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Examples of GSHP and UTES Systems in Germany

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ABSTRACT

Despite the difficult economic situation for Germany in the beginning of the 21st century, a substantial number of medium to large geothermal heat pump plants has been realised, and the interest still is growing. The fact that modern office buildings usually require cooling, even in the moderate German climate, enhances the economic chances of shallow geothermal installations drastically. Ground coupling is usually done by either borehole heat exchangers (BHE, or "vertical loops" in US terms) or by groundwater wells, but also energy piles are present. The building types include schools, small and large offices, a specific "low energy office" combined with one of the largest BHE fields within Germany, commercial buildings like warehouses, a sports hall, etc. Some of the systems are designed in such a way that the underground temperature is influenced intentionally, and thus qualify as Underground Thermal Energy Storage.

Proven design procedures, including in-situ measurements and simulation, are used to guarantee trouble-free long-term operation. In most cases of commercial GSHP, the possible cooling load is the key factor for layout and for the potential economic and ecological benefits. The paper explains the development of such systems and gives some general numbers, and then focuses on certain successful examples.

INTRODUCTION

To begin, some abbreviations should be mentioned, which are used frequently throughout this text:

- GSHP Ground Source Heat Pump (a.k.a. Geothermal Heat Pump)
- BHE Borehole Heat Exchanger (in USA, the term "Vertical Loop" is common)
- UTES Underground Thermal Energy Storage (with ATES and BTES for aquifer and borehole heat exchanger storage, resp.)

In Germany, the heat pump market showed a rather strange development (fig. 1). After a boom in 1980, a strong decrease could be seen with a minimum around 1990. The reason for that was the second oil price crisis, pushing heat pumps on the market without the necessary industrial and professional infrastructure for their manufacturing and installation. The vast majority of this heat pumps used air as a heat source, and usually was incorporated in older systems with existing boilers or in new ones with peak boilers. The problems with quality and correct system integration lead to a crash of the market, long before the oil price decreased again (fig. 1). Well into the late 90s the heat pump in Germany had to cope with the image of a non-reliable technology.

Among the heat pumps in this first boom around 1980 were only very few GSHP with BHE (see below as an example the project Verolum). The majority were air-source heat pumps. A reliable statistic distinguishing between heat sources started in 1996. Since then we can see a steady increase in GSHP (fig. 2). Guidelines, quality certificates, etc. are existing or under development to keep the quality of work and thus the satisfaction of the consumer high, and to prevent another sales crash like in 1981-1986. The neighbouring countries of Austria and Switzerland did, by the way, not experience this sales crash.

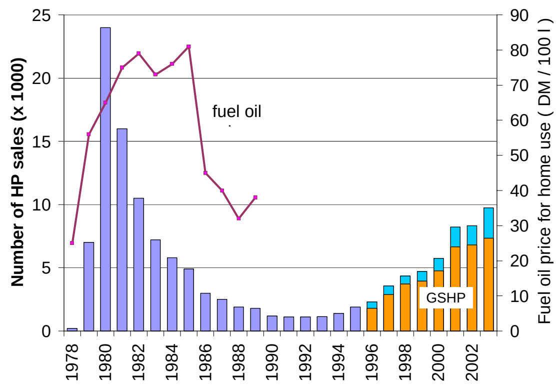

Figure 1: Heat pump sales in Germany from 1978-2003; from 1996 onward a distinction is made between air- and ground-source heat pumps (after data from Zaugg, 1993, and statistics from BWP)

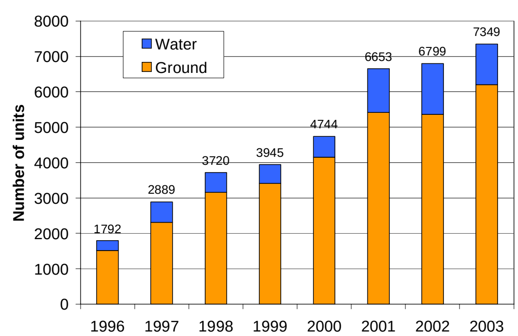

Figure 2: Ground-source heat pump sales in Germany from 1996-2003 (after statistics of BWP)

TYPICAL DESIGN AND CONSTRUCTION PROCEDURE FOR LARGER GSHP PLANT

For a larger GSHP plant, some site investigations have to be done first to get the basic data for design calculations. Depending on the uncertainties in the knowledge of the underground and on the size of the project, a preliminary test drilling may be required. This borehole is either equipped with a BHE or, in case of a groundwater system, completed as a well, and later can become part of the final energy system (fig. 3). The cost for a single borehole in advance of a whole borehole field are usually slightly higher than for the rest of the drilling work, and cost for testing has to be added, but this is worthwhile because the final design can be made closer to the real needs and without too large safety margins.

Figure 3: Test BHE at the site Wetzlar-Spilburg, ready for Thermal Response Test (photo Lund, June 2004)

For a BHE system, a Thermal Response Test is performed to determine the thermal conductivity of the underground (Sanner et al., 2005). In case of groundwater use, standard hydrogeological well testing is made. Usually, for these activities a permit from the authorities is required; for the testing phase it rarely is a problem.

With the knowledge of the underground parameter and the building load data, a design calculation can start. The building load data also have to meet some minimum requirements. For small projects, sometimes only the maximum heating and cooling load is given. Because, other than a natural gas pipeline or a fuel oil supplier, the earth has only a limited amount of heat and cold to offer for a given time period, the load distribution over the year has to be considered also. A typical example of suitable data, derived from a building simulation, is given in table 1. The data have been prepared for an energy optimisation of the project shown in figures 3-6. (see also table 5) The maximum building heating load is 290 kW, which for the GSHP means a heat extraction from the ground of 212 kW (evaporator capacity), while the maximum cooling load of 145 kW is achieved directly, without running the heat pump (principle see Sanner, 1990; Sanner et al., 1991)

Table 1: Monthly heat and cold on the ground side for Wetzlar example (data courtesy of GEFGA GmbH)

Month	Heating [KWh]	Cooling [KWh]
January	63718	432
February	52677	667
March	36469	3861
April	19276	14031
May	9761	20777
June	5199	23926
July	3586	28951
August	3619	21679
September	7320	15338
October	19560	6904
November	36011	2069
December	59665	292
total	**316860**	**138927**

In the example from Wetzlar, the thermal response test at the BHE (110 m deep, fig. 3) resulted in an average effective thermal conductivity of λ = 2,7 W/m/K, a typical value for the paleozoic sedimentary rocks on site. With the Software EED (Hellström & Sanner, 2001) the necessary number of BHE and the resulting fluid temperatures were calculated. The temperature development over the 25th year of operation is shown in fig. 4.; the number of BHE is 32 in a pattern of 4 x 8, the depth of BHE is 110 m. Drilling and installation of the remaining 31 BHE was done in autumn 2004 (fig. 5).

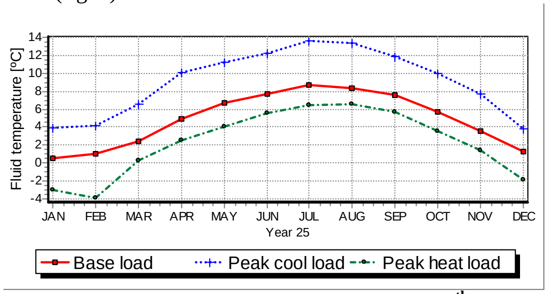

Figure 4: Fluid temperature curve for the 25th year of operation of the Wetzlar example, calculated with EED

Figure 5: Drilling of the 4th borehole for the plant in Wetzlar-Spilburg; an already installed and grouted BHE can be seen in the right foreground, the borehole field will extend towards the earth mound in the background (photo UBeG, Nov. 2004)

The design of a GSHP plant, the manufacturing and installation of BHE, as well as the connection to the building (example see fig 18) are governed in Germany by guideline VDI 4640, which also is used in some neighbouring countries (VDI, 2000-2002). For smaller plants with less than 30 kW heating capacity, simple tables can be used for design, for larger plants design calculations have to be made (EED meanwhile is a standard tool for that). For very large installations, e.g. for UTES, and also for other cases where groundwater flow is of substantial importance, numerical simulation using FD or FE techniques is done.

BHE should be prefabricated, with the welding at the footpart done under controlled conditions in a factory. One brand in Germany meanwhile is available without welding of the foot at all, the pipes are bend to a 180°-curve with a special procedure. BHE usually are made of polyethylene and can be delivered to the site in coils (fig. 6). Pressure testing for tightness is also a part of VDI 4640.

In most cases in Germany, and in general with BHE more than 50 m deep, grouting has to be done. A tremie pipe is used to grout the borehole from the bottom towards the top.

Thermally enhanced grout meanwhile is used in most cases (Sanner et al., 2005), some brands of pre-mixed grouting material are on the market.

Figure 6: Factory-made BHE in coils at the site in Wetzlar-Spilburg (photo UBeG, Nov. 2004)

The need for individual design of a large GSHP plant is highlighted by fig. 7. Because of different system concepts, resulting in a wide range of full-load hours per year or in different balances of heating and cooling, and because of the various ground conditions found throughout Germany, the total length of BHE for a given maximum heating or cooling capacity can be quite different. Only when site-specific ground conditions, building loads and operation strategy, and BHE number and pattern are all taken into account, a satisfactory design concept can result. Fig. 8 shows the same relation for the smaller plant (< 100 kW heating capacity) only; the fact that the deviation from the trend line is smaller with smaller plants also points to the impact of the system concept. The trend line corresponds for the GSHP ground side to an average heat extraction rate of ca. 35 W/m in fig. 7 and 42 W/m in fig. 8.

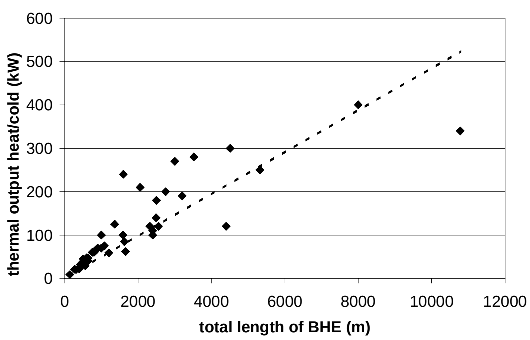

Figure 7: Heat pump heating (or cooling) capacity versus total length of BHE for the BHE-plants listed in tables 2 and 5

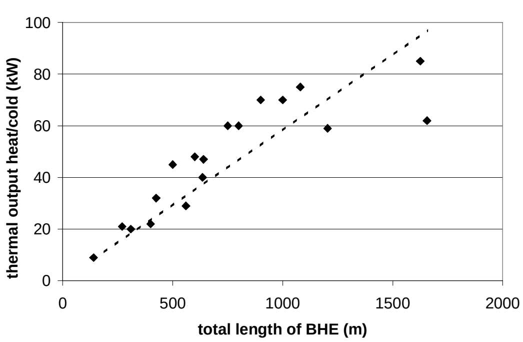

Figure 8: Heat pump heating (or cooling) capacity versus total length of BHE for smaller BHE-plants listed in table 2

SOME INTERESTING SMALLER PLANTS

The area around Wetzlar has some of the earliest applications of BHE in Europe. It can claim to have the probably first BHE application for a commercial building in Germany, built in 1980 for a new, small production site for optical glass fibres (fig. 9). The ground part consists of 8 BHE of a coaxial design (tube-in-tube), each 50 m deep in paleozoic rock, feeding the evaporator of a heat pump with 22 kW heating capacity.

Even in this early plant a cooling function was realised, as it was possible to reject heat from the electric glass-melting furnaces into the BHE during summertime, for thermal recovery of the underground. The BHE are located beneath the bushes to the left and front (photo below) of the building; they obviously did not hinder vegetation growth.

Figure 9: "Verolum"-building in Schwalbach south of Wetzlar, first GSHP with BHE in a commercial application in Germany, built 1980; above in 1985, below in 1995 (photos Sanner)

Beside that very early example, some other interesting plants with less than 100 kW heating/cooling capacity will be described in this chapter. Table 2 gives a list of examples, from which several have been selected for further explanation. The basic data on the ground systems can be seen in table 2.

The first example (Hänel, 1999) was built in Cottbus in 1995 in the context of a horticultural exhibition. The building design follows a passive solar approach (fig. 10) and makes use widely of natural building materials. The "Umweltzentrum" houses seminar rooms, offices and a restaurant, and is heated by floor heating, supplied from heat pump and BHE. The heat pump provides heating and domestic water, while cooling is done directly by cooling ceilings and fan coil units (fig 10).

A special type of heat pump plant is situated in the Maas office in Gütersloh (fig. 11). Here a small CHP-unit driven by a diesel engine (fuel oil) provides the power for an electric heat pump. The building with offices on three floors (900 m^2) and a large hall for storage and dispatching of goods (1600 m^2) is heated by radiators and fan-coil-units, the maximum heat demand is ca. 190 kW. The heat pump and the CHP-unit together provide 90 kW of heat, an additional gas boiler (105 kW) is used for peak heat which accounts for ca. 10 % of annual usage. The nominal heating capacity of the heat pump is 60 kW, that of the CHP engine ca. 30 kW (while it generates about 30 kW electric power).

In a feasibility study the emissions of the total system have been calculated compared to a conventional fuel oil heating and the standard GSHP with electric heat pump (fig. 12), and a reduction of emissions of ca. 50 % compared to fossil fuel can be expected.

Table 2: Interesting smaller GSHP plants in Germany (key to abbreviations see table 5)

Name	data and remarks
GSHP in municipal buildings	
Schwabhausen, town hall, BY	85 kW (H), 65 BHE each 25 m deep
Cottbus, Umwelt-zentrum, BB	48 kW (H), 32 kW (C) 12 BHE each 50 m deep
Uttenweiler, multi-functional hall, BW	45 kW (H), 4 BHE each 125 m deep
Unlingen, town hall, BW	40 kW (H), 6 BHE each 106 m deep
Angermünde, Blum-berger Mühle, BB	23 kW (H), 15 BHE each 32 m deep (solar recharge)
Hessisch-Oldendorf, sports complex, N	21 kW (H), 3 BHE each 90 m deep (solar recharge)
Bernau, kindergarten, BY	20 kW (H), 10 BHE each 31 m deep
GSHP in schools (under construction in autumn 2004)	
Glashütten-Schlossborn, HE	75 kW (H) / 62 kW (C), 9 BHE each 120 m deep
Bad Homburg - Oberstedten, HE	62 kW (H) / 12 kW (C) 18 BHE each 92 m deep
GSHP in the private sector	
Wermelskirchen, Hof Kolfhausen, NRW	70 kW (H), 10 BHE each 80-100 m deep (old house)
Bönnigheim, Villa Amann, BW	70 kW (H), 4 BHE each 250 m deep (historic house)
Gütersloh, office and store “Maas”, NRW	60 kW (H), 8 BHE each 100 m deep (CHP-coupled)
Altglashütten, hotel “Schlehdorn”, BW	60 kW (H), 3 BHE each 250 m deep
Aachen, low-energy office building, NRW	55 kW (H), 59 kW (C), 28 BHE each 43 m deep
Wetzlar, UEG laboratory, HE	47 kW (H) / ca. 20 kW (C), 8 BHE each 80 m deep
Wetzlar, MT-Logistik, HE	32 kW (H) / 28 kW (C), 5 BHE each 85 m deep
Frechen, apartment building, NRW	29 kW (H), 7 BHE each 80 m deep
Schöffengrund, factory Verolum, HE	22 kW (H), 8 BHE each 50 m (built 1980)
Cologne, Architect´s office, NRW	9 kW (H) / 7 kW (C), 5 BHE 28 m deep

Only a few metres from the border to Belgium a low-energy office building was erected in Aachen (fig. 13). This examples can be used to demonstrate the application of concrete floor slabs and ceilings to provide heat and cold to the rooms (fig. 14), a technology popular in new office buildings in Germany. Due to the large surface, a relatively low supply temperature is sufficient for heating, and the building mass allows for some night-to-day-storage. A disadvantage of this storage effect is the slow reaction time to system control. Thus the concept is not popular in residential applications, and sometimes it is complemented with e.g. fan-coil units to provide faster temperature control,

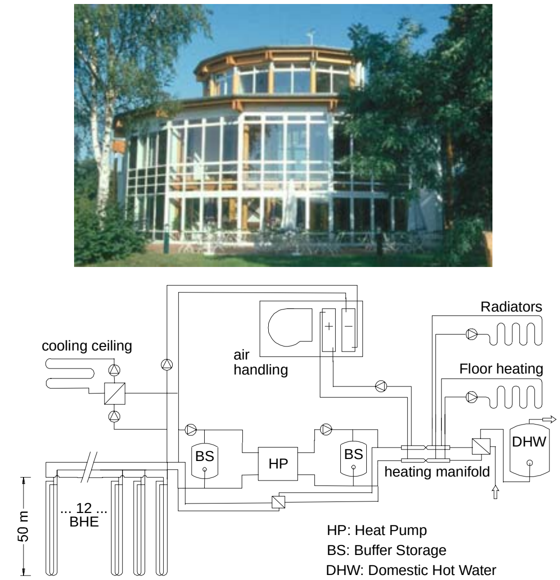

Figure 10: Umweltzentrum (“Environment Centre”) Cottbus, view from outside and system schematic (photo Sanner)

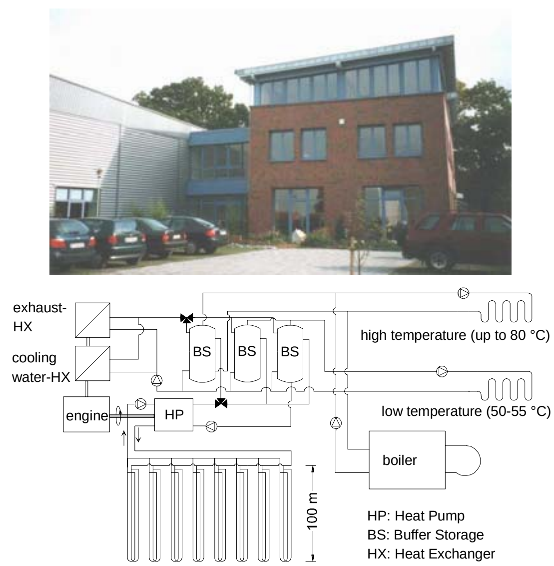

Figure 11: Office and shop “Naturwaren Maas”, Gütersloh, view from outside and system schematic (photo EWS)

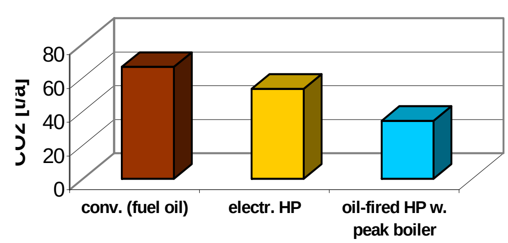

Figure 12: CO_2-emissions of the Gütersloh plant compared to conventional and standard GSHP alternatives (after data from feasibility study AgRo-Energie)

Figure 13: Office building Vika in Aachen, with the borehole field in front, and view to the BHE field with sand layer in trenches ready for receiving the connecting pipes (photo EWS)

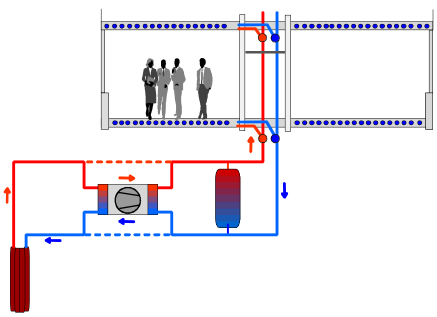

Figure 14: Heating and cooling with GSHP and pipes in the concrete slabs for floor and ceiling in Vika office, Aachen (graph courtesy of Vika)

For the office building Vika, the concrete slab heating worked fine, even the direct cooling in the rather hot summer of 2003. The operational cost for cooling in 2003 were a total of ca. 250 € (equalling 0.12 €/m²).

A relatively small example is located in Cologne. The office of an architect is located partly beneath ground level, it looks like a single-storey building, but has internally two floors, and makes use of passive solar gains (fig. 15). The architecture symbolises the living with the ground, and so the building is aptly equipped with a GSHP. The heat load of the building is small, because of good insulation and the thermal mass of the surrounding ground, and thus allows for only 140 m total length of BHE (5 x 28 m) to be sufficient.

Last of the examples from the commercial sector is the privately owned chemical laboratory UEG in Wetzlar, already built in 1991. Equipment like Atomic Absorption Spectrometry and Gas Chromatography is used for environmental investigations. This equipment produces heat, but it also is confined to certain ambient temperature levels to work correctly. A steady cooling load thus is guaranteed throughout most of the year, and this cooling can be provided very economically directly from the BHE (fig. 16). The system was monitored in the mid 1990s (Sanner & Gonka, 1990).

Figure 15: Architect´s office, Cologne (photo EWS)

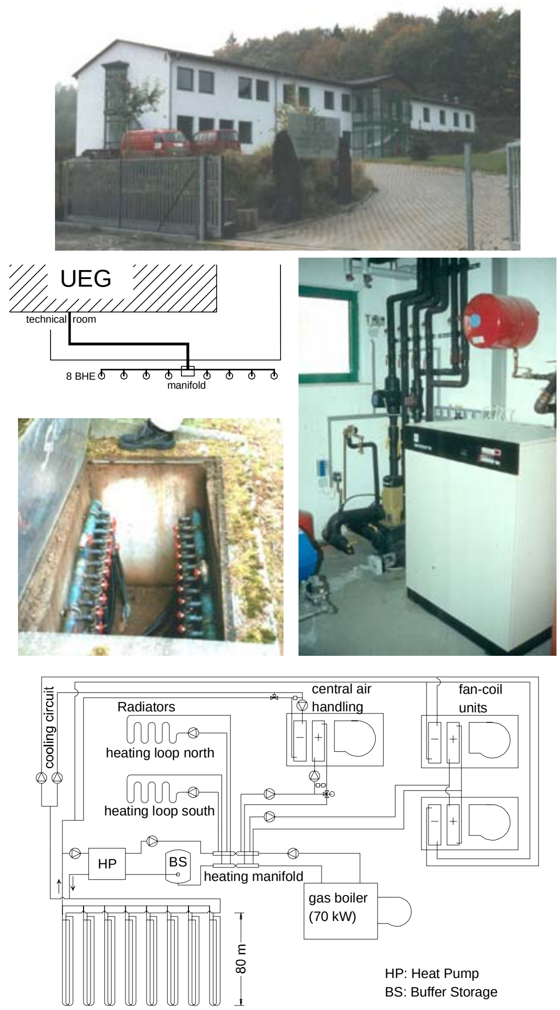

Figure 16: Chemical laboratory "UEG", Wetzlar, view from outside (photo Sanner), location of BHE, manifold (photo Lund), heat pump (photo Sanner), and system schematic

The manifold (fig. 16) shows the state-of-the-art of 1991, with a mixture of copper and plastics (today manifolds can be welded completely from polyethylene, avoiding all risk of corrosion). With 8 double-U-BHE, the manifold has 16 connections in the supply and 16 in the return line. Cooling in the UEG building is done directly from the BHE; pipes (the insulated pipes in black at the left of the heat pump in fig. 16) circulate the cold water-antifreeze-mixture (brine) to the central air handling unit above the corridor, and to fan-coil units in rooms with high cooling loads. For 1 kW of cooling only ca. 35-50 W of pumping power are required. The reduction in CO_2-emissions compared to a theoretical, conventional system with fuel oil boiler and electric chiller are almost 50 % (fig. 17)

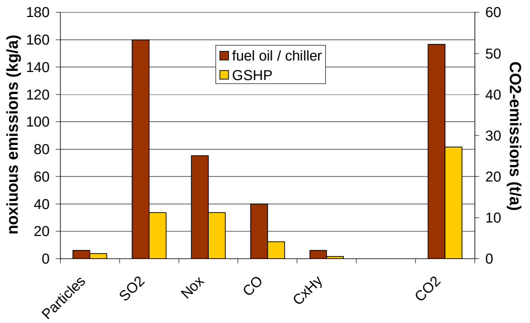

Fig. 17: Emissions of noxious gases and CO_2 for UEG building and a theoretical conventional system

In the residential sector, first a modern house in Frechen (near Cologne), containing 10 flats, shall be mentioned. The 7 BHE are connected to a central manifold at the building; the 2 return- and 2 supply-lines of each double-U-BHE are welded at the top of the BHE to a Y-pipe, reducing the number of pipes to be laid in the trenches by half (fig. 18). The site conditions for a relatively large 3-storey-building on a small lot required some special attendance to the optimum use of the area.

Figure 18: Apartment house in Frechen and head of a BHE with connecting pipes (photos EWS)

Meanwhile also older buildings get equipped with BHE. One example was realised for the complete refurbishment of a country mansion some centuries old, Hof Kolfhausen in Wermelskirchen. Most of the interior was removed (fig. 19), however, the basic structure and the vaulted basement was kept intact. The rebuilt house and the heat pump in the basement is shown in fig. 20.

Figure 19: Hof Kolfhausen, reconstruction (photo EWS)

Figure 20: Hof Kolfhausen, refurbished old country mansion with GSHP and passive solar architecture; heat pump in historic vault, with GSHP-designer (left) and architect/owner (right) (photos EWS, Lund)

The GSHP in Hof Kolfhausen provides heating and DHW (domestic hot water), and serves also some new, additional houses beside the mansion. Because of the complete rebuilding of the site, the number of BHE and the choice of the low-temperature heating system was not limited.

In Bönnigheim in Southwestern Germany, a mansion from art nouveau times also was refurbished (fig. 21), albeit not as drastically as Hof Kolfhausen. To accomodate a GSHP system to this building, Villa Amann, also the heat distribution system had to be adapted to allow for the lower supply temperatures of a heat pump. To cover about the same heat load as for Hof Kolfhausen, only 4 deeper BHE have been chosen here instead of the 10 BHE there; this allowed for less drilling sites and piping in the existing garden.

Fig. 21: Villa Amman in Bönnigheim, equipped with 4 BHE each 250 m deep (photo: Systherma)

Even in the higher reaches of the Black Forest, at an elevation around 800-900 m a.s.l., the use of GSHP is possible. The area is a touristic spot in summer and winter, and so it is no surprise to find a hotel with a geothermal heat pump in Altglashütten (fig. 22) just east of the highest peak in the Black Forest, the Feldberg (1493 m a.s.l.). The ground is crystalline rock with good thermal conductivity, and due to the long heating season, BHE of 250 m have been installed there.

GSHP systems in public buildings are of particular importance, as they allow to inform about the technology. In table 2, some examples from municipal buildings (e.g. town halls), sports facilities, a kindergarten, and schools are listed.

Figure 22: Annex to hotel "Schlehdorn" in Altglashütten under construction, and large reel with 250 m BHE (photos Systherma)

Two of this public buildings use solar heat to recharge the ground. Because the majority of smaller GSHP in Germany serve only for heating, the natural thermal recovery of the ground is a key factor to sustainable use of the resource. Hence total BHE length usually has to be slightly higher than for similar projects in heating and cooling applications. A solution is possible where solar collectors exist for DHW. The excess solar heat which cannot be used for more water heating during summertime is injected into the BHE, thus re-charging the ground surrounding the BHE. In small plants, a real storage effect (see UTES, below) cannot be achieved, however, the forced recovery of natural ground temperatures helps to save some metres of BHE.

One example is the information centre "Blumberger Mühle" in the natural reserve Schorfheide northeast of Berlin. The building is shaped like a huge stump of a tree (fig. 23), with solar collectors on the roof (and also PV for electricity). Excess heat from the solar collectors is injected into 15 BHE each 32 m deep. A similar system is used for a sports hall (gym) in Hessisch-Oldendorf (which, despite its name, is located in Lower Saxony). Solar collectors provide DHW (for showers, etc.), and the excess heat again is used for ground thermal recovery of 3 BHE each 90 m deep. The possible reduction of BHE length compared to the necessary length without solar recharge is 12 %.

Figure 23: GSHP-plants with solar recharge; natural park information centre "Blumberger Mühle", with solar panels in the right foreground (above, photo GTN) and gym in Hessisch-Oldendorf, with solar collectors (below, photo EWS)

Town halls with GSHP are listed in table 2 for Baden-Württemberg and Bavaria. One is located in Unlingen in the upper Danube valley, and is integrated into a historic ensemble in the town centre. Fig. 24 shows the drilling rig on site for that project.

Figure 24: Drilling for BHE at the town hall in the historic centre of Unlingen (photo Systherma)

Renewable energy applications in schools can help to educate the children early about the technologies and potential. A geothermal system mainly is not visible, so material for teachers has to be developed to help them show this source of energy to their pupils. Having a shallow geothermal system in their school might give an extra emphasis, in particular when cooling is provided (which is all but standard for German schools). Three new school near Frankfurt are under construction in autumn 2004 to include GSHP, and in the years to come children will play on the then lawn in front of the school in figure 25, on top of their geothermal heating system.

Figure 25: Construction site of a school in Usingen-Eschbach (table 5), view to the southern BHE-field (20 BHE) in an area to become later a garden and open-air-theater (photo UBeG)

LARGE GSHP SYSTEMS IN GERMANY

A rather comprehensive list of the largest GSHP plants in Germany is given in table 5 at the end of this paper. The ground side of the projects can be divided into three groups: BHE, groundwater wells, and energy piles. Because the necessary area for horizontal loops to cover large thermal loads is usually not given in Germany, table 5 contains only one example where horizontal loops are used in addition to BHE. Another combination is made in the case of energy piles, when the thermal use of the required pile foundation does not meet the desired heating/cooling load, and BHE are installed to cover the remaining load.

The largest example in table 5 is located in a wetland area near Munich, and the groundwater wells also serve to keep the natural groundwater table low. Thus the re-injection of the whole amount of groundwater into the same aquifer, as usually is required by authorities in Germany, is not an issue here.

In general, groundwater wells can deliver a much higher thermal capacity per borehole than BHE. The reason is that in groundwater wells the transport of the heat from the ground into the borehole and to the surface installations can be done by a hydraulic pressure difference, while in BHE the transport from the ground into the borehole and vice versa requires a temperature gradient. The energy that is intended to be used for heating and cooling also has to power the heat transport motor, limiting the heat transport to the maximum allowable temperature changes, while in groundwater wells this is de-coupled. As a result, if possible according to hydrogeological site conditions, the largest systems usually use groundwater wells because the higher cost for investigation, planning and maintenance is offset by the considerably smaller number of boreholes and thus lower cost. In smaller projects, the usually trouble-free operation of a BHE-system requiring no specifically trained personnel counts more. Also in USA the largest GSHP system makes use of groundwater wells, the 19-MW-plant for the Gault House Complex in Louisville, Kentucky.

The restricted construction sites in city centres like in Frankfurt/Main usually do not allow for larger BHE systems. However, groundwater wells are an alternative in Frankfurt, because fractured limestones covered by marl and claystone provide a suitable aquifer. The licensing with the authorities imposes strict limitations, in order not to create a downward groundwater movement from a higher, locally slightly contaminated aquifer into the deeper Tertiary aquifer (fig. 26, in spite of the fact that the water in the Tertiary can hardly be used for drinking water due to its salinity and H_2S-content).

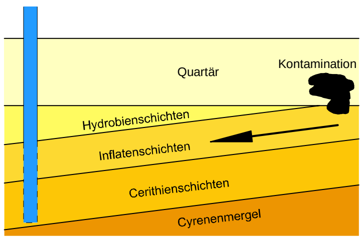

Figure 26: Alleged contamination movement restricting pumping rates from Tertiary aquifer and requiring monitoring in downtown Frankfurt/Main (graph UBeG)

Two examples in table 5 are using groundwater in the city of Frankfurt/Main. One is already in operation, a building complex with shops, offices and flats at Baseler Platz just south of the central railway station (fig. 27). Drilling and construction of the system had to be done in very confined site conditions, and the wellheads now are located in the lower level of the underground parking beneath the buildings (flooding of the empty parking occurred once during construction, when workers did cut the well piping not taking the necessary precautions, as the piezometric head is above the floor of the parking). The water in 80 m below ground surface already has a temperature of 21 °C, a testimony to the thermal waters at the northern end of the Upper Rhine Graben system, which is good for heat pump efficiency in the heating mode, but does not allow for direct cooling (so the heat pump has to work as a chiller during summertime). For the other example in the heart of Frankfurt, the twin towers of "WestendDuo", the pumping tests in the completed wells were underway in autumn 2004.

Figure 27: Architectural simulation of the building "Living and Working at Baseler Platz" in Frankfurt/Main (graph FAAG)

Another problem with groundwater in the Frankfurt area may also affect BHE systems. Towards the northwest the Taunus mountains are responsible for an artesian pressure in the Tertiary fractured limestone aquifer, covered by impermeable layers of marl and clay. So for another plant listed in table 5, in 1993 boreholes of 98 m depth were planned (Sanner & Euler, 1994). The first drilling revealed artesian water in 70 m depth in the limestone, with ca. 2 bar pressure at the wellhead (fig. 28), 15 °C (slightly warmer than average), and TDS 3360 mg/l. Because of the relatively high pressure, grouting the hole around BHE was deemed impossible, and thus the borehole was abandoned and thoroughly closed and cemented. The number of BHE was doubled, and the length restricted to 50 m, in order to stay well inside the marls. In addition, baryte was added to the grout to add weight. The drilling, installation and connecting of the double number of BHE (fig. 29) was a challenge. to be done on the small strip between street and building, but it was the only solution to realise a BHE-system on that site.

Figure 28: Artesian water flow from drilling in Frankfurt-Hoechst, 1993 (photo Sanner)

Figure 29: Drilling for shallower BHE in Frankfurt-Hoechst, and connecting pipes (photos Sanner)

GSHP using BHE or energy piles for large buildings usually cannot cover the peak heating and cooling loads, either due to site restrictions or due to economic considerations. Thus a suitable base-load is defined which can be met by the GSHP. In this case, the full-load hours per year of such a system usually exceed those of a small GSHP, and the high annual heat turnover has to be taken into account. As a result, and in accordance with the heat storage component in a large BHE field, for such systems the annual turnover of heat and cold should be balanced in the average over some years. An example with a typical base-load operation is the plant for DFS in Langen (see table 5).

The German Air Traffic Control (DFS) has built new headquarters in Langen, just a few kilometers southeast of Frankfurt airport. The office building offers room for ca. 1200 employees, and was planned as a Low-Energy-Office (LEO) (fig. 30). The basic data of the building are:

- total building volume 230'000 m^3
- total floor area 57'800 m^2
- heated/cooled area 44'500 m^2

A total of 154 BHE each 70 m deep are integrated into the heating and cooling system. The BHE system covers the base load of the building cooling and a part of the heating load (fig. 31). The BHE supply a total cooling capacity of 340 kW and 330 kW heating capacity, equaling 80 % of the annual cooling energy and allowing 70 % of the annual heating being covered by the heat pump.

Figure 30: Part of headquarters of DFS in Langen, Low Energy Office (photo Kohlsch)

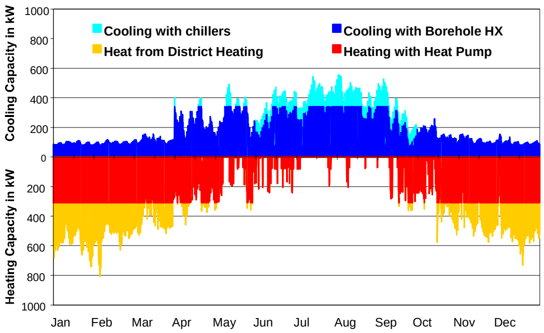

Figure 31: Annual heating and cooling loads of DFS, with geothermal part (blue and red) and peak part (light blue and orange) (after Seidinger et al, .2000)

For the first time in Germany, a thermal response test (carried out in summer 1999) was used as a basis for dimensioning a BHE field (Sanner et al., 2005) The underground consists of quaternary and tertiary sand, gravel and clay, and the measured ground thermal conductivity was β = 2,8 W/m/K.

There is a particularity of the BHE system for the German Air Traffic Control (DFS) headquarters. While most GSHP systems make use of an antifreeze to cope with temperatures below 0 °C, in Langen only pure water is used. This is possible due to the priority of the cooling operation and the very exact design calculations. Operation without antifreeze has an ecological advantage in the case of a leakage (the site is in the outer part of a groun77dwater protection zone), and also the cost for filling the large system with antifreeze can be avoided. Design with minimum heat supply temperatures of +4 °C also allows for a very good seasonal performance factor in heating mode.

The 154 BHE are grouped into two fields under the lawn alongside two building sides (fig. 32). The temperature changes in the groundwater towards the municipal wells in the west have to be kept within certain limits. as required by the regulation of the groundwater protection zone This requires balanced operation of the system at least in the average over several years, and a monitoring scheme comprising three observation wells and temperature readings at given intervals.

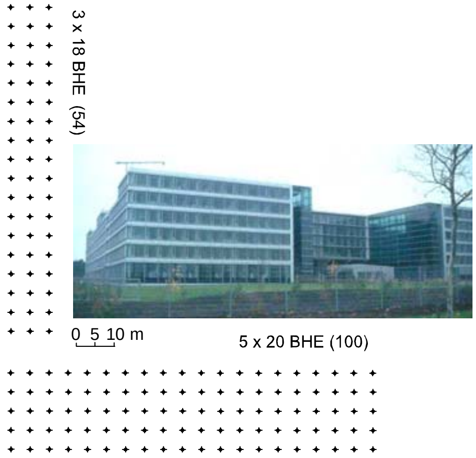

Figure 32: Layout of the BHE field for DFS Langen and location in respect to the building (photo Sanner)

A thorough economical analysis of the design was done (Seidinger et al., 2000). The BHE system allows, even with higher first cost, an annual cost saving compared to conventional heating and cooling plants. The cost comparison (fig. 33), regarding energy, maintenance and capital cost of the heat and cold generation, reveals that the Low Energy Office with BHE is the most economical solution for this building at this site. The system was tested in winter 2001/02 and is fully operational since spring 2002.

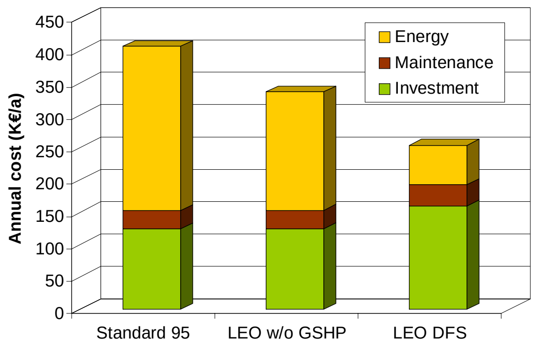

Figure 33: Economic comparison from the feasibility study, cost basis 1999 (after Seidinger et al., 2000; redrawn, and values converted into Euro)
- Standard 95 building code in force in 1999
- LEO Low Energy Office

Under German climatic conditions the annual heating demand in most cases is higher than the annual cooling demand. In order to somehow balance large GSHP systems, a suitable approach usually is to design the system to meet the cooling demand, and to add extra peak boilers or other additional heating. The economical advantage of the GSHP is more in the cooling part, in particular when direct cooling can be applied. An optimum harmonisation of building loads and ground system requires e.g. suitable simulation on both sides, and a certain amount of experience.

SUBDIVISIONS AND SUBURBAN DEVELOPMENT

Air conditioning is not yet common in the residential sector in Germany. GSHP here usually only extract heat from the ground in winter, and to a somewhat lesser extent during summer, if DHW is heated by the system. No heat is injected into the ground, and the sustainable use of GSHP relies on the natural ground temperature recovery by heat conduction and groundwater movement.

For individual houses, this fact does not impose a problem. However, if whole subdivisions are equipped with BHE, the mutual influence has to be considered. A steadily decreasing ground temperature in a certain area has to be avoided, by limiting the heat extraction to a value which keeps the equilibrium with natural thermal recovery. In regions where summer cooling is standard, the decreasing temperature is not a problem, on the contrary, in warm climatic zones like the southern USA sometimes a problem with heating up the ground does arise.

In table 5 some "geothermal" residential development areas are listed. In all these cases building lots are rather small, and each house is equipped with its own BHE. Modelling the whole area in advance had to be done to ensure a sustainable design and operation. For the case of heating, the only way is to increase the depth of BHE in order to access a larger ground volume and to reduce the specific heat extraction per metre of BHE; fig. 34 gives an example of the necessary changes.

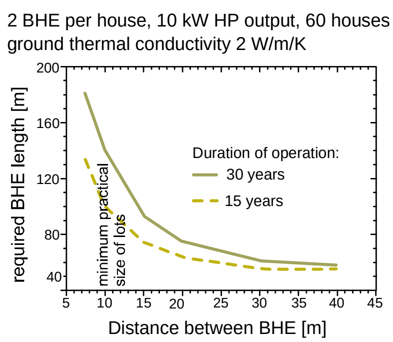

Figure 34: Required increase in BHE length for small lots in an area where all houses use GSHP in heating-only mode, calculated with EED

The largest geothermal subdivision in Germany currently exists in Werne, north of Dortmund. A total of 134 houses are planned (fig. 35), development began in 2000, and about 80 % of construction has been finished in autumn 2004. The first house owners moved in in 2000, however, due to the general economic situation in the past years sales and construction of the houses did proceed slowly (fig. 36).

Fig 35: Plan of geothermal subdivision in Werne (each house with own BHE, graph Behr+Partner) and drilling for BHE in Werne (photo Sanner)

Figure 36: Construction and finished houses in Werne geothermal subdivision, status Dec. 2001 (photo Sanner)

Further geothermal subdivisions are under design in Leverkusen and in Cologne. In countries where GSHP have been very popular in the past, like Sweden and Switzerland, already some regulations exist, requiring certain distances of a BHE location from the limits of the building lot.

UTES SYSTEMS

Underground Thermal Energy Storage (UTES) is defined by an intentional change of ground temperatures from the natural status towards lower or higher temperature, for use in cooling or heating (or both). Storage can either be done in aquifers, using groundwater wells (ATES), or in the ground itself, using BHE (BTES) The distinction from large GSHP is gradual, and a limit has been suggested of less than 25 % of the annual thermal turnover being exchanged with the ground surrounding the storage volume to qualify as UTES (Sanner & Stiles, 1997). Because in the natural ground an insulation can only be made on top of the store (and no insulation usually in case of ATES), UTES is only possible in large systems where the envelope of the store becomes small compared to the volume. Thus only the few installations listed in table 3 exist in Germany so far.

Table 3: Underground Thermal Energy Storage (UTES) plants in Germany (key to abbreviations see table 5)

Name	data and remarks
Berlin, site of the Deutscher Bundestag, BE	cold storage in aquifer, 5 + 5 wells each 60 m deep, (H/C) heat storage in aquifer, 2 wells each 320 m deep, (H)
Neckarsulm-Amorbach, BW	528 BHE each ca. 30 m deep, solar thermal heat, (H)
Frankfurt, Maintower, HE	ca. 500 kW (C), ca. 210 energy piles 30-34 m deep, winter cold
Attenkirchen, BY	ca. 250 kW (H), 90 BHE each 30 m deep, water tank 500 m^3, solar loading, HP
Rostock, MV	110 kW (H), 2 groundwater wells 30 m deep, solar loading, HP

The most well known example is the (double) ATES for the German parliament in Berlin. A detailed description is given in Sanner et al. (2005) and thus is not repeated here.

Because of their relatively small size, the UTES systems in Attenkirchen and Rostock require heat pumps to make use of the solar heat stored underground. It does not make sense here to increase the temperature level to a value usable directly, because storage losses will become excessive in that case. In Rostock (fig. 37) another limitation is given by the relatively shallow aquifer used, where a convective breakthrough to the surface might occur at high temperatures. So the storage loading temperature in Rostock is kept at a maximum of ca. 50 °C. In Attenkirchen a water tank is added for the high temperature part.

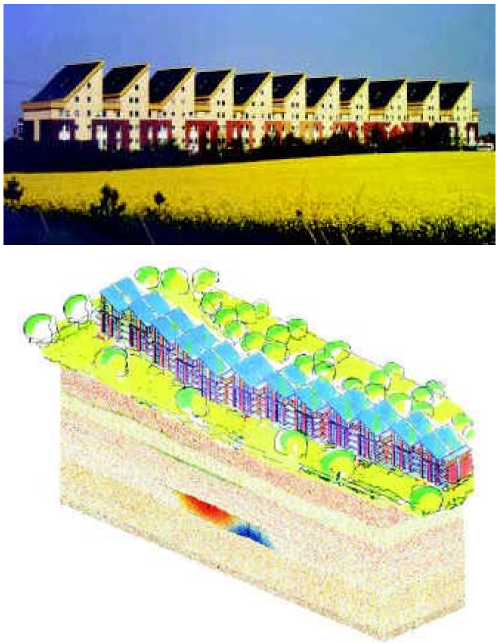

Figure 37: Row of residential houses in Rostock-Brinckmannshöhe, with location of ATES system (below) (photo and graphics: Aetna Energysyteme)

The orientation of the row of houses in Rostock is north-south, so the building design had to be adapted in order to use the roofs of the houses for solar collectors (fig. 37). The predicted storage efficiency (rate of heat retrieval) of the ATES according to simulation is 63 %. Throughout the first years any UTES will have a lower storage efficiency, before the surroundings of the store have been warmed up or cooled down sufficiently. In Rostock already in 2002 a storage efficiency of above 64 % was monitored (table 4). This is due to the heat pump operation and the low return temperature on the order of 35 °C from the well-insulated buildings with modern heat distribution.

Table 4: Storage efficiency of the Rostock ATES, heat retrieval supported by heat pump (after data from Schmidt & Müller-Steinhagen, 2004)

	2001	2002	2003
heat input (loading)	214 MWh	245 MWh	295 MWh
heat retrieved	78 MWh	158 MWh	143 MWh
storage efficiency	36,4 %	64,5 %	48,5 %

In Neckarsulm-Amorbach a different storage technology is used (BTES). A total of 528 BHE each 30 m deep enclose a storage volume of 63360 m^3 (fig. 38). On top of the BHE field an insulation layer 20 cm thick of closed-pore polystyrole foam is placed in a sand bed, and covered with 2-3 m of earth. Because of the high storage loading temperatures of up to 85 °C, the BHE have to be made from polybutene. The ground in Neckarsulm-Amorbach consists of Triassic marls (Keuper).

The system concept is shown in fig. 39. Solar heat is either used directly for house heating or, in times when no heating load exists, is stored into the BTES. Because on a sunny summer day the solar collectors provide more heat than can be stored simultaneously, two large water tanks are used as accumulators to level solar radiation peaks and to shift part of the loading into the night.

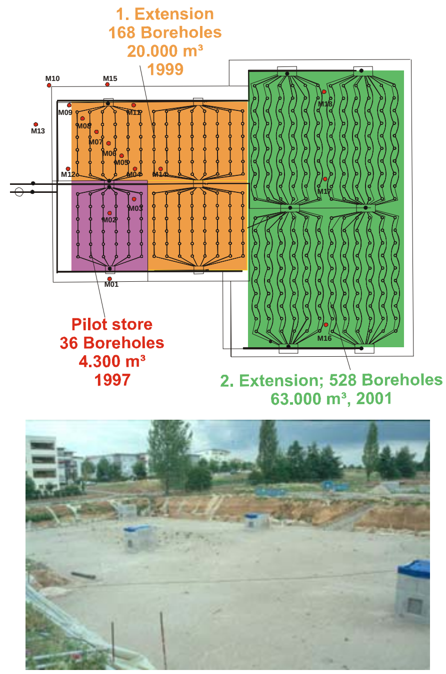

Figure 38: Plan of the store with 3 different construction stages, in 2004 final size 528 BHE (graph ITW); below 2nd extension under construction, BHE installation completed, before top insulation (photo Sanner)

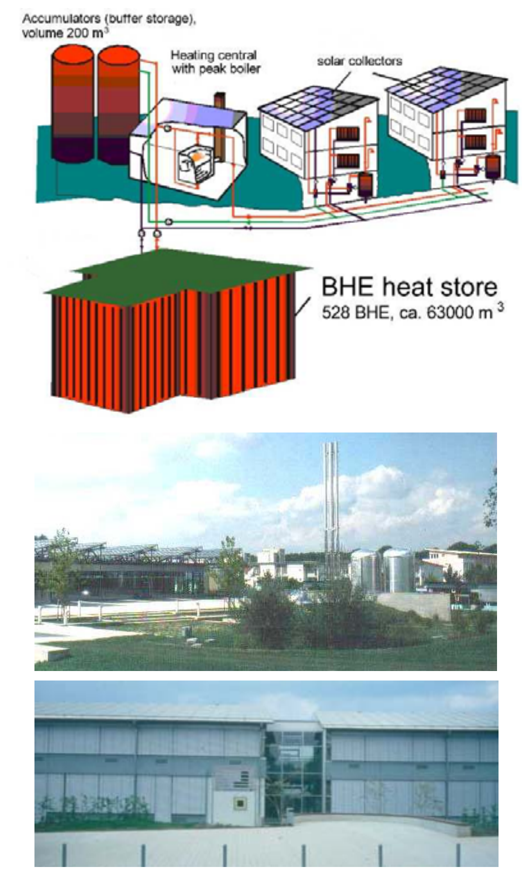

Figure 39: System concept of Neckarsulm BTES (graph after ITW); below view to the gym with solar collector on the roof and accumulator tanks right, and school with roof-integrated solar collectors (photos Sanner)

The solar collectors are placed on top of public buildings like the school´s gym, or are integrated into the roofs as on the school itself. Retrieval of the heat is done directly, without a heat pump, and peak loads and load towards the end of winter, when storage temperatures are getting low, are covered by gas boilers. The heating of the store had to be done over several seasons, and 65 °C had been reached in the centre of the store in summer 2003. During the year 2003 a total of 1492 MWh had been injected into the store (Nussbicker et al., 2004). In the first years only small amounts of heat had been retrieved as experiments, however, the final storage efficiency has been simulated to be 70 %.

With the growing number of houses in the area the store will probably be enlarged. Another option is to include a heat pump in order to get a higher temperature difference in heat retrieval mode. A similar store is in the design phase for a residential area in Crailsheim, there the storage volume would be in Mid-Triassic limestone (Muschelkalk).

SUMMARY

According to estimates based on the sales numbers and a certain rate of older plants to be set out of operation, end of 2004 exist about 45’000-50’000 GSHP in Germany. The total geothermal capacity installed in these plants sums up to ca. 450 MW_{th}, resulting in an installed heat pump heating capacity of ca. 660 MW_{th}. The annual geothermal energy used by GSHP in Germany is about 660 GWh/a, again resulting in heat provided by the heat pumps of 930 GWh/a (see also Sanner & Bussmann, 2005). An estimate of the space cooling capacity of GSHP in Germany is not yet possible.

For small plants, in some states authorities and geological surveys provide information not only on the licensing procedures, but also for design. In Nordrhein-Westfalen the Geological Survey in Krefeld issued a CD-ROM with relevant subsurface information for design of BHE for GSHP up to 30 kW heating capacity, including information on groundwater protection zones. The area of the whole state has been evaluated and the possible “geothermal yield” (specific heat extraction per year, in kWh/m/a) evaluated in accordance with VDFI 4640.-Fig. 40 shows an example of an area where the uppermost 40 m provide very good conditions, changing to average when drilling deeper.

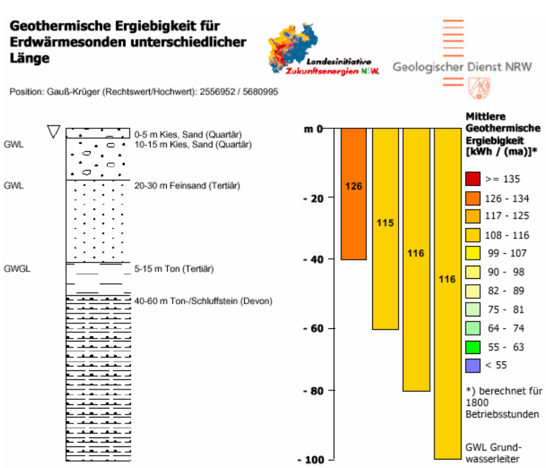

Fig. 40: Example from the CD-ROM on shallow geothermal resources in Nordrhein-Westfalen, showing an area with groundwater-saturated sand and gravel over paleozoic rock in Düsseldorf (from GD-NRW)

Other states like Baden-Württemberg and Hessen just publish guidelines on legal regulations and possible areas where small plants (like for single-family houses) can be built without licensing procedure (fig. 41) Following guideline VDI 4640 for design, drilling and installation in these cases is mandatory, and larger plants need a license in all cases (see Sanner & Bussmann, 2005).

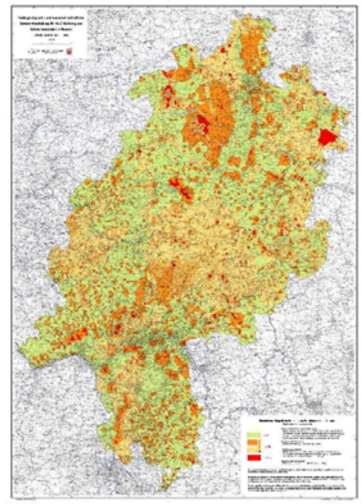

Figure 41: Map of the state of Hessen showing areas in green where small GSHP (<30 kW) can be built without special licensing, areas where an application for license is required (in yellow/orange), and areas where no GSHP will be allowed (e.g. inner groundwater protection zones, red); a large version of the map can be downloaded from http://www.hlug.de (from HLUG)

For large plants, site investigation, design and construction meanwhile usually follow proven concepts. The infrastructure with geologists, design engineers, specialised drillers and building contractors has developed over the past decade. Prefabricated BHE, grouting material, manifolds, etc. are available on the market. The associations Geothermische Vereinigung e.V. (GtV, geothermal) and Bundesverband Wärmepumpen (BWP, heat pumps) work towards a quality certification system for GSHP planners and installers.

This paper is intended to present an overview of the German situation in shallow geothermal applications, and to showcase examples in order to disseminate experience and proven ideas.

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Table 5: Large shallow geothermal plants in Germany

City, Name, State ("Land")	Installed capacity, kW_{th}	Application	Type
München, Dywidag, BY	840 (H) / 500 (C)	H, C	Several groundwater wells total 500 m^3/h, HP
Golm b. Potsdam, MPI, BB	ca. 800	H, C	160 BHE each 100 m deep, HP
Bonn, „Bonnvisio", NRW	600 (H) / 550 (C)	H, C	2 + 2 groundwater wells, each 11 m deep, HP
Langen, DFS, HE	330 (H) / 340 (C)	H, C	154 BHE each 70 m deep, HP
Frankfurt, Baseler Platz, HE	300 (H) / 180 (C)	H, C	2 groundwater wells (doublet) 80 m deep, HP
Fulda, Sparkasse, HE	<300	H, C	49 BHE each 98 m deep, HP
Gladbeck-Wiesenb., NRW	280 (H) / 180 (C)	H, C	32 BHE each 60 m deep, addit. horiz. loop, HP
Güstrow, Env. Edu. Ctr., MV	270	H	60 BHE each 50 m deep, HP
Frankfurt-Höchst, HE	240	H, (C)	32 BHE each 50 m deep, HP
Rostock, Businesscenter, MV	220	H, C	264 energy piles 19 m deep, surface water, HP
Kochel, BY	210	H	21 BHE each 98 m deep, HP
Emden, Kunsthalle, N	155 (H) / 200 (C)	H, C	11 BHE each 250 m deep, HP
Todtmoos, hotel, BW	180	H	10 BHE each 250 m deep, HP
Crailsheim, office, BW	140 (H) / 116 (C)	H, C	30 BHE each 74-90 m deep, HP
Prien, hotel, BY	125	H	2 groundwater wells (doublet)
Düsseldorf-Lichtenbr., NRW	120 (H) / ca. 40 (C)	H, C	73 BHE (steel) each 35 m deep, rammed, HP
Donaueschingen, bank, BW	110 (H) / 250 (C)	H, C	56 BHE each 90-100 m deep, HP
Rendsburg, ZET, SH	110 (H) / 87 (C)	H, C	24 BHE each 100 m deep, HP
Kolbermoor, office, BY	ca. 100	H	13 BHE average 122 m deep, HP
Kaiseresch, TGZ, RP	ca. 100 (?)	H, C	32 BHE each 75 m deep, HP
Minden, WAGO, NRW	100 (H) / 120 (C)	H, C	44 BHE each 100 m deep, HP
Rostock, Univ. Library, MV	60 (H) / 120 (C)	H, C	28 BHE each 80 m deep, HP
Bietigheim, industr. hall, BW	100 (H) / 70 (C)	H, C	10 BHE each 100 m deep, HP
Bremen, Buhlmann, HB	100	H, C	energy piles + 13 BHE each 77 m deep, HP
Berlin, Strahlauer Platz, BE	ca. 100	H, C	ca. 200 energy piles (cast concrete) 7 m deep
Hannover, NLB, N	n/a	H, C	122 energy piles (cast concrete) each 20 m deep
Under construction in autumn 2004 (drilling either completed or ongoing):			
Frankfurt, WestendDuo, HE	ca. 400	H, C	2 + 3 groundwater wells each 140 m deep, HP
Gelnhausen, MK-Forum, HE	ca. 400	H, C	ca. 80 BHE each 100 m deep, HP
Wetzlar, Philips APM, HE	290 (H) / 145 (C)	H, C	32 BHE each 110 m deep, HP
Usingen-Eschb., school, HE	190	H	32 BHE each 100 m deep, HP
Bonn, BA Natur, NRW	125 (H) / 110 (C)	H, C	16 BHE each 85 m deep, HP
Subdivisions / suburban development:			
Werne, NRW	ca. 700	H	134 houses 1 BHE 100-150 m deep each, HP
Stutensee, BW	ca. 550	H	79 houses 1 BHE 77-123 m deep each, HP
Dortmund-Mengede, NRW	ca. 500	H	98 houses 1 BHE 100-150 m deep each, HP
Gütersloh, NRW	ca. 150	H	24 houses 1 BHE 90 m deep each, HP

H: Heating C: Cooling BHE: Borehole Heat Exchanger HP: Heat Pump

State name abbreviations:

BB	Brandenburg	HB	Hansestadt Bremen	NRW	Nordrhein-Westfalen
BE	Berlin	HE	Hessen	RP	Rheinland-Pfalz
BW	Baden-Württemberg	MV	Mecklenburg-Vorpommern	SH	Schleswig-Holstein
BY	Bayern	N	Niedersachsen		