

Examples of integration and optimization of operation of shallow geothermal energy systems in commercial and non-residential buildings within project geo:base

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ABSTRACT

In commercial and other non-residential applications, installations for heat and cold supply often are quite complex, with an array of different energy sources and supply units and numerous consuming points of heat and cold, often active at the same time. The integration of shallow geothermal energy into such systems requires well-designed connections and sophisticated control to achieve an optimum operation. The size of the borehole heat exchanger (BHE) field usually makes such installation a borehole thermal energy storage (BTES).

Scientific monitoring, documentation and evaluation are done at two industrial facilities, one with BHE and the other with energy piles. For comparison, two more production facilities using different, non-geothermal storage systems (ice, water) as key component for heat and cold supply are considered in the project. Monitoring of the two production facilities without shallow geothermal installations allows for evaluating the potential of BTES in comparison to more short-term storage options, addressing in particular the specifics of thermal inertia of the underground during loading and unloading of BTES. A fifth installation, the building of the E.ON Energy Research Center (E.ON-ERC) in Aachen, equipped with 41 BHE of 100 m depth each and monitored since several years, is used to calibrate the ground-side simulation and to test advanced control mechanisms.

The main objective of the project is an analysis and optimisation of the operation of these plants. Of particular interest is the energetic and economic evaluation of the integration of shallow geothermal energy into the systems and the interaction of the ground side with the various storage facilities (like

water tanks), heat sinks and heat sources in the production facilities and processes.

Numerical models for the underground and building side can be validated with monitored data, and used for parameter studies of different operation modes. Such simulation is intended for subsequent system optimisation and will be the basis for design recommendations and strategies for operation and control.

1. INTRODUCTION

Shallow geothermal energy is a proven technology to provide heat and cold to buildings, both residential and non-residential (Sanner, 2017), with meanwhile about 2 Mio installations all over Europe. However, the use in industry and in particular in industrial processes is still not widespread, albeit shallow geothermal technology being highly suitable for industrial application. Technologies comprise thermal energy storage in the underground (UTES), with or without the use of heat pumps, and classic geothermal heat pump systems, which, when used in industrial environment, usually make some use of underground storage effects.

The use for cooling purposes and for low-temperature heat (up to about 50 °C, which is similar to residential applications) is done routinely, with good economy and reliability. UTES at higher temperatures (50-95 °C) still is in a pilot phase after many years of development (Sanner, 2003), and the BTES (borehole thermal energy storage) system in a factory in Emmaboda, Sweden is one of few applications (Andersson and Rydell, 2012). Temperatures close to 100 °C or higher do not seem suitable for shallow geothermal technologies, as experiments in the 1990s showed. Not yet explored are the opportunities for providing cold at low temperatures e.g. for refrigeration.

Also direct uses of deep geothermal energy are increasingly addressing industrial applications, with

many examples e.g. in the food industry (cheese, beer, drying of fruit, vegetables and fish, etc.). Higher temperatures are attempted, and the first enhanced geothermal system (EGS) for industrial heat purposes in the range of 150 °C was developed in Rittershoffen, France (Baujard et al., 2016).

The project described in this paper is investigating the use of shallow geothermal energy for heat and cold supply in production facilities and related processes. It looks at two examples of existing, operating installations, the manufacturing facilities of Leica Camera AG in Wetzlar, Germany, and a production hall at the Volkswagen AG works in Emden, Germany.

2. INTEGRATION OF SHALLOW GEOTHERMAL ENERGY IN INDUSTRIAL FACILITIES

The use of heat pumps and shallow geothermal energy in industry is generally limited to meeting base-load demand, since the energy demand is usually very high, the investment costs for the technical equipment are high, and the space requirements are correspondingly high. But in the actual context of increasing energy costs the use of renewable energy and in this case of shallow geothermal energy for heating and cooling purposes can contribute to lower annual costs in spite of higher investment costs even in industry. With regard to the thermal balance of the ground and the typical high permanent and peak loads demand patterns must be carefully analysed during planning. In addition, the integration into the energy supply concept must be coordinated and evaluated. An overarching control system with integration of the various energy sources for base and peak load supply must be developed to ensure the targeted high shares of renewable energies in the energy supply.

Shallow geothermal energy was integrated into the energy supply system at Leica Camera AG in Wetzlar and at Volkswagen AG in Emden. On the basis of these two plants possible problems as well as optimization potentials shall be shown. On the basis of measurements of the real plant technology as well as by simulation of the plant operation statements are to be made.

2.1 Volkswagen AG Emden

The Volkswagen AG plant in Emden is located directly at the northern bank of the river Ems not far from the mouth into the North Sea. Therefore the subsoil at the location is not very stable. For this reason, a pile foundation had to be used to transfer the weight of the hall and all facilities to deeper, load-bearing strata during the construction of Hall 18. For the pile foundation, about 5000 concrete piles have been installed, with an average length of 18 m. This construction method provides the best conditions for the use of shallow geothermal energy. 3000 of the foundation piles were designed as energy piles. The cold and heat of the ground is used for heating of the hall and cooling of the production processes.

The integration of the geothermal energy into the energy supply systems is organized by the feeding of buffer storage devices with the function of a hydraulic switch. In each of the 4 equally organized sub-centrals for 4 identical sectors of the production hall distributors of the Zortström type organize the heat and cold delivery. Cool water is delivered to the welding robots and waste heat is collected. On the other hand, energy is provided to the cold side of a large-scale heat pump, and the cooled-down return flow flows back to the storage. The Zortström distributors are the main gateway between earth energy on the source side and thermal use on the demand side. The heat pumps of the 4 hall sections deliver 45 °C heat to the air handling units. The HVAC systems are equipped with a heat recovery and air heaters. They supply the hall sections with fresh air heated to a low temperature level for heating. The waste heat from the robots is fed directly into the Zortström storage tank. The earth pile field is used on the one hand to cool the Zortström storage tank in summer and on the other hand to charge it with the stored heat in winter.

The current problem in plant operation is that the ground continues to heat up over the operating period since the building was constructed in 2014, due to a heat imbalance. Figure 1 shows the energy balance of the ground for the year 2017. From the difference between the heat absorption of the evaporators and the heat output from the cooling circuit of the robots, the amount of heat that is either stored in the ground or extracted from the ground can be determined.

It is clear from the picture that in summer the largest amounts of heat are stored in the ground. In the winter months, however, not the same amount of heat is extracted. Instead, heat is also stored in the ground during some winter months. The red line in Figure 1 shows the resulting total amount of energy stored in the ground. If the field would be operated in a balanced manner, an approximately sinusoidal curve could be expected, showing about the same value after one year. The cumulative value from December 2017 indicates that approximately 1,500 MWh of waste heat from the robots was stored in the soil during the year. This excess heat accounts for the heating of the ground since the borehole heat exchanger field was put into operation.

In addition to the amounts of energy, the temperatures in the ground were investigated. The data are measured at ten measuring points at 2 depths, each at about 7.5 m and 11 m. To record the temperatures, one pile in each grid in which the piles are arranged (4 x 4 m) has not been thermally activated and has been equipped with measuring sensors for this purpose. The evaluation of the monthly temperature monitoring from the complete earth field shows that only 4 % of the temperature values are in the range between 18 °C and 19 °C. The temperature of the piles is also below this range. More than 80 % are below 17 °C. Since some parts of the borehole heat exchanger field are apparently heated more intensively than others, this suggests great

potential for more efficient use. If the heat input could be distributed evenly, a balanced heating would take place. However, this would not prevent the problem of unbalanced heating and the associated overheating over a longer period of time. The fact that the field continues

to warm up is made clear by comparing the mean ground temperature. At the beginning of July 2018, the mean value of all measurement points in the soil was 15.7 °C. After one year, this mean value increased by 0.5 K to 16.2 °C.

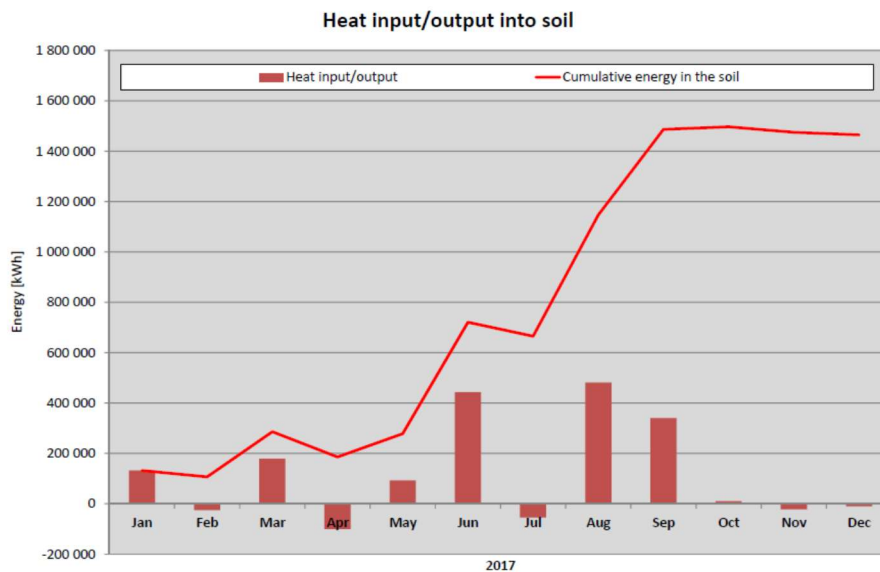


Figure 1: Heat input and output into the ground, Volkswagen Emden (2017)

2.2 Leica Camera AG

The supply system of the main building of Leica Camera AG must meet various requirements. In addition to the air conditioning of the administration and office areas, this includes the supply of heat and cold to production. Therefore, a complex plant system with a wide variety of components has been created. In addition to two gas-fired combined heat and power units (CHP), a gas condensing boiler is available to cover peak loads. The low-temperature heating circuits, which consist of underfloor heating and concrete core activation, are supplied by a heat pump. The geothermal field is used as the heat source for the secondary side of the heat pump. This is located below the parking lot on the north side of the building. The field consists of 80 borehole heat exchangers (BHE) drilled to a depth of 120 m. In order to make better use

of the field in different operating phases, it was divided into two sections of 50 and 30 BHE, respectively. In addition, the heat pump can run in reverse mode (reversible) to increase the required cooling capacity. This has the advantage that cooling can be done very economically (pure pump operation for the circulation of the water, without operation of cooling generators) and at the same time a partial regeneration of the ground takes place via the reversible heat pump. As soon as the cooling load exceeds the capacity of the heat pump, cooling is generated by an absorption chiller, which is supplied with high-temperature heat from the CHP unit. (combined heat, power and cooling). Two additional compression chillers are available for peak loads. The machines are cooled from a sprinkler tank with a capacity of about 560 m³, which can be re-cooled via the geothermal BHE field.



Figure 2: The Leica Camera AG offices and factory in Wetzlar, shortly after inauguration in 2014; the two BHE fields are located under the parking to the left (photo Leica Camera AG).

In the course of the operation of the plant, there is also a constant heating of the ground. In the run-up to the research project, the project partner UBeG has already started to investigate the causes. It has already become apparent that the heat input into the borehole heat exchanger field is significantly greater than the extraction. It has to be clarified which causes for the discrepancy can be found in the operating mode and how large the heat potential from the overheating of the ground is. Finally, a strategy must be developed to remove the heat and to enable a balanced mode of operation. This requires a detailed analysis of the measurement data within the research project and the simulation of the behaviour of the plant and the ground.

Another problem is the different requirements of the building parts to be air-conditioned. Due to the differences in orientation and glazing percentage of the individual rooms, there are very differentiated requirements and thus often different building areas are too cold or too warm at the same time. Inadequate control is implemented here, so that an employee is always required to intervene and set manually the operating modes of the system in order to ensure comfortable room temperatures.

In both industrial companies, the ground is heated. Thus, process cooling in industrial companies is the biggest challenge of using shallow geothermal energy. It is very important to keep the balance, otherwise the ground will continue to heat up over the years and as a result the ground will no longer be able to provide cooling.

3. SIMULATION

The simulation of the complete plant systems at the reference sites is divided into 3 subareas. First, the requirements of the buildings are to be simulated in order to determine the necessary heating and cooling load curves. In addition to the floor plans and the boundary conditions of use, the physical structure of the room enclosure surfaces is also taken into account.

The second part of the simulation is the system technology required to supply the buildings. Preset models for individual components are available in the simulation program, which must be parameterized as accurately as possible with the values of the actual system components.

The last part of the simulation is related to heat transfer and distribution in the ground. While the first two parts of the simulation are performed with the software "TRNSYS", separate programs like "FEFLOW", "EWS" or "EED" are available for the ground

simulation. The results of the soil simulation are then used as input and integrated into the plant technology.

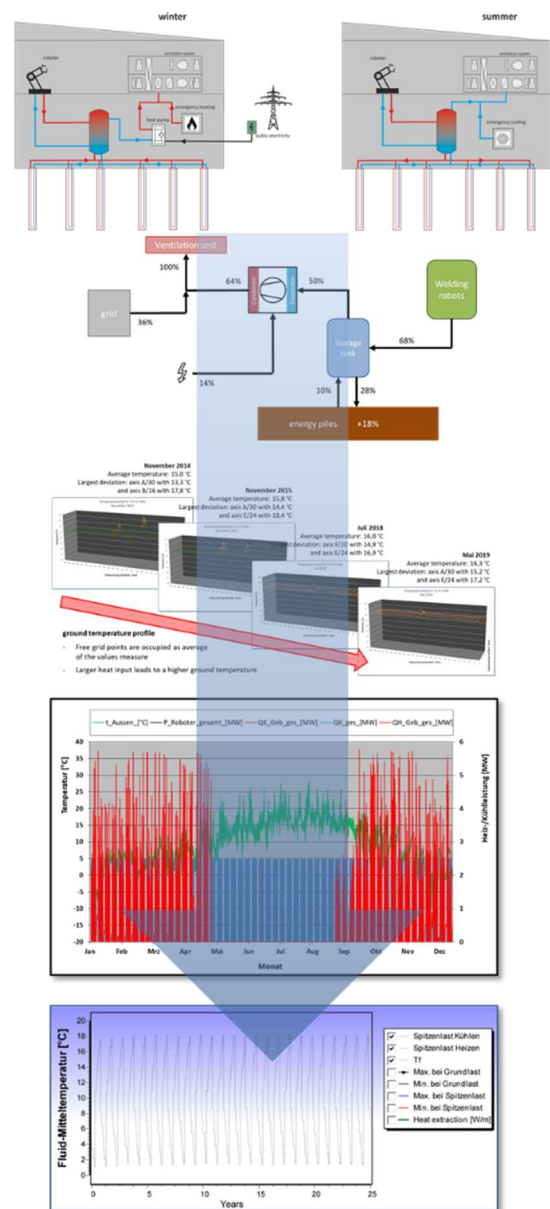


Figure 3: From operation analysis over balancing and model development to optimization – strategy for system optimization by simulation

4. OPERATIONAL STRATEGY DEVELOPMENT AND DERIVATION OF GENERIC RULES

In addition, values from a facility of Technical University of Aachen (RWTH Aachen), the E.ON Energy Research Center built in 2006, will be used for testing and validating the geothermal simulations.

Heating and cooling of this building is assisted by 40 BHE each 100 m deep, each equipped with temperature sensors at inlet and outlet, and with DTS cables (glass fibre) to determine the ground temperature development.

The geothermal BHE are divided into three fields, with a manifold in a shaft for each. These can be switched

on or off individually. Therefore, different modes of operation can be tested here. The following cases are examined:

- a rolling operation with connection and disconnection of shafts according to power demand,
- an operation where all shafts are active in summer and winter, and only one shaft is active in the transitional period
- an operation with one basic shaft, which is selectively heated in summer and serves as storage in winter, and two shafts for heat support.

5. CONCLUSIONS

A further activity in the project is the evaluation of cost and benefits of design and installation of shallow geothermal installations. Finally, the monitoring shall lead to improved efficiency, functionality and reliability of complex energy supply systems based on shallow geothermal technologies for production facilities, and to enhanced accuracy in design and increasing efficiency in operation of such installations. The goal is also to improve the possibilities for making use of residual heat and integrating renewable energy sources into the energy supply of production facilities. A substantial contribution to the reduction of CO₂-emissions in the industrial sector is envisaged altogether.

The duration of the project is May 2018 to April 2023; it is coordinated by the Institute of Optimized Energy Systems (EOS) of Ostfalia University of Applied Sciences, Wolfenbüttel, in cooperation with the Institute for Energy Efficient Buildings and Indoor Climate (EBC) of RWTH Aachen. UBeG GbR, Wetzlar, works on the simulation of the geothermal systems in the framework of the project. Project geo:base is funded by the Germany Federal Ministry for Economic Affairs and Energy (BMWi) under contract 03ET1552.

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