Research on Shallow Geothermal Energy Utilization in the Helmholtz Association

UFZ
JProf. Dr. Haibing Shao
haibing.shao@ufz.de

Dr. Uwe-Jens Görke
uwe-jens.goerke@ufz.de

Prof. Dr. habil. Olaf Kolditz,
olaf.kolditz@ufz.de

Dr. Thomas Vienken
thomas.vienken@ufz.de

DBFZ
Markus Lauer
markus.lauer@dbfz.de

GFZ
Dr. Guido Blöcher
guido.bloecher@gfz-potsdam.de

KIT
Prof. Dr. Veit Hagenmeyer
veit.hagenmeyer@kit.edu

TU Freiberg
Prof. Dr. Thomas Nagel
thomas.nagel@ifgt.tu-freiberg.de

Technical Background

In the shallow subsurface (<200 m depth), the soil temperature is often kept as a constant. The amount of geothermal energy stored there is increasingly employed for heating and cooling of buildings through the Ground Source Heat Pump Systems (GSHPS). In the heating mode, the general principle of a GSHPS is to extract heat from the shallow subsurface by circulating heat carrying fluid through single or multiple borehole heat exchangers (BHE), which are typically operating at a relatively low temperature.
The energy carried by the circulating fluid is then lifted by heat pump to a level suitable for domestic applications (see ▶ *Figure 1*).

For cooling applications, the system can be reversed, and the excess heat can be removed from the building and stored in the ground.
As the temperature in the shallow subsurface remains constant, GSHPS are very efficient in comparison to other technologies. For example, if 1 kWh of energy is required to heat the building, only 0.25-0.3 kWh of electricity are consumed to drive the heat pump. The substitution of coal and gas burning boilers by GSHPS will not only reduce fuel costs, but also lead to substantially lower emission of CO_2 and air pollutants. Therefore in the context of energy transition, GSHPS have become a very attractive technology for reducing the CO_2 emission of the domestic heating sector.

Quantification of Sustainably Exploitable Shallow Geothermal Energy

For policy makers and city planners, it is important to know how much thermal energy can be sustainably extracted from the shallow subsurface. Traditionally, such kind of evaluation was carried out via a volumetric approach. Putting into simple words, the evaluation was conducted by multiplying the subsurface volume together with the heat capacity of the soil and also by assuming uniform temperature drop of 2-6 °C in the aquifer. Although this approach has been carried out widely, the 2-6 °C of temperature drop is considered an empirical parameter and its sensitivity remains unknown.

Recently, the researchers from the Helmholtz Centre of Environmental Research (UFZ = Helmholtz-Zentrum für Umweltforschung) have conducted a more comprehensive study to answer the above question. As shown in Hein et al. [2], a numerical model has been constructed to re-produce the operation of ground source heat pump system over a long period of time. Numerical experiments have been perfor-

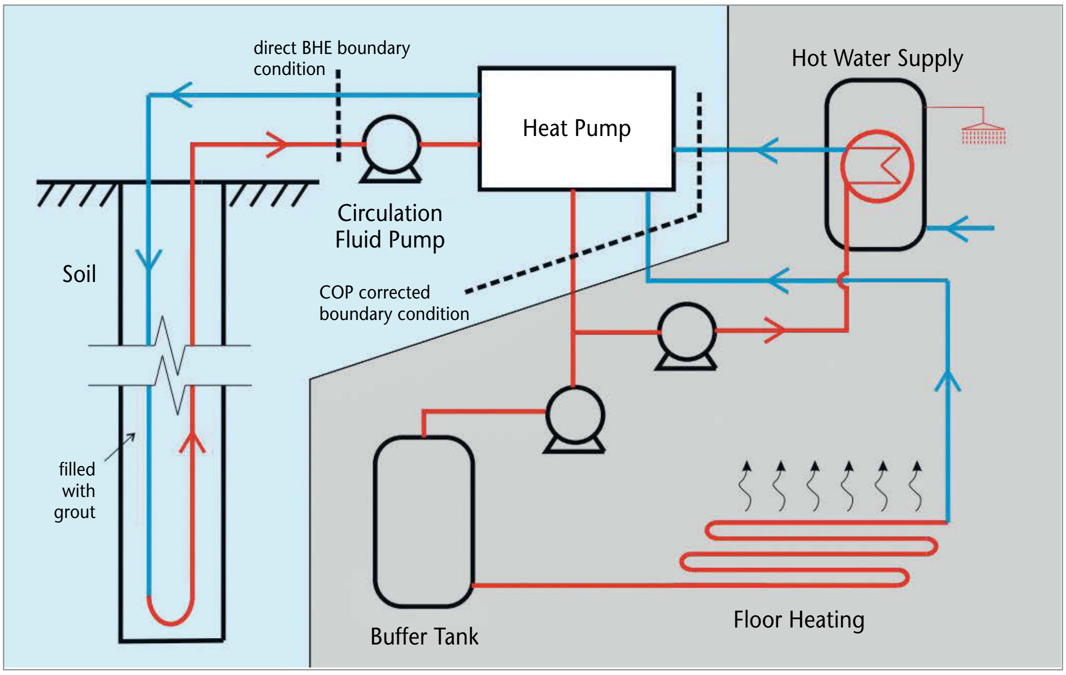


Figure 1

Shallow geothermal energy extraction through borehole heat exchangers (BHE)

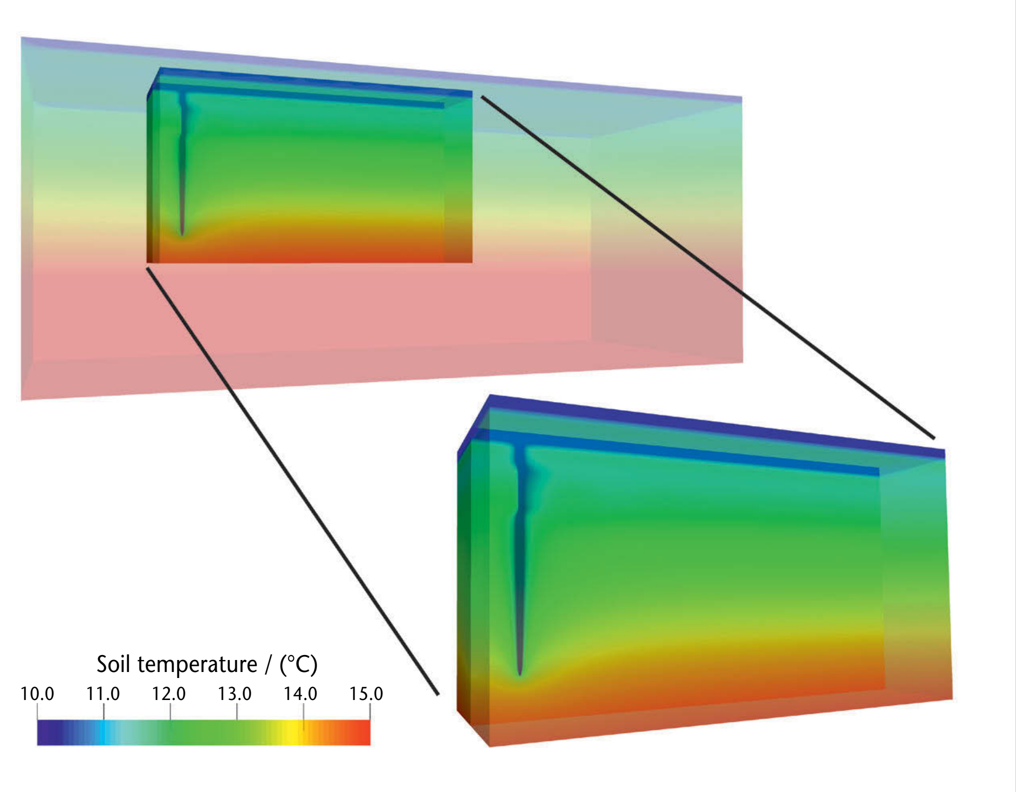


Figure 2

Numerically simulated temperature distribution *in the shallow subsurface due to geothermal energy extraction*

med by simulating the evolution of the subsurface temperature field. As illustrated by the simulation results in ▶ *Figure 2*, the change of subsurface temperature distribution is subject to the operation of borehole heat exchangers and varying parameters like subsurface thermal conductivity and groundwater flow velocity.

The concept of equivalent temperature drop is proposed as an auxiliary quantity for the subsurface. With the help of this parameter, a procedure has been established to quantify the amount of shallow geothermal potential. Following this approach, a realistic equivalent temperature reduction is found to be from -1.8 to -4.4 °C in the subsurface over a period of 30 years. This can be translated to an annual extractable geothermal energy value in a unit surface area, and it ranges from 3.5 to 8.6 kWh per square meter per year.

Environmental Impact of Shallow Geothermal Energy Utilization

According to the current trend, the shallow geothermal energy is utilized in a more extensive way to help cut CO_2 emission in the building heating sector. It is interesting to the researcher that, if the subsurface energy is continuously extracted over a long period of time, what kind of environmental impact will it be in terms of downstream groundwater?

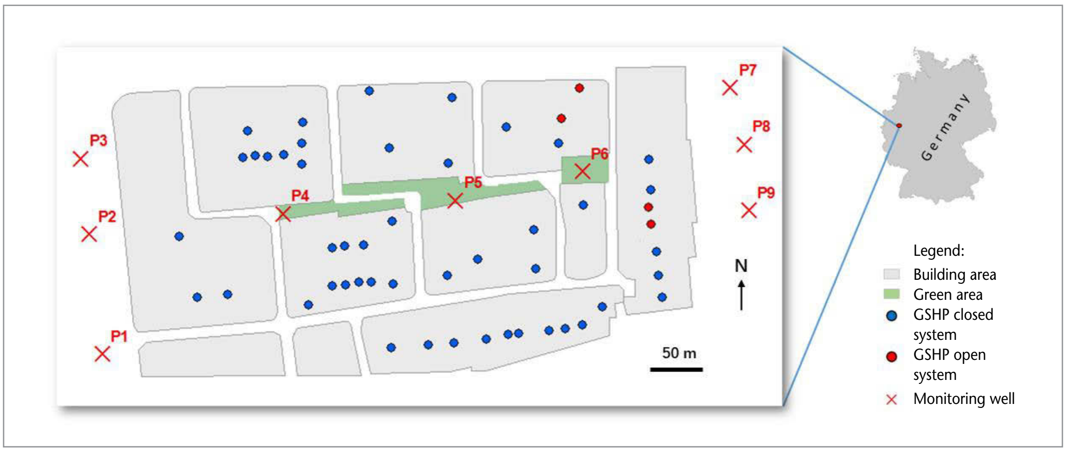
In this context, a suburban neighborhood in Cologne, Germany, was chosen as the study area. In this neighborhood, high-density Ground Source Heat Pump systems have been installed for the heating and cooling of houses.

▶ *Figure 3* illustrates the position of the GSHP systems and their respective types (open or closed loop). In total, there are 51 GSHP installations, of which 47 are closed loop BHEs while the remaining 4 are open systems. All the installed GSHP systems are at least used for heating during the winter. The minimum distance between adjacent installations is about 10 m, which is quite typical in German urban settings.

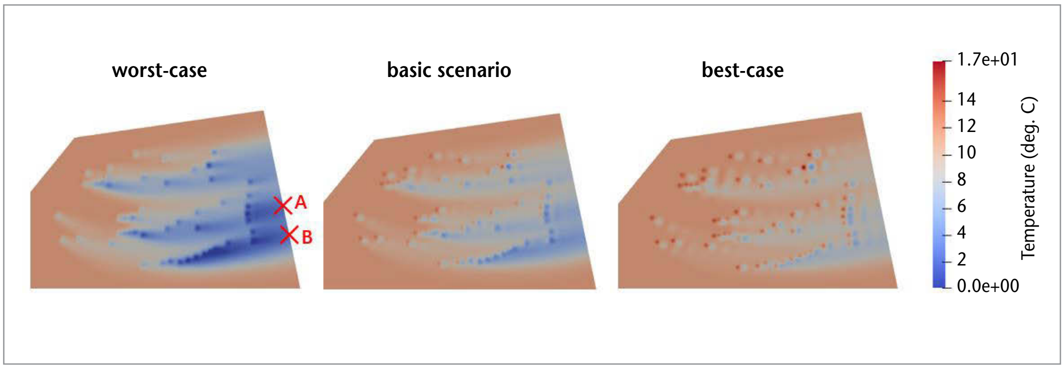
As part of the monitoring activities, the groundwater level and temperature in the wells of this neighborhood have been continuously monitored from 2013 to 2017. As suggested by the groundwater level measurements, the groundwater flow direction of the study area is in general from west to east. Combining with the documentation of drill cuttings acquired during BHE installation, it can be inferred that the aquifer is partially-saturated. The measured groundwater temperature in the downstream of GSHP installations exhibited a decrease of ~0.4 °C within the monitored 5-year period.

Figure 3

(a) Location of the study area and the location of GSHP systems in this neighborhood.



(b) Modelled downstream groundwater temperature distribution.



Based on the monitoring data and field measured aquifer parameters, a 2D numerical model has been established to predict the long term evolution of groundwater temperature. The simulation of 25 years showed that the downstream groundwater temperature will be around 6 °C, which is nearly compatible with the regulatory requirements.
However, for locations in the downstream of a series of GSHPS in the east-west direction, groundwater temperature is likely to drop more than 6 °C, as the groundwater is continuously cooled along its way (see Meng et al. [3]).

From this modelling study, two recommendations can be given:

(1) For small neighborhoods where the shallow geothermal energy is planned to be used intensively, an overall geological survey and planning is needed to avoid any interference between different GSHP systems, which is beneficiary for the long-term interest of individual owners.
(2) In the German climate condition, house cooling load is much smaller than the heating demand. Thus, it is recommended to use the GSHP system in both the cooling and heating modes. This will greatly reduce the risk of heat or cold accumulation in the subsurface.

Thermal Energy Storage in the Urban Subsurface

Following the idea in the above section, Aquifer Thermal Energy Storage (ATES) has been proposed as one technology to bridge the time gap between energy production and demand. Through an ATES system, thermal energy storage and recovery are achieved by extraction and injection of groundwater from aquifers using groundwater wells.

The ATES systems are commonly operated in a seasonal mode:
In summer, the groundwater is extracted and excess heat is transferred to the groundwater by means of a heat exchanger. Subsequently, the heated groundwater is injected back into the aquifer, which creates storage of heated groundwater.
In winter time, the flow direction is reversed such that the heated groundwater is extracted and can be used for heating, often with the help of a heat pump.
In order to achieve a successful ATES project, the hydraulic properties of the targeted aquifer are the key parameters for its long term performance and sustainability.
To analyze the potential of an ATES in the center of Berlin a research drilling campaign on the campus of Technische Universität Berlin was conducted by GFZ

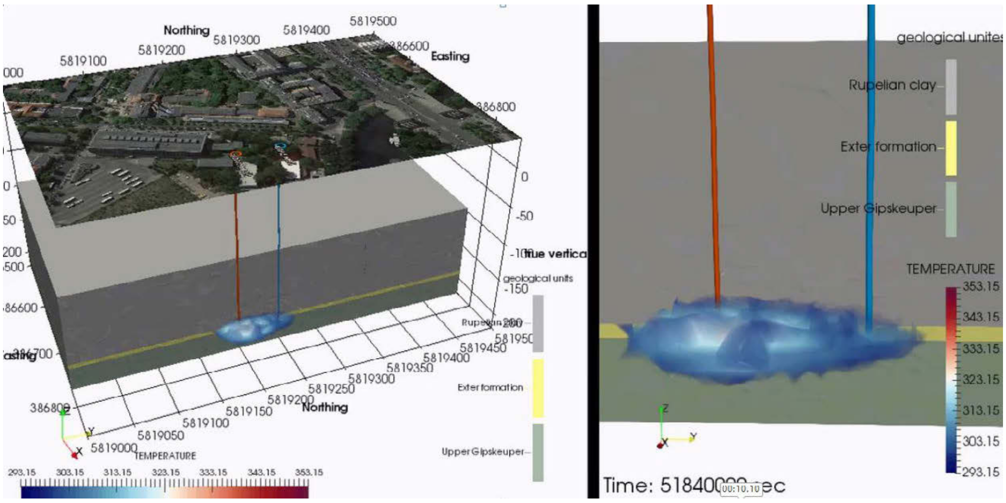


Figure 4

Aquifer Energy Storage System (ATES):

Numerically simulated operation process of a proposed ATES in the campus of Technische Universität Berlin.

German Research Centre for Geosciences in the framework of the research project "Effizienz und Betriebssicherheit von Energiesystemen mit saisonaler Energiespeicherung in Aquiferen für Stadtquartiere" (BMWi – Bundesministerium für Wirtschaft und Energie FKZ 03ESP409A). The main work has been focusing on the aquifer geological characterization and hydraulic tests. The Exter-sandstone formation was chosen as the target aquifer formation. This aquifer formation has a temperature of 17 °C at a depth between 220 und 230 m below ground surface. Several hydraulic tests including slug-withdraw tests, a step-rate-test, production tests, and push-pull-tests were performed during 40 days' operation in 2017 in order to quantify the key aquifer parameters. These tests were accompanied by Distributed-Temperature-Sensing (DTS) which allows a continuous and spatial distributed temperature profiling in the well. These temperature measurements provide indications of injection areas based on the warm back period during a push-pull test with 90 °C hot water. Each one slug-withdraw test was performed at the beginning and at the end of the test campaign to evaluate the changes of the hydraulic performance during testing and to compare the results to the conventional well-testing methods like production and step rate tests.

The results indicate that the aquifer horizon, although only 4 m in thickness, is suitable for aquifer thermal energy storage. The aquifer transmissibility T = 3.2*10-5 m^2/s was calculated based on the shut-in and build up measurements after the step rate tests. During the well development and the subsequent hydraulic testing the productivity increases from initial 0.7 m3/h/bar to 1.8 $m^3/h/bar$ allowing maximum flowrates of about 10 m^3/h. The storage capacity of the aquifer can reach approx. 700 MWh and maximum load capacity can be 200 KW.

Geothermal energy resources for urban heating cooling supply is of great interest world-wide, a recent German-Chinese geothermal research workshop was elaborating the potential for cooperation between the two countries.

References

[1] Guido Blöcher, Simona Regenspurg, Stefan Kranz, Jan Henninges, Ben Norden, Ali Saadat, and Ernst Huenges (2018): Hydraulic performance of a scientific Aquifer-Thermal-Energy-Storage (ATES) site in Berlin (Germany), (Geophysical Research Abstracts, Vol. 20, EGU2018-12831) , General Assembly European Geosciences Union (Vienna 2018).

[2] Philipp Hein, Ke Zhu, Anke Bucher, Olaf Kolditz, Zhonghe Pang, Haibing Shao (2016) Quantification of exploitable shallow geothermal energy by using Borehole Heat Exchanger coupled Ground Source Heat Pump systems, Energy Conversion and Management 127: 80-89.

[3] Meng, B., Vienken, T., Kolditz, O., Shao, H. (2018) Modeling the groundwater temperature response to extensive operation of ground source heat pump systems: A case study in Germany (Conference Paper), Energy Procedia 152: 971-977.