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# Geothermal energy use for heating and cooling of a low energy building

Ursula Eicker, Ruben Pesch, Felix Thumm, Antoine Dalibard
University of Applied Sciences Stuttgart, zafh.net, Germany
Schellingstrasse 24, 70174 Stuttgart, Germany
ursula.eicker@hft-stuttgart.de

## Abstract

Vertical geothermal heat exchangers can be used for heating and cooling of buildings and entire neighbourhoods. In winter operation, they provide heat at temperature levels close to the mean annual ambient temperatures to heat pumps and thus improve the heat pump seasonal performance factor. In summer they can be used for direct cooling of buildings, if surface cooling provides large areas for cold distribution. Furthermore, heat rejection of chillers at temperature levels well below ambient is an interesting option for low depth geothermal energy use. Geothermal energy use is possible for decentral building installations, but also on a district level, where either a district heating network can be supplied with a geothermal heat pump or cold distribution with decentral heat pumps takes place. The paper presents monitoring and simulation results from a low energy building using a heat pump with vertical ground heat exchangers.

## Introduction

Water or brine filled ground heat exchangers are either designed in a horizontal configuration with a shallow depth of about 2 m or installed as vertical loops. Vertical ground heat exchangers are usually constructed by inserting one or two high density polyethylene U-tubes in vertical boreholes of 75 to 220 mm diameter. Vertical loops are usually connected in parallel to reduce pressure drop. In Europe, double U-tubes are common, whereas in the United States single tubes prevail. Zeng et al. [9] show that double U-tubes reduce the borehole resistance by 30 - 90% and thus improve heat transfer.

Vertical pipes up to a depth of 100 meters are mainly used for heat pump applications, but also increasingly for closed - loop direct cooling of buildings, with water as the heat transfer fluid. The high heat capacity of water is advantageous, as the electrical energy needed for circulating the fluid through the earth heat exchanger is considerably lower than if air is used. The water cooled through contact with the earth is then distributed in the building using either activated concrete slabs with buried pipes or an air - based ventilation system, in which the air is cooled by the water in an additional heat exchanger.

If the ground temperature level is too close to the desired room temperature, the cooling power of such a system is too low to be cost effective. This problem may be overcome by one of two methods:

- By employing indirect cooling systems, such as reversible heat pumps (chillers), which use the ground as a heat sink and are therefore more efficient compared to similar systems exposed to cooling tower temperatures or hot ambient air (Karagiorgas et al [3]).
- By cooling the soil below its undisturbed temperature prior to circulating fluid through the heat exchanger. When horizontal heat exchangers at shallow depths are used, soil temperature may be influenced by surface treatment. At greater depths, the ground may be cooled in the winter season, as heat pumps in the heating mode extract energy from the soil. Li et al. [5] show that unbalanced heat extraction from the ground reduces temperature levels by 6°C within 5 years for heat pump operation only. If only heat is rejected to the ground from a cooling machine, after 13 years the soil temperature was over 35°C and no longer suitable for air conditioning. Only balanced heat fluxes kept ground temperatures constant over a 30 year period.

The main task of the design process is to determine the required length of tubing for the required thermal energy to be extracted or rejected. Modelling the thermal response of the surrounding soil requires information about the ground temperature distribution, the moisture content, groundwater movement, freezing or thawing of the soil and the geometry of the heat exchanger. Furthermore, experimental results showed that the temperature distribution around soil tubes is often not symmetric (Bi et al. [1]). The soil surrounding the borehole is usually considered as homogeneous with a mean thermal conductivity and mean diffusivity.

Numerical models offer more flexibility in the temperature field calculation for arbitrary geometries and time varying heat fluxes and inlet temperature levels (Signorelli et al. [7]. Such models were developed and implemented in this work and implemented in the simulation environment INSEL [8] to carry out parameter studies. The potentials and limits of geothermal energy use for heating and cooling of buildings is analysed in the following.

## Monitoring results from a low energy building

### *Building design and performance*

A low energy building with geothermal energy supply has been designed and implemented in the Southern German City of Ostfildern with a low energy district Scharnhauser Park. The building was constructed in 2006 with a gross surface area of 475 m² and is used as a Youth Centre. Its location is special in the sense of urban planning in Scharnhauser Park because it is situated outside the main area of the urban master plan at the end of a series of sports fields. The distance of the Youth Centre to the last building supplied by district heating was too long and the calculated heating demand was too small in relation to the effort to connect the building to the grid. Furthermore there would have been hydraulic problems because of the small flow of heating energy to the dead-end pipe. Supply of natural gas could also be excluded because a new gas pipe to the Youth Centre building would have had high costs. Systems based on other fossil combustibles like oil where not taken into account. From the point of building legal requirements, the Youth Centre had to fulfil the German EnEV 2004 (Energieeinsparverordnung). The level of insulation of the building envelope is almost as good as at the level of the passive house standard.

The heating distribution is done by a floor heating system and the ventilation system. The ventilation system is a central ventilation unit (Zehnder Comfoair 3200 B with a size of 2.45 x 1.40 x 1.40 m). Additionally it is equipped with a summer by-pass in case that the use of the earth heat exchanger is not necessary. The maximum electric power of the unit is 2370 W. Fresh air can be drawn in from a 48 m long earth heat exchanger consisting of a tube 400 mm in diameter equipped with a special anti-bacterial layer. With this equipment, hot air in summer can be pre-cooled and in winter pre-heated. This can happen at three different levels: 1520 $m^3$/h, 2000 $m^3$/h or 3000 $m^3$/h.
The pre-heater of the ventilation unit has a power of 5.2 kW with 1700 l/h and temperatures of 0/4°C. In winter, the pre-heater can transmit a thermal load of 7,4 kW of fresh air with 636 l/h and a temperature of 25/35°C.

### *Geothermal heat supply and distribution system*

All the requirements led to a concept for heating supply based on a heat pump in connection with geothermal energy. The necessary drilling took place in March 2007 when two bore holes (each 134m deep) were made. The U-formed tubes are of polyethylene (PE) with a diameter of 1½" and are installed as double U-tubes. Within 1.5 days the drilling was finished and later on connected to the heat pump. At the same time a geothermal profile of the soil coming out of the drilling hole was established and the heat-gains could be calculated more in detail.
The geothermal circuit was connected to the heat pump (Vitocal 300 Type BW from Viessmann) that works on two levels. The maximum output power is 16.6 kW. The thermal energy goes into a storage tank where temperatures up to +35°C are provided for the floor heating and the ventilation. The calculated temperature levels range from 25-35°C for the supply temperature related to an outside temperature of a minimum of -12°C.
The coefficient of performance in the datasheet of Viessmann is specified with 4.61 (calculated by DIN EN 255; supply temperature 35°C and 0°C heat source temperature). In its primary circle, 4200 l/h are circulating with a temperature minimum between 0° and 4°C, in its secondary circle 1400 l/h with temperatures of 25°/35°C.

The supply system for the heat with the geothermal heat exchangers is also the source for cooling in summer. Cool ground heat exchanger water goes into the floor heating system which operates in that case as cooling equipment. The primary circle is driven with 10/14°C and the secondary circle within 12/20°C supply temperature.

The heat pump has an integrated regulation (CD 60) that works outside temperature based and is connected to the building management system.

The heating distribution goes from the storage tank to several low temperature floor heating distributors. Altogether there are 30 circuits divided into three main groups: Entrance, activities area and kitchen (12 circuits with altogether 672 l/h), sanitary rooms (5 circuits with altogether 194 l/h), group rooms, dancing room and secondary rooms (13 circuits with altogether 647 l/h). All the heating circulation pumps are automatically regulated pumps from the Stratos series of the pump producer Wilo.

### *Energy consumption data*

During the first measurement periods in the year 2008 and 2009, the Youth Centre had excellent heating consumption values of around 6700-7000 kWh/a, which corresponds to 14 kWh/m²a (2008), 15 kWh/m²a (2009) and 20 kWh/m²a (2010).

On the other hand, electric consumption with around 13000 kWh/a excluding the electric consumption of the heat pump, is relatively high and efficiency improvements had to be implemented. In 2009 the consumption value could be brought down by about 1000 kWh by lowering the very high illumination level without negative effects for the users. The specific electricity consumption for lighting is 12.6 kWh/m²a (2008), 10.9 kWh/m²a (2009) and 10.9 kWh/m²a (2010)

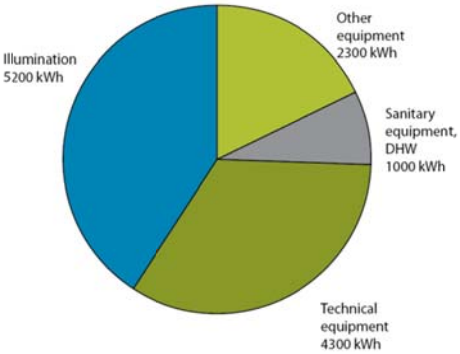

**Figure 1: Measured electricity consumption without the heat pump electricity**

The consumption values show a significant change in the relation of heat and electricity consumption. For future buildings, electric consumption must be monitored — as done in the Youth Centre — with various sensors to monitor consumption, e.g. for illumination, technical equipment or other user-defined electrical appliances.

Costs and $CO_2$ emmissions are by far higher for electric energy than for heat.

## Heat pump monitoring and improvements

The heating consumption consists of the need for floor heating and ventilation air heating. The domestic hot water is produced separately electrically and is not considered in this analysis. The heating season of this energy efficient building is short and when the average ambient temperature rises above 5 ° C, the heat consumption is very low.

The gap in the data, at the end of January, is due to a power failure related data-recording interruption.

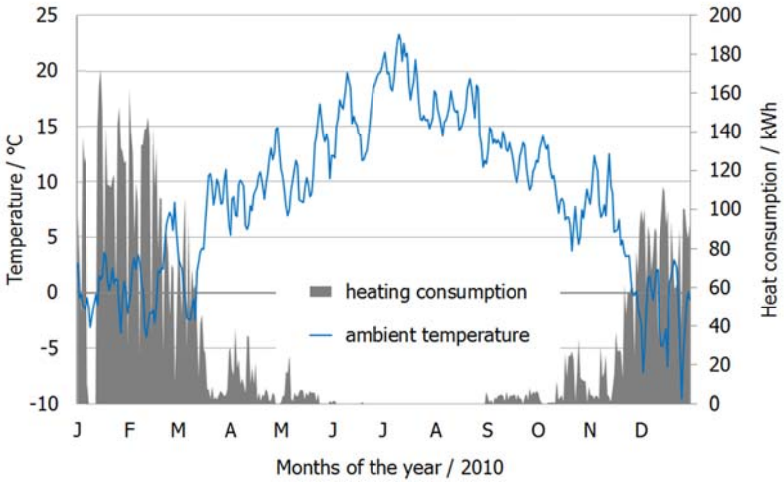

**Figure 2: Monitoring results for heating of the low energy building.**

The monthly seasonal performance factor (SPF) for the year 2010 was determined from measurements of the heat pump in the Youth Centre building. The SPF is a quality criterion of a heat pump and describes the ratio of benefits (heating energy) to effort (electrical input energy). The graphical presentation includes, in regard to system boundaries, different SPF calculations (see Figure 3). The pure SPF of the heat pump (without auxiliary power), as it is often measured by the manufacturers for specific operating points is 3.94. This value is significantly higher than the SPF of the whole heat pump system at 2.63, which includes the electric power for the brine pump.

From the analysis it was clear that there is a significant potential in reducing the running times of the brine pump. Especially in the transitional period (March, April, May, September, October) the supply pump of the borehole is nearly always in use, although the compressor of the heat pump is not working and therefore there is no need to supply the heat pump. With proper control of the brine pump based on the compressor running times, a much higher SPF for the heat pump system can be achieved.

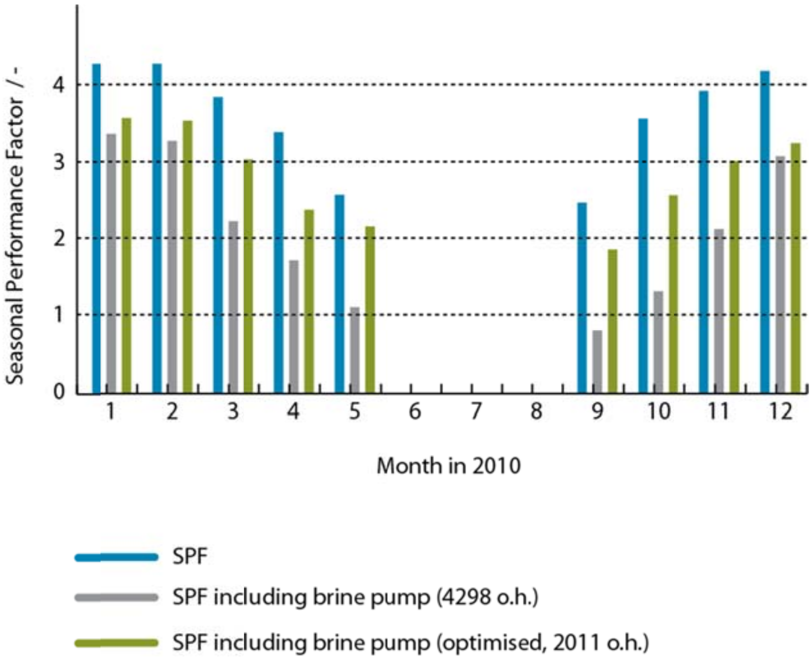

**Figure 3: Heat pump seasonal performance factor with brine pump electricity.**

This can also be seen in the annual performance factor for the optimized brine pump (see Figure 4). An optimized operation of the heat pump system, for which the operating hours of the brine pump are significantly reduced, results in an annual SPF of 3.14. The energy input includes the energy on the primary side, which is obtained from the bore holes as geothermal energy and the electrical energy of the compressor. In addition, the amount of electric energy for the brine pump is shown. The brine pump energy was calculated from the measured operating time and the connection power of the brine pump.

The heat distribution in the building is divided into a floor heating part and a ventilation part. The design of the system includes a floor heating to cover the basic load of the building with slow dynamics. The fast reacting ventilation covers only the peak load and the required minimum air exchange.

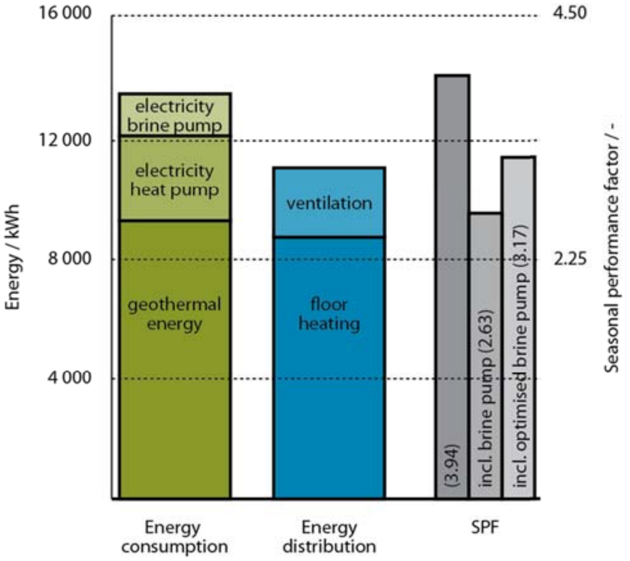

**Figure 4: Energy consumption of heat pump system with energy delivered to the building and seasonal performance factor**

The difference between total energy input (geothermal energy and electricity of the heat pump) and heat consumption of the heating system can be quantified as losses. The heat meters are installed directly after the buffer storage, so the losses caused by the distribution system are not recorded. The monitoring includes only the storage losses and losses on the circuit between the condenser of the heat pump and the buffer storage. The relatively high losses in 2010 of about 1000 kWh/a are not only due to storage losses. It is an indication that the water circulates between the condenser and the buffer storage, even when the compressor and thus the heat pump is not working. The assumption could be verified by measurement in a four-month period (February to April 2011). There is a further potential for optimization in the management of the heat pump system.

The double-U-borehole heat exchangers are filled with a heat transfer medium (Mono-ethylenglycol-water mixture, concentration: ≤ 25%), which is circulated with a high-efficiency pump with a measured electrical power of 300 W. There is a heat meter installed at the brine circuit, which measures the flow rate and temperature of supply and return. The specific extraction power of the borehole for the year 2010, depending on outside temperature, typically reaches up to about 40 W/m (see Figure 5). As the flow of brine is relatively constant, the demand depends mainly on temperature difference between brine supply and return.

The scatter plot shows that brine power over 40 W/m, corresponding to an absolute power of 10 kW (with a tube length of 260 m), is exceeded only rarely. The temperature difference between supply and returns is mostly about 4-5 K (see Figure 6). This low power at the evaporator side suggests that heat pump is not operated at full load, in most cases. A larger temperature difference is possible, which occasionally occurs with power levels up to 70 W/m, corresponding to an absolute power of about 18 kW.

The few performance peaks of the borehole occur mainly in the morning, when the heat pump turns on for the first time and not at the lowest outdoor temperature.

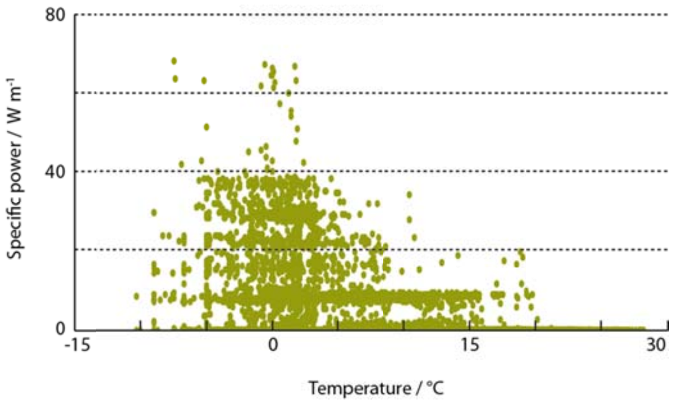

**Figure 5: Power delivered by the geothermal heat exchangers**

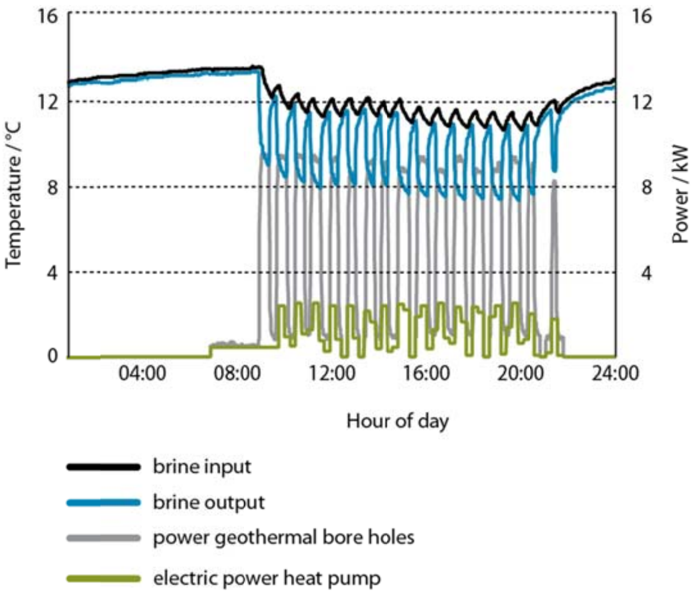

**Figure 6: Temperature levels of geothermal heat exchanger together with power extracted and electrical power consumption of the heat pump.**

The total primary energy consumption of the existing system has been compared with a reference condensing boiler system. Also full system simulations were carried out to simulate the performance for an optimized system with reduced brine pump operation and for an air/water heat pump. All heat pump systems perform better than the condensing boiler. In the best case, 50% primary energy can be saved.

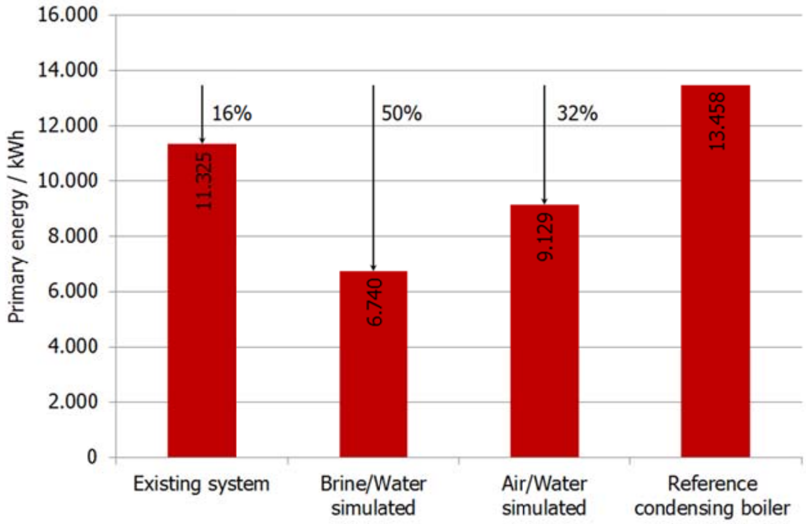

**Figure 7: Measured and simulated primary energy performance for the existing system, a reference condensing boiler and optimized heat pumps with air or brine as input.**

## Conclusions

The Youth Meeting Centre in Scharnhauser Park/Ostfildern showed that very low heating energy consumption values are achievable. The electric consumption has been relatively high, mainly due to technical building facilities and illumination. The heat pump performance was extensively monitored including the vertical ground heat exchangers. The heat pump is overdimensioned and therefore has very short cycle times. One major point for optimisation is the long running time of the brine circulation pump, which significantly lowers the overall seasonal performance factor.

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