Umwelt Baugrund Geothermie Geotechnik

The Low-Energy-Office of Deutsche Flugsicherung (German Air Traffic Control) in Langen, with geothermal heat and cold storage

The German Air Traffic Control builds new headquarters in Langen, just a few kilometers southeast of Frankfurt airport. The office building (fig. 1) will offer room for ca. 1200 employees, and is planned as a Low-Energy-Office (LEO). A borehole thermal energy storage (SANNER et al., 1996) with two borehole fields comprising a total of 154 borehole heat exchangers (BHE) each 70 deep is integrated into the heating and cooling system. Both fields supply a total cooling capacity of 340 kW and 330 kW heating capacity. The basic data of the building are:

- total building volume 230'000 m^3 (8'122'450 cu ft)
- total floor area 57'800 m^2 (622'160 sq. ft)
- heated/cooled area 44'500 m^2 (479'000 sq. ft)

Fig. 1: Architect's concept of German Air Traffic Control (DFS) headquarters

Early in the design process it was decided to realize an economic, but also ecologically sustainable office building. The building also should offer a high quality working environment and great flexibility in the interior layout. The Swiss consulting group Amstein + Walthert from Zurich was asked to prepare the technical standards and requirements and to accompany the design.

In a first step, a Low-Energy-Office target value for the specific project was defined, using a guideline from the State of Hessen and the recommendation SIA 380/4 of the Swiss Association of Engineers and Architects. The LEO target value (electricity and heat/cold-demand of the building) was set to:

- 100 kWh/m^2/a (incl. electricity for the catering kitchen)

This value means an energy reduction of about 35 % compared to conventional offices.

An energy simulation for the building was performed by Amstein + Walthert, concerning the seasonal distribution of heat- and cold demand. The design of the borehole heat exchangers was done by UBeG in Wetzlar. Based upon simulations of the building and the underground, an optimization of the subsurface and HVAC plant could be achieved through several steps, leading to a reduction of energy cost by approx. 300’000 DM annually.

Energetic and technical concept

The following items characterize the energy concept (cf. fig. 2):

- Optimum building skin with perfect shading (to minimize the impact of the outdoor climate on the indoor climate)
- Use of the thermal storage capacity of the mass of the building (only few suspended ceilings and double floors)
- Thermo-active ceilings („TAC“)
- Borehole heat exchangers (154 BHE each 70 m deep, with 5 m horizontal distance) as seasonal heat- and cold storage
- Heat pump with environmentally benign refrigerant NH_3 and high COP above 6 for low temperature heat up to 30 °C
- Local heating net for temperatures >30 °C
- Cost-effective compact chiller for peak cooling loads
- Optimum use of daylight, lighting controlled e.g. by occupancy sensors

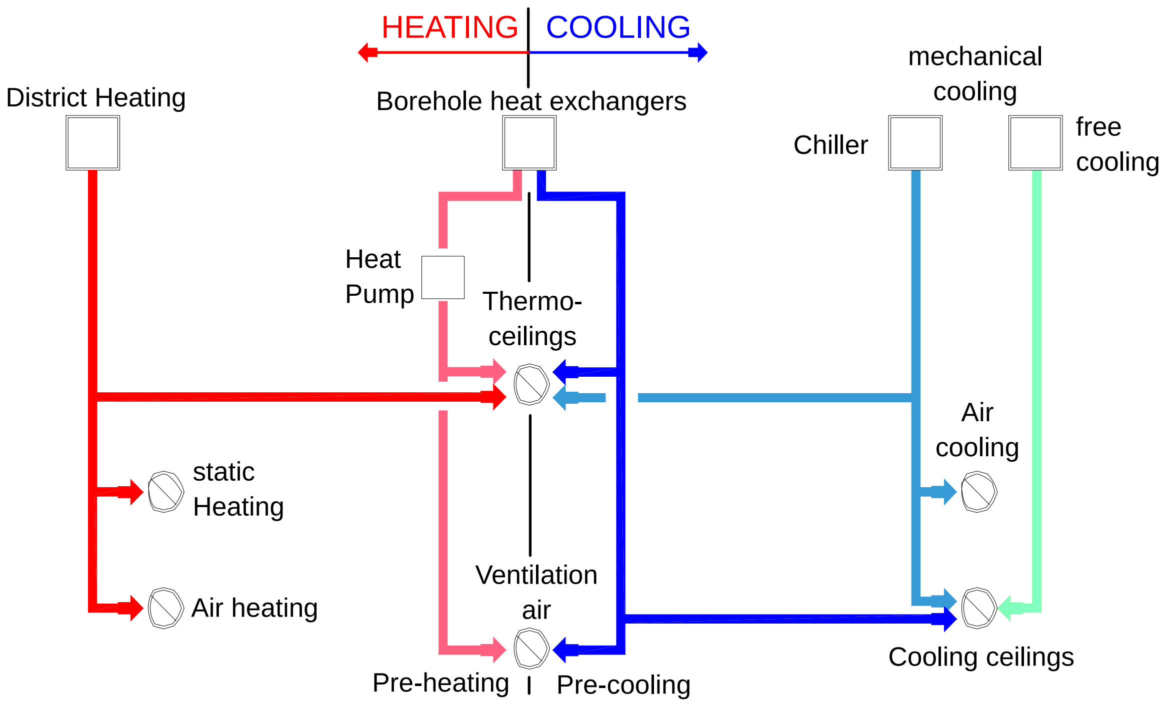

Fig. 2: Schematic of the heating- and cooling concept for the German Air Traffic Control (DFS) headquarters

During summer the cold water from the borehole heat exchangers is used directly to cool the cooling ceilings, and the underground is slowly heated (a system concept first used in Germany in 1987; cf. SANNER, 1990). In winter this heat is used as heat source for heat pumps. The peak cooling loads are met by conventional chillers, and the peak heating loads are covered by districted heating.

Borehole heat exchanger system

A central part of the energy concept is the borehole heat exchanger system. It covers the base load of the building cooling and a part of the heating load. 154 borehole heat exchangers with 70 m depth each allow a thermal output of 340 kW for heating and 330 kW for cooling (fig. 3). This equals 80 % of the annual cooling energy and allows 70 % of the annual heating with the heat pump. The borehole heat exchangers are located in 2 fields (5 x 20 and 3 x 18), located in the shape of a L (fig. 4). The borehole heat exchangers are of the double-U-type made from polyethylene (fig. 5). There are only a few plants in Europe with a capacity and number of BHE like in Langen.

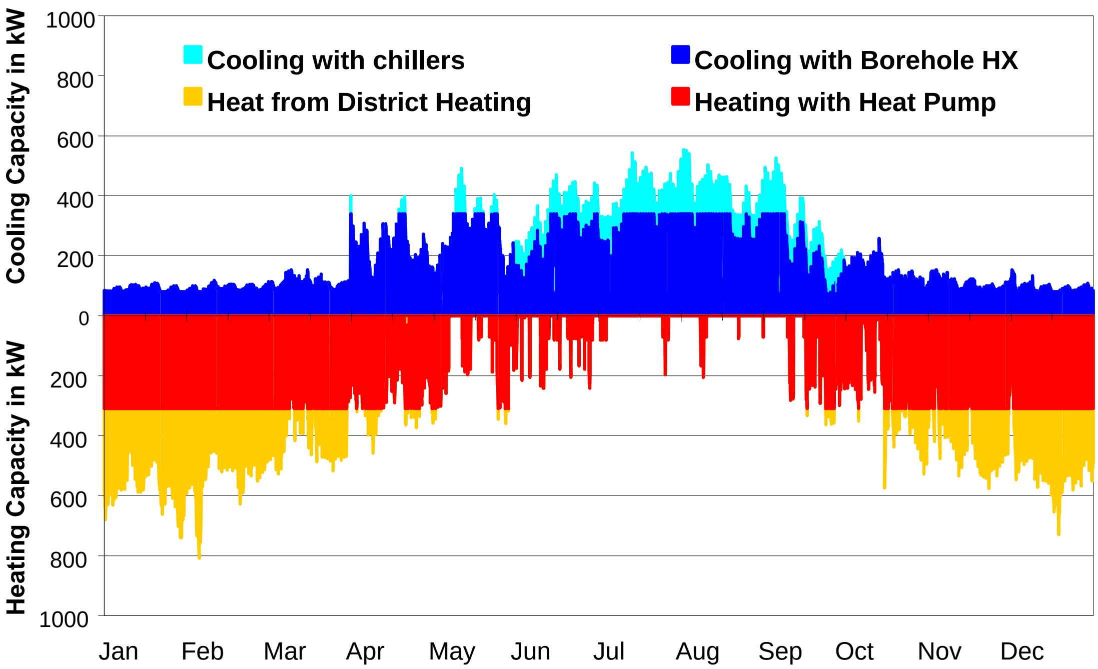

Fig. 3: Heating and cooling demand for the German Air Traffic Control (DFS) headquarters, data from simulation

For the first time in Germany, a thermal response test (carried out by UBeG in summer 1999) was used as a basis for dimensioning a borehole heat exchanger field (SANNER et al., 2000). An almost 100 m deep test borehole was equipped with a borehole heat exchanger (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 β = 2,8 W/m/K
- Borehole thermal resistance r_b = 0.11 K/(W/m)

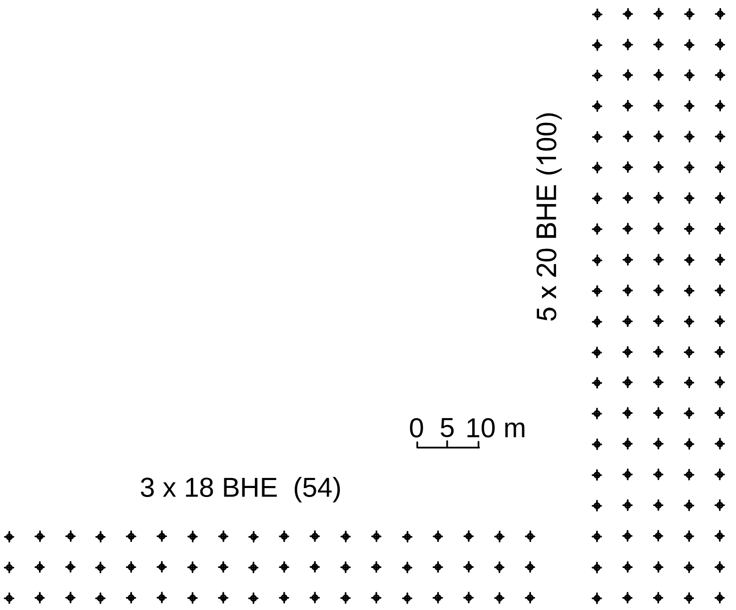

Fig. 4: *Layout of the two BHE fields for the German Air Traffic Control (DFS) headquarters*

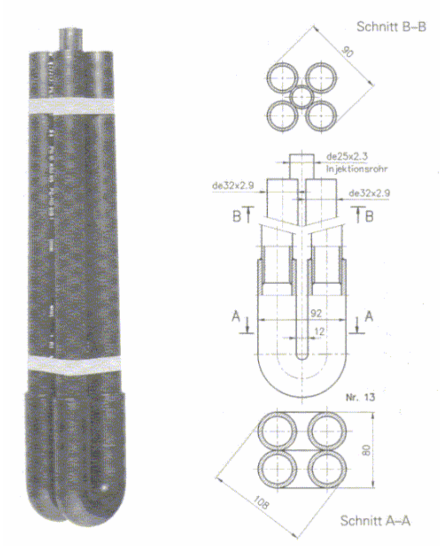

Fig. 5: *Double-U-tube borehole heat exchanger (BHE), made by HAKA (Switzerland)*

There is a particularity of the borehole heat exchanger 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, 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 the heating mode.

To extract an energy amount as high as possible with source temperatures above +4 °C, the borehole thermal resistance has to be lowered. From the USA, thermally enhanced grout is known for backfilling. By addition of ecologically sound materials with high thermal conductivity (e.g. fine quartz), the thermal conductivity of the borehole filling can be pushed from a normal 0.6-0.8 W/m/K to ca. 1.6 W/m/K. A material suitable for the German conditions and available at acceptable cost could be developed by UBeG, and the heat transfer in the borehole can be enhanced substantially.

A second thermal response test (fig. 6) was done at one of the final borehole heat exchangers (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. 6: Thermal Response Test equipment on site in Langen

The layout calculations were done with the computer program „Earth Energy Designer" (EED), jointly developed by universities in Sweden and Germany (HELLSTRÖM & SANNER, 1994; HELLSTRÖM et al., 1997). 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. A temperature curve for the final design is given in fig. 7.

The borehole heat exchangers in Langen are located inside zone III of a groundwater protection area (City Waterworks Langen). Thus the plant required a specific license, and it was necessary to prove by calculations and expertises the absence of any noxious impact to the water wells. This could be done successfully, and the water authorities granted the license.

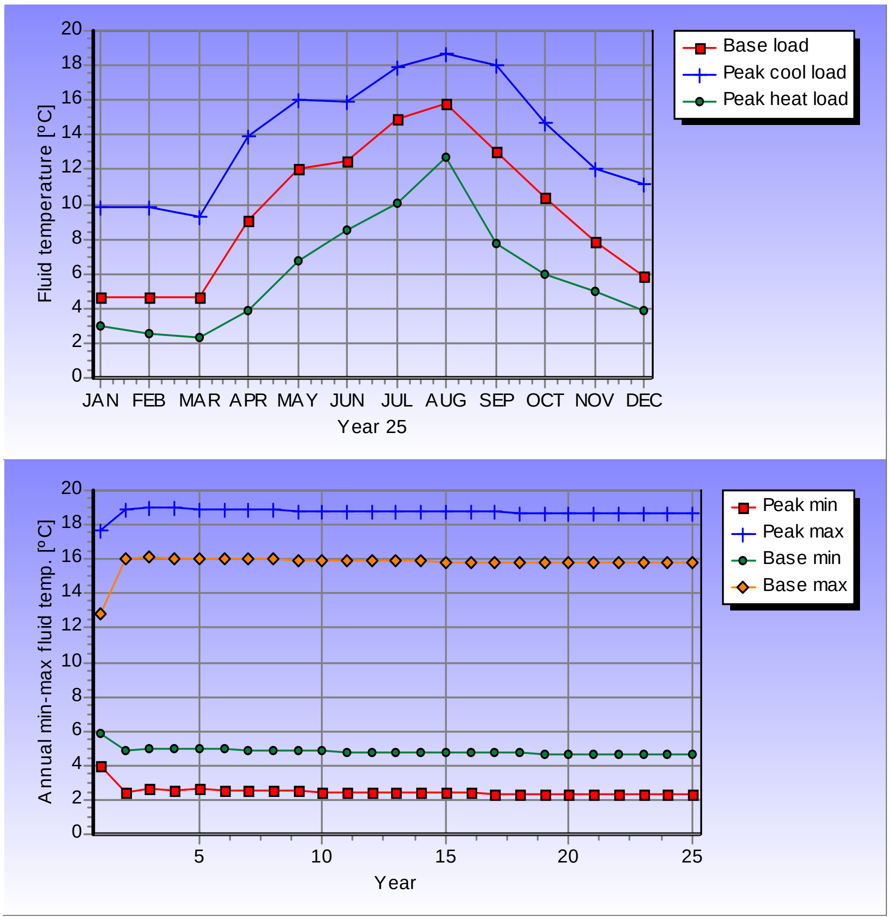

Fig. 7: *Mean temperature of the heat carrier in the optimized version, in the 25th year of operation (above) and showing the minimum-maximum temperatures over 25 years*

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.

Economical aspects

The borehole heat exchanger systems allows, even with higher first cost, an annual cost saving compared to conventional heating and cooling plants. The cost comparison (fig. 8), regarding energy, maintenance and capital cost of the heat and cold generation, reveals that the Low Energy Office with borehole heat exchangers is the most economical solution, due to the low energy cost.

References

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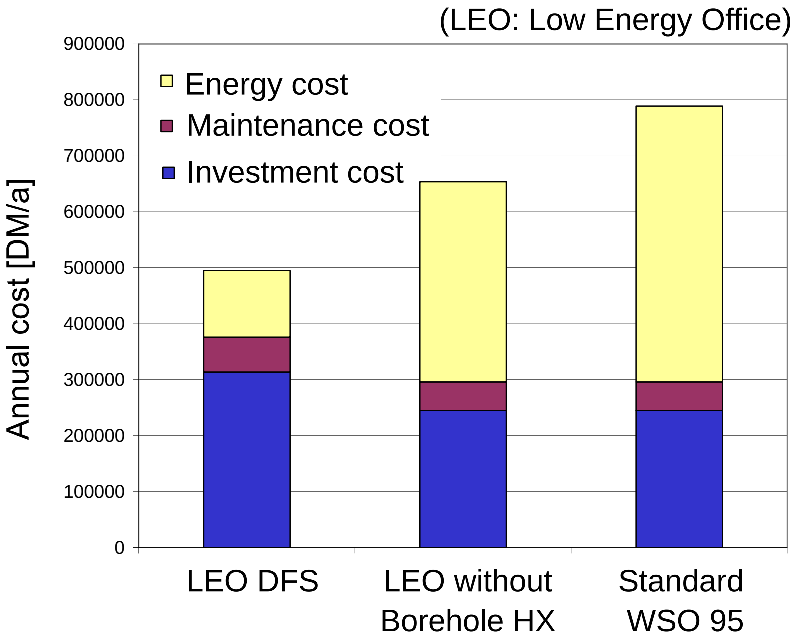

Fig. 8: *Annual cost comparison for heating and cooling the German Air Traffic Control (DFS) headquarters*

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

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