Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

# Cascade Heating and Cooling of a Hotel Resort - 6 Years Operational Experience with a 400m Deep BHE Alignment in an Alpine Dolomite Karst Aquifer

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**Keywords:** Cascade heating, Middle deep System, Karst Aquifer, Cooling, Operating Data

## ABSTRACT

A luxury resort in the Tyrolean Alps was extended in 2013/2014 for the fifth time. This opportunity was used to install borehole heat exchangers (BHE) in a dolomitic karstified aquifer. The aquifer sharply declines from a thrust fold contact to the Tauern Window into the deeper underground. Enhanced geothermal response tests have been carried out before and after completion of the geothermal array. Optical frequency domain reflectometry methods have been applied to assess the hydrogeological and geothermal properties of the subsurface and integrity of the BHE itself. The first eGRT thermal conductivity profile shows sections of conductive dominated heat transfer in the upper section and convective in the lower karstified well bore section. The second one shows reduced influence of groundwater flow which is interpreted as a clogging effect by cementation of the neighboring BHEs. The linear borehole heat exchanger systems have been percussion drilled. In total 3.600 m BHE were completed in nine wellbores. The BHE have been drilled in an alignment.

The underground installation was connected to three heat pumps and three thermal storage tanks with different temperature ranges. Two years were used to optimize the cascade operation and another four years of operational routine were monitored and evaluated. The presentation will compare the designing approach (1 GWh/a heat extraction and 0.4 GWh/a cooling load) with the obtained performance after five years of full operation in heating and cooling this particular hotel complex. The systems was dedicated to supply the 25 x 12.5 m outdoor swimming pool e.g.. It will be demonstrated how the systems performance and COP developed and how optimization measure could be implemented. The mean temperature level (heating) that is needed for building equipment and appliances are 55 °C.

## 1. INTRODUCTION

This paper shows a scope of planning and operation of a Middle Deep Geothermal Borehole Heat Exchanger Storage for a large Spa-resort (Sass et al., 2014; Sass et al., 2016). The geothermal installation was designed for about 1 GWh/a heating and 400 MWh/a cooling demand. The site is located at Finkenberg (839 m asl) in Austria, Tirol. The installed heat pump capacity is 378 kW (three heat pumps). Due to the karstic subsurface it was necessary to investigate the geological and hydrogeological environment with view on drilling and completion purposes (Sass & Lehr, 2013). It was also essential to determine the thermo-physical properties of the subsurface for simulation and design of the geothermal array. In 2013 a 400 m investigation drilling with BHE completion had been installed. The completion was additionally equipped with a hybrid copper-fiber glass cable that was used for Enhanced Geothermal Response Tests (eGRT). eGRT is an investigation method giving information about thermo-physical properties of subsurface and groundwater influence on the BHE with high spatial resolution over depth. While drilling and completion works were in process surrounding springs were monitored with a hydrogeological preservation of evidence program (Schäffer et al. (2014); Heldmann & Sass (2014); Sass et al. (2015). With this particular program based on hydrochemical and hydrological sum parameters any impact of the drilling, completion or grouting works on neighboring spring catchments could be detected immediately.

After start of operation of the geothermal array in August 2014 operational data were collected until now. At this state these data are compared to the prognosis design in 2013. The results are given in this paper.

## 2. SITE AND LOCAL GEOLOGY

The site is located in an alpine marble karst aquifer of upper Jurassic Hochstegen formation, representing the autochton/allochton border between the Tauern Window and the Alpine Nappes. Following figures show the drilling (BHE) locations and associated geologic profiles.

The reservoir formation is the Jurassic Hochstegen Formation. It strikes 60° ENE parallel to the valley and dips approximately 70° NNW. From base to top, the Hochstegen Formation contains thin layers of quartzite, phyllite, and brownish marble, followed by sequences of greyish-blue banded calcitic and dolomitic marbles. Within the footwall of the Hochstegen Formation the topographically more elevated Ahorn Gneiss is exposed. It consists of orthogneisses, mainly augen gneiss. According to different authors, the contact between both units is described as autochthonous, parautochthonous or allochthonous (Frisch, 1968; Thiele, 1976; Frisch, 1980). Low mineralized, lime-unsaturated and cold waters from the Ahorn Gneiss infiltrate the Hochstegen Formation, having a high karstification potential (Sass et al, 2016b).

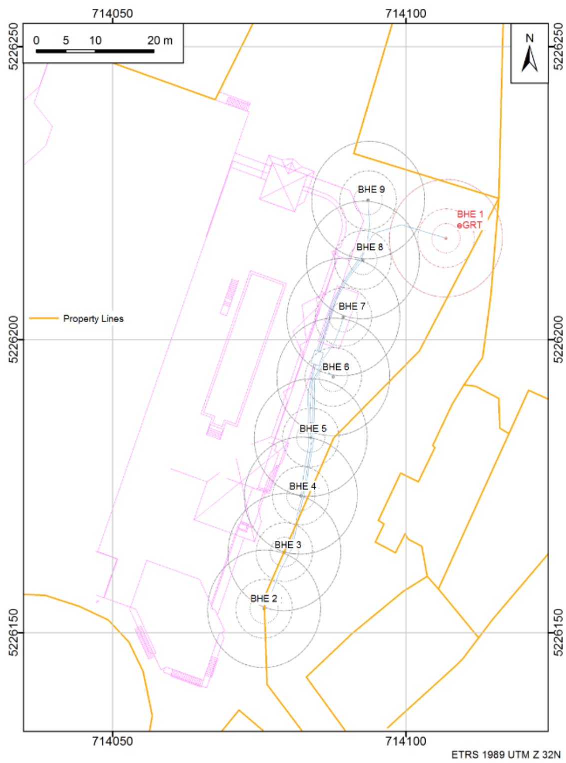


**Figure 1: Site with BHE locations.**

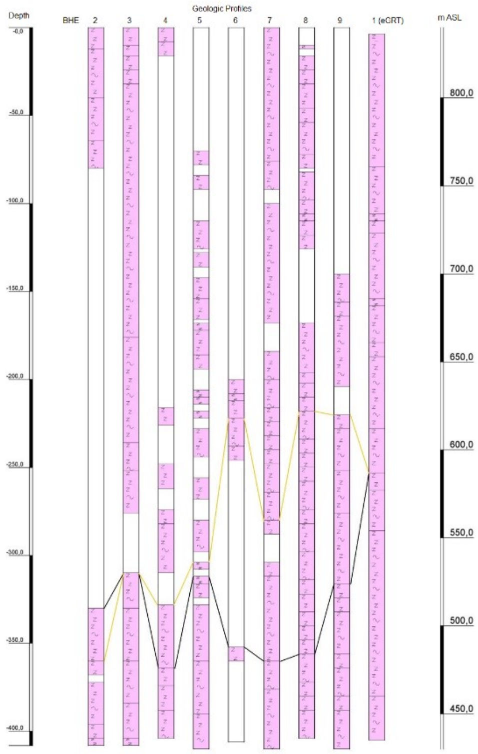


**Figure 2: Geologic profiles with correlation of Pyrite (yellow) and mesoscopic Quartz (black) leading sections.**

## 3. HYDROGEOLOGICAL AND GEOPYSICAL INVESTIGATIONS

For planning and design of the BHE array hydrogeological and geophysical investigations had been made. Initial research studies revealed the hydrogeology of Tux Valley (Heldmann, 2012). In the project realization step I (May 2011 - Oct 2012) a 400 m exploration drilling had been made. The borehole was completed with a Double U Borehole Heat Exchanger (HDPE 4x50 mm) and a shank parallel running hybrid cable (copper leader and glass fiber). The hybrid cable was used for Enhanced Geothermal Response Tests to obtain the thermo-physical properties of the subsurface modeling (parameter figure 3.11) for the design and numerical prognosis of temperatures in operation. Because of the highly detailed information which had been obtained from the geophysical investigations it was possible to get a design with a reduced number of required BHEs (from 12 to 9).

Due to their heterogeneity, karstified rocks can exhibit very different hydrogeological properties. The research and exploration of these formations is still challenging (Bakalowicz 2005, Goldscheider & Ravbar 2010, Stevanović & Milanović 2015). Comparatively high flow velocities and flow rates are the main reasons for the vulnerability of karst aquifers. Therefore, careful exploration is necessary before operations into the underground are begun. Conflicts of use are well known, for example between drinking water supply and geothermal energy utilization (Goldscheider et al. 2010).

The first eGRT was carried out 7/2012 (BHE 1). The thermal conductivity log (TC) over depth shows the influence of the karstic groundwater system in the lower part of the BHE (Lehr & Sass, 2014). The mean thermal conductivity was determined to 4, 8 W/ (mK). Cause to the uncertainty of the groundwater flow in the karstic system over the year a reduced thermal conductivity of 4, 0 W/ (mK) was used for design. As visible in Figure 3 the mean thermal conductivity from the eGRT (4/ 2013) which was carried out after installation of the complete BHE array is 3, 8 W/ (mK). Due to the results of the groundwater monitoring (Figures 6 and 7) and greater quantity of cement when grouting BHE 9 the reduced groundwater influence was interpreted as cementation clogging effect on the karstic system. Even though changing groundwater flow could have similar effects on the BHE array it shows that more than one measurement is needed to proof karstic environments.

Sonar logging was applied (BHE 6) to validate the results of the Optical Frequency Domain Reflectometry (Figure 4). The Karstification intensity increases with depth. BHE 6 showed a peak of caving beginning in 260 m below ground level. This is 70 m below Tux creek level which has a horizontal distance to the wellbore of 220 m. Cavities can reach 30 cm in height; typical widths are 5 to 10 cm. Hydraulic recovery testing resulted in hydraulic conductivities with a mean value of kf = 1.4·10-5 m·s-1. The deviation range will be within two orders of magnitude.

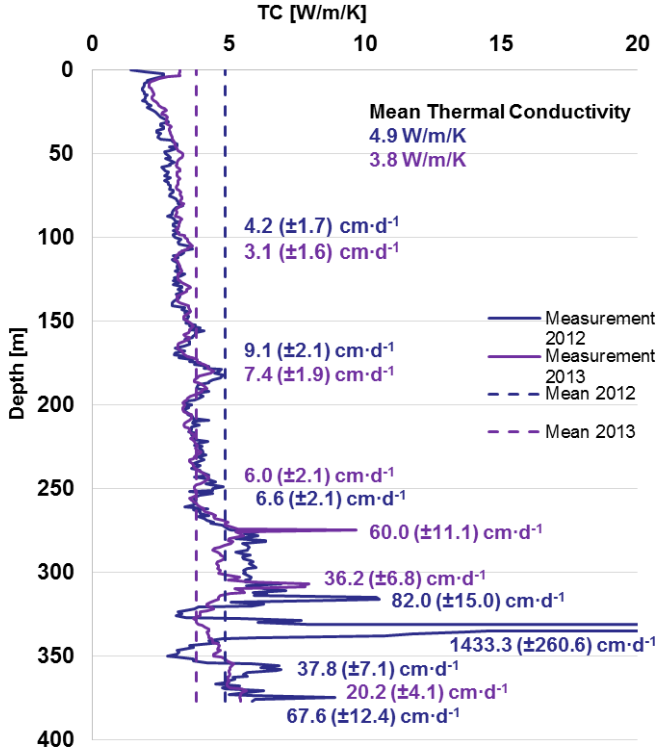


**Figure 3: eGRT 12.07.2012 (blue) and 13.04.2013 (violet). Variability of thermal conductivity due to groundwater flow. Péclet number analysis reveals velocities over to 14 m·d-1 in the lower parts of the BHE. Interpretation: Visible is the effect of the grouting on BHEs which were installed after the 1. eGRT (reduced flow in the lower parts of the BHE).**

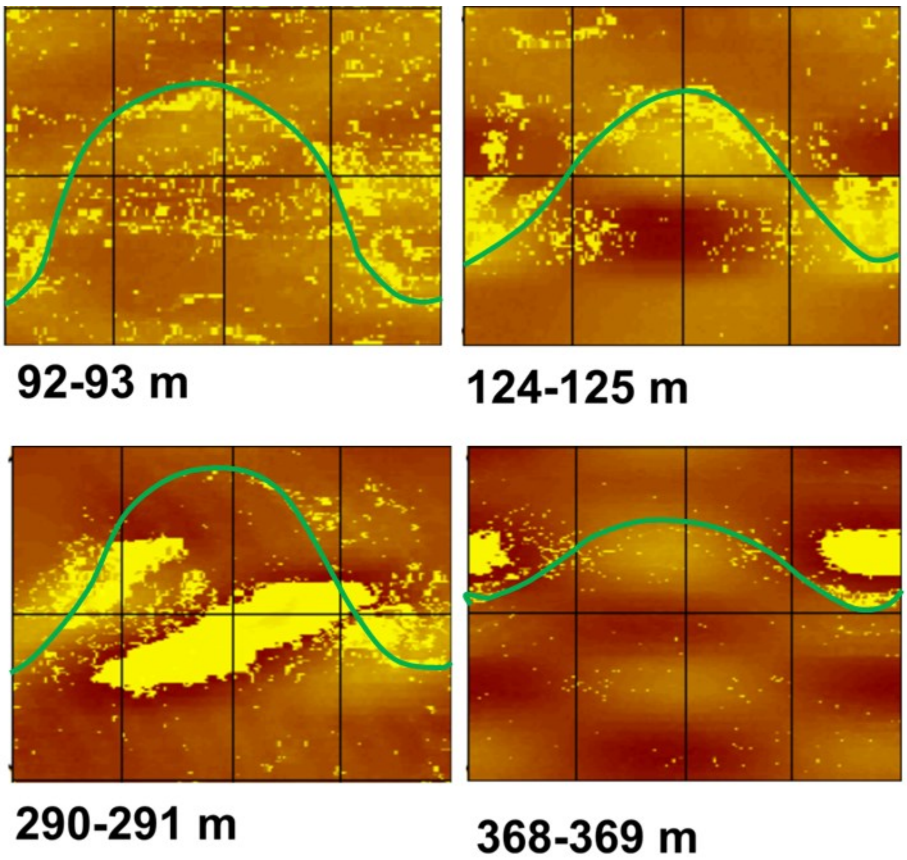


**Figure 4: Cavities (yellow) and fractures (green) in sonar logging.**

Due to the vulnerability of the karst aquifer (Hochstegen Marble Bed) a number of related springs were hydrochemically monitored.

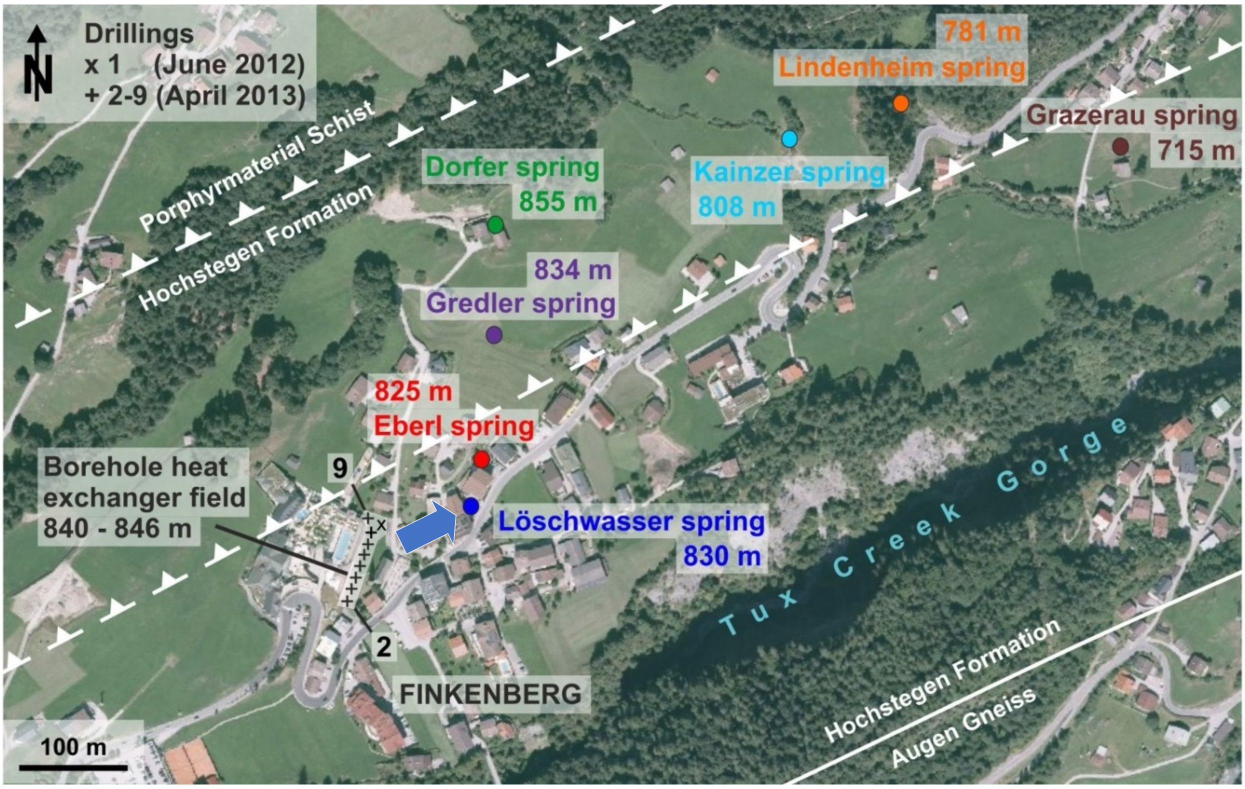


**Figure 5: Monitored springs while drilling.**

All wellbores started and ended in the Hochstegen Marble Bed. The dip angle varies between 64° and 74° to N – NNW. Löschwasser spring downstream of the site (in the line of the strike) was temporarily influenced by drilling (blue arrow) (Sass et al. (2016); Schäffer et al. (2018a); Schäffer et al. (2018b); Schäffer et al. (2019)).

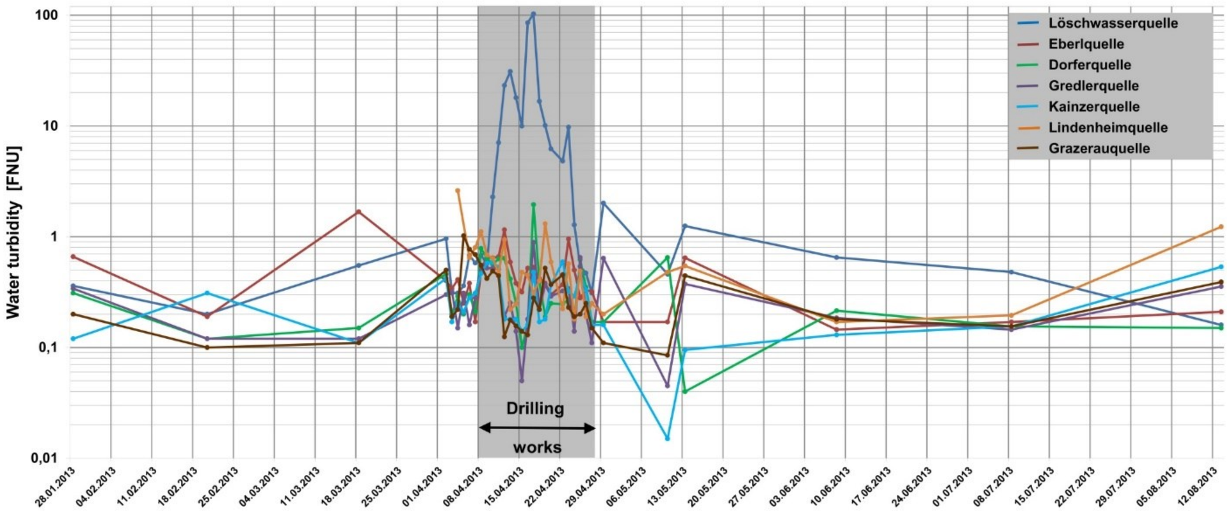


**Figure 6: Turbidity values show influence of completion works in Löschwasser spring only.**

## 3. COMPARISON OF DESIGNING APPROACH WITH THE OBTAINED PERFORMANCE AFTER THE FIRST FIVE YEARS OF FULL OPERATION

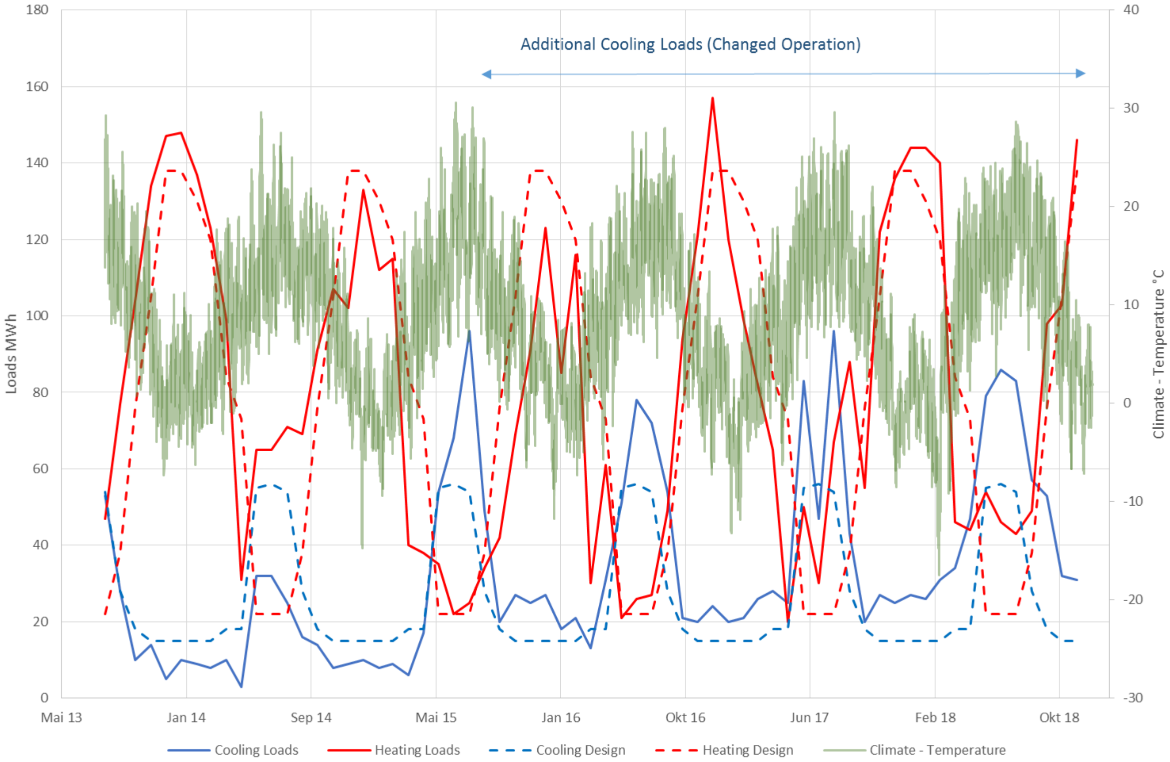


**Figure 7: Heating and Cooling Loads. Operation vs. Design**

The graph in Figure 7 shows that design and operation of the geothermal system are very close. In 2015 the operation design had been changed. Additional cooling devices were coupled to the geothermal system bringing additional cooling loads. The climatic boundary conditions were almost steady. The booking of the Resort was constant, too. All in all an amount of 6.940 MWh geothermal power has been gained from subsurface in approx. 5 years of operation (design 6.880 MWh).

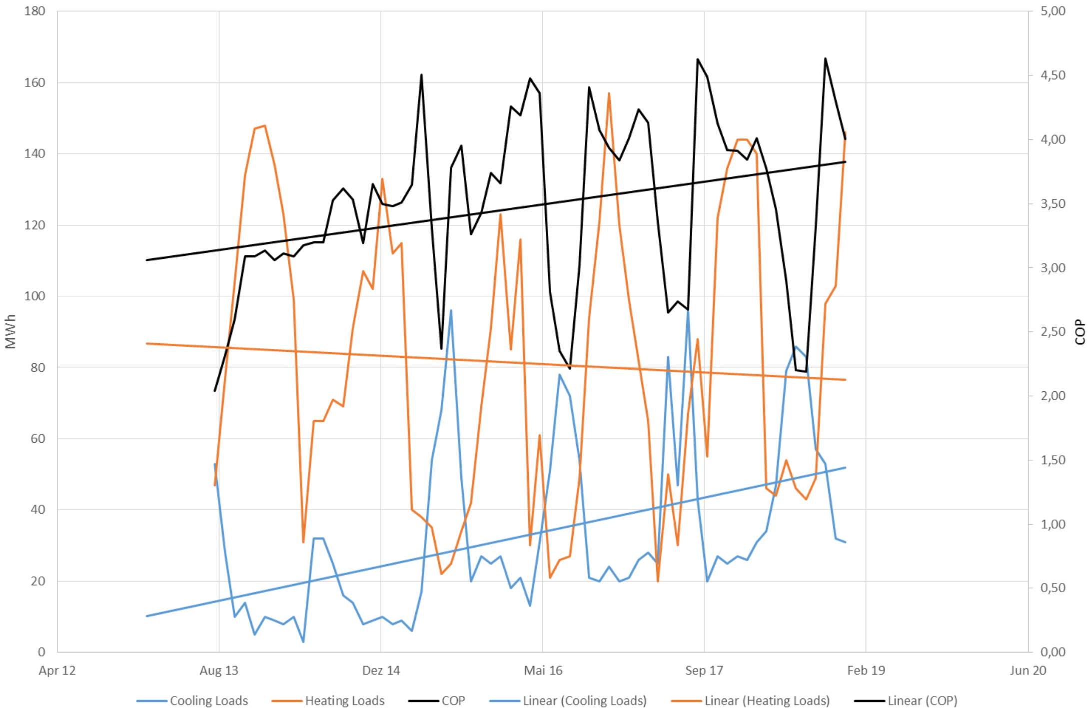


**Figure 8: Heating/ Cooling Loads and COP**

Over the past five years of operation the heating demand is slightly shrinking. Due to the additional cooling loads the cooling demand was rising. This has to effects: On one hand the COP is rising due to the rising brine temperature (Figure 10) and on the other hand the COP for cooling operation is getting quite poor. In the layout of Figure 9 the periods of low efficiency are good visible. To avoid negative influence of the heating cooling balance on the SCOP some design changes have to be considered for future.

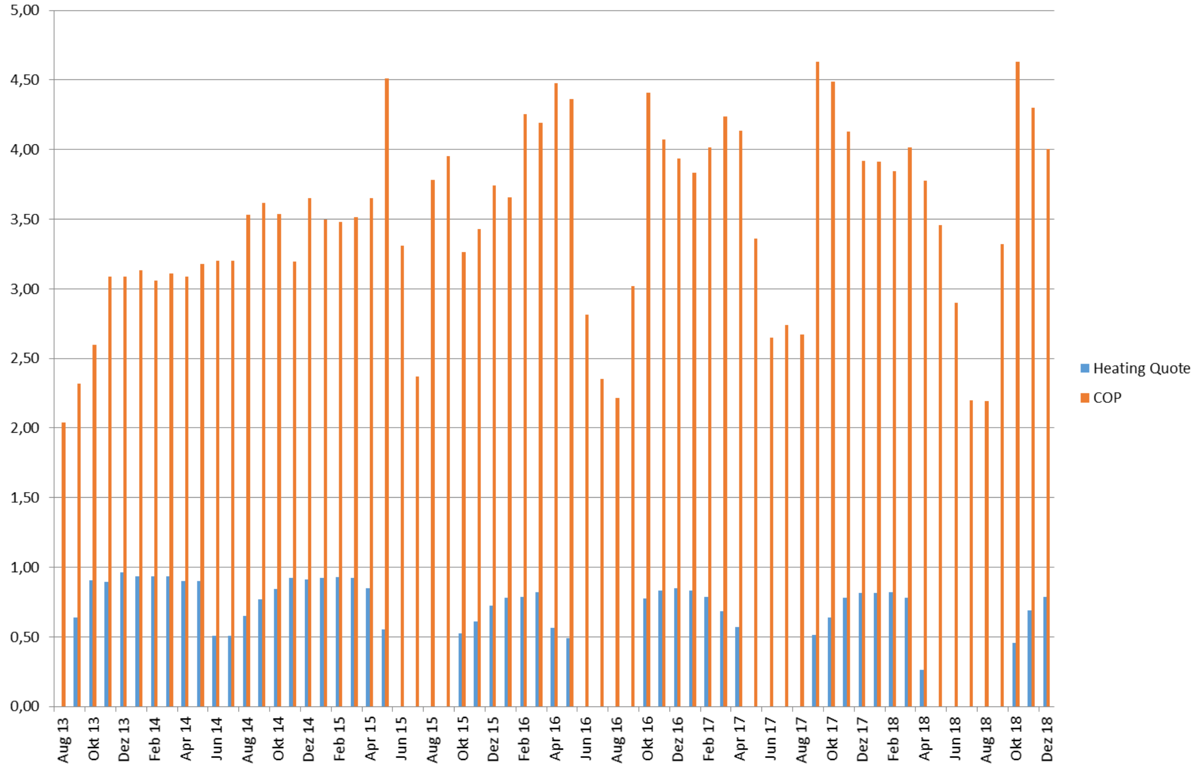


**Figure 9: COP vs. (Heating Load - Cooling Load)/Heating Load**

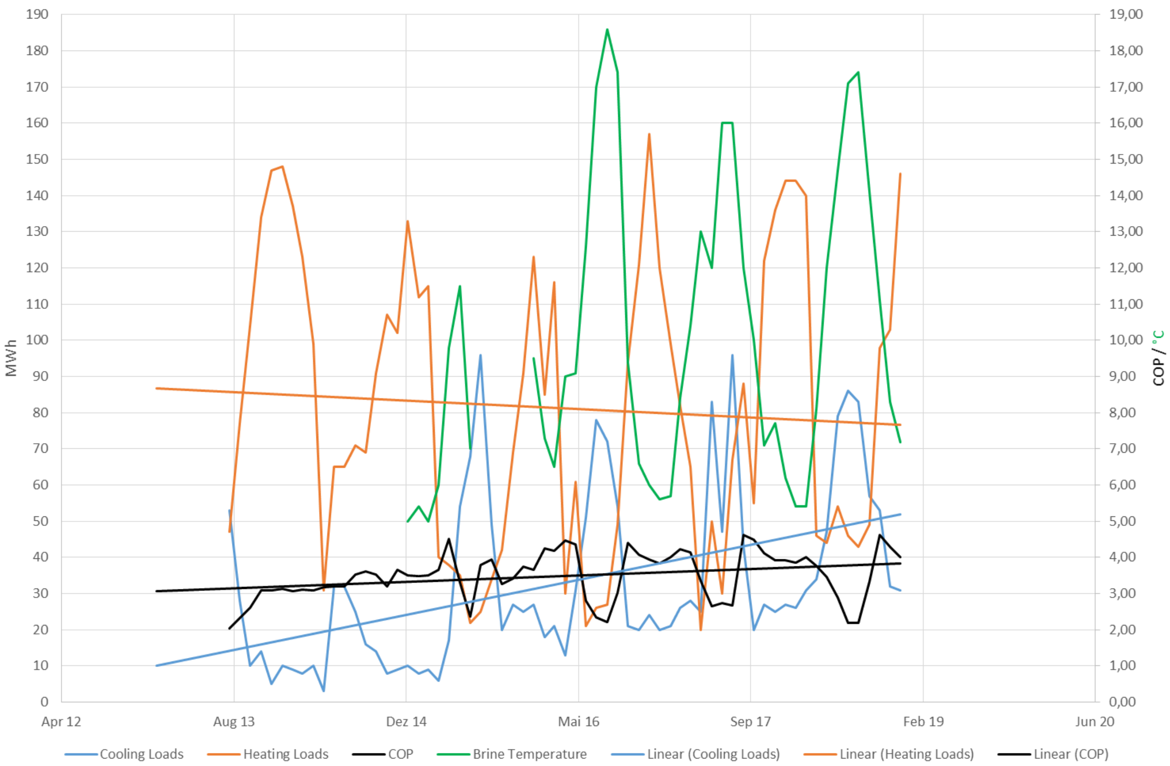


**Figure 10: Brine Temperature and Operation Data**

Figure 10 shows the brine temperature and operational data. The lowest temperatures are measured after heating period (4 – 5 °C). Figure 11 shows a numerical simulation (software Geologik SF) of the array. The simulation shows mean temperatures in the same range. BHE 8 has the lowest single temperature (approx. 2 °C) because of the three surrounding BHEs (1, 7, and 9). The spatial influence is very close to the property border. Due to the balanced design based on solid geophysical investigations a good fitting prognosis could be given. The fitting after 5 years of operation shows the proof.

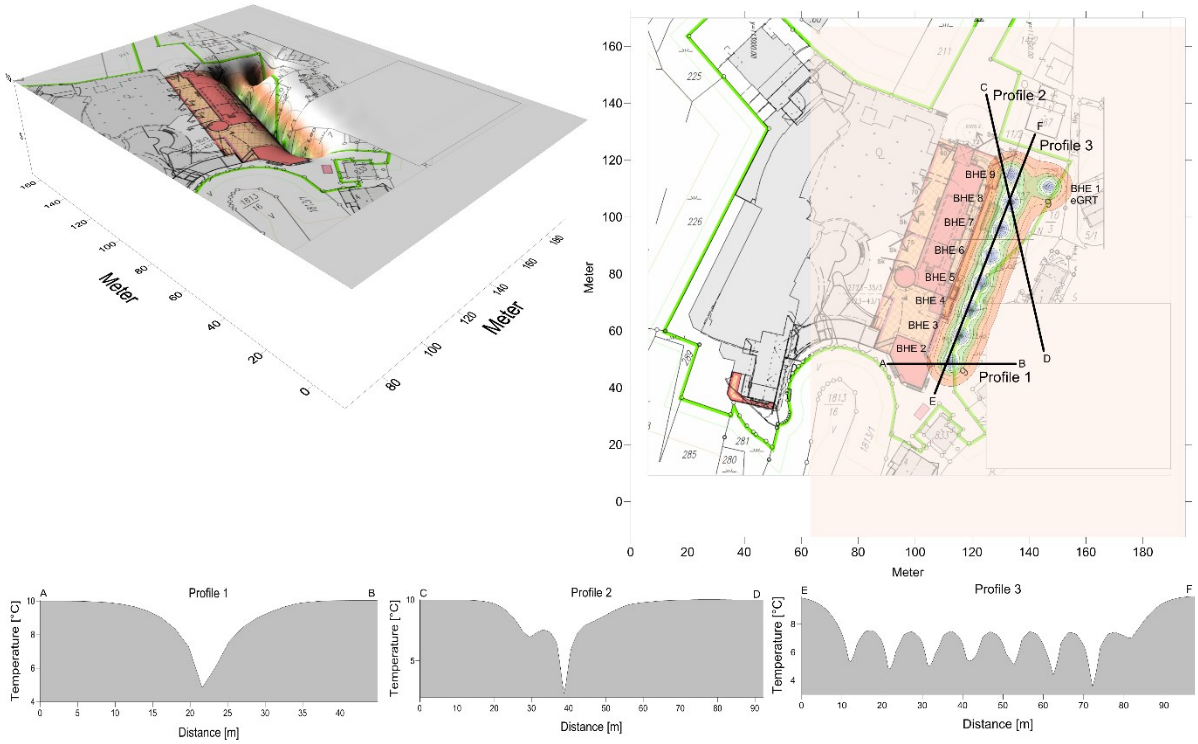


**Figure 11: Numerical Simulation (Design) of Brine Temperatures and Spatial Temperature Influence on Subsurface (End of Winter after 5 y of Operation)**

## 4. CONCLUSIONS

It is shown that a karstic environment is utilizable for geothermal use. The BHE array has been working efficiently since 2013.

It is evident that most precise geophysical information is needed for designing a geothermal array in a karstic environment. More than one eGRT at different construction states are necessary to describe and understand the operating conditions of the BHE surrounding subsurface.

It is highly recommendable to monitor the operating data from geothermal building equipment and appliances over several years to rate the efficiency of operation. In this case the changed operation design leads to consideration if augmentation of the array is needed to raise SCOP and satisfy the growing cooling demand. Additional installations of 3 BHEs and a heat pump for cooling purposes only will be approved in the near future.

The resort actually has 210 beds. The mean booking rate is 80% or 168 guests. 6.940 MWh geothermal power has been gained from subsurface over approximately 5 years of operation. According to the Austrian ministry of environment 1 kW are equal to 0, 2 kg $CO_2$ emission (http://www5.umweltbundesamt.at/emas/co2mon/co2mon.html). Therefore 1880 tons of $CO_2$ have been saved by the geothermal array. An Austrian citizen has a $CO_2$ emission equivalent of 9.1 t $CO_2$/ y (https://de.statista.com/themen/5119/ treibhaus-gasemissionen-in-oesterreich/). 153 guests of the resort are emission compensated by the $CO_2$ savings of the geothermal power supply (91% - approx. 18%/ y).

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