Larger geothermal heat pump plants
in the central region of Germany

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Abstract

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.

The paper 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:

- UEG Wetzlar, a building with chemical laboratories and one of the first examples of direct cooling from BHE
- 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
- other examples and aspects

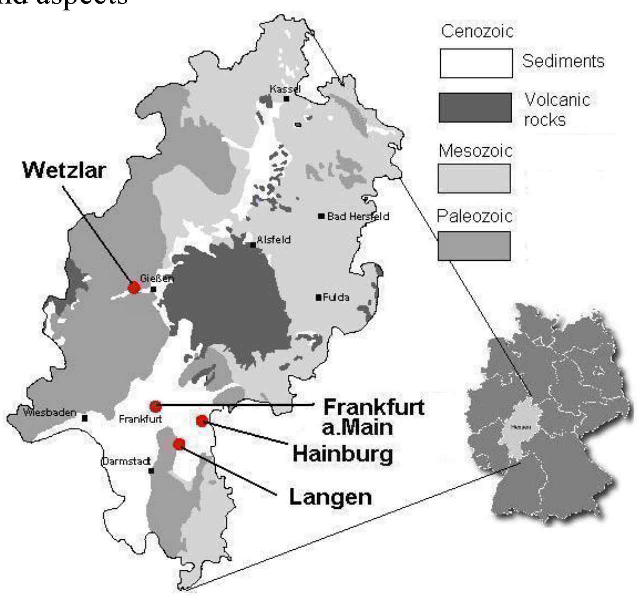

Fig. 1: Location of the plants described, on the basis of the geology of Hessen state

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

Keywords

Ground Source Heat Pumps, Commercial Buildings, Heating and Cooling

Introduction

First, two 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)

The area around Wetzlar is one of the birthplaces 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. 2). 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 summer-time for thermal recovery of the underground.

Fig. 2: "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

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 (BMFT 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. 3) [1]. In this installation, experiments with two types of BHE were carried out (fig 4): 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. [2]. Towards the end of the project, also experiments with direct expansion in BHE were carried out (fig. 3, right). The results of the R&D-project are published in [3].

Fig. 3: 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

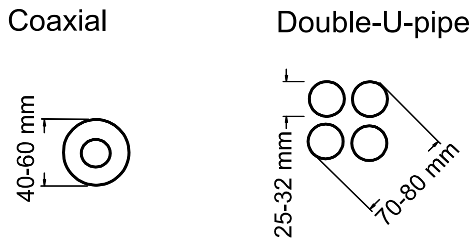

Fig. 4: Cross-section of typical BHE, as used in Schwalbach

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. 5). 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.

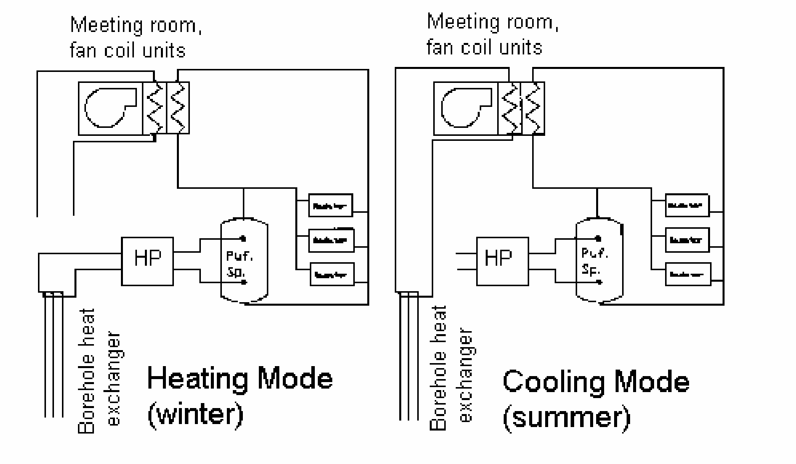

Fig. 4: Schematic of the first experiment with direct cooling from BHE, GSHP plant for heating and cooling in the office building of Helmut Hund GmbH (from [4])

Chemical Laboratory UEG, Wetzlar

UEG building (fig. 5) houses 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 (fig. 6).

Fig. 5: Chemical laboratory "UEG" in Wetzlar, heated and cooled with BHE

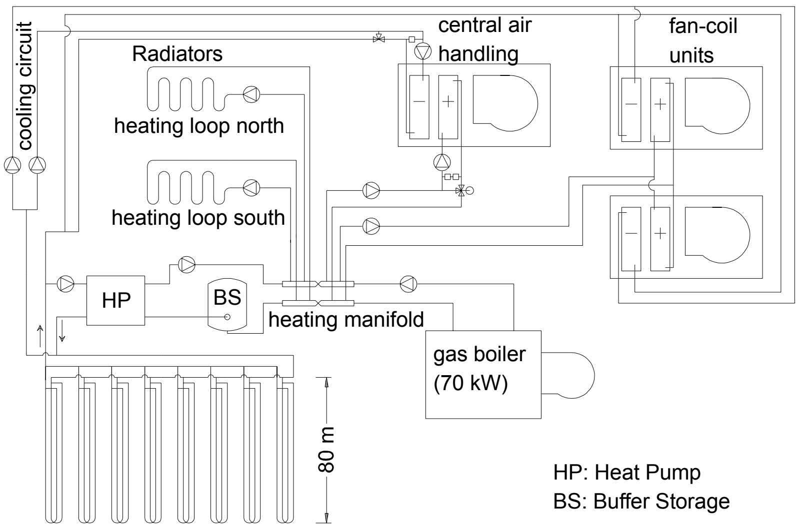

Fig. 6: Schematic of the GSHP plant for heating and cooling in UEG building, Wetzlar

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 problem 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 substances. 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 [5]. Fig. 7 gives the details of the energy flows and the environmental impact, compared to a conventional system with fuel oil for heating and electric air conditioners. The efficiency in heating mode could even be better with a different (floor) heating system, because the radiators require a higher supply temperature than a good floor heating; however, the constraints due to the building use do not allow for that.

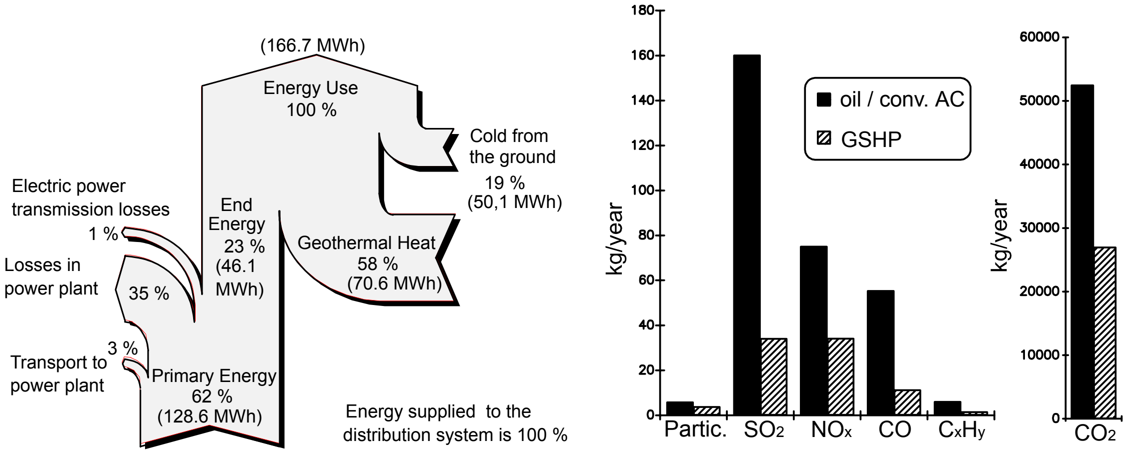

Fig. 7: <u>left:</u> Energy flow for UEG plant, Wetzlar, in 1995/96, starting from primary energy; the values given for electricity production are from a utility report
<u>right:</u> Emission reduction compared to a conventional plant (design values)

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 m^3
- total floor area 57’800 m^2
- heated/cooled area 44’500 m^2

A borehole thermal energy storage with two borehole fields (fig. 8) 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, equaling 80 % of the annual cooling energy and allowing 70 % of the annual heating being covered by the heat pump (fig. 9). There are only a few plants in Europe with a capacity and number of BHE like in Langen.

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 [6]. 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.

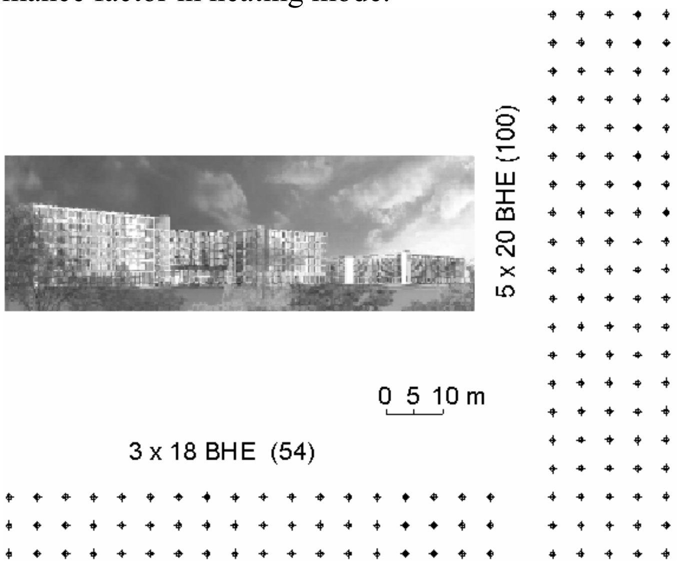

Fig. 8: *Layout of the two BHE fields for the office building in Langen, with the architest´s impression of the building to show its location in regard to the BHEs*

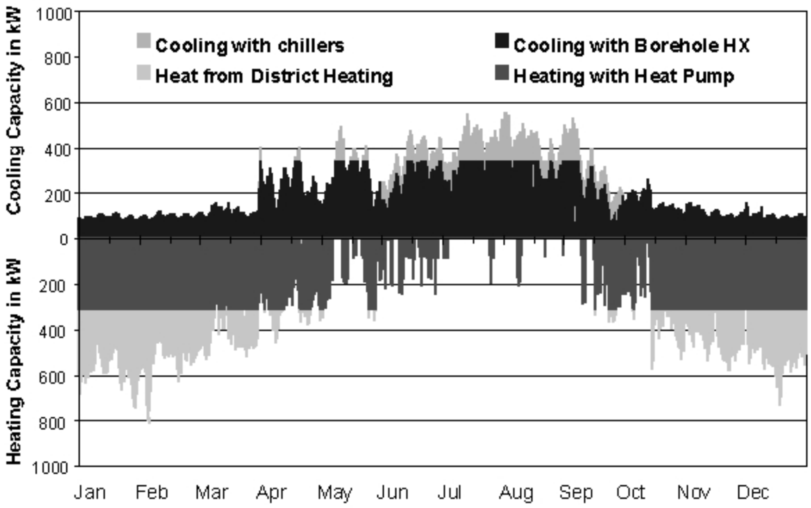

Fig. 9: Heating and cooling demand for the German Air Traffic Control (DFS) headquarters, data from simulation

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 conductivity of the borehole filling from a normal 0.6-0.8 W/m/K to ca. 1.6 W/m/K has been developed, and the heat transfer in the borehole could be enhanced substantially. A second thermal response test (fig. 10) 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 r_b = 0.11 K/(W/m)
- with thermally enhanced grout r_b = 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.

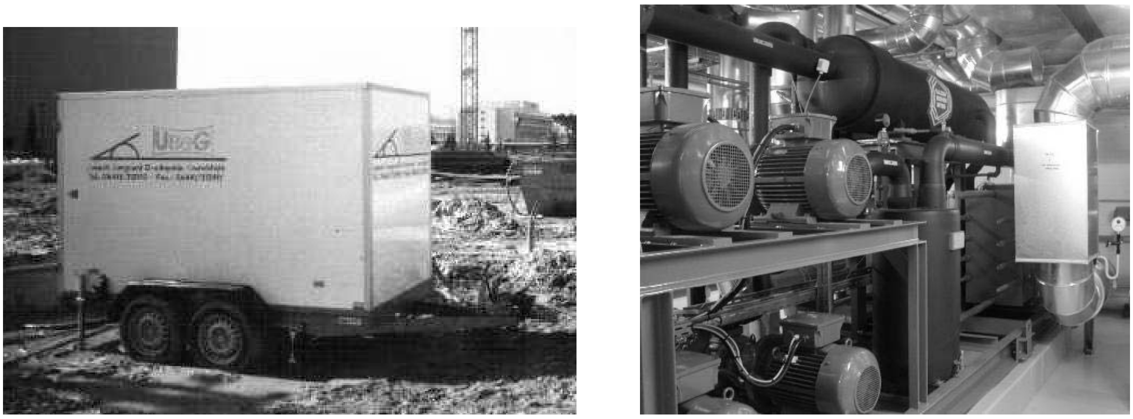

Fig. 10: left: Thermal Response Test equipment on site in Langen
right: Heat pump in DFS-headquarters, Langen; to the left four motors driving the compressors. in the background and above evaporator and condensor.

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. 11 shows the development of groundwater temperature in an aquifer 20-26 m deep.

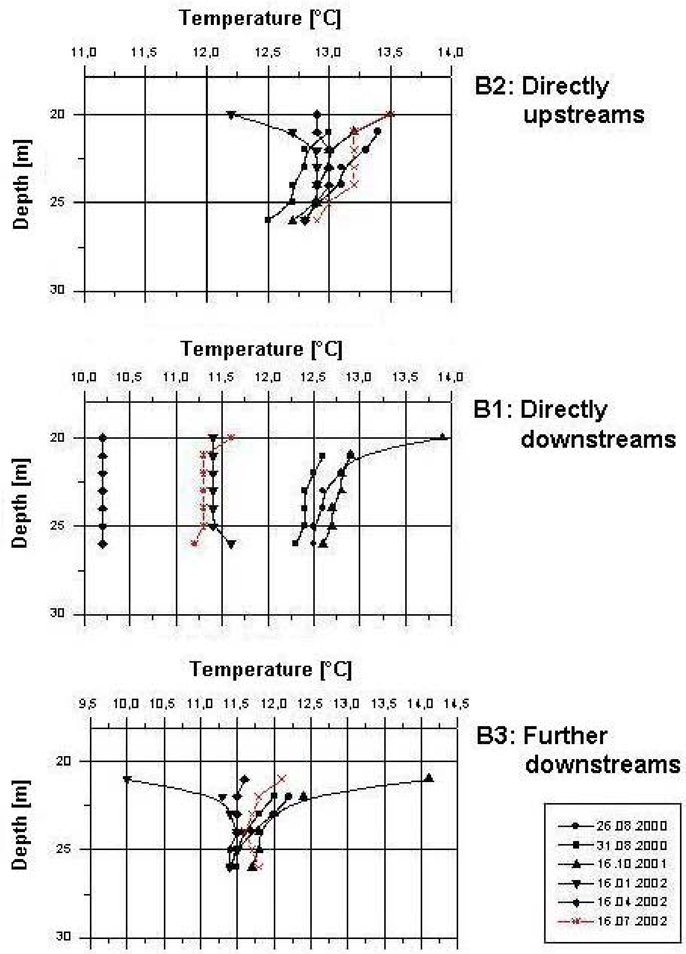

Fig. 11: Monitoring of the impact of the BHE-field on groundwater temperature

The layout calculations were done with the computer program „Earth Energy Designer“ (EED), jointly developed by universities in Sweden and Germany [7], [8]. EED allows 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 [9]. The BHE system allows, even with higher first cost, an annual cost saving compared to conventional heating and cooling plants. The cost comparison (fig. 12), 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.

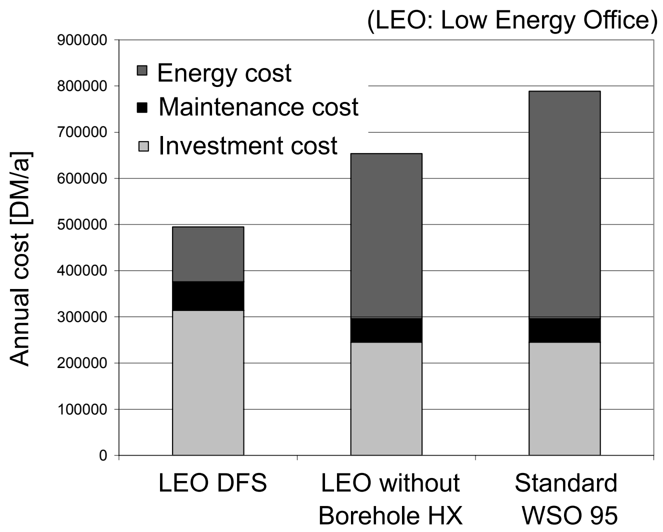

Fig. 12: Annual cost comparison for heating and cooling the German Air Traffic Control (DFS) headquarters (after [9])
Version LEO DFS: Borehole heat exchangers, heat pump, local heat net, chiller, first cost 4.5 million DM
Version LEO without BHE: Local heat net, chiller, first cost 3.5 million DM
Version Standard WSO 95: Local heat net, chiller, first cost 3.5 million DM

Larger GSHP-plants with groundwater wells

The Southern part of Hessen 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. 13). It is intended for heating and cooling of a multi-storey building with offices and apartments. There were several problems and constraints that had to be dealt with:

- 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. 14), 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.

Fig. 13: Architectural simulation of the FAAG-building “Living and Working at Baseler Platz” in Frankfurt/Main

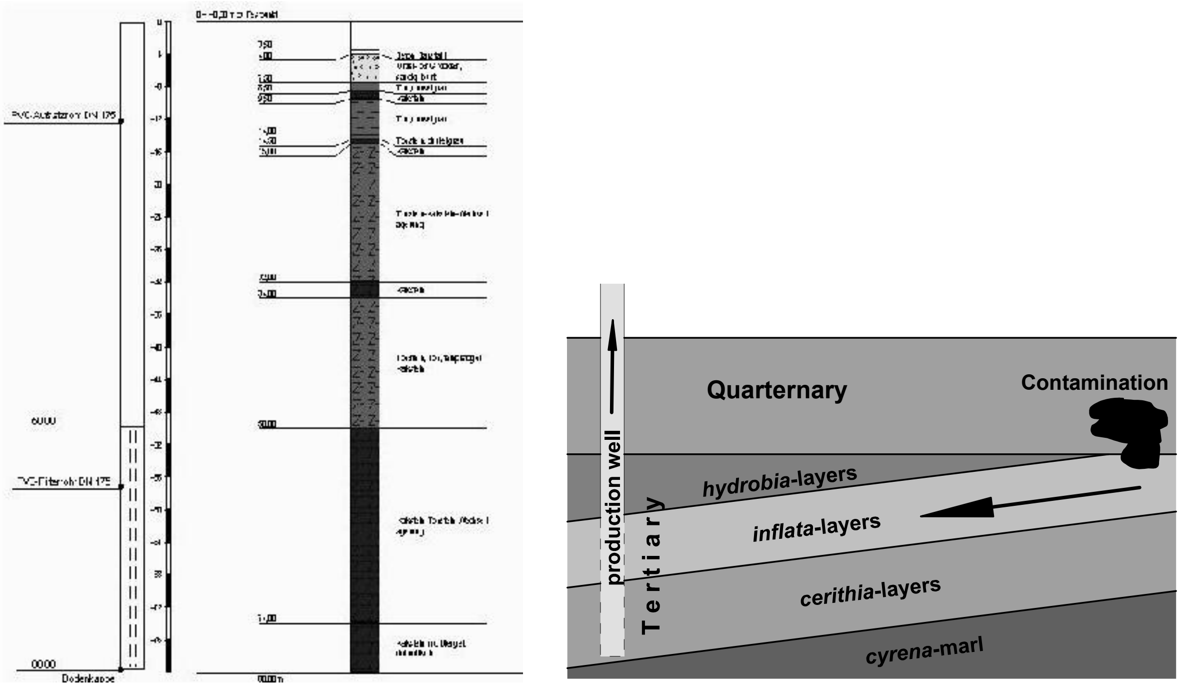

Fig. 14: <u>left:</u> Production well for FAAG-building, Frankfurt
<u>right:</u> Permeable layers could allow transport from a contaminated area in several hundred meter distance, monitoring is required

Another groundwater heat pump currently is under construction to heat and cool a commercial area with several smaller shops in Hainburg (fig. 15). Two wells to a depth of ca. 200 m already have been drilled, and pumping test showed sufficient flow. The geology was somewhat 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 [10] revealed that no problems with scaling should be expected within the planned temperature range.

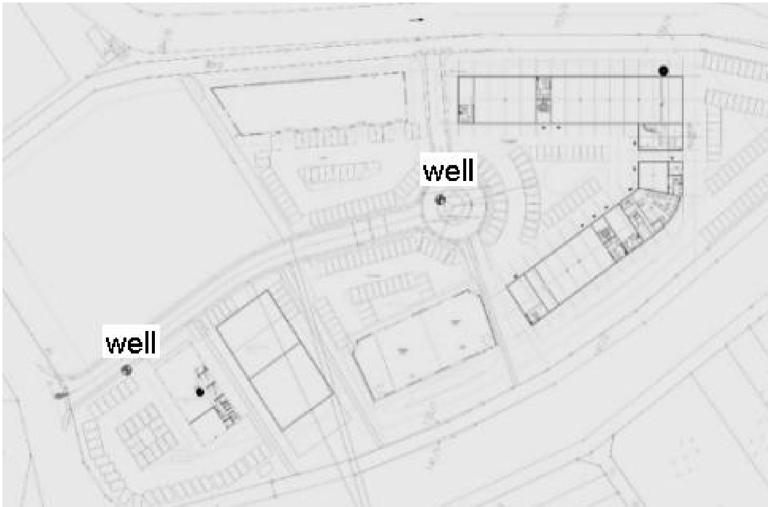

Fig. 15: Plan of the commercial area in Hainburg to be heated and cooled by GSHP

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 (how 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 2003/04.

Conclusions

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 in a specific area 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 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 [11]. 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.

A very specific application has been studied for the largest sports stadium in Frankfurt, the “Waldstadion”. A geothermal lawn heating was considered (fig. 16), with two wells down to about 300-500 m and direct heating. However, the study showed that the geological conditions on the site of the stadium are not too favourable, and that water with sufficient flow rate and temperature is rather unlikely, due to the vicinity of a horst structure with relatively impermeable Permian sediments. A version using a heat pump on shallower groundwater with lower temperature would be possible, but will most likely be not applied due to the poorer economy of this alternative. In general, for sites with suitable underground conditions, a geothermal lawn heating may be a good choice to save energy and reduce emissions.

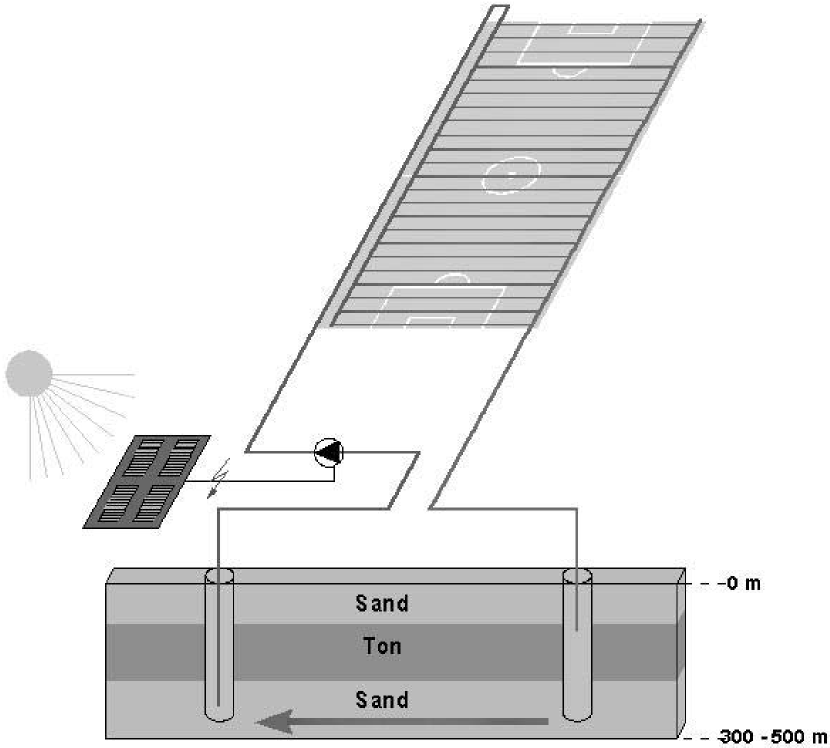

Fig. 16: Suggestion for a geothermal lawn heating for Frankfurt Waldstadion

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