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The Use of the Underground as a Geothermal Storage for Different Heating and Cooling Needs

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ABSTRACT

The heating and cooling needs of a building show usually a strong daily and seasonal variation. The shallow underground is a cost-efficient store for compensating the daily and seasonal delay between need and supply of heat and cold. Mostly borehole heat exchangers (BHE) are used to develop and operate the geothermal store. The leading parameters for the design of optimized installations are demonstrated by a project with complex energy demand.

1. CRITERIA FOR BHE-SYSTEMS

Today, the borehole heat exchanger technology is technically matured. Compared to conventional installations borehole heat exchanger systems are competitive and even attractive for energy production and storage especially for objects with very large heating and cooling demands. Due to the comparatively high cost fraction for drilling, the proper design of BHE systems is crucial for large-scale projects to optimise costs and sustainable functionality. The most important constraints come from the energy concept of the building. BHE-systems are very efficient, if they are not only used for heat production, but also used to store waste heat from cooling systems into the ground. This seasonal use of the ground improves the coefficient of performance of the heat pumps and also reduces the cooling down effect of the ground during the heating season. The efficiency of the so-called seasonal storage is much higher, if the heating and cooling energy demand is equilibrated over a specific period.

The main advantage of BHE-systems compared to other techniques is its free cooling potential. By free cooling, the return from a cooling distributor is transported directly to the BHE circuit without using a cooling machine. This has two major effects: the cooling energy is practically for free and the size of a BHE array can be significantly reduced. Therefore the seasonal values for heating and cooling demand are the key parameters for the cost-utility analysis of different energy supply systems.

However, in the run-up to the cost-utility analysis a few principal boundary conditions must fit for BHE-systems. Restrictive or preclusive condition for BHE are the available space for drilling, the interaction of the drilling process with other work on the construction site, official orders (ground water protection) or availability of suitable and sufficient drilling equipment.

In the cost-utility analysis of a large-scale project all options for heating and cooling supply are pre-designed based on engineering-standards and empirical values. Based on such pre-dimensioning, installation costs and operating costs of different systems are calculated and then compared. Although the pure installation costs for BHE-systems are in general higher than for other systems, the operation costs are quite low. The important and still increasing market of BHE systems shows, that these systems are competitive to conventional systems. In addition it seems that systems based on fossil fuels are widely critically seen due to the strong price fluctuations in the recent past.

After the decision has been taken for a BHE-system the ground thermal properties, like thermal conductivity, ground temperature and only to a small extent heat capacity, become important as design parameters for the optimisation work. Nevertheless thermal ground properties are parameters which do not influence the principal decision process for the energy supply system.

2. REQUIREMENTS FOR PLANNING BHE-SYSTEMS

2.1 Soil Measurements

For the optimised design of BHE-systems, the knowledge of ground thermal properties such as thermal conductivity and ground temperature is important. These parameters are measured by carrying out Thermal Response Tests (TRT). TRT are carried out only for larger BHE arrays (more than 10-20 BHE) because of the measuring costs. If the BHE array is small (less than approx. 20 BHE), ground properties are estimated based on geological information or on empirical values, including an appropriate safety margin.

A TRT measures thermal conductivity, thermal borehole resistance and ground temperature as average values over the entire length of the BHE. These parameters can be used as input values for dimensioning tools. By means of power regulated TRT device and numerical evaluation (in contrast to still practiced graphical evaluation), the relevant ground properties can be measured with high and appropriate accuracy (Signorelli et al., 2007).

Especially if a BHE-system shall be used also for direct cooling ("freecooling") it can be decisive for the energy concept to know not only the mean temperature of the soil but the temperature-depth-profile. This can be carried out in the first installed BHE of an array. Particularly in regions with complex geology, e.g. in regions in or close to mountain belts or in urban regions this can be crucial for an efficient design.

It can also be important to determine not only the mean thermal conductivity but the profile over the entire length of BHE. This can be done if temperature-depth-profiles are logged before, during and after a TRT is carried out. The combination of a classic TRT measurement with temperature logging is sometimes called eTRT-method (enhanced TRT, Poppei et al., 2008). The advantage of thermal conductivity profiles over a classical TRT evaluation is that appropriate temperature and thermal conductivity values can be extracted for different BHE lengths in an array and used as input parameters for dimensioning tools. In addition the eTRT method also allows to identify zones of groundwater movement which is characterised by strongly increased apparent thermal conductivity values.

Figure 1 shows an example of a thermal conductivity profile, which was derived from an eTRT-measurement. This example shows a sudden increase of thermal conductivity in approximately 110 m depth. This discontinuity corresponds exactly with the transition from unconsolidated rock to solid rock.

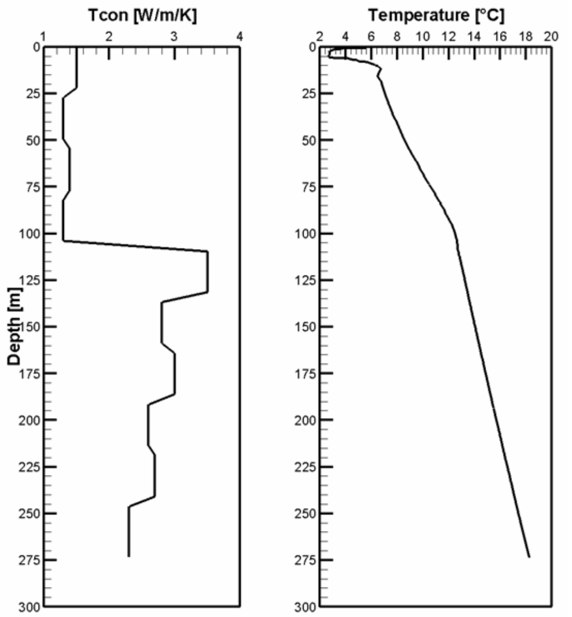

Figure 1: Thermal conductivity profile (left side, Tcon: thermal conductivity) and temperature-depth-profile (right side), derived from an enhanced TRT measurement in a 270 m deep Test-BHE in Andermatt (Switzerland).

2.2 Design of BHE-Systems

Beside the thermal properties of the ground the principal design of a BHE array (number, length, distance and geometry of BHE) is influenced mainly by the energy management of the building. The main influencing parameters are:

- Hourly need for heating
- Hourly need for cooling
- System temperature levels
- System components (dry air coolers, …)
- Controls
- Hydraulics

It can be advantageous to split the BHE array in two or more separate arrays, if direct cooling (free cooling) is desirable. In this case, one or more BHE arrays, which are designed for optimum storage behaviour, must be cooled down as far as possible during winter in order to provide a maximum of free cooling potential during the cooling season. BHE array separation makes free cooling possible even at very deep cooling temperatures of 10°C. The heating and cooling energy is moved between consumers and BHE arrays via ring lines. This ring line system operates like a district heating network, but can also be used for cooling purposes. Individual consumers receive their energy demand for heating and cooling independently via the ring lines (Figure 2).

The temperature as a function of time can be calculated using modern simulation tools. This is done usually for 25 or 50 years of operation in order to evaluate the sustainability of the whole system under the assumed heating and cooling energy needs. The BHE fluid temperature must not get colder than –3°C and 0°C at the inlet and outlet of the BHE during the entire operation period. Otherwise, permanent frost damage might occur in the soil.

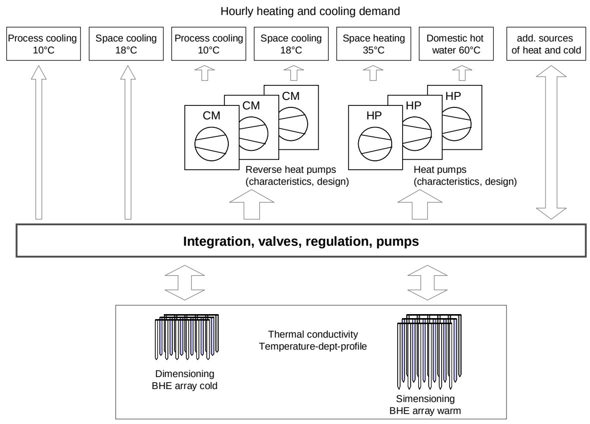

Figure 2: Simplified example of a BHE system, which consists of two BHE arrays with different design, optimized for heating and storage purposes, a ring line system, and different types of consumers with energy demand for heating and cooling at different temperatures.

2.3 Quality Control

The lifetime of BHE tubes (PE 100) is assumed as 100 years, if pressure and temperature conditions in the BHE stay within the limits defined by the manufacturer. However, a BHE can be damaged easily during installation of the tubes in the borehole or during flooding of the connection pipes to the distributor or heat pump. If BHE are installed properly, the risk of damaging the BHE during operation is very low.

BHE, which are damaged, have to be identified as soon as possible after installation, because in many cases, the BHE array is situated under a building with no access afterwards. Immediately after the backfilling is inserted, the BHE is tested for closeness following the contraction procedure of EN SN 805. Also, the quality of the backfilling can be checked with a TRT measurement. The measured thermal resistance yields information about the thermal conductivity of the backfilling. Before the connection to the heat pump is established, borehole heat exchangers have to be tested for functionality by the drilling contractor. To wash out possible dirt particles, the borehole heat exchanger is flushed loop per loop with water. By doing this, one assures that no unusual hydraulic resistance is present.

The real BHE temperature can be compared with the simulated results, if heat pumps or the brine circuit is equipped with temperature sensors. The energy demand of the heat pumps should also be monitored during operation. The energy engineer can take action in time, if a significant deviation between predicted and measured temperatures occurs within the first years of operation.

3. PROJECT EXAMPLE

"Richti-Areal" is a complex of buildings in Wallisellen (Switzerland), which will consist of more than 500 apartments and offices for different kinds of services (Figure 3). The energy demand will be approximately 6.0 GWh/a for heating and 3.0 GWh/a for cooling. The cooling systems operate at different temperatures.

A cost-utility analysis was done in the run-up of the project. Geothermal energy and heating energy from an existing district heating network in the vicinity of the project location were the only two options for this project. The installation and connection costs for energy from the district-heating network are almost twice as much as the installation costs for BHE (which are approx. 6 Mio. CHF). The same factor was found for the operating costs. Additionally, the CO2-emission of the BHE system is only about 15% of the CO2-emission of the district-heating network (because this energy is produces in a garbage incineration plant). It was then decides to install a BHE system, which provides energy for cooling without emissions as well.

A pre-dimensioning yields a total BHE length of 57 km. The BHE will be installed in four separate BHE arrays under the base plate of the building. Although the BHE systems seems to be very expensive, it was shown that other energy systems (district heating, gas, BHE and gas) were more expensive – mainly because the cooling energy can be provided via free cooling.

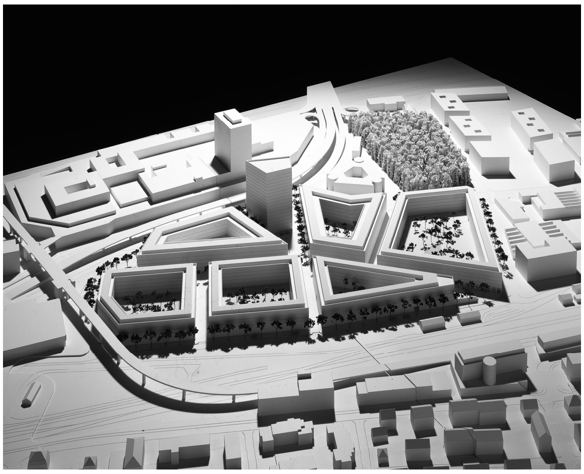

Figure 3: Model of the complex of building "Richti-Areal" (72000 m^2, www.richti.ch).

The cooling energy (2.5 GWh/a space cooling at 18/21°C and 0.5 GWh/a for process cooling at 8/14°C) must be provided mainly by freecooling. Therefore, the BHE arrays will be separated into two groups. One BHE array group (BHE array A) will consist of BHE with 150 m length at short distances of 7 m. BHE array A will be cooled down as far as possible during winter in order to achieve a maximum storage potential for free cooling energy in summer. If the BHE storage gets too warm for free cooling, the remaining cooling need will be provides by reversely operated heat pumps. The waste heat from the reversed heat pumps will be stored in BHE array B, which consists of 250 m deep BHE at 10 m distance to each other (Figure 4, 5).

This concept makes it possible to achieve 100% of the required cooling energy via BHE without dry air coolers. The friction of cooling energy, which can be delivered by free cooling, increased with time and reaches more than 80% after 5 years of operation (Figure 6).

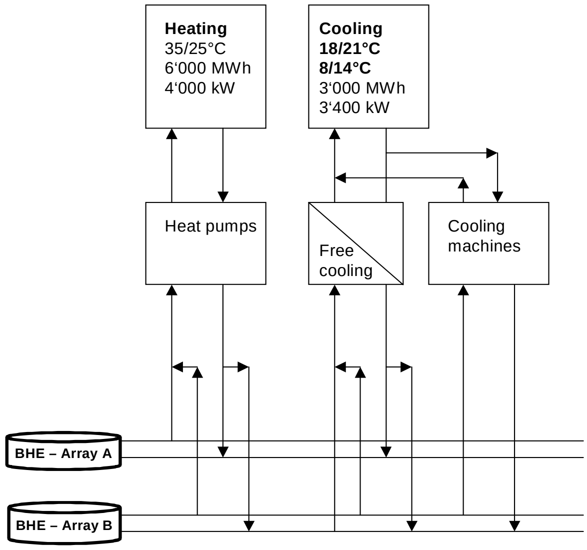

Figure 4: Simplified geothermal concept. BHE Array A is optimized for free cooling. Waste heat from cooling machines is stored in BHE array B only.

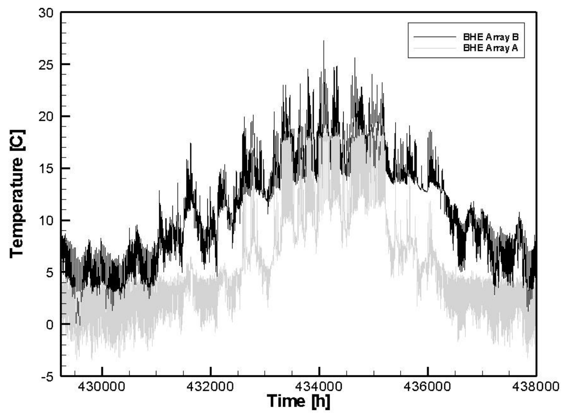

Figure 5: Average BHE temperatures in BHE Array A and B after 50 years of operation. BHE Array A is cooled down to the limit in winter in order to enable a high potential for free cooling during summer.

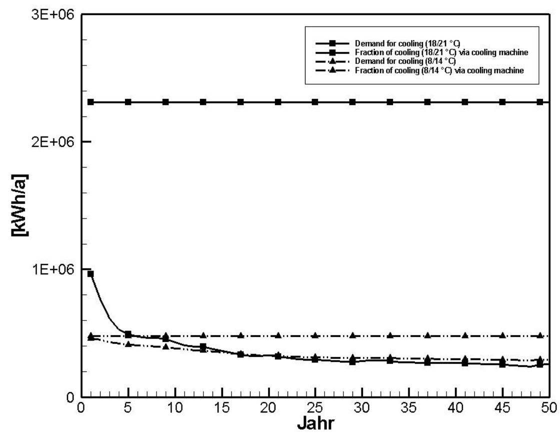

Figure 6: The horizontal lines show the energy demand for two different cooling systems at high and low temperatures. The remaining two lines show the fraction of the cooling energy demand, which has to be provided by cooling machines.

For the presented concept it is essential, that the real energy demand is consistent with the assumed energy demand during the planning phase (within a certain range). The energy balance of the BHE arrays will change if the real energy demand for heating/cooling increases or decreases. In worst case, all BHE will cool down to the engineering limit of –1.5°C and must be shut down.

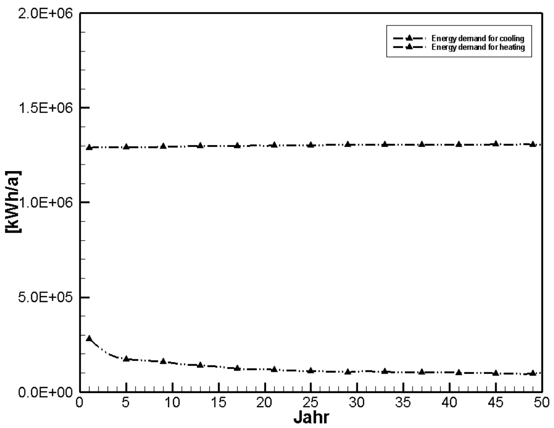

Figure 7: Estimated energy consumption for heating and cooling, including electrical energy demand for heat pump compressors and pumps for energy distribution.

To make the system flexible to changing demands during operation dry air coolers are integrated in the system. A dry air cooler (or hybrid cooler) can balance unexpected variations of the real cooling and heating energy need. The dry air cooler can also operate during night times or during spring and autumn in order to charge or discharge BHE. The integration of a dry air cooler is a very efficient energy source. The COP of a dry air cooler is greater than 50 and can operate, if the temperature difference between ground and outside air temperature is greater than 2-3°C. Dry air coolers can also improve the COP of a well-balanced BHE system, because they reduce the maximum temperature difference in the ground between summer and winter time. Also dry air coolers can reduce the total size of BHE arrays, if they are integrated into a BHE systems right from the beginning.

4. CONCLUSION

Today, BHE arrays are competitive energy sources, although the investments are higher than at other energy systems. One main advantage of BHE arrays over all other energy systems is the free cooling potential. Then, BHE operate as energy storage, which must be designed to balance the asynchronous seasonal heating and cooling demand. The operating costs are very low in comparison to other energy systems.

Except for locations with significant groundwater flow, artesian water or special geology, which could cause geotechnical problems (gypsum, anhydrite), BHE arrays can be installed almost everywhere, principally independent of the thermal properties of the ground. Accurate thermal properties are usually needed for the planning phase of a BHE system, not for the preliminary cost-utility analysis.

During the detailed planning of a large-scale BHE storage, measurements of ground thermal properties in test-BHE are recommended in order to achieve the ground parameters for the dimensioning tools. However, the crucial planning parameters are determined by the location, the construction and the utilisation of a building, i.e. by the energy concept and the energy load profiles. Quality control during the installation of the BHE-system and control of the operational behaviour by monitoring must be part of a modern geothermal engineering concept.

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