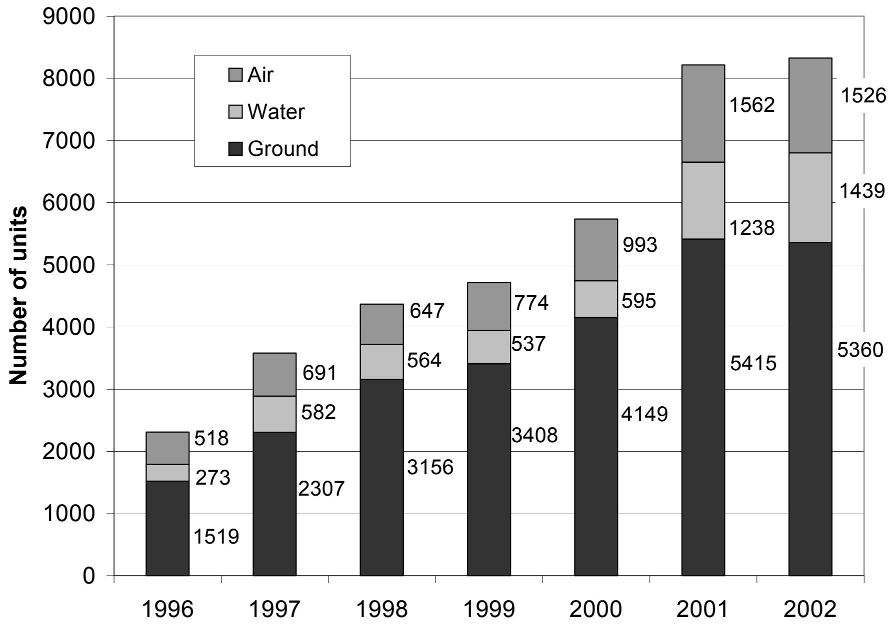

Figure 13: Number of annual heat pump sales in Germany, according to heat sources (after data from IWZ e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included).

3.3 GSHP examples

Some quite large examples of ground source heat pumps exist in Europe; two are mentioned here. For the new headquarters of the German Air Traffic Control (DFS) in Langen near Frankfurt, Germany (Figure 14), a system with 154 BHE was installed for heating and cooling. The ground provides the base load of ca. 330 kW in both heating and cooling, and has been operational since spring 2002. Figure 15 shows how the borehole heat exchangers are integrated in the system. The total building is designed as a low-energy-office, with good insulation, energy-saving appliances and light, etc.

Figure 14: New headquarters of DFS, heated and cooled by GSHP.

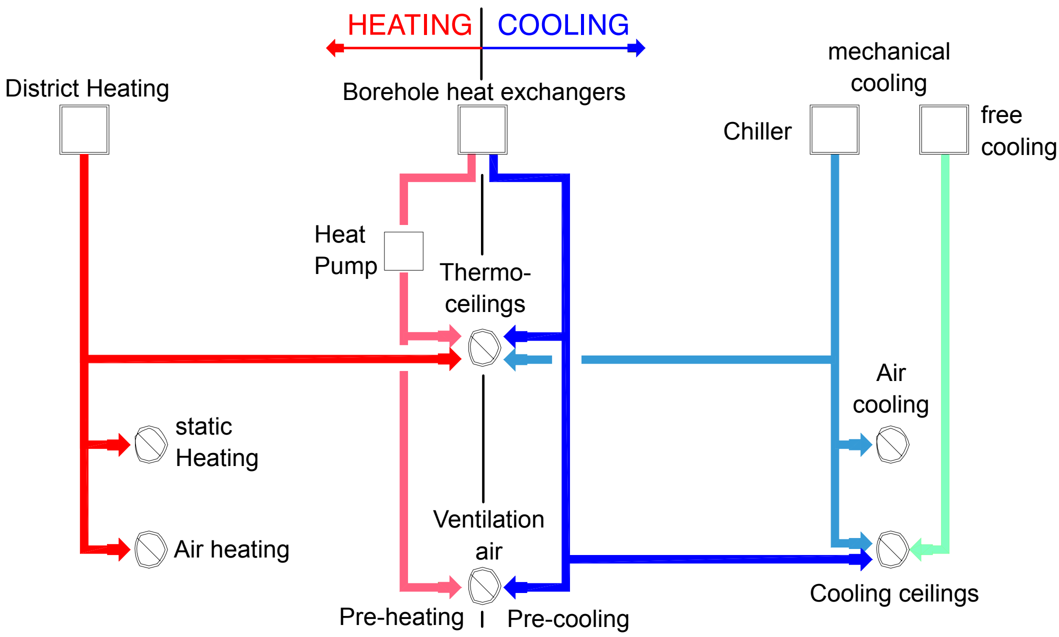

Figure 15: Schematic of the heating and cooling system in DFS, Langen.

Another example is in Nydalen, a site in the city of Oslo, Norway. Currently it is the largest BHE field in Europe, with 180 boreholes each 200 m deep, equipped with single-U-tubes in water-filled, open boreholes. Figure 16 shows part of the field. Still larger fields exist in the USA, where the GSHP-system for Richard Stockton College, in Pomona, NJ, with 400 BHE each 130 m deep just lost the lead to a new, even larger project in North Carolina.

Figure 16: BHE-field in Nydalen, Oslo, Norway, before completion of the buildings (May 2003).

4 Underground storage of heat

Three different basic types of Underground Thermal Energy Storage (UTES) can be distinguished (Figure 17); within the IEA Energy Storage Group. Terminology is in use as follows:

- ATES Aquifer Thermal Energy Storage - open system, using wells.
- BTES Borehole Thermal Energy Storage - closed system, borehole heat exchangers.
- CTES Cavern Thermal Energy Storage - underground man-made caverns.

Because geothermal techniques are used to achieve the necessary access to the underground, these systems should be mentioned here. Different heat sources can be used, of which only solar heat and waste heat are already realized. Also storage of geothermal heat has been suggested, but not yet done in practice (Figure 18). While storage systems using waste heat can come close to economic operation, the storage of solar heat still is way too expensive and has been done only in demonstration plants supported by public funds.

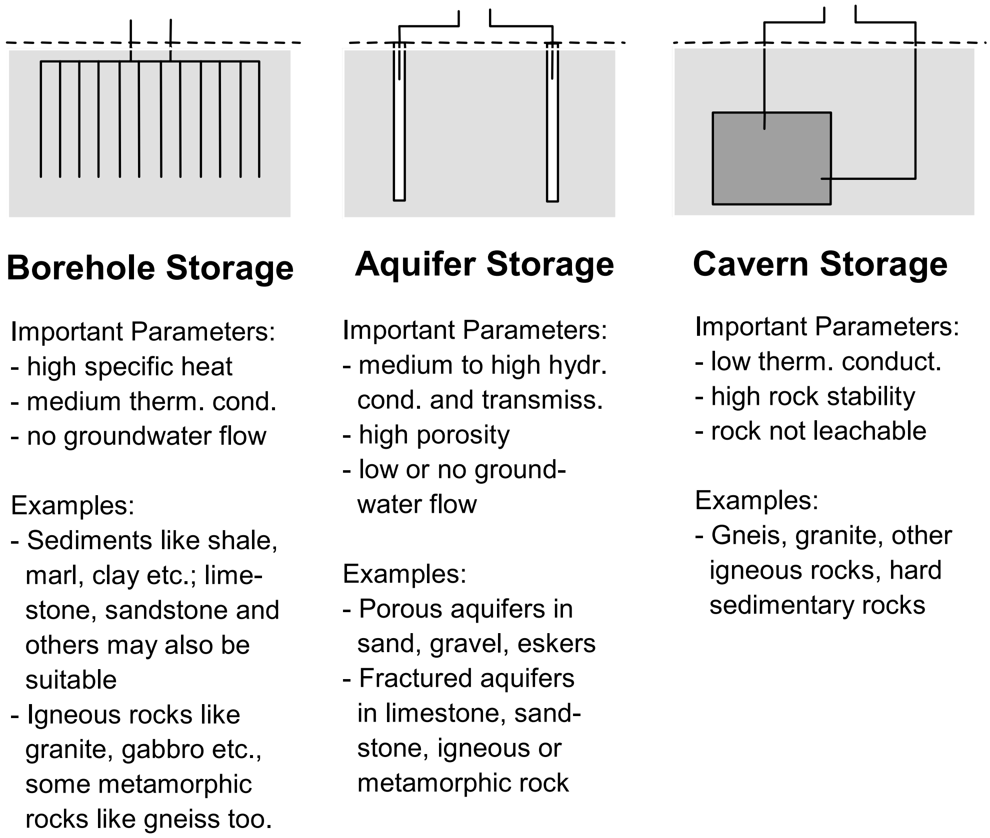

Figure 17: Different generic types of Underground Thermal Energy Storage.

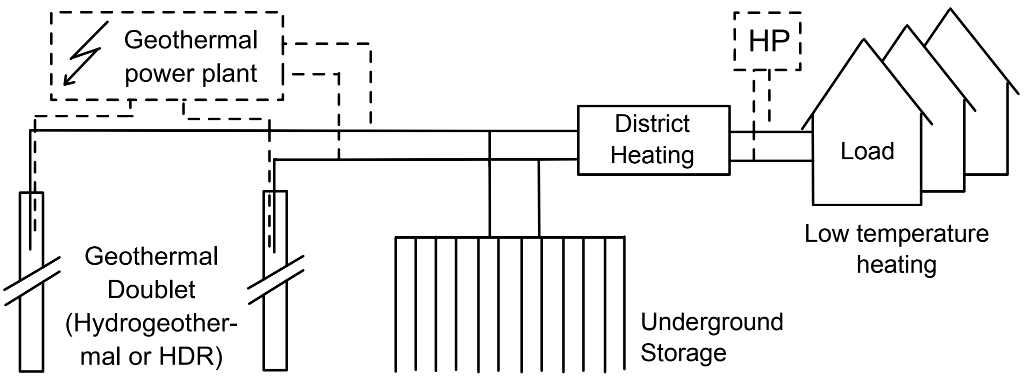

Figure 18: Suggested scheme for underground storage of geothermal heat, in order to increase full-load hours of the geothermal doublet.

4.1 Solar heat

Solar thermal energy in cold and moderate climates has one disadvantage. It is available in abundance during summertime, when no heating is needed, while solar radiation is quite limited in winter. In the search for improved solar heating systems, seasonal storage concepts have been developed to overcome this problem. Besides insulated water tanks, water-filled pits with insulating cover, and tanks with phase change materials, underground concepts for storing solar heat have been realized (Figure 19). Some examples exist, and the largest one, in the South-German city of Neckarsulm, is described here in more detail. Table 2 lists the currently operational solar heating systems using underground storage.

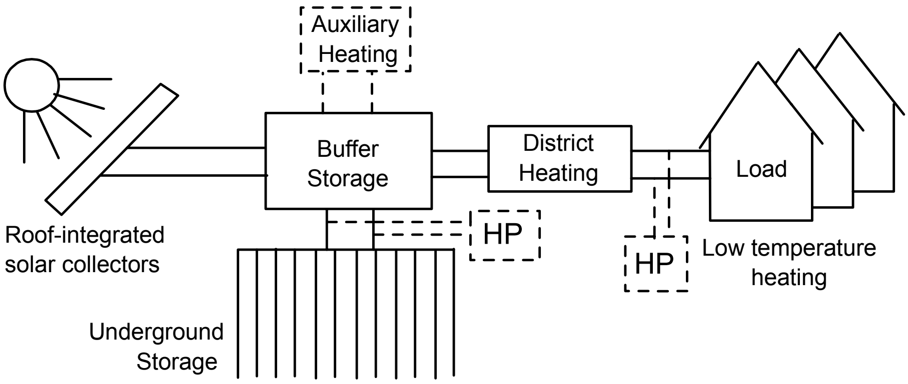

Figure 19: Basic concept of underground storage of solar heat.

Table 2: Existing solar heating systems with underground storage.

Amorbach	Neckarsulm, D	BTES, residential area with solar heat (meanwhile enlarged to >500 BHE)
Anneberg	Danderyd, S	BTES, residential area with solar heat
Attenkirchen	near Freising, D	BTES with central water tank, residential area with solar heat
Brinckmannshöhe	Rostock, D	ATES, apartment houses with solar heat
Groningen CSHPSS	Groningen, NL	BTES, residential area with solar heat, 360 BHE
Kullavik	near Göteborg, S	BTES, row-houses with solar heat
Lyckebo i Storvreta	near Uppsala, S	CTES, residential area with solar heat

The site of the Neckarsulm solar BTES is within a new residential area (Amorbach) in the northeastern part of the city. The project started in 1994 with geological investigations, continued with the completion of the first test store in 1997, and was enlarged in several steps to its current size of a total of 528 boreholes each 30 m deep, accessing a ground volume of 63,360 m³ (Figure 20).

Technical data:

- Borehole spacing 2 m in the first phase; 1.5 m (in the centre) – 2.5 m (at sides) in the second phase.
- Polybutene-double-U-pipes (25 x 2.3 mm) as borehole heat exchangers.
- Grouting: suspension of bentonite, sand, cement and water.
- Total storage volume 63,360 m³.
- Insulation 20 cm extruded polystyrene.

- Solar collector area: 6,450 m² (planned); 5,007 m² (installed).
- Storage supply temperature is up to 80°C.
- There are 18 additional boreholes for temperature measurement to monitor the thermal behaviour (incl. heat losses) of the heat store, 9 boreholes are also equipped for moisture measurements.

The store is part of a solar-assisted district heating system in a new building area with approximately 1,300 flats and terraced houses in the final stage, to be realized in the next years. A solar contribution of about 50% to the total heat demand (space heating and domestic hot water) is planned. The duct store is connected directly to the district heating network without a heat exchanger to avoid temperature drops (Figure 21). Peak load is covered by a gas boiler. Two buffer stores (water tank, each 100 m³) support the system to cover short-time load peaks and solar collector production peaks.

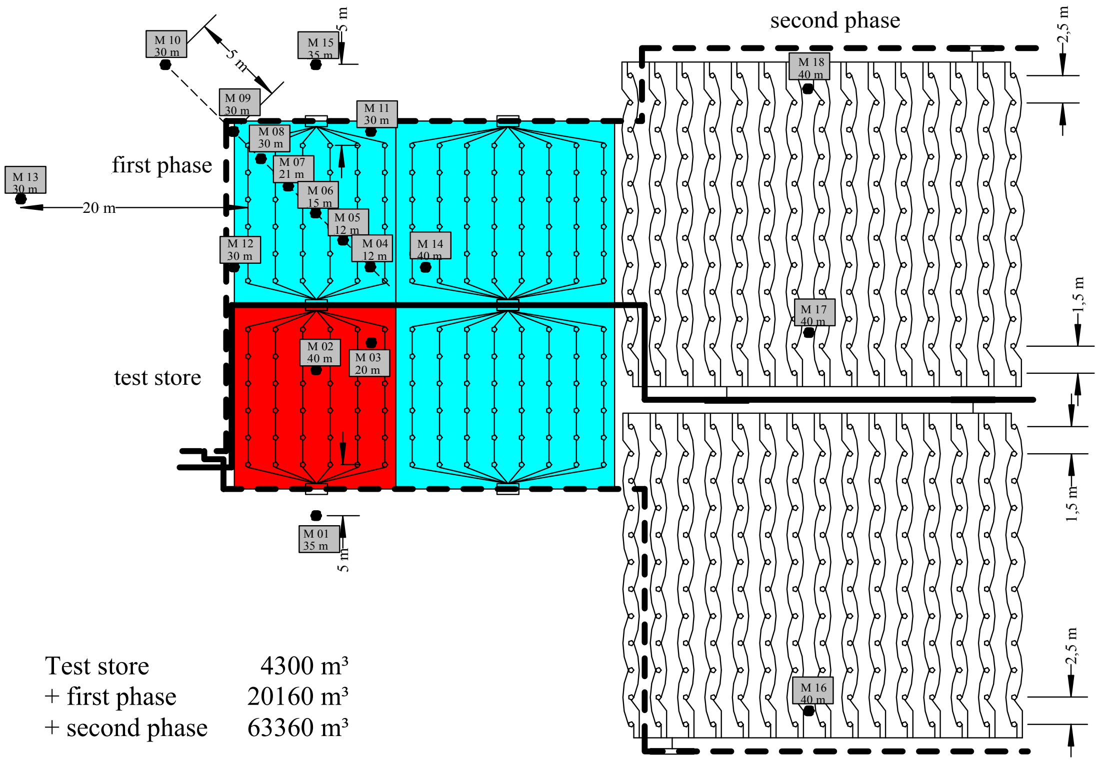

Figure 20: Plan of the borehole thermal energy store (since 2002) with location of the boreholes for temperature and moisture measurement (source: ITW, Univ. Stuttgart).

The store including the second extension (status as shown in Figure 20) is in operation since March 2002. During the year 2002, the test store and the first extension were not charged to adjust all parts to the same temperature. The temperatures in the ground are shown in Figure 22. 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 m². According to present simulations, a storage volume of about 150,000 m³ will then be necessary to achieve a solar fraction of 50%. 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 simultaneously increasing the collector area. The extension will take place in the eastern direction. 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.

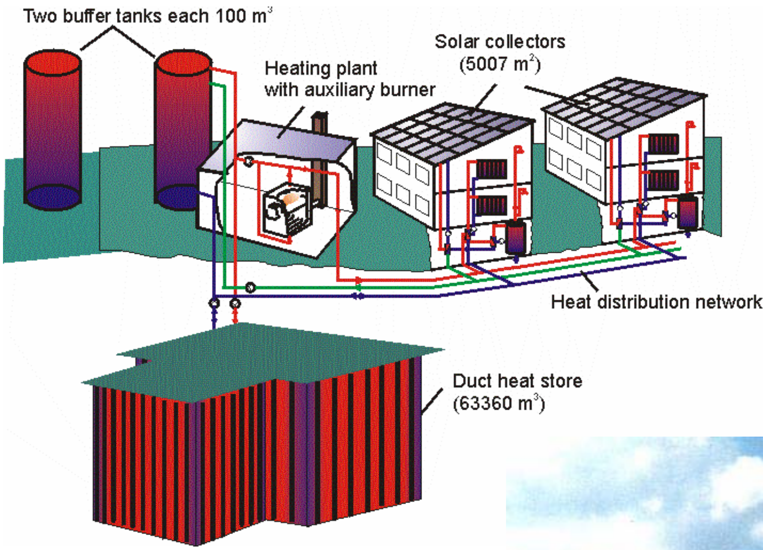

Figure 21: Schematic and photo of Neckarsulm solar district heating system. In the photo, to the left, is part of the solar collectors; in the middle chimneys of peak boilers; and to the right two buffer storage tanks (source: ITW, Univ. Stuttgart).

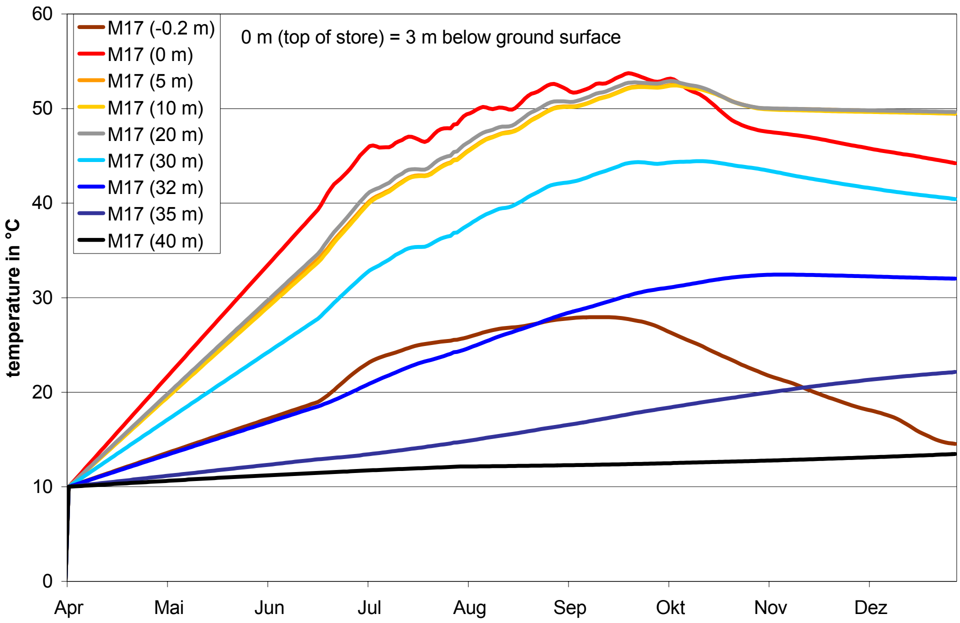

Figure 22: Temperatures in the ground in the middle of the second extension in the year 2002 (source: ITW, Univ. Stuttgart).

5 Geothermal heat and power in Central Europe

Even in low-temperature geothermal aquifers (about 100°C), the production of electric power is feasible, however, with quite poor efficiency. Hence such systems only make sense in combination with geothermal district heating. A few plants exist meanwhile or are under construction in Central Europe; two examples are given.

5.1 Geothermal heat and power plant Altheim, Austria

In the city of Altheim, Austria, only a few km from the German border, a geothermal district heating system has existed since about 1990, serving a circuit inside the town and one to the school and sports-centre (Figure 23). In 2000, a ORC-turbine with a 1MW generator was installed. The ORC-unit, developed by the Italian company Turboden, uses a non-flammable working medium because the site is just behind the town hall. The thermal water entrance to the system is 106°C, with a production rate of 81.7 kg/s (294 t/h). Figures 23 and 24 give more details of the plant.

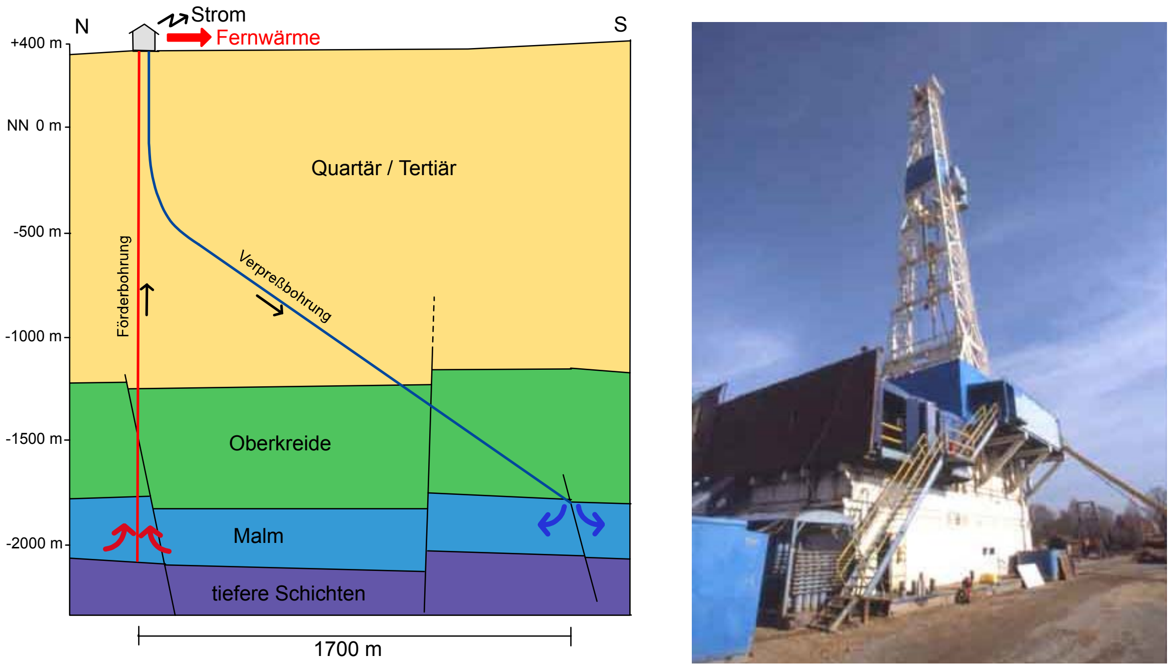

Figure 23: Geothermal power plant in Altheim, Austria. Left: geological cross-section, simplified. Right: drilling rig for the re-injection well (deviated) (photo: O. Joswig).

5.2 Geothermal district heating Neustadt/Glewe to be equipped with power station

The geothermal district heating with the highest production temperature (95-98°C) inside Germany exists in Neustadt-Glewe. The plant (Figure 26) has supplied district heating and process heat to a factory since 1992. Two vertical wells of more than 1 km distance reach a depth of ca. 2,800 m. The addition of a small ORC-turbine (ca. 250 kW) is underway, with the official inauguration scheduled for November 2003.

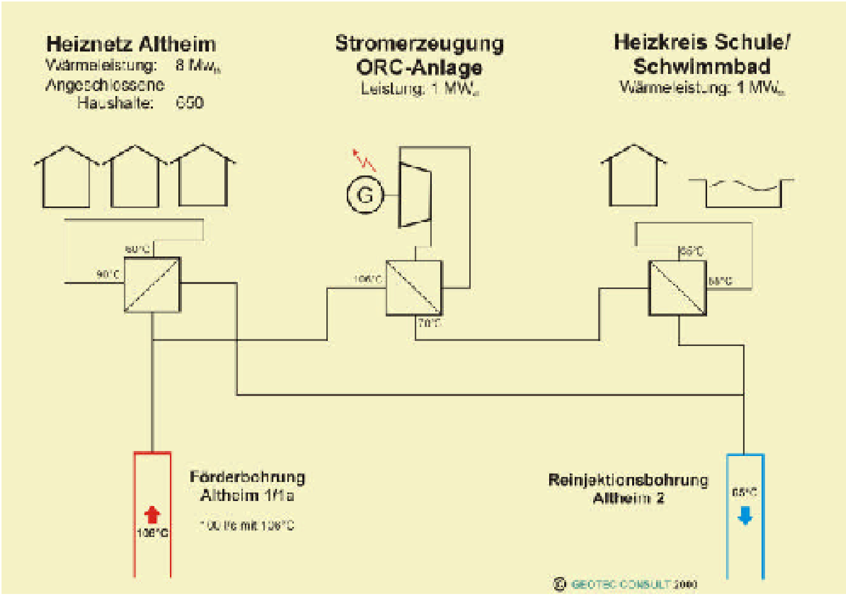

Figure 24: Schematic of Altheim geothermal heat and power plant (source: Geotec, Marktschwaben).

Figure 25: Power plant building and evaporator/condenser of the ORC-circuit in Altheim (photo: O. Joswig).

Figure 26: Geothermal district heating plant Neustadt-Glewe, central building with control, heat exchangers, district heating circuit pumps and peak boilers (photo: O. Joswig).

6 References

Donnerbauer, R. (2003). Neuer Trend: Vom Boden an die Wand. – VDI-Nachrichten 16/2003, p. 11, Düsseldorf).

Sanner, B. (1999). Prospects for ground-source heat pumps in Europe. – Newsletter IEA Heat Pump Center 17/1, pp. 19-20, Sittard.

Van den Ven, H. (1999). Status and trends of the European heat pump market. Newsletter IEA Heat Pump Center 17/1, 10-12.

Wilhelm, J., and Rybach, L. (1999). Statistik der Erdwärmenutzung in der Schweiz 1990-1997. Geothermie CH Vol. 9/Nr. 23, 5.