# CASE STUDIES (and lessons learned)

## *Direct heat projects and heat pumps*

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# 3.4.
# CASE STUDIES AND LESSONS LEARNED IN SHALLOW RESOURCES AND HEAT PUMPS IN GERMANY

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## ABSTRACT

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. With BHE geothermal heat pumps can offer both heating and cooling at virtually any location, with great flexibility to meet any demands. More than 25 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.

In recent years, several larger plants for offices or commercial areas have been designed and built in the central region of Germany, and mainly in the Rhein-Main-area. Both systems with borehole heat exchangers (BHE) as well as with shallow geothermal doublets (ground water wells) are operational. New solutions had to be found to adapt the technology to certain site constraints, and innovative components like thermally enhanced grouting material have been used.

## 1. INTRODUCTION

First, some abbreviations have to be mentioned, which are used frequently throughout this text:

- GSHP Ground Source Heat Pump
- BHE Borehole Heat Exchanger (in USA, the term Vertical Loop is common)
- UTES Underground Thermal Energy Storage

In Germany, there are three main areas of geothermal energy use:

- Shallow geothermal energy for heating and cooling purposes, including Underground Thermal Energy Storage (UTES)
- Deep geothermal plants for large heating demand (district heating)
- Electric power production by geothermal energy; this technology still is in the design and construction phase, with the first plant operational since Nov. 2003 in Neustadt-Glewe
- The legal framework in Germany is given by the Federal Mining Act (BBergG), protecting the use of geothermal energy as to be licensed by the state authorities. Most smaller plants in shallow geothermal are exempt from this license and are subject to approval by the water authorities only.

The definition for geothermal energy in Germany is, according to the guideline VDI 4640 [1]: “Geothermal energy is energy stored in form of heat below the surface of the solid earth”

In the following, the target will be on shallow resources only (down to ca. 400 m). As many European countries do not boast abundant hydro-geothermal resources that could be tapped for direct use (some exceptions are e.g. Iceland, Hungary, France), the utilization of low-enthalpy aquifers that enable the supply of a larger number of customers by district heating is limited so far to regions with specific geological settings. On the other hand, geothermal heat pumps (GSHP) and UTES allow for geothermal energy use almost everywhere.

## 2. EXAMPLES OF SMALL-SCALE APPLICATION OF GSHP IN GERMANY

### Early GSHP-plant with BHE in Germany

The area around Wetzlar is one of the birth-places of BHE in Europe. It can claim to have the first BHE application for a commercial building in Germany, built in 1980 for a new, small production site for optical glass fibers (fig. 1). 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 had a cooling function, as it was possible to reject heat from the electric glass-melting furnaces into the BHE during summertime for thermal recovery of the underground.


*Fig. 1: "Verolum"-building in Schwalbach south of Wetzlar, first GSHP with BHE in a commercial application in Germany, built 1980, photo from 1995; the BHE are located beneath the bushes to the left and front of the building*

**Research plant Schöffengrund-Schwalbach**

The owner of the Verolum plant, Helmut Hund, who was convinced of the potential of GSHP, started a R&D-activity to better understand the heat transport processes in the underground and to collect the necessary data and experience for correct design of BHE systems. With support from the Federal Ministry of Research and Technology (B-MFT in this times), and in co-operation with Justus-Liebig-University in the neighbouring city of Giessen, a full-scale field experiment was installed adjacent to the Verolum building in 1985 (fig. 2) [2]. In this installation, experiments with two types of BH-E were carried out (fig 3): The original coaxial one as developed by Helmut Hund, and a double-U-tube design following an example from Switzerland, developed by Ernst Rohner sr. [3]. Towards the end of the project, also experiments with direct expansion in BHE were carried out (fig.2, right). The results of the R&D-project are published in [4].

## First direct cooling application

For commercial applications, space cooling during summertime is an issue even in a country with moderate climate, like Germany. On the other hand, space cooling by many is considered a luxury, and the installation and operational cost for electric air conditioners or chillers are not widely accepted. Thus, in 1987 an experiment was conducted to use the cold from 7 BHE each 50 m deep directly to cool a single room in an office building in Wetzlar (fig. 4). Fan coil units with two separate heat exchanger (one for the warm water of the hydronic heating circuit, the other for the water/antifreeze mixture from the BHE) were installed, and with only 120 W for a small circulation pump and the fans, a cooling power of roughly 2,5 kW could be achieved.

*Fig. 2: left: Schwalbach GSHP research station, with light drilling rig, borehole field and buildings for HP and monitoring; photo from January 1988*
*right: Direct Expansion experiments in Schwalbach GSHP research station in 1989; note ice development on evaporator pipes leading to special BHE*

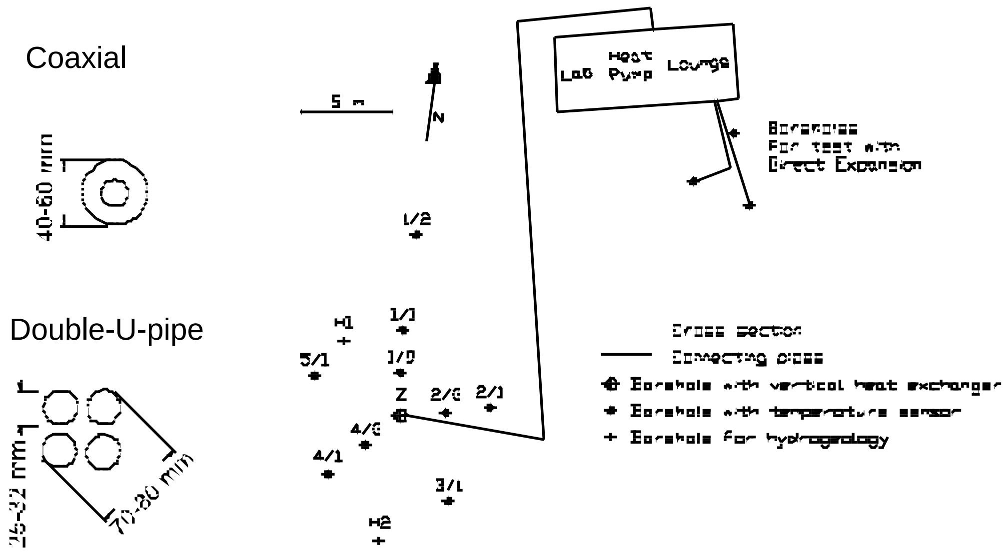



*Fig. 3: left: Cross-section of typical BHE, as used in Schwalbach*
*right: Schematic plan of the test plant in Schwalbach*

**Residential houses**

From the beginning, GSHP were used in residential houses, which still account also for the largest number of applications. The basic principle did not change, but fine-tuning of the system design, manifolds, circulation pumps, etc., and also the use of new refrigerants like R 290 or R 407 c, allowed an increase in the seasonal performance factor from 2.5-3.0 in 1985 to around 4.0 in 2000. A state-of-the-art example for an individual residential house is selected from the city of Delbrück in the Northwestern part of Germany. The basic data are given in fig. 5. Another, relatively new house was investigated by [6], it is located in Burg/Spreewald close to the Eastern border of Germany. The data are listed in fig. 6.

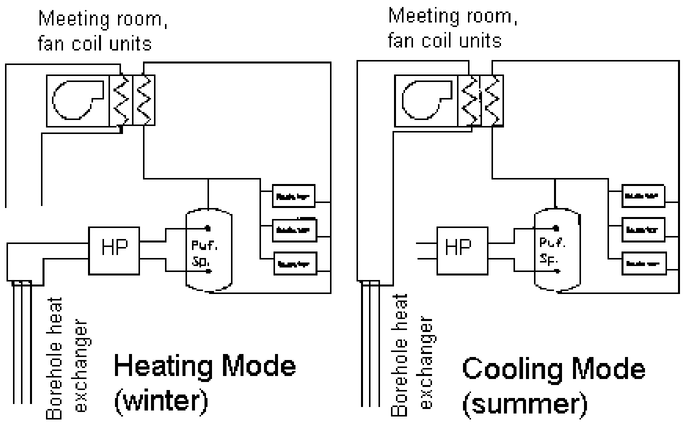
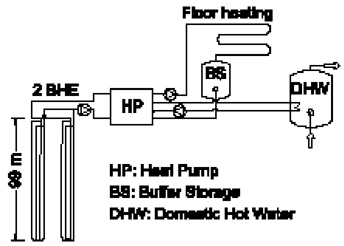



*Fig. 4: Schematic of the first experiment with direct cooling from BHE, GSHP plant for heating and cooling in the office building of Helmut Hund GmbH (from [5])*

Over many years, most of the GSHP in residential houses were individual plants in the middle of houses heated by fuel oil or natural gas. Meanwhile, the first whole subdivisions are equipped with GSHP. Examples are two new residential areas (fig. 7) in the Dortmund area with ca. 100-130 houses, where individual GSHP systems for each house are installed. A rather simple system schematic with only one BHE in the >100 m range is used in most houses, with a few exceptions. The heat pumps provide for heating and domestic hot water; there is no cooling, thus no artificial recharge of the ground. The heat extraction is larger than the possibility of natural recharge, and a low, but continuing decrease of temperature would occur. To counteract this and to secure long-term operation, the BHE length has to be increased (fig. 7).

- New residential house (1998), two storeys, with high insulation standard, heated by floor heating. The heat pump provides the heating and hot water.
- Floor area is 331 $m^2$, ca. 60 % of heating through floor heating with supply water temperature max. 35 °C, ca. 40 % of heating through radiators with supply water temperature max. 50 °C
- Brine-to-water heat pump, type Bartl, with 13.6 kW nominal heating capacity
- 2 vertical borehole heat exchangers (double-U), each 99 m deep; the geology consists of cretaceous sediments (marl)



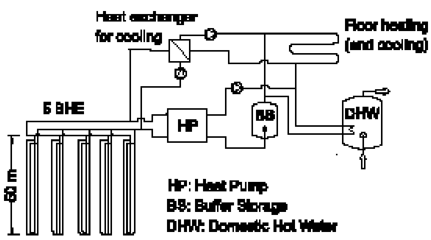

system schematic, Delbrück

| Energy cost for 1999: | | |
|---|---|---|
| total | 666.17 € | (1302.92 DM) |
| specific | 2.01 €/$m^2$/a | (3.94 DM/$m^2$/a) |

| Energy efficiency 1999 | |
|---|---|
| HP consumpt. total: | 7.616 MWh/a |
| Total heat delivered: | 29.48 MWh/a |
| Seasonal performance factor: | 3.87 |

*Fig. 5: Residential house in Delbrück*

- New residential house (1997), heated by floor heating. The heat pump provides the heating and hot water. Some cooling is provided by using the floor heating coils. Floor area is 180 $m^2$ in two storeys, with nominal heat demand 11.5 kW
- Floor heating supply temperature max. 35 °C, brine-to-water heat pump, with 18 kW nominal heating capacity; cold supplied from BHE via heat exchanger
- 5 vertical borehole heat exchangers (double-U), each 50 m deep; the geology consists of cenozoic sediments




system schematic, Burg/Spreewald

Total investment cost :
23,300 € (45,600 DM)

| Energy between 12/1997 and 2/1999: | |
|---|---|
| HP consumption total: | 11.86 MWh/a |
| Seasonal performance factor | 3.0-3.6 |

*Fig. 6: Data for residential house in Burg*

## 3. LARGER GEOTHERMAL HEAT PUMP PLANTS IN THE CENTRAL REGION OF GERMANY

This chapter reviews shortly the early development of GSHP for commercial buildings, gives details on a selection of recent plants and explains specific problems during their realisation. The examples comprise, among others:

- UEG Wetzlar, a building with chemical laboratories and one of the first examples of direct cooling from BHE
- Naturwaren Maas, Gütersloh, a building with motor-driven GSHP
- DFS Langen (German Air Traffic Control Headquarters), with 154 BHE for heating and cooling, operating without antifreeze
- Baseler Platz Frankfurt, a building right in the center of Franfurt/Main, with very confined construction site and the need to avoid contamination by groundwater pollution found in the neighbourhood
- Arcade Hainburg, a small commercial district heated by a heat pump on a doublet more than 200 m deep

The lessons learned from this plants, and the economic circumstances will allow successful realisation of further geothermal heat pump systems in the region.

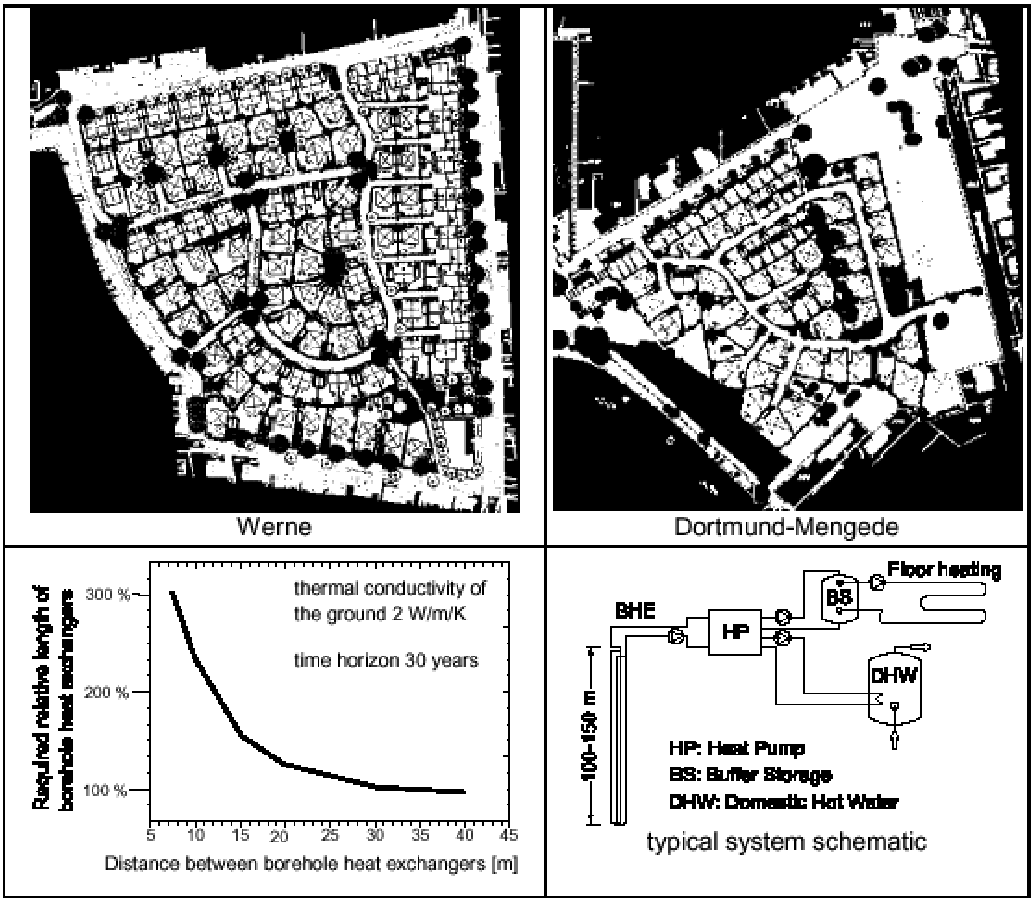



*Fig. 7: Artist´s concept of geothermal subdivisions (above, graphics Behr + Partner, Schwerte); lower line left: Necessary increase in borehole length for 120 BHE with decreasing distance and lower line right typical system schematic for a house in Werne subdivision*

**Commercial plants for heating only**

Since the first plants in Germany, commercial applications were part of the picture (e.g. the „Verolum“ building [7]). In 1987, a small commercial building was monitored (Fig. 8); more information on that plant is given in [8]. With a floor heating system, a heat pump using R 22, and a seasonal performance factor of 2.9, it shows the state-of-the-art performance of the late 1980s.

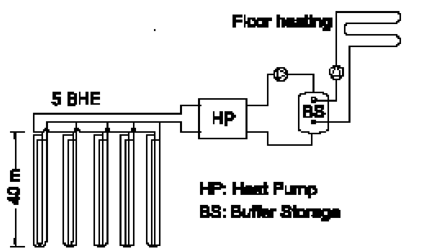
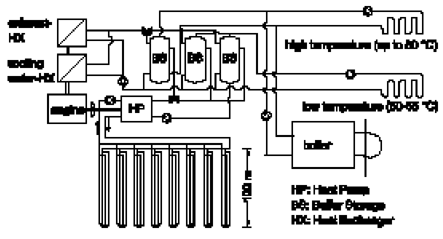
| | |
|---|---|
| • Small commercial building (1987), heated by floor heating. The heat pump provides the heating, no hot water. The single-floor building houses offices and workrooms (manufacturing of electronic equipment)<br>• floor heating with supply temperature ca. 35 °C, brine-to-water heat pump with 22 kW nominal heating capacity<br>• 5 vertical borehole heat exchangers (double-U), each 40 m deep, the geology consists paleozoic sediments (sandstones/shales) under tertiary overburden (sand, silt) | <br>system schematic, Hüttenberg |
| Total investment cost :<br>15,950 € (31,200 DM)<br>specific energy cost, incl. investment:<br>70.56 €/MWh (138 DM/MWh)<br>(Prices 1987) | Energy between 11/1987 and 10/1988:<br>HP consumpt. total: 12.9 MWh/a<br>Total heat delivered: 36.9 MWh/a<br>Seasonal performance factor 2.9<br>Specific heat extraction 71 W/m, 119 kWh/m/a |

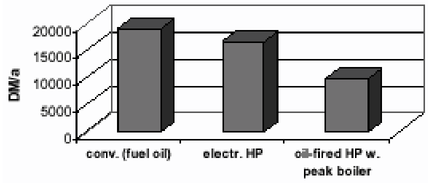
*Fig. 8: Small commercial building from 1987 in Hüttenberg/Hessen*

A very interesting plant has been built recently in Gütersloh (fig. 9). The heat pump compressor is not activated by an electric motor, but by a fuel-oil operated diesel engine. The heat from engine cooling is also used for house heating, and an additional peak boiler exists. This example may show that ground source heat pumps do not necessarily rely on electric power for operation.

- The building from 1999 with offices and a large storage hall is heated by radiators and fan-coil-units. The heat pump provides the heating, and no domestic water. An additional oil boiler provides peak heat
- The building consists of an office wing with three floors (900 $m^2$) and a large hall for storage and dispatching of goods (1600 $m^2$)
- Heating with two different temperature levels, brine-to-water heat pump with 30 kW nominal heating output, operated by fuel oil engine, thermal output ca. 30 kW, and fuel oil boiler (105 kW) for peak load (ca. 10 % of annual heat)
- 8 vertical borehole heat exchangers (double-U), each 100 m deep in cretaceous sediments




system schematic, Maas Gütersloh




Comparison of annual operation cost (from feasibility study); realized alternative right

*Fig. 9: Commercial building "Maas Naturwaren" in Gütersloh*

**Chemical laboratory UEG in Wetzlar**

Because of the tremendous savings in direct cooling mode (no power for compressor required), today cooling is a standard feature of most commercial GSHPs in Germany. A well investigated example is the UEG building in Wetzlar (fig. 10), housing offices and laboratories. The GSHP with 47 kW heating capacity heats the building through low-temperature radiators (a floor heating was not thought appropriate due to the special laboratory floors), and heats the ventilation air; in summertime, cold is provided directly from 8 BHE, each 80 m deep, for cooling the ventilation air and, in addition, some specific rooms with high internal heat load.

In the chemical laboratories, a number of high-precision analytical equipment is operated, including Atomic Absorption Spectrometry (AAS), Gas-Chromatography (GC) and Mass Spectrometry (MS). Also a substantial number of PC's is in use. All those devices produce heat, and have strict requirements for ambient temperatures to work correctly. In consequence, cooling is crucial in the relevant rooms.

A specific pro blem in UEG-plant are the chemical exhausts. Air pressure in the rooms has to be kept higher than that in the exhausts at any time, to prevent inflow of possible toxic sub-stances. The result are high quantities of ventilation air even at very low or high outdoor air temperatures, whenever the chemical exhausts are operated. In the heating mode, a natural gas boiler assists the heat pump in this case. In cooling mode, the store covers all the load. The cooling circuit is divided into a loop for the central air handling unit, which is operated only when required, and a loop for the fan-coil units in the relevant rooms, in almost continuos operation.

UEG plant became operational in spring 1993 and thus started with a cooling season. During a full heating-cooling cycle in 1995/96, the performance of the plant could be monitored closely [9]. In fig. 24 the details of the energy flows are shown. The efficiency in heating mode could even be better with a different (floor) heating system, because the ra-diators require a higher supply temperature than a good floor heating; however, the constraints due to the building use do not allow for that.

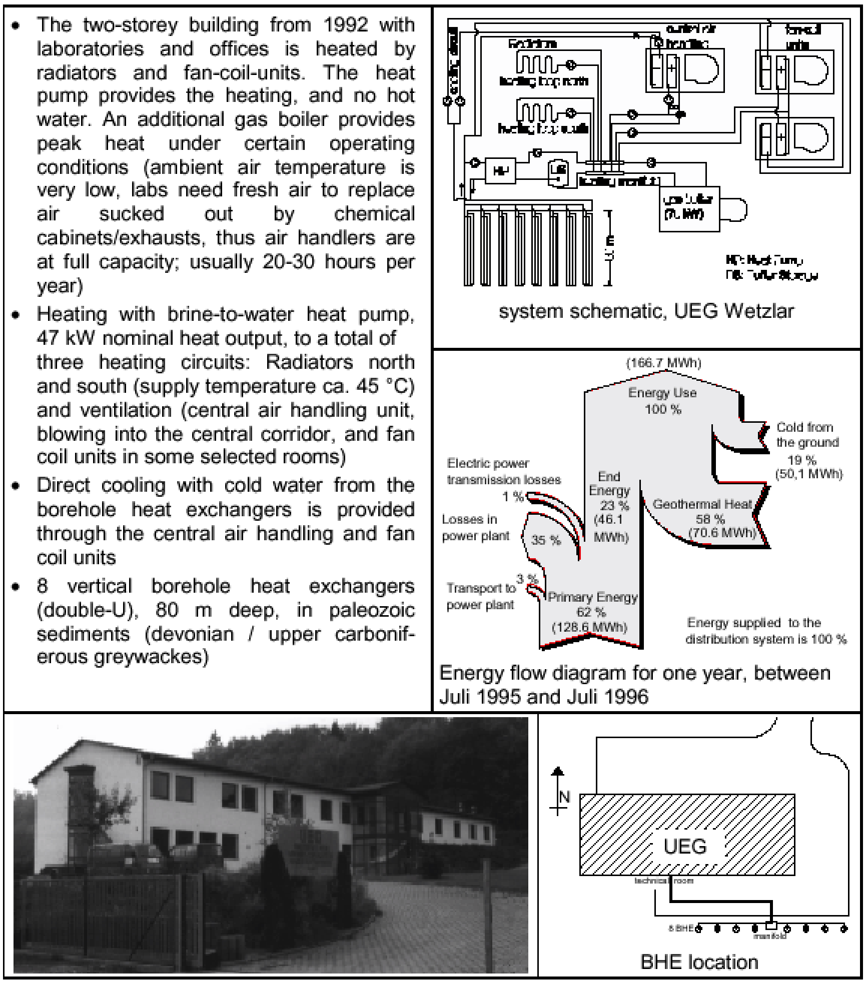



*Fig. 10: Chemical laboratory "UEG" in Wetzlar, heated and cooled with BHE*

Fig. 11 shows the reduction in emissions of that plant, calculated for the monitored data from 1995/96 and compared to a conventional system with fuel oil for heating and an electric chiller for cooling. The reduction of CO2-emissions amounts to 48 %!

**Other commercial plants**

Another well-monitored example of a building with direct cooling is the "Umweltzentrum" Cottbus, housing teaching and meeting facilities for environmental issues. Fig. 12 shows the relevant data of this building from the eastern border of Germany. Table 1 lists some other larger plants in Germany.

**German Air Traffic Control (DFS) Headquarters, Langen**

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

- total building volume 230'000 m3
- total floor area 57'800 m2
- heated/cooled area 44'500 m2

A borehole thermal energy storage with two borehole fields (fig. 13) comprising a total of 154 BHE each 70 deep is 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. Both fields supply a total cooling capacity of 340 kW and 330 kW heating capacity, equalling 80 % of the annual cool-ing energy and allowing 70 % of the annual heating being covered by the heat pump (fig. 14). There are only a few plants in Europe with a capacity and number of BHE like in Langen.

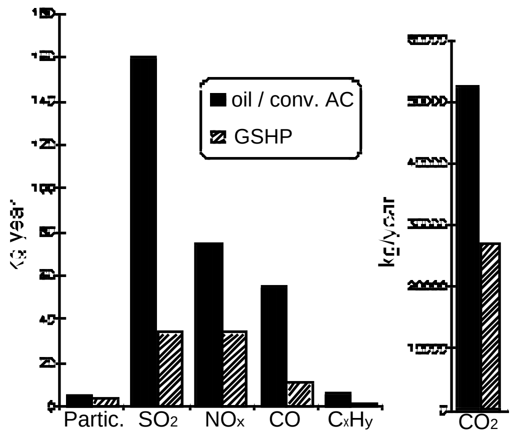
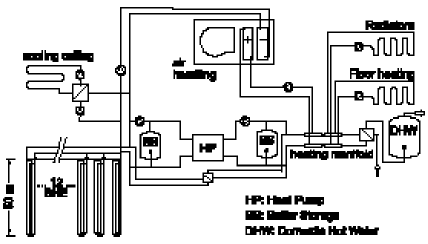



*Fig. 11: Emission reduction for UEG building, compared to a conventional plant (design values)*

- The building with seminar rooms, offices and a restaurant is heated by floor heating. The heat pump provides the heating and domestic water. Cooling is provided by cooling ceilings and fan coils.
- The building has 48 kW nominal heat demand, uses passive solar architecture and has three floors:
  - Ground floor restaurant, kitchen, etc.
  - Second floor seminar rooms, offices
  - Small third floor with offices
- Heating with brine-to-water heat pump, two compressor stages with 70 kW total heating output; radiators in most rooms, floor heating in ground floor, and air handling units (total flow 9720 $m^3$/h). This results in relatively high supply/return water temperature of ca. 55/45 °C.
- nominal cold demand 37 kW (of which air handling 26 kW and cooling surfaces 11 kW); direct cooling with cold fluid from the borehole heat exchangers, heat pump used as chiller for peak cooling




system schematic, Umweltzentrum Cottbus

- 12 vertical borehole heat exchangers (double-U), 50 m deep, in cenozoic sediments

Energy between 9/1995 and 8/1996:

| | |
|---|---|
| HP power consumption: | 45.65 MWh |
| Total heat delivered: | 142.14 MWh |
| Annual performance factor | 3.1 |
| Additional energy for heating,pumps, fans | 30.17 MWh |

*Fig. 12: Seminar building „Umweltzentrum“ in Cottbus, after [10] and [11]*

*Table 1: Data from some larger plants in Germany*

| Project name | heating/cooling capacity | No. BHE | Depth BHE |
|---|---|---|---|
| WAGO Minden | 100 / 120 kW | 44 | 100 m |
| Gladbeck-Wiesenbusch | 280 / 180 kW | 32 [1] | 60 m |
| DFS Langen | 330 / 340 kW | 154 | 70 m |
| MPI Golm | ca. 1000 / 1000 kW | 160 | 100 m |

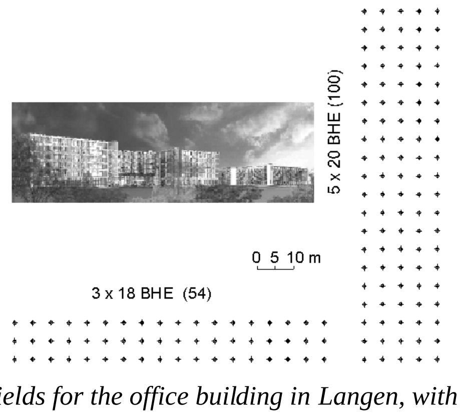



*Fig. 13: Layout of the two BHE fields for the office building in Langen, with the architest´s impression of the building to show its location in regard to the BHEs*

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 [12]. An almost 100 m deep test borehole was equipped with a BHE (later to become a part of the BHE field). The underground consists of quaternary and tertiary sand, gravel and clay. The measured values are:

- Ground thermal conductivity $\beta$ = 2,8 W/m/K
- Borehole thermal resistance $r_b$ = 0.11 K/(W/m)

There is a particularity of the BHE system for the German Air Traffic Control (DFS) headquarters. While most ground source heat pump 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 groundwater 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.

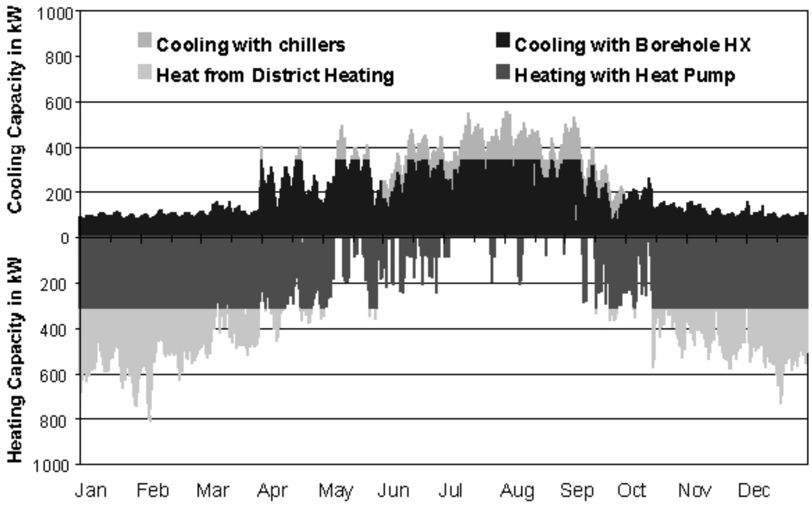



Fig. 14: Heating and cooling demand for the German Air Traffic Control (DFS) headquarters, data from simulation

*Fig. 15: left: Thermal Response Test equipment on site in Langen*
*right: Heat pump in DFS-headquarters, Langen; to the left four motors driving the compressors. in the background and above evaporator and condensor.*

To extract an energy amount as high as possible with source temperatures above +4 °C, the borehole thermal resistance has to be lowered. A material suitable to push the thermal con-ductivity of the borehole filling from a normal 0.6-0.8 W/m/K to ca. 1.6 W/m/K has been de-veloped, and the heat transfer in the borehole could be enhanced substantially. A second thermal response test (fig. 15) was done at one of the final BHE (now with 70 m drilling depth). This allowed for measuring the influence of the thermally enhanced grout on the borehole thermal resistance:

- with conventional grouting rb = 0.11 K/(W/m)
- with thermally enhanced grout rb = 0.08 K(/W/m)

The lowering by more than 27 % is in good agreement with the theoretical calculation for an almost doubled thermal conductivity of the filling.

Another problem imposed by the groundwater protection zone is the requirement to keep temperature changes in the groundwater within certain limits. 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. Fig. 16 shows the development of groundwater temperature in an aquifer 20-26 m deep.

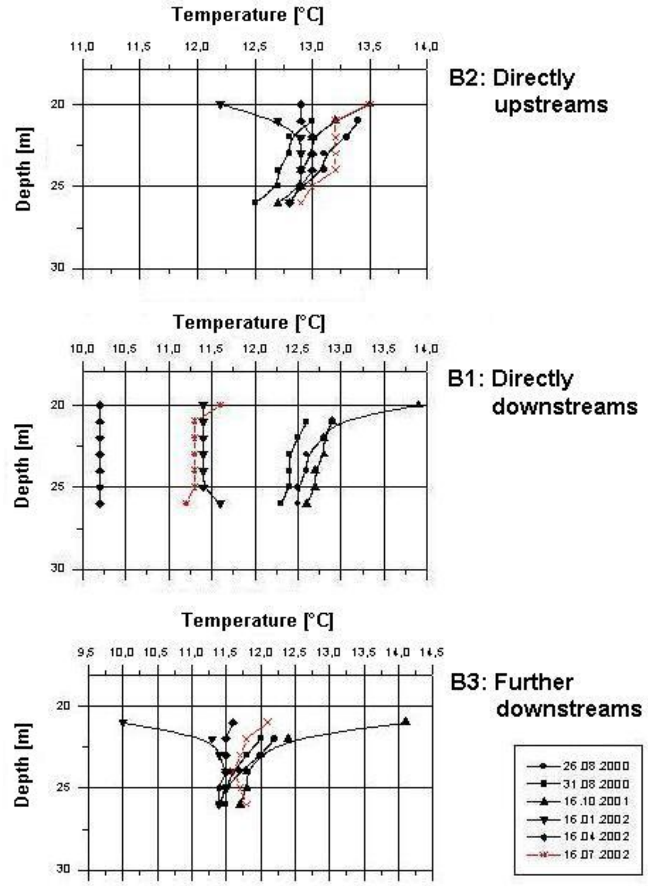



*Fig. 16: Monitoring of the impact of the BHE-field on groundwater temperature*

The layout calculations were done with the computer program „Earth Energy Designer“ (EED), allowing for calculation of the temperature of the heat carrier medium according to ground thermal parameters and heating/cooling loads. Several design alternatives were investigated, and the most promising optimized with further calculations. The design procedure resulted in a use of shallow geothermal energy adapted at optimum to the building needs. The innovative application of thermal site investigation, thermally enhanced grouting material, and the layout with pure water as heat carrier promises a high system efficiency.

A thorough economical analysis of the design was done and published in [13]. The BHE system allows, even with higher first cost, an annual cost saving compared to conventional heating and cooling plants. The cost comparison (fig. 17), 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 and this site, due to the low energy cost. The system was tested in winter 2001/02 and is fully operational since spring 2002.

**Larger GSHP-plants with groundwater wells**

The Rhein-Main-area is characterised by regions with good groundwater conditions. Hence the use of groundwater as heat source and sink for GSHP can be considered, in particular for larger installations. One groundwater well can deliver a much higher thermal output than one BHE, however, groundwater wells require certain hydrogeological and hydrochemical conditions and are also subject to maintenance.

One GSHP system with groundwater wells was constructed under particularly difficult conditions, right in the heart of the city of Frankfurt (fig. 18). It is intended for heating and cooling of a multi-storey building with offices and apartments.

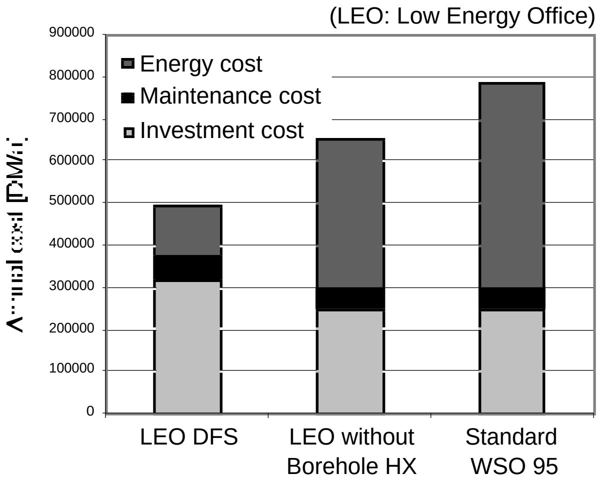



*Fig. 17: Annual cost comparison for heating and cooling the German Air Traffic Control (DFS) headquarters (after [13])*

| | |
|---|---|
| *Version LEO DFS:* | *Borehole heat exchangers, heat pump, local heat net, chiller, first cost 4.5 million DM* |
| *Version LEO without BHE:* | *Local heat net, chiller, first cost 3.5 million DM* |
| *Version Standard WSO 95:* | *Local heat net, chiller, first cost 3.5 million DM* |

*Fig. 18: Architectural simulation of the FAAG-building "Living and Working at Baseler Platz" in Frankfurt/Main*

There were several problems and constraints that had to be dealt with for the Baseler Platz project:

- Very limited area for drilling and installation
- Wellheads in the underground parking, below the static surface of the Tertiary water level; this did result in a temporary flooding of the lowest level of the parking during construction time, when the well pipes were cut by workers without permission from the planners
- Groundwater temperature of 21 °C in only 80 m depth (not suitable for direct cooling)
- Existence of contamination in the upper aquifer; because there are some possible connections between the aquifers in some distance from the site (fig. 19), an early warning system had to be developed to detect inflow of younger water into the Tertiary. This is done by testing, at regular intervals, the produced water for the Tritium content, which is higher in the younger water; an increase in Tritium will precede a possible contamination by some time.

Another groundwater heat pump currently is under construction to heat and cool a commercial area with several smaller shops in Hainburg (fig. 20). Two wells to a depth of ca. 200 m already have been drilled, and pumping test showed sufficient flow. The geology was some-what different than expected, because the sedimentary layers in this area are influenced by the vicinity of the paleozoic rocks of the Spessart mountains to the East. Investigations with a mobile equipment for hydrochemical tests [14] revealed that no problems with scaling should be expected within the planned temperature range.

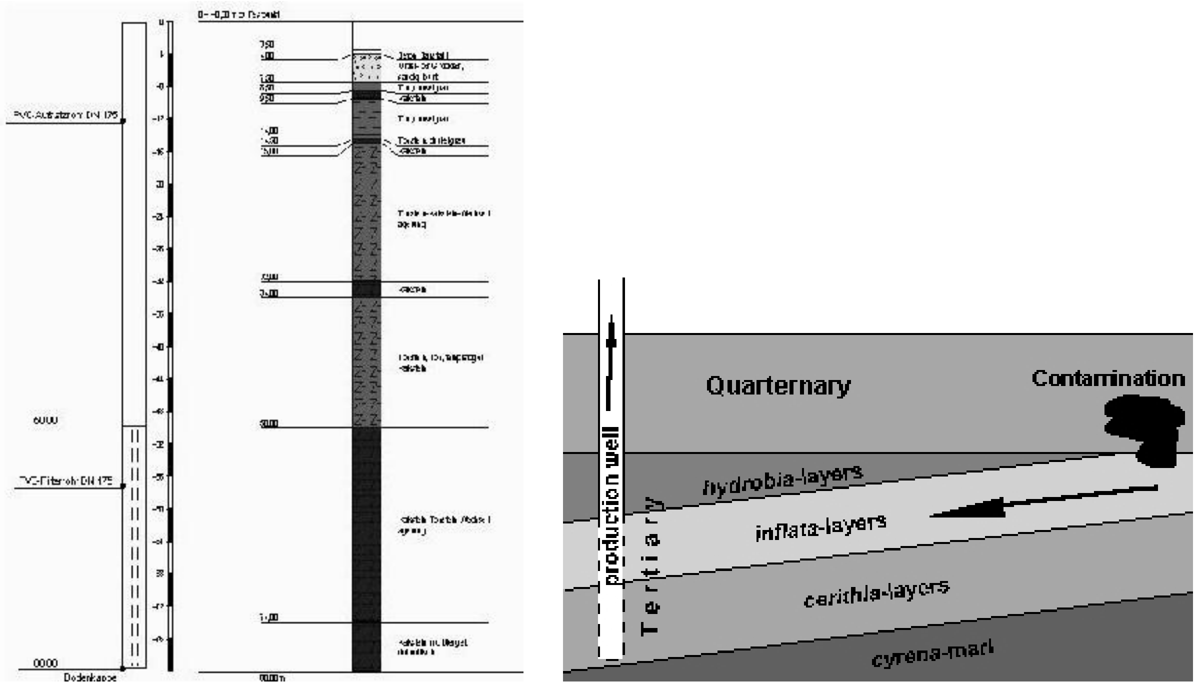



*Fig. 19: left: Production well for FAAG-building, Frankfurt*
*right: Permeable layers could allow transport from a contaminated area in several hundred meter distance, monitoring is required*

The two wells are locate beside the access road, with the connecting pipeline being buried beneath the road. From there, the individual lots receive the water and can use it as heat source or sink for individual heat pumps. The shop tenants (who might become owner of the lots or just lease the place) will be billed according to the amount of water they get from the central pipeline. This scheme allows for keeping the central pipeline on common grounds, with operation and maintenance of wells and pipeline by e.g. an Energy Service Company,, and the equipment in the shops in the hands of the tenants. Start of operation is expected for the heating season 2004/05.

## 4. UNDERGROUND THERMAL ENERGY STORAGE (UTES)

While in GSHP-systems a heat pump is used to bring the temperature from the ground to a useful heating temperature, or to dump heat from space cooling into the ground, the ground itself is heated or cooled in a UTES system. Again, a distinction can be made between open and closed systems (fig. 21). The heat sources for heat storage can be various, however, waster heat or solar heat are typical. For cold storage, the cold ambient air in wintertime or during night is the cold source. The basic principle of an ATES can be seen in fig. 22.

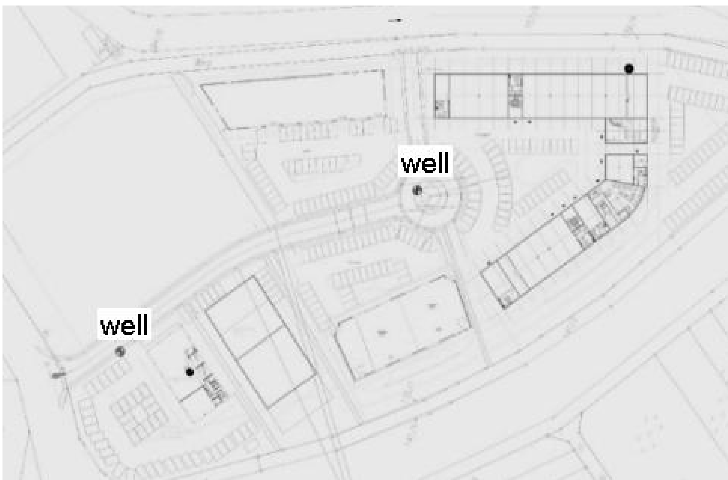



*Fig. 20: Plan of the commercial area in Hainburg to be heated and cooled by GSHP*

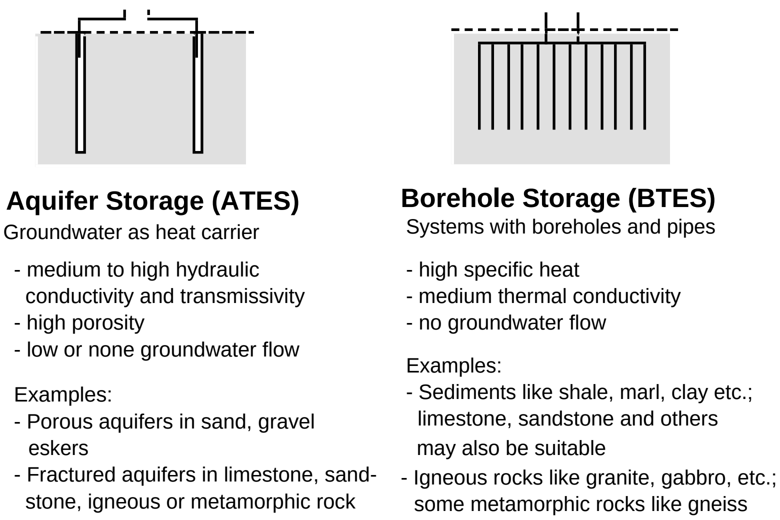



*Fig. 21: Distinction of UTES-systems*

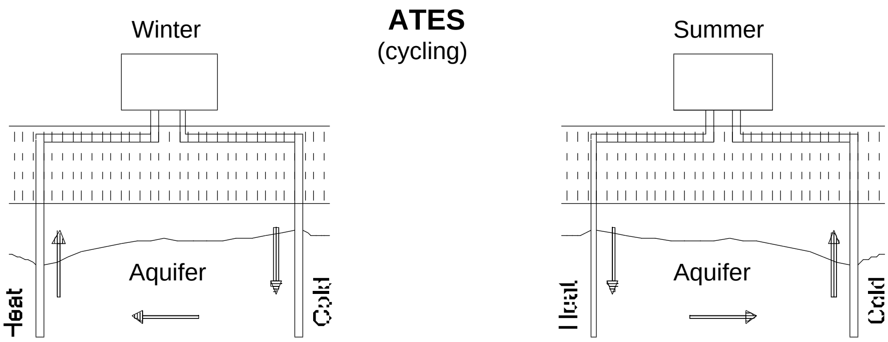



*Fig. 22: Operating principle of an ATES-system, with cycling operation ("warm" and "cold" wells)*

Two examples are shown here to illustrate the principle. The technology is well established for cooling purposes, in particular in the Netherlands, but still some R&D has to be done to achieve reliable and economic UTES for heat storage at elevated temperatures. One example, of a real heat store with temperature up to 80 °C, is a BHE store in Neckarsulm, using solar energy (fig.23 and table 2).

**BHE storage system in combination with solar heat in Neckarsulm**

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

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

The store consisted of 36 double-U-pipes with a depth of 30 m and a borehole distance of 2 m. The bore-hole diameter was 115 mm. Each 6 boreholes were connected in series. This store was mainly used for charging and discharging experiments. The heat transfer capacity of the BHE used first was found to be not as good as estimated. Reasons for that are a closer than planned distance between the U-pipes (65 mm shank spacing) and a lower thermal conductivity of the grouting material. This effect decreased the performance of the overall system. In addition, the discharging of the store was reduced due to the network return temperature.

Simulations showed that the heat transfer capacity of the BHE could be improved significantly by enlarging both the borehole diameter from 115 to 150 mm and the pipe shank spacing from 65 to 100 mm. Therefore the extension of the store from 4.300 m_ to 20'000 m_ with additional 132 boreholes was made with this new borehole geometry.

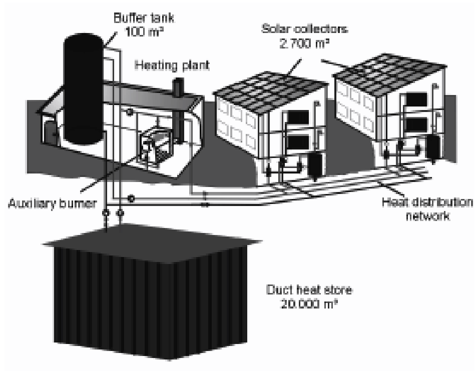
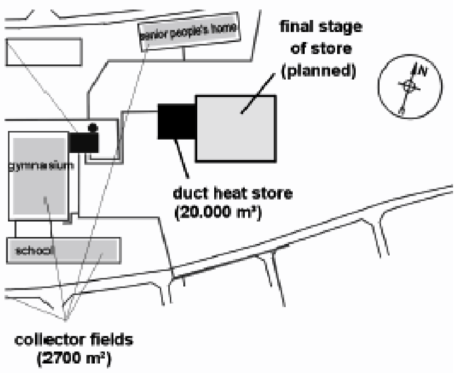
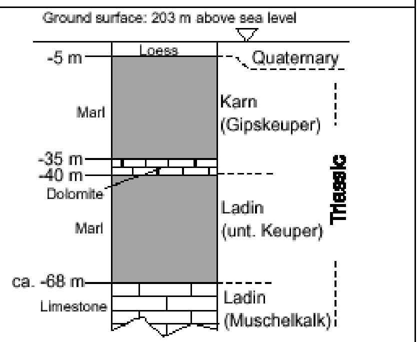
| | |
|---|---|
| Subdivision Amorbach in Neckarsulm, Germany | start of operation 1/1999 |
| Short description of plant:<br>BTES<br>>600 vertical BHE, depth 30 m<br>Borehole spacing 2 m with a sqare drilling pattern (fig. 6)<br>Polybuthene-double-U-pipes as BHE<br>After the installation of the heat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

*Fig. 23: Basic data for the BTES (BHE-store) in Neckarsulm*

*Table 2: Geological situation at Neckarsulm BTES*

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

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

If the ongoing project leads to sucessful results it is planned to extend the duct store stepwise according to the growth of the building area and simultanuosly increasing collector area. The extension will take place in eastern direction. At the final stage the total heat demand of the building area will amount to approximately 10'500 MWh/a and the available collector area to 15'000 m_. According to present simulations a storage volume of about 150'000 m_ will be necessary to achieve a solar fraction of 50%. The heat recovery factor of the store will reach 75 to 80 % depending on the depth of the store, i.e. on the surface/volume-ratio. A quasi-steady- state operation will be reached after approximately 5 years.

**Aquifer store for the Reichstag area in Berlin**

The most prominent example for aquifer storage (ATES) in Germany has been built for heating and cooling of the Reichstag building in Berlin, now seat of the German Parliament (Bundestag). Fig. 24 gives some details.

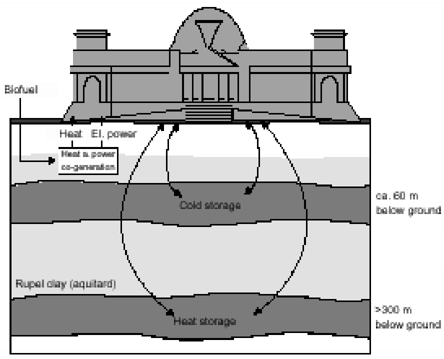
| | |
|---|---|
| Plenarbereich Reichstagsgebäude (seat of the Bundestag, the German Parliament) in Berlin, Germany | start of operation 1/1999 |
| Short description of plant:<br>ATES<br>Two different stores, separated vertically<br>• The upper ATES is cold storage for space cooling, with temperatures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

*Fig. 24: Aquifer storage for the German Parliament in Berlin*

## 5. MARKET AND ECONOMY

It is rather difficult to find reliable numbers of installed heat pumps in Europe, and in particular for the individual heat sources. Fig. 25 gives some recent data for the number of installed units in the main European heat pump countries. The extremely high number for Sweden in 2001 is the result of a large number of exhaust-air and other air-to-air heat pumps; however, Sweden also has the highest number of GSHP in Europe (see 1998 values in fig. 25). In general it can be concluded, that market penetration of GSHP still is modest throughout Europe, with the exception of Sweden and Switzerland (table 3). There is still ample opportunity for further market growth, and the technological prospects endorse this expectation. In Germany, the trend is positive (fig. 26), with a share of GSHP (ground and water) of about 82 % in 2002.

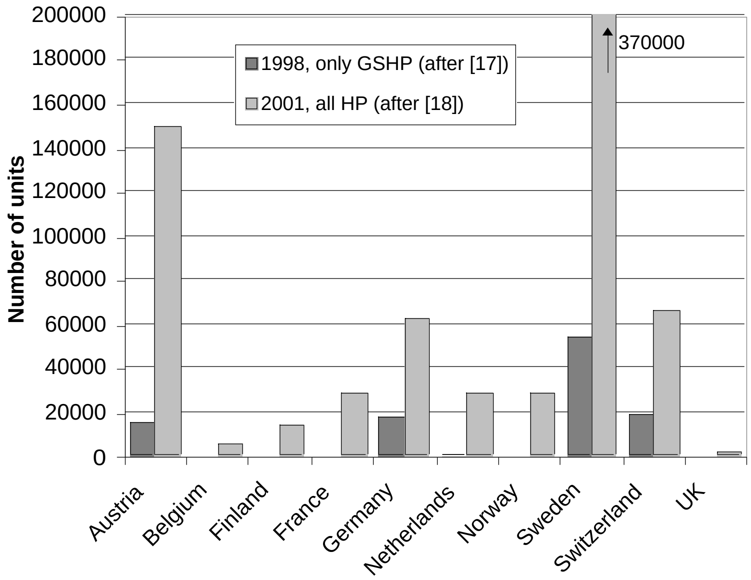



*Fig.5:* *Number of installed heat pump units in some European countries (after data from [16] and [17])*

*Tab. 3:* *Share of ground coupled heat pumps in total residential heating market (after data from [18])*

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

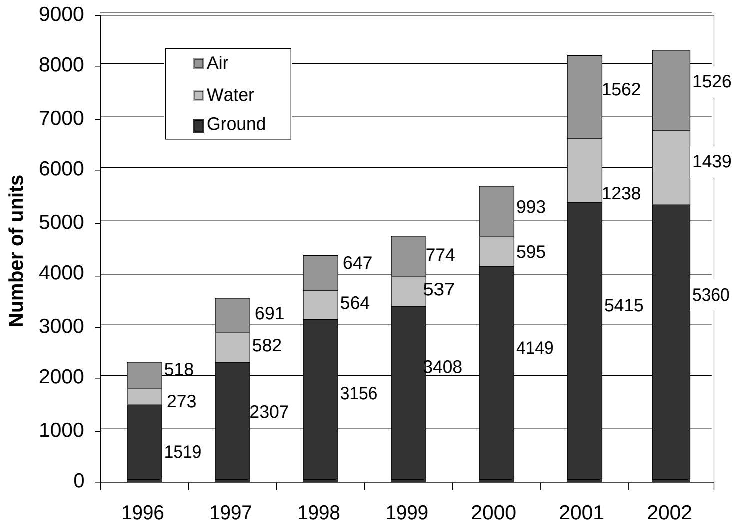



*Fig. 6:* *Number of annual heat pump sales in Germany, according to heat sources (after data from IZW e.V., Hannover and BWP e.V., Munich; heat pumps used for hot tap water production only are not included)*

## 6. CONCLUSIONS

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

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

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