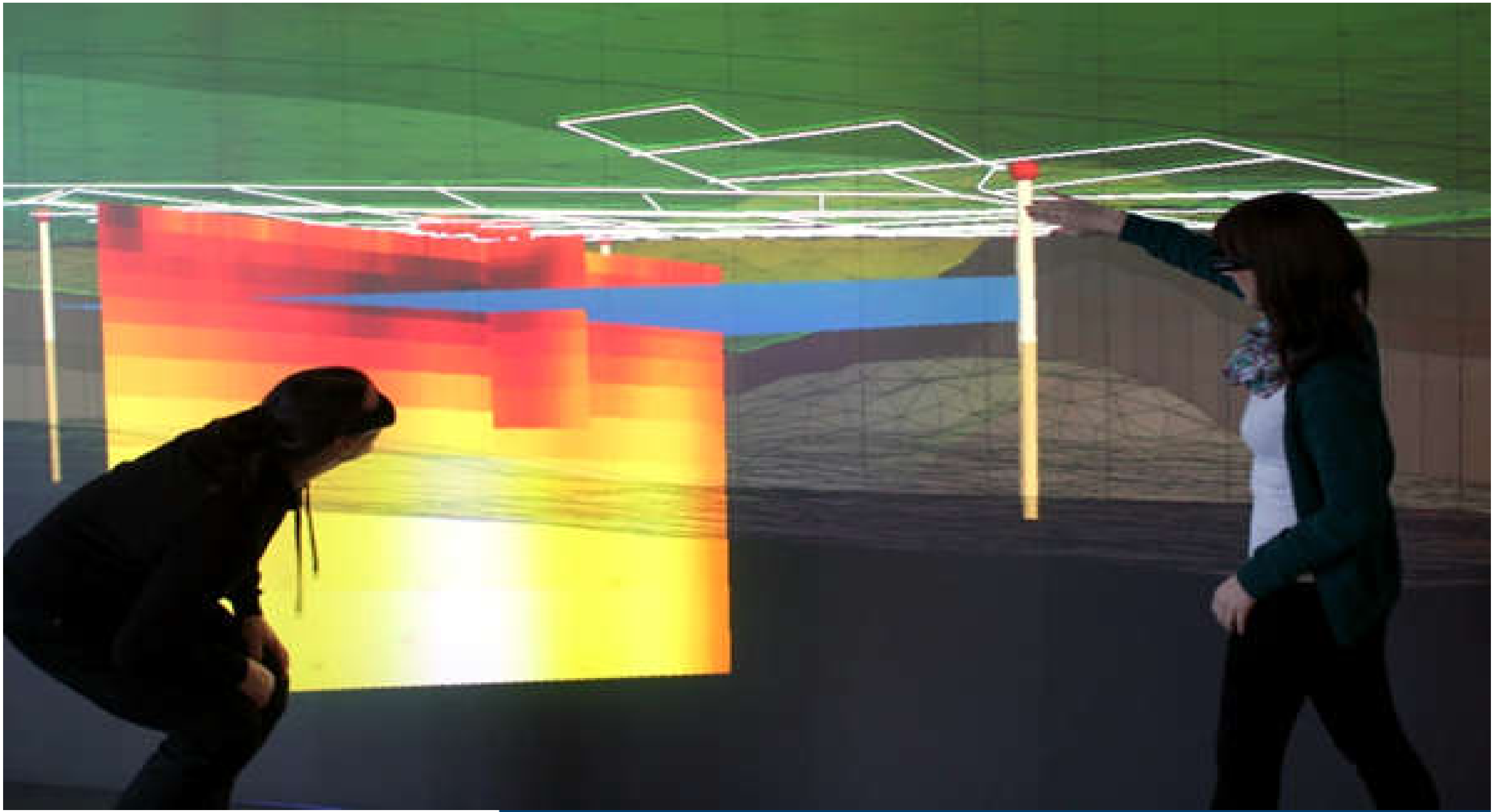


Numerical Modelling of Shallow Geothermal Energy Exploration Process

Haibing Shao, Thomas Vienken and Olaf Kolditz
83 Jahrestagung der Deutschen Physikalischen Gesellschaft
Rostock, Germany. 13.03.2019

HELMHOLTZ
CENTRE FOR
ENVIRONMENTAL
RESEARCH – UFZ

Overview

1) Introduction of Ground Source Heat Pump (GSHP) systems

1) Numerical Modelling of heat transport around BHE

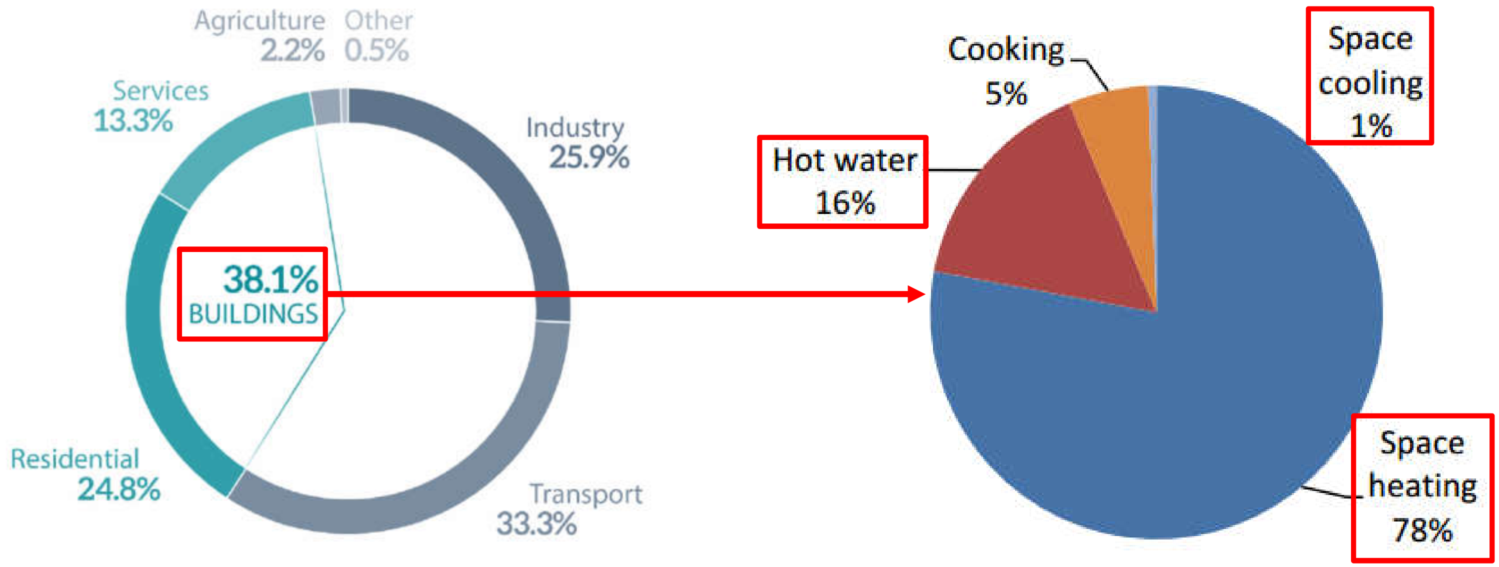
2) What are the influencing factors for BHE efficiency?

3) How much energy can be sustainably extracted from shallow subsurface?

4) What will be the potential environmental impacts, e.g. on downstream groundwater temperatures?

Motivation: Building Heating consists of a large part of our Energy Consumption

- Energy consumption in the EU



source: Eurostat, 2014

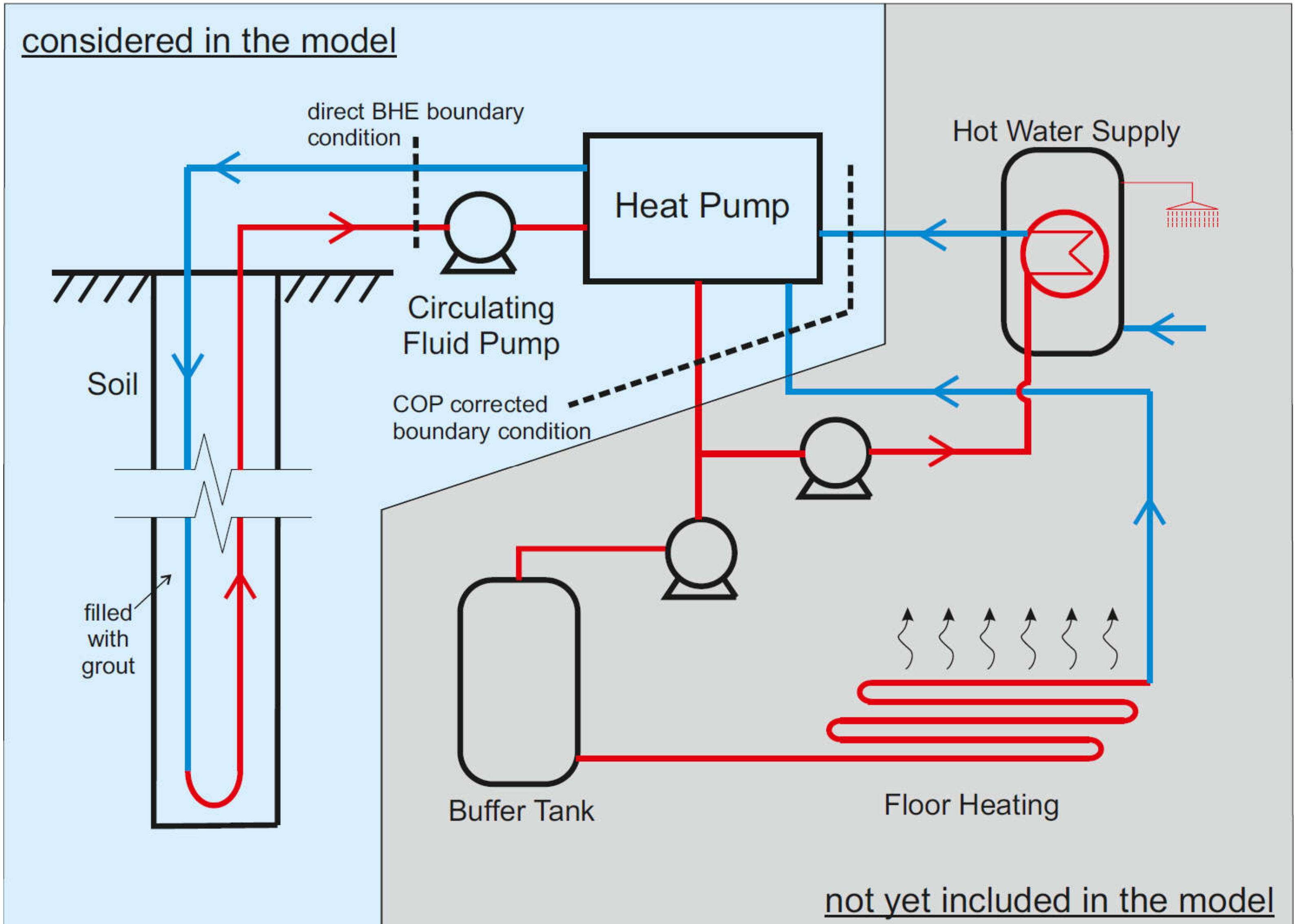
source: European Commission, 2016

- 84% of H&C is still generated from fossil fuels
- EU <u>carbon reduction</u> target: 80% by 2050

  EU <u>renewable energy</u> target: 12% of heat from renewable energy by 2020
- Using shallow geothermal energy for H&C is a viable option.

  ✓ *local, clean and efficient!*

GSHP – Technical Background



Operation Principle of Borehole Heat Exchangers

Distributor and collector with pressure gauge.
Q: which one is the inlet and which one is the outlet?

Open/close valve

Two boreholes are both 2U setup.

Source: International Geothermal Association, Training Center Bochum

De-gassing air releasing valve.

Q: think about what is the purpose of this device?

This is the valve to bleed or fill up the system.

Additional weight at the bottom to pull the pipelines down the borehole.

Operation Principle of Borehole Heat Exchangers

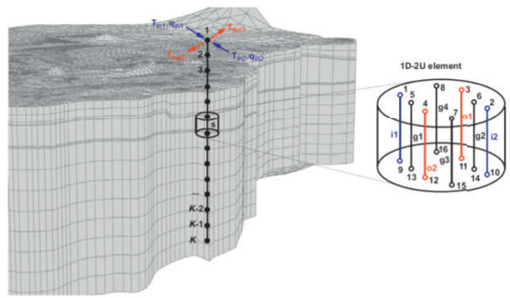
Source: BINE Information Services

Source: http://www.groenholland.com

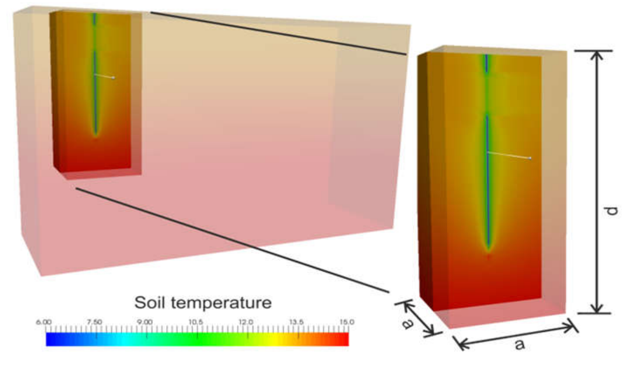
Integration of Data in the numerical model for the process analysis

- **Monitoring and Modelling**

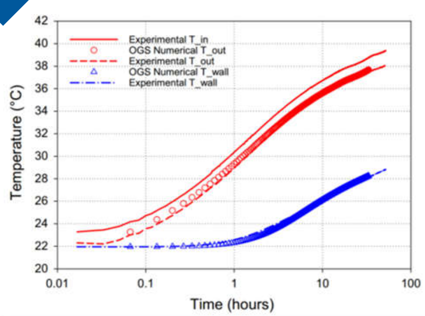
- **Data Driven Model Developmen**



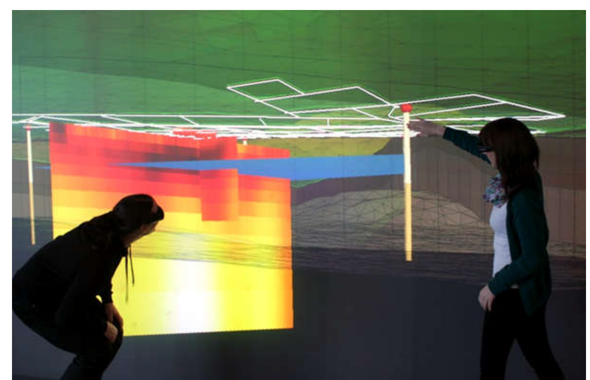
- **Mechanistic Understanding of underlying processes**



- **Model Validation and Parameter Calibration**

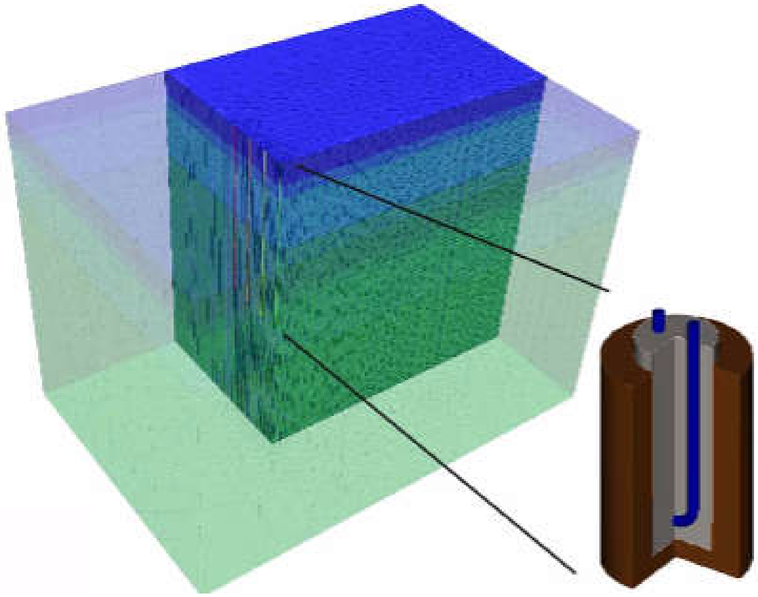


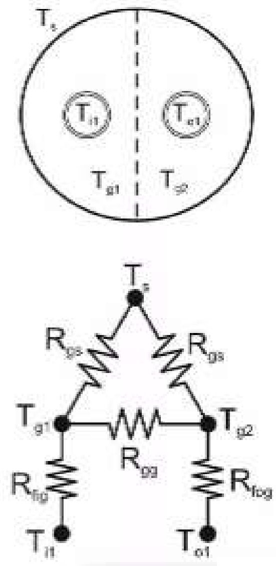
- **Visualization and Analysis of Modelling Result**



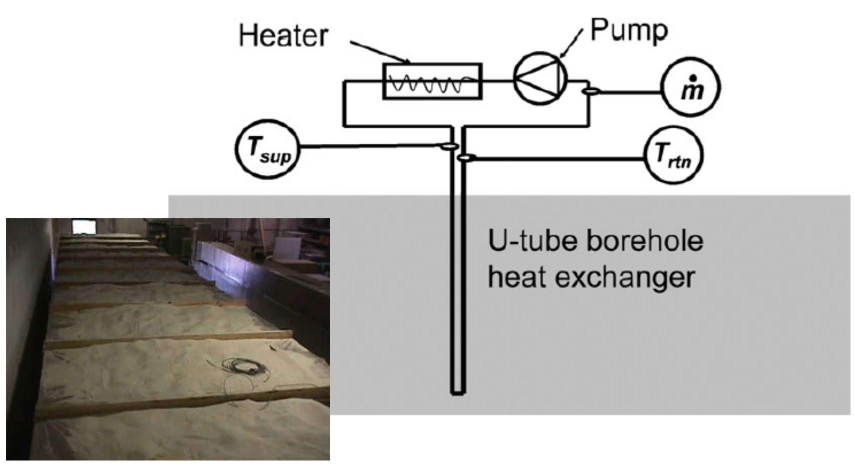
- **Prognosis of System Performance and Environmental Impact**

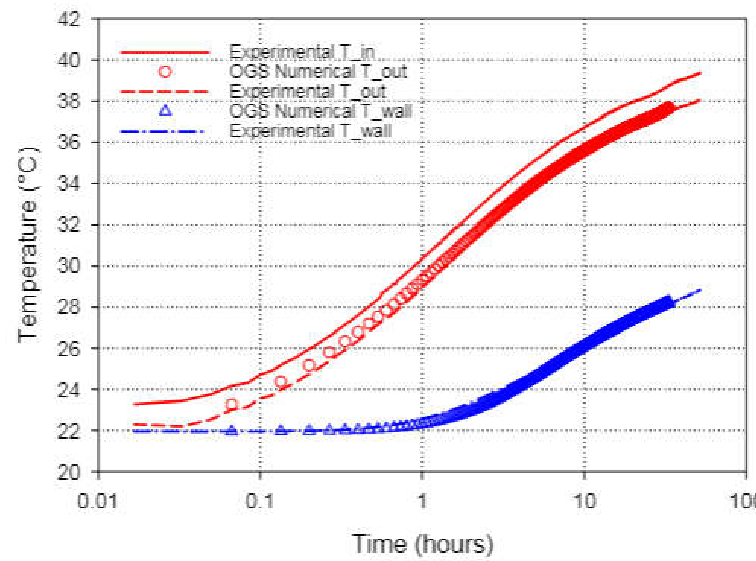
OpenGeoSys FEM solution with dual-continuum





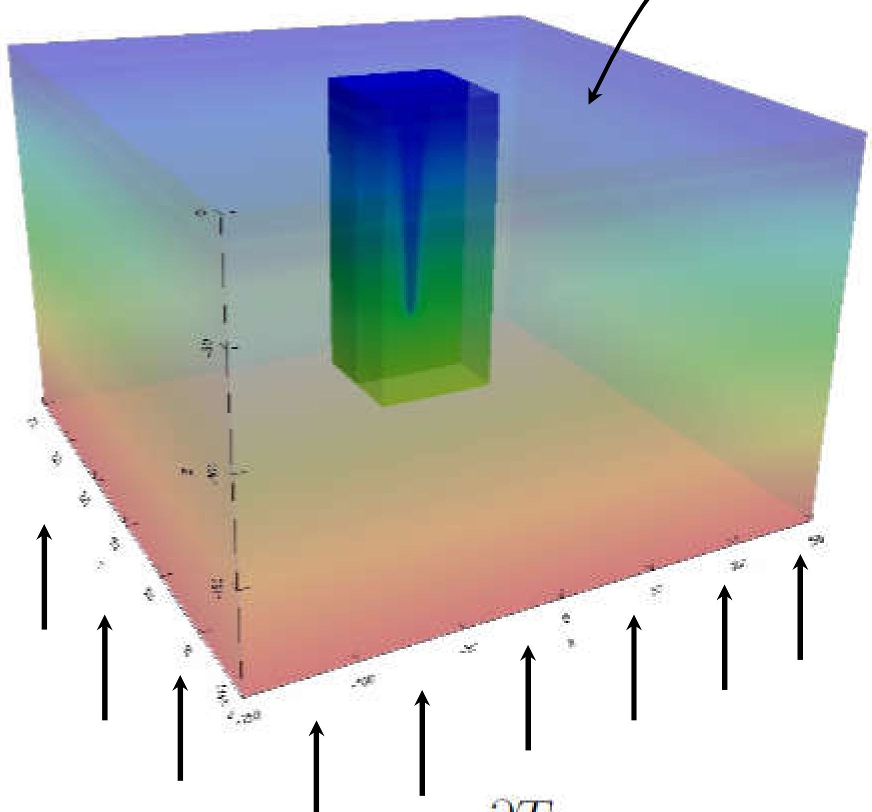
- ✓ Implementation of BHE as a secondary domain, based on the Approach of Al-Khoury (2009) and Diersch (2013).
- ✓ Model verified against analytical solution and in-door experiment from Beier (2011) and Beier (2014).



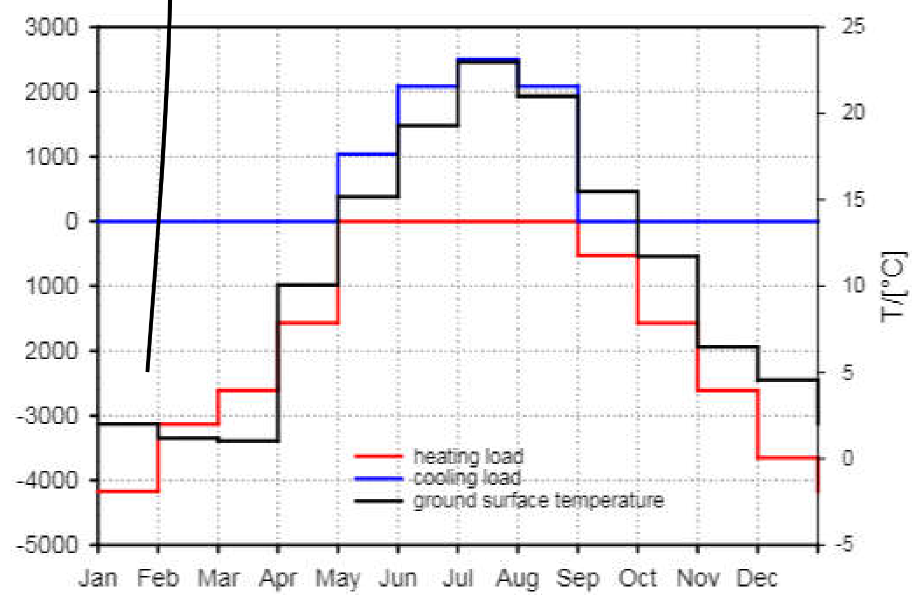


Reference scenario as a single-family house in Leipzig

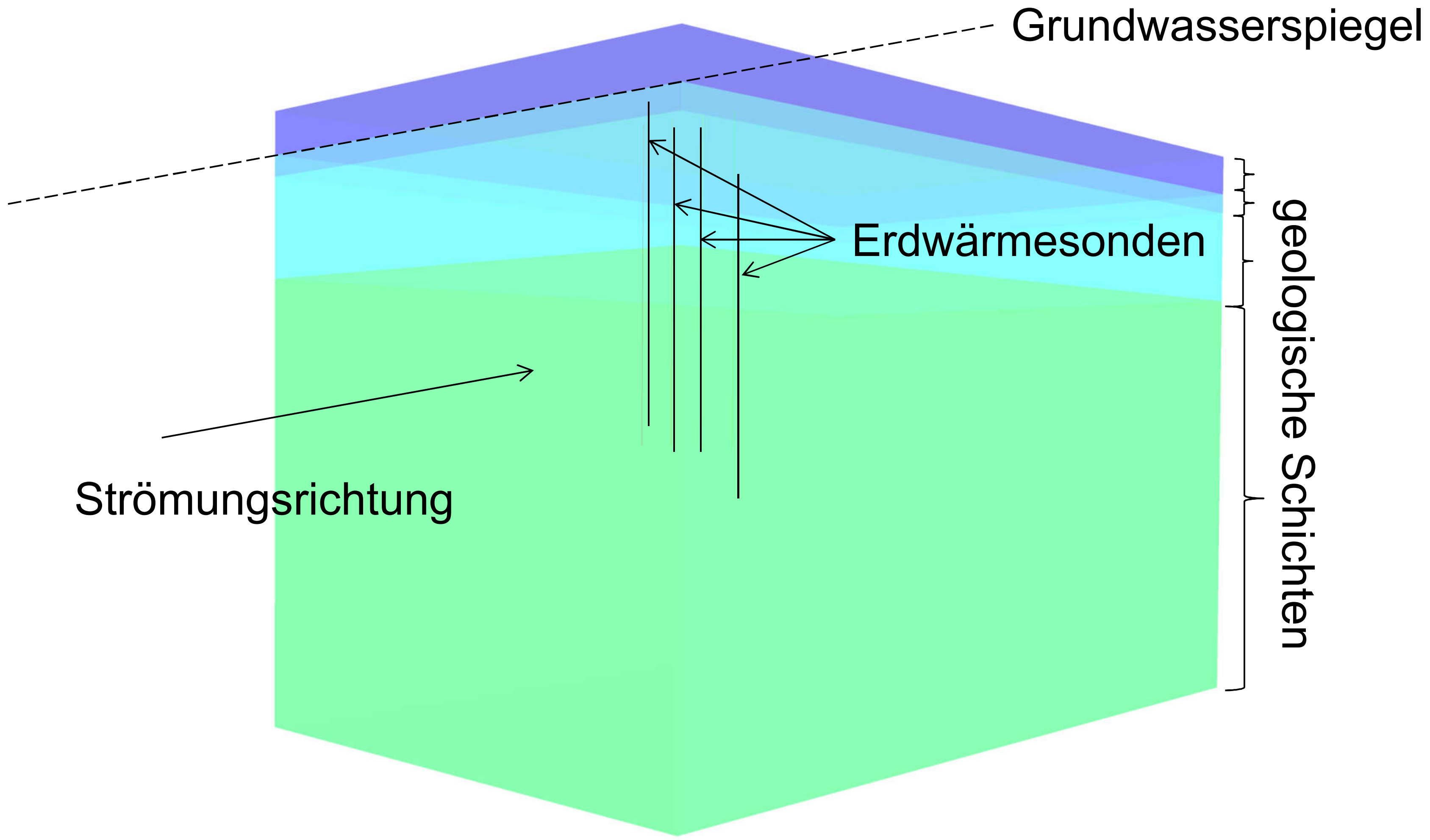
- Reference scenario built based on the site characteristics of Leipzig.
- Fluctuating surface temperature on the domain surface, according to the metalogic data of Leipzig.
- Thermal flux boundary condition at the bottom, based on a measured geothermal gradient of 0:0384 W/m2.
- Building thermal load calculated for a 150 m2 single family house.



$$q_{geo} = \lambda_{soil}\left(\frac{\partial T}{\partial z}\right)_{geo}$$



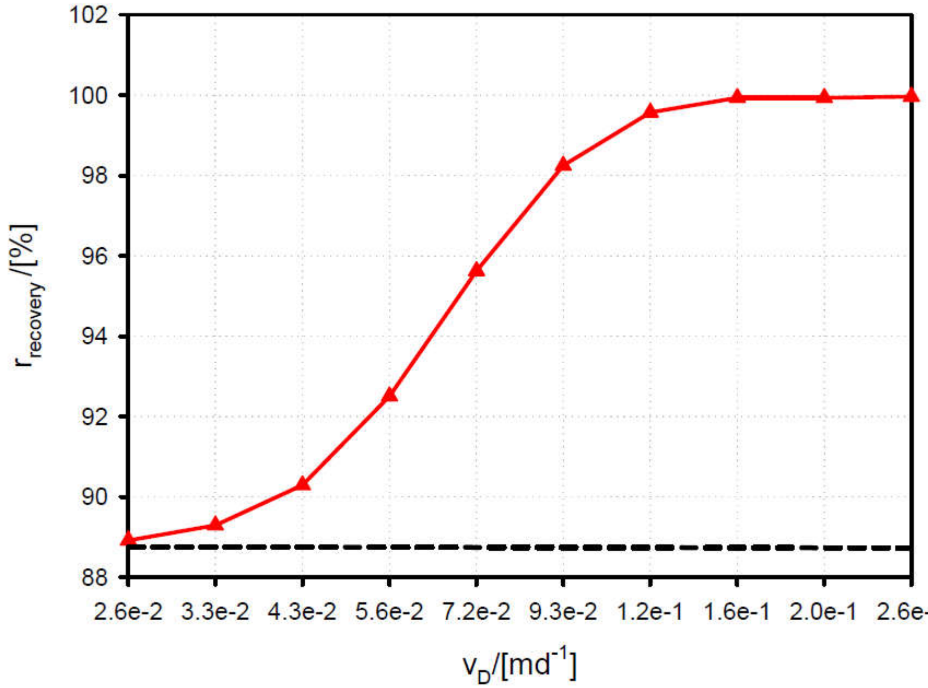
Configuration of the subsurface structure



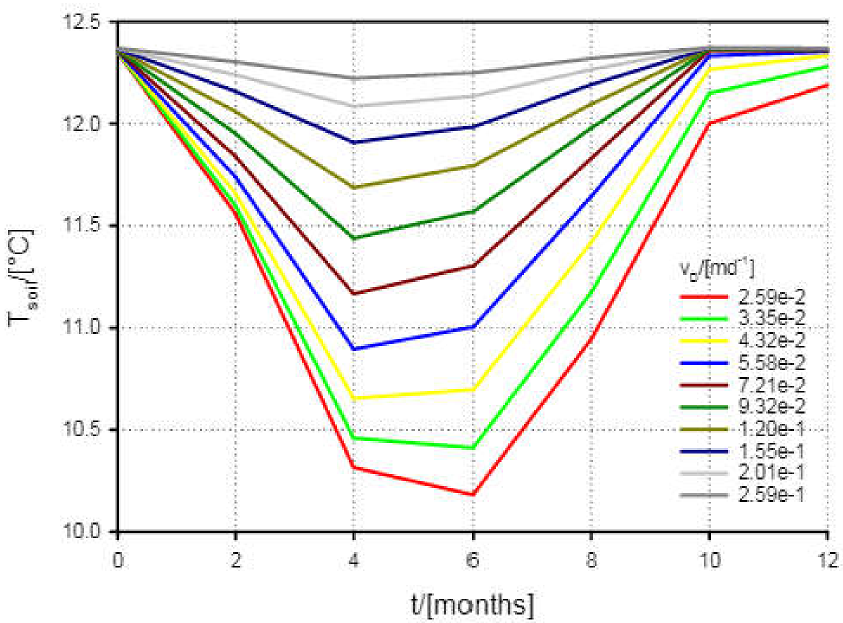
Impact of groundwater flow

- It is observed that the recovery ratio increases with increasing Darcy velocity.

- The curve has a sigmoid-like shape. While Darcy velocity increases, also the recovery ratio increases in an exponential manner until reaching a turning point, from which on the recovery ratio converges asymptotically towards full recovery.



Groundwater flow - Recovery ratio as a function of Darcy velocity



Groundwater flow - Subsurface temperature at a distance of 1 m beside the BHE

- Here, it can be clearly observed that the perturbation of the temperature field in the vicinity of the BHE decreases with increasing groundwater flow velocity.

- Also, it is found that the heat pump COP is further increasing, although almost full recovery is reached with higher groundwater flow velocities.

Economics of different BHE length

	46 m	92 m
Drilling borehole	2 300	4 600
Buried pipe	300	601
Spacer	31	31
Grouting	202	405
Heat pump	444	444
Accessories	111	111
Total initial investment	3 388	6 192
Annual electricity cost	1 300	992
Present value of 30 years' electricity cost	38 720	29 572
Total cost	42 109	35 763

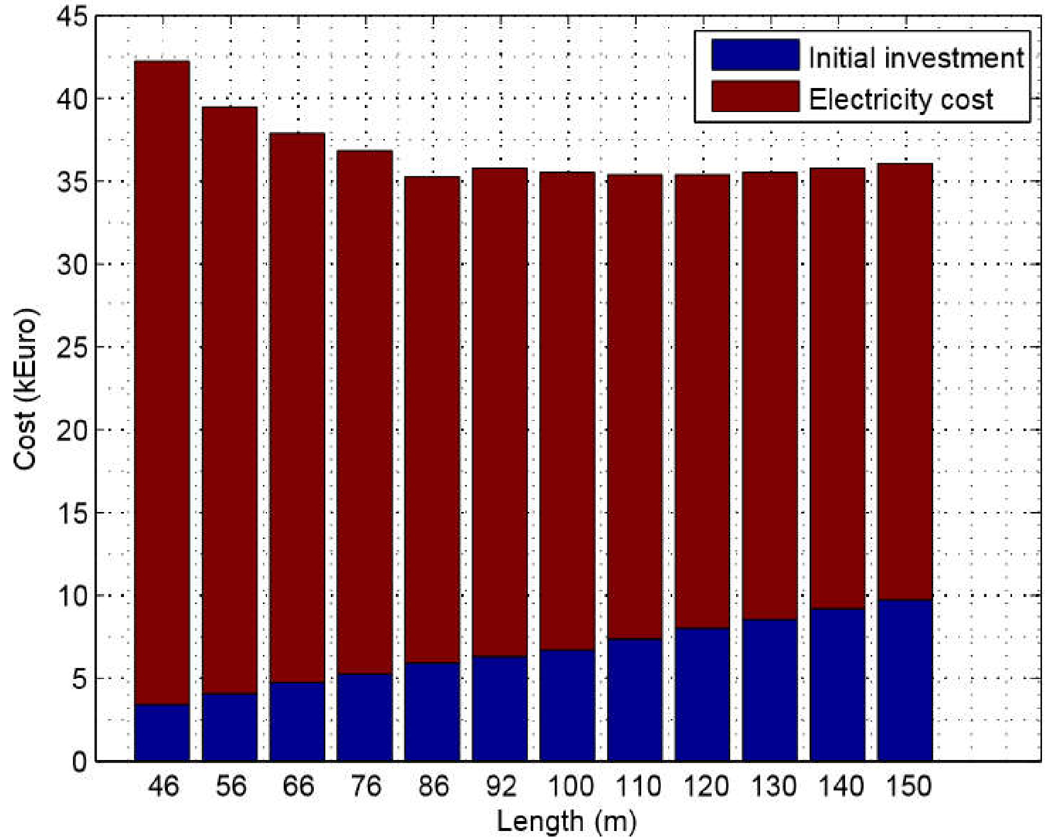
- The two configurations are compared in terms of total cost, which includes the initial installation together with 30 years' of electricity consumption.
- Installation cost is estimated based on the per meter long BHE, and the electricity cost is based on ~0.30 Euro/kWh price in Germany.

- The time value of the electricity cost in the future is corrected with an interest rate of 0.05% as in Germany.

$$C_{\text{current}} = \frac{C_{\text{future}}}{(1+e)^n}$$

- The total cost will be clearly higher for the 46m configuration in Germany.

- From 46m to 150m, the total cost first drops quickly, then is smooth. With our setup, the optimal length is a 86m long BHE.

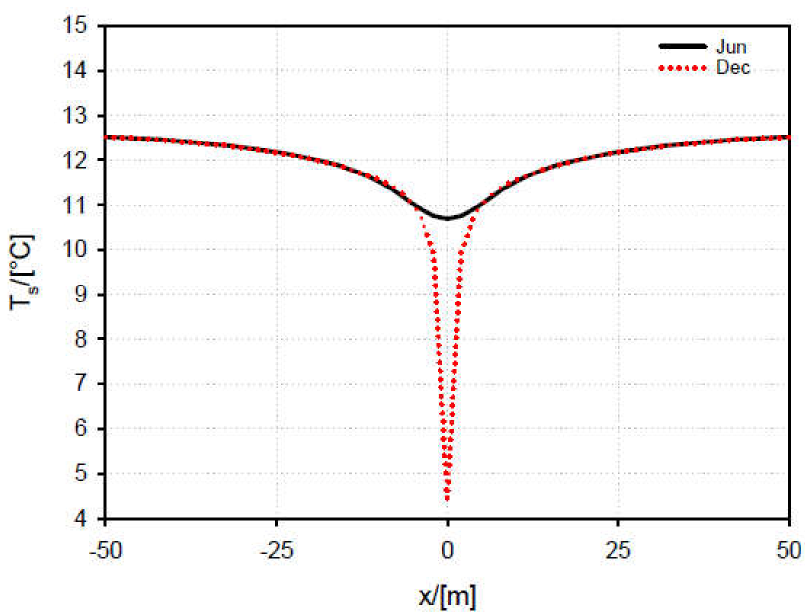


How much energy can we sustainably extract from the shallow subsurface?

<u>Standard approach:</u>
Volume based accounting with a uniform Delta_T value:

$$E_{geo} = E_S + E_W = V(1-\epsilon)C_S\Delta T + V\epsilon C_W\Delta T$$

<u>In the reality:</u>



- Temperature profile in the vicinity of the well is funnel shaped – uneven distribution.
- Temperature profile in the soil changes over season.
- The recovery of the soil temperature must be put into consideration.

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Introducing the Equivalent Temperature Drop:

(1) Calculate the average temperature in a controlled volume.

$$\overline{T}_s = \frac{1}{V}\int^{\Omega} T_s(x,y,z,t)dV$$

(2) Find the difference of averaged temperature between one year.

$$\Delta T_{s,eq} = \overline{T}_s(t_1) - \overline{T}_s(t_0).$$

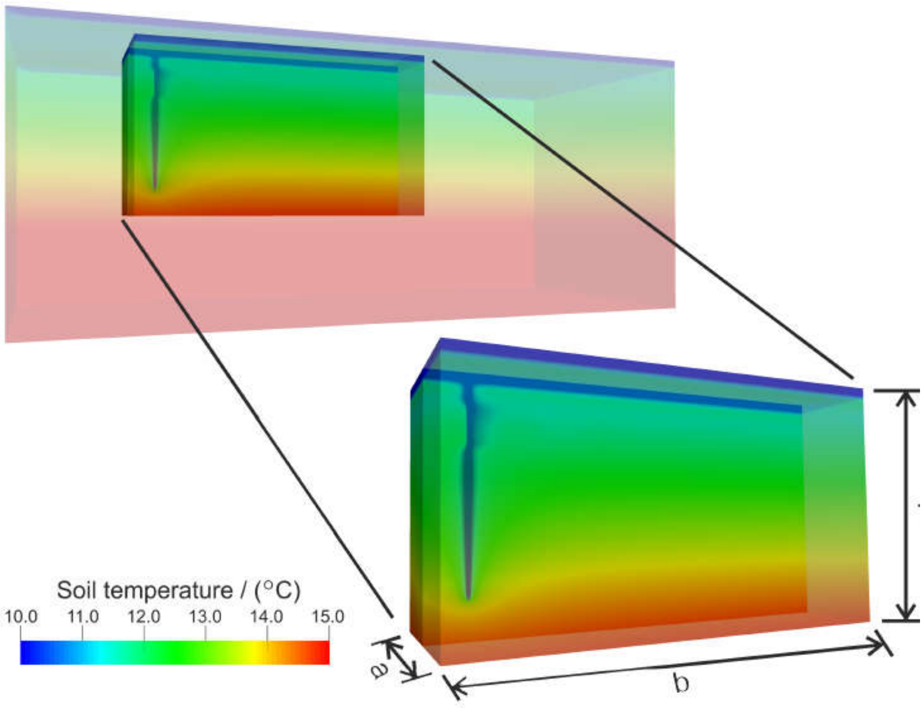


Figure 3: Visualized soil temperature distribution after 30 years of operation, with data presented at t... end of December.

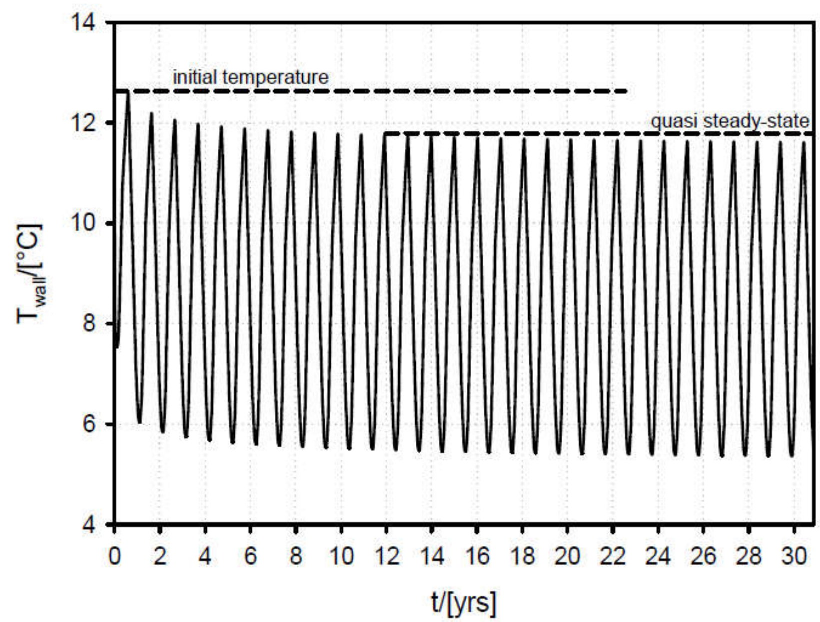
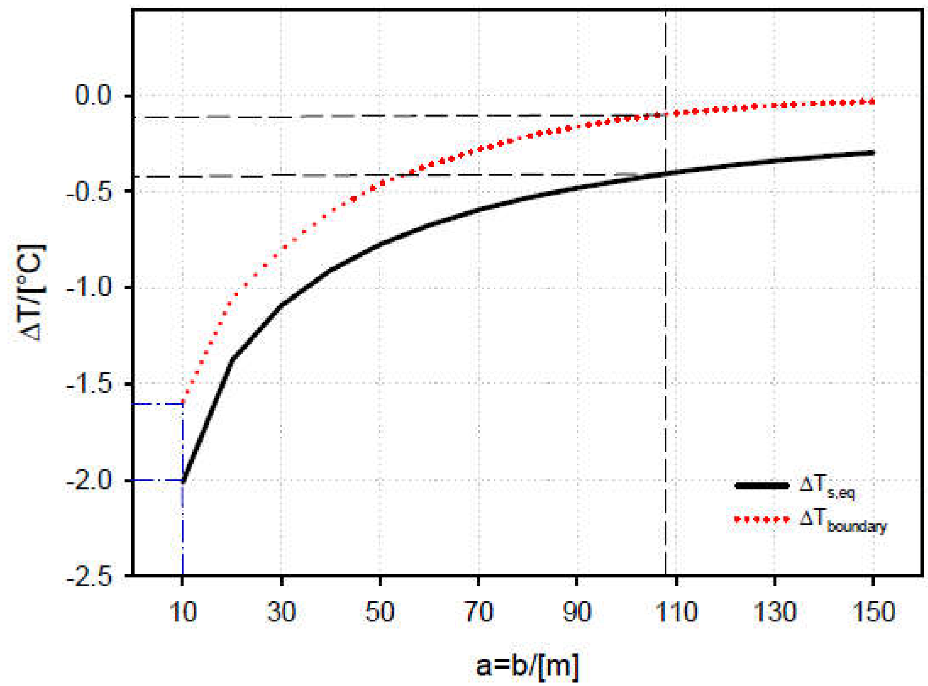


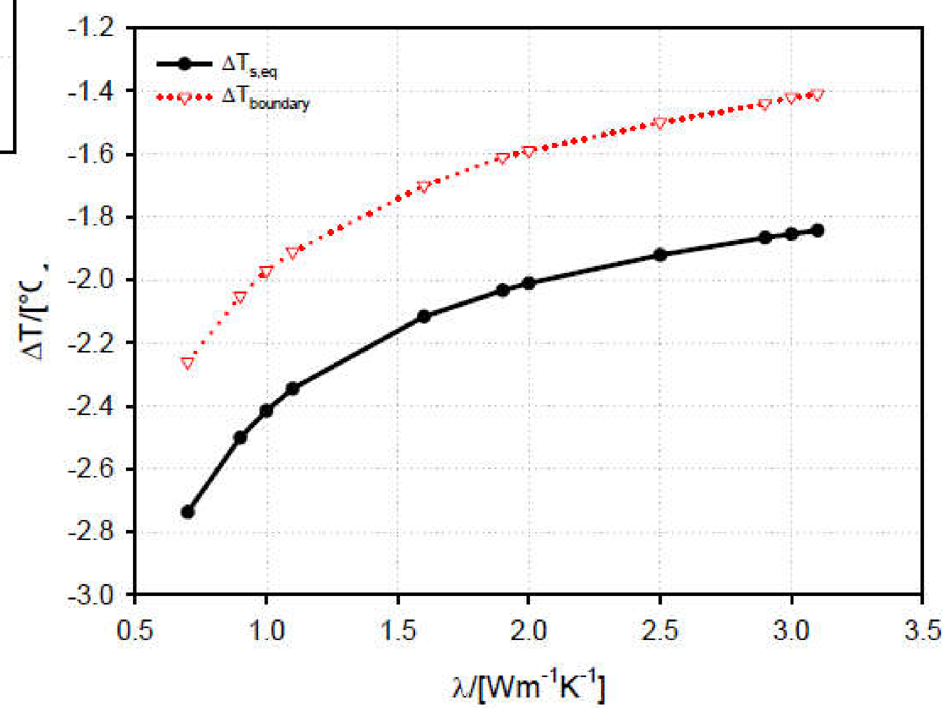
Figure 5: Temperature fluctuation at the BHE wall, measured at the top of the BHE. The initial and quasi steady-state temperatures are marked with dashed lines.

How des the equivalent temperature drop respond to CV size and soil thermal conductivity lambda?



- The boundary of undisturbed temperature is quiet far away.
- At the boundary, if temperature change is less then 0.1 dC, the radius is about 110 m (with soil conductivity of 2.0 W/m/K)

- With higher lambda value, the equivalent temperature is smaller. (with a=b fixed at 10 m)



How does the arrangement of multiple BHEs affect the equivalent temperature drop?

- Arrangement of 1x4 and 2x2 BHEs is tested.
- 2x2 arrangement shows larger delta_T drop.
- Large BHE systems needs to be further investigated.

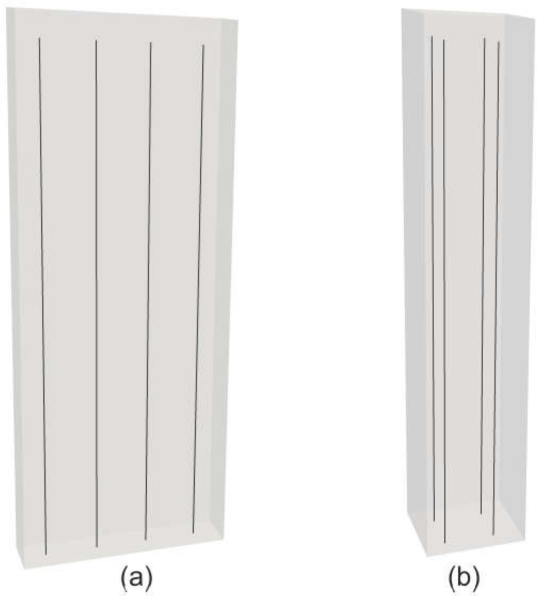
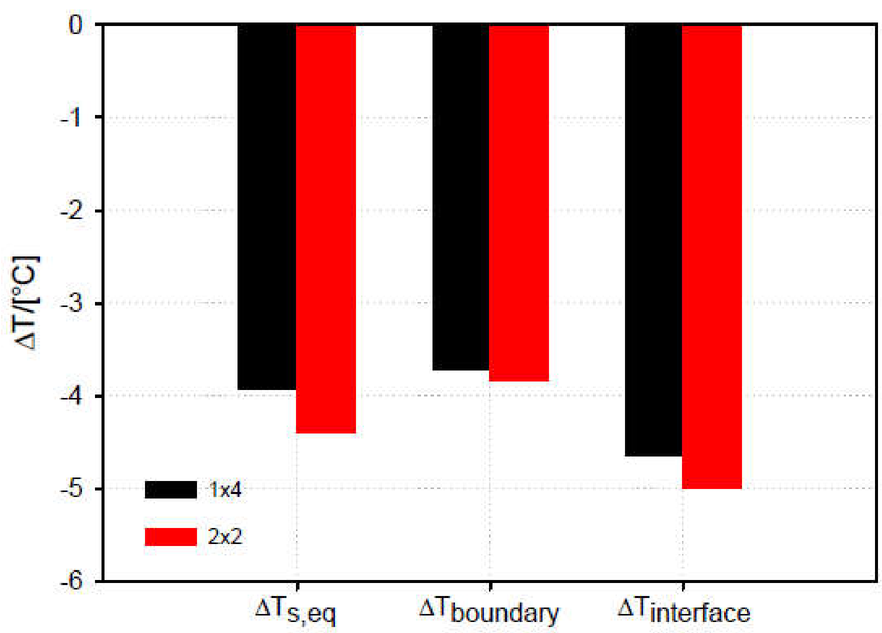
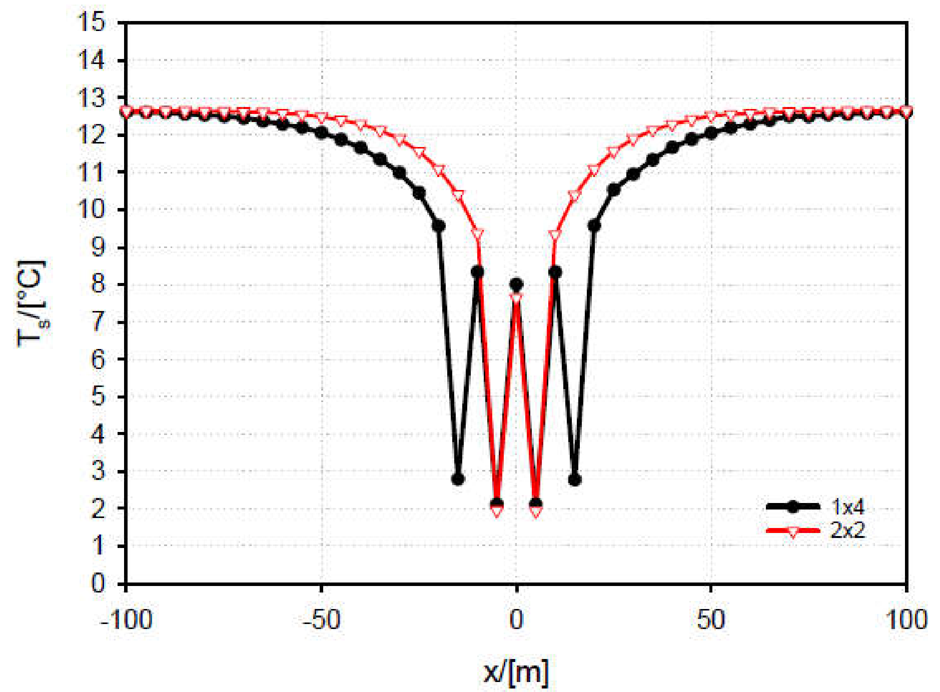


Figure 2: Multiple GSHP systems: a) 1 × 4 arrangement, b) 2 × 2 arrangement.





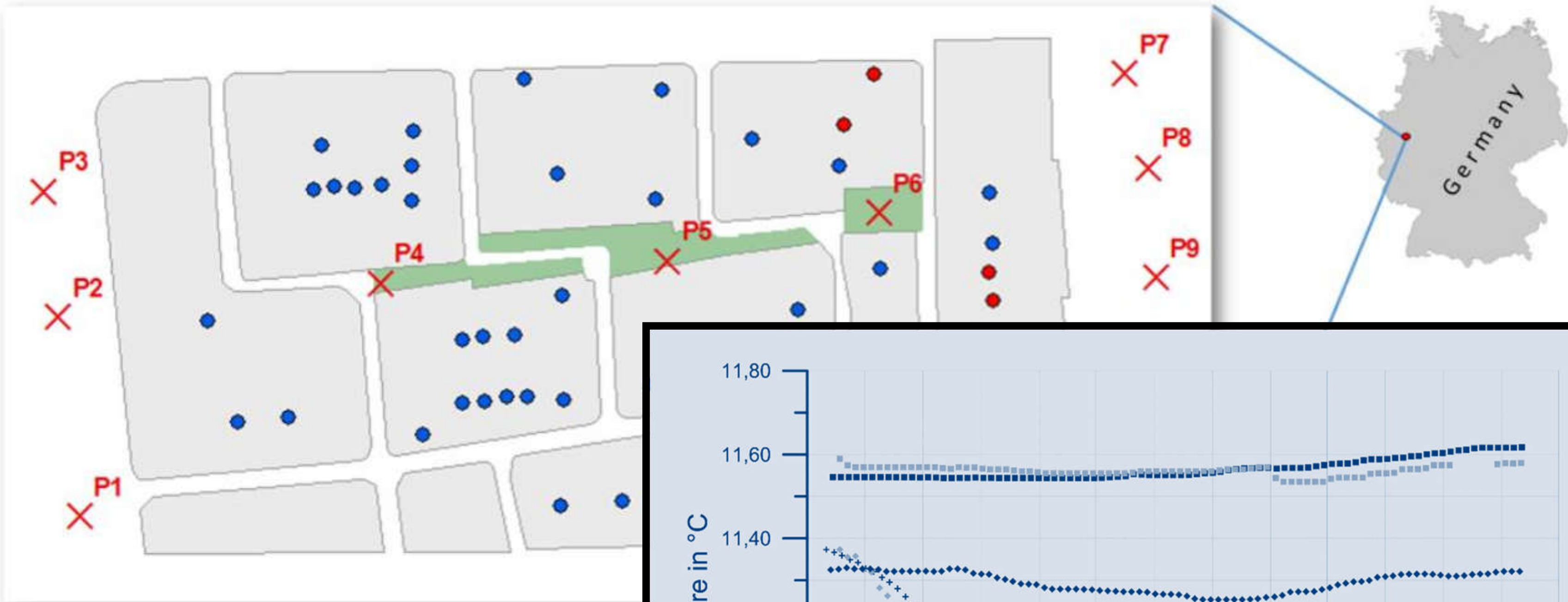
How much energy can we sustainably get from shallow subsurface?

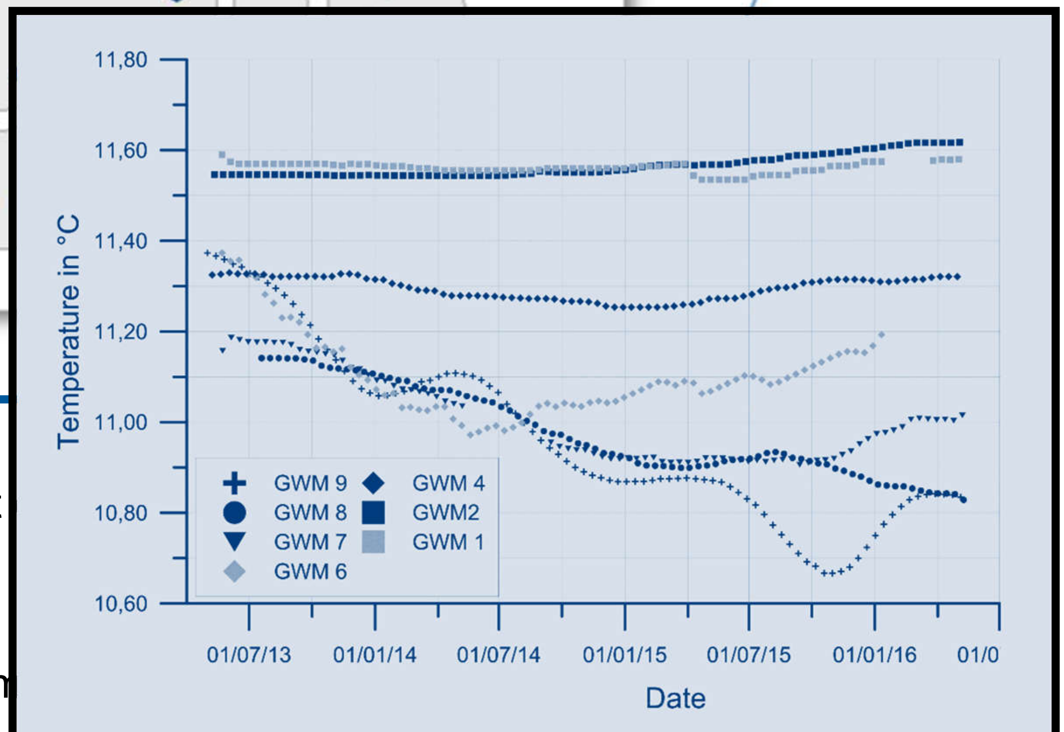
- Single BHE GSHP system: -2.8 dC and -1.8 C for a typical range of subsurface thermal conductivity values over a period of 30 years.

- With a configuration of 4 individual BHE GSHP systems, the equivalent temperature drop ranges between -3.9 dC and -4.4 dC.

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

A Case Study on the Environmental Impact of Shallow Geothermal Energy Utilization



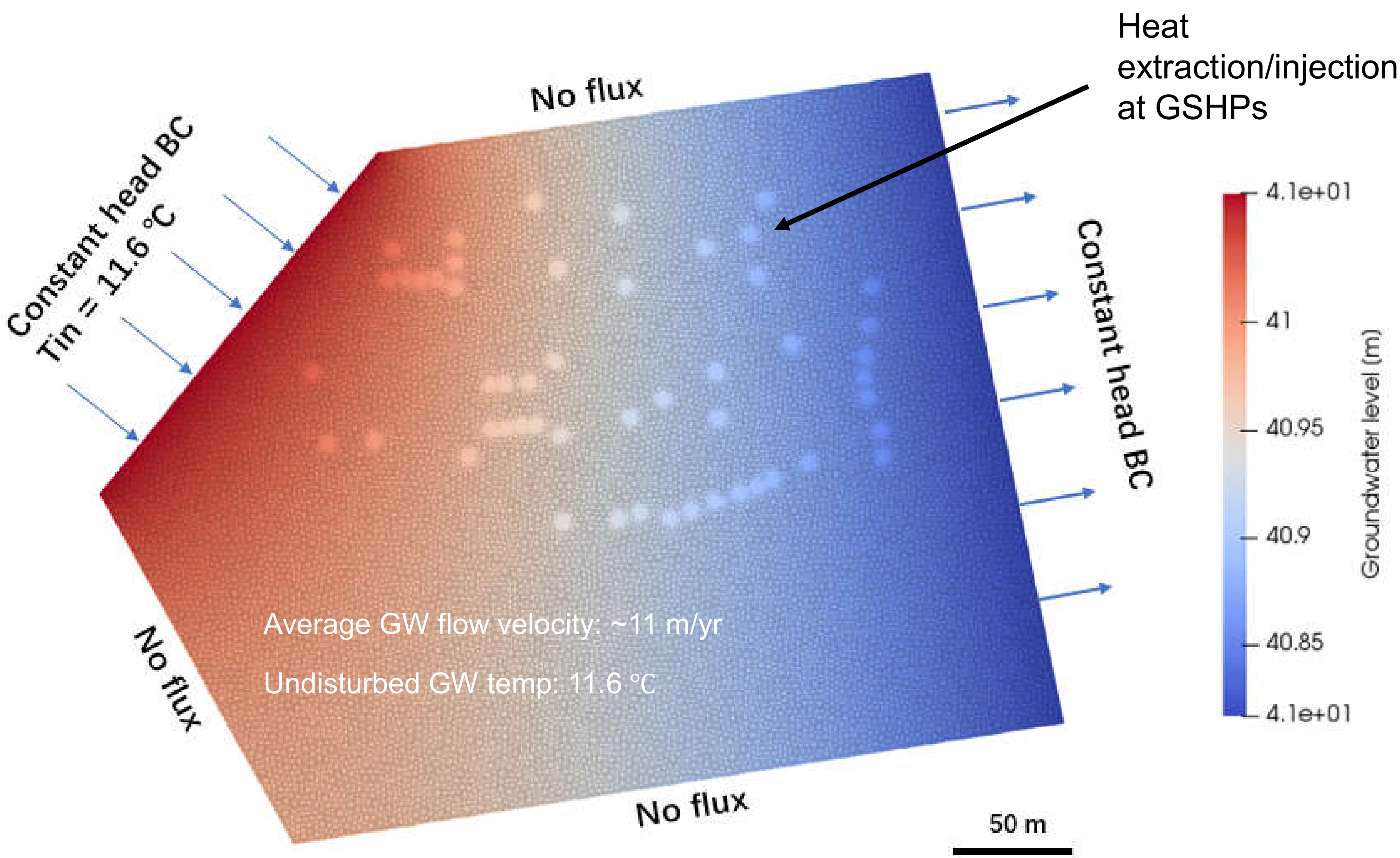


- 47x closed systems (borehole heat
  closest distance < 10 m
- Measurement of GW levels and tem
- Unsaturated flow, hydraulic gradient: 6×10^{-4} (±35%)

ENVIRONMENTAL RESEARCH – UFZ

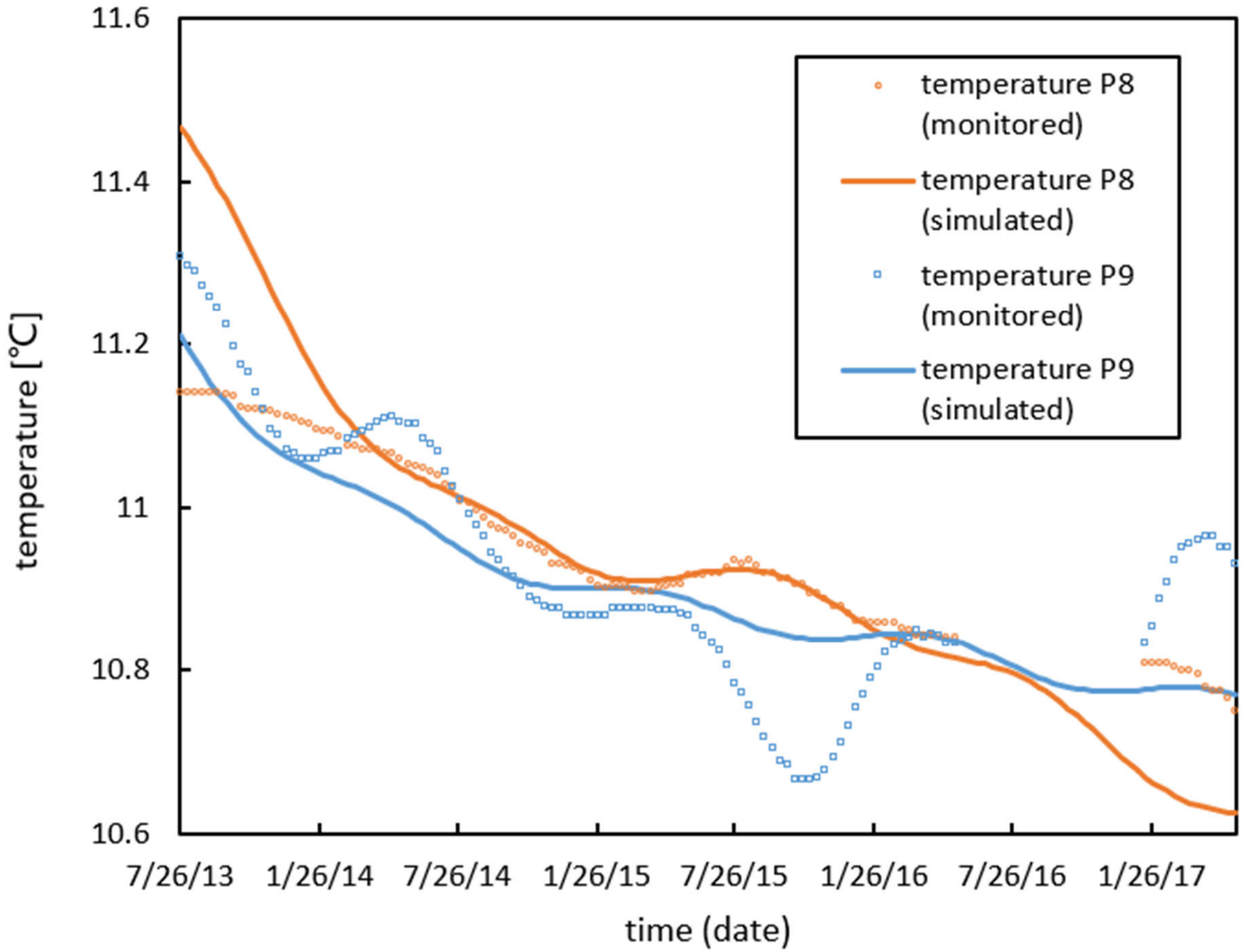
2D GW flow and heat transport model constructed with OpenGeoSys

- assuming fully-saturated flow → depth-averaged model
- finite element mesh, refined around GSHP nodes

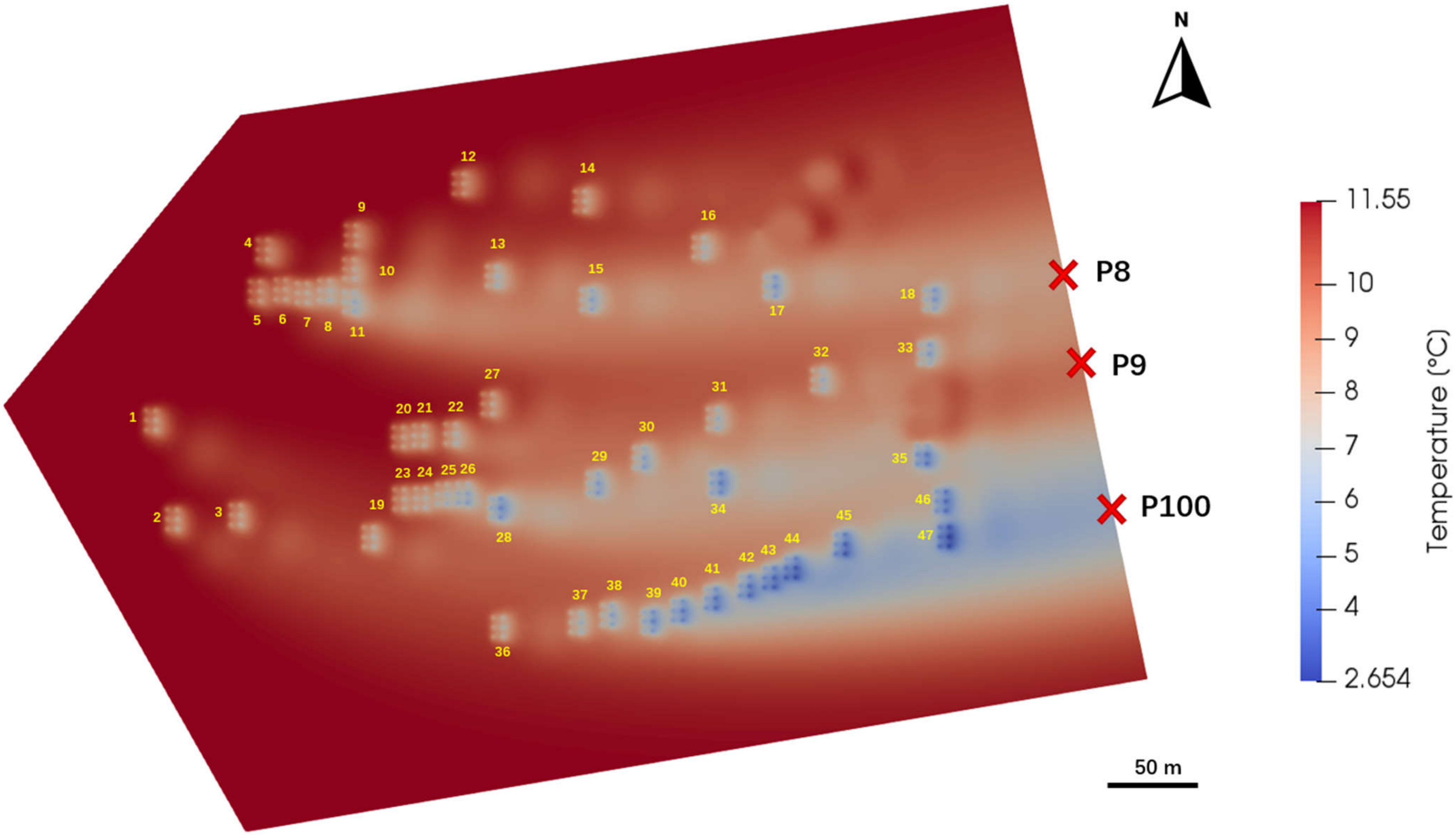


Steady state GW flow field

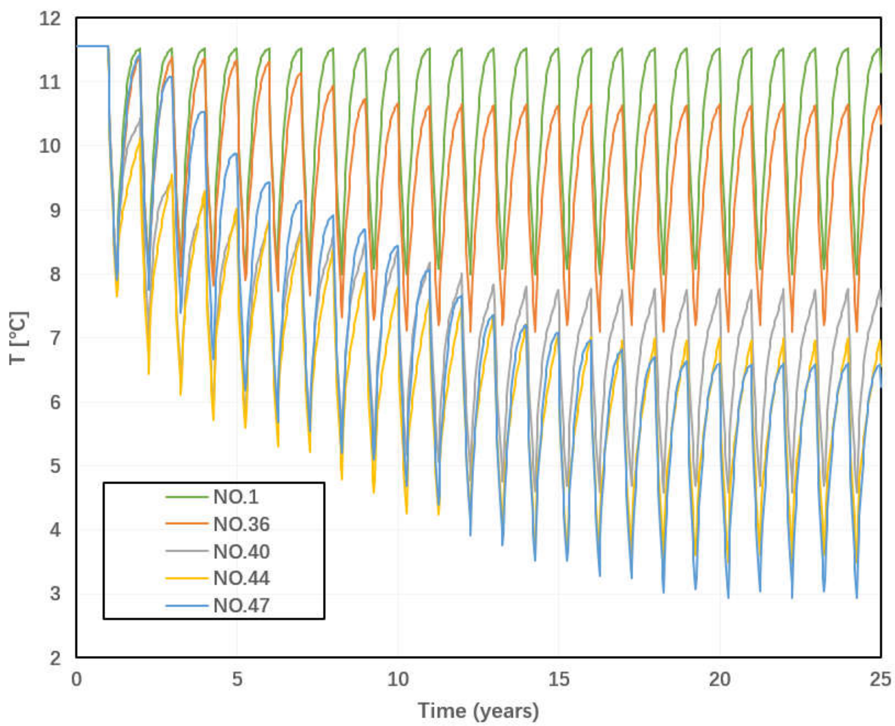
Calibration of the Numerical Model by Measurement Data

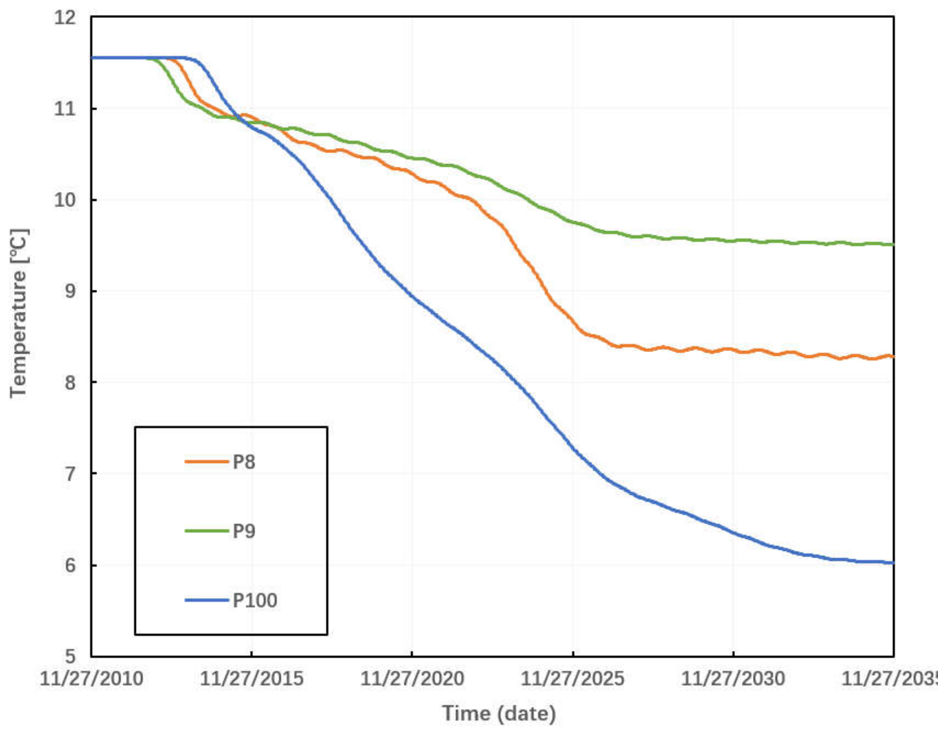


Long-term (25 years) Simulation Result on the GW Temperature Distribution



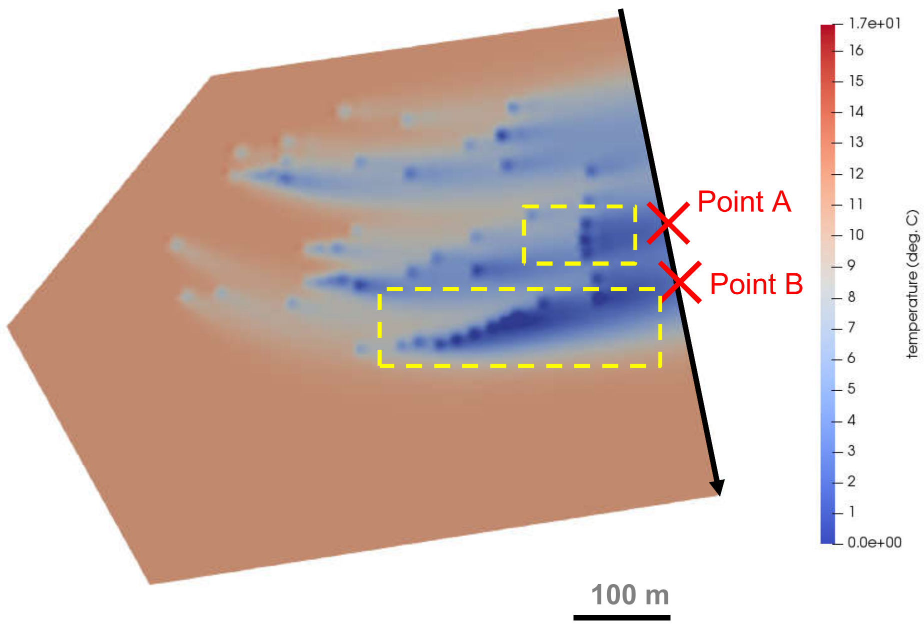
Will the GW temperature continue decreasing?
- Due to the dispersion effect, probably not.



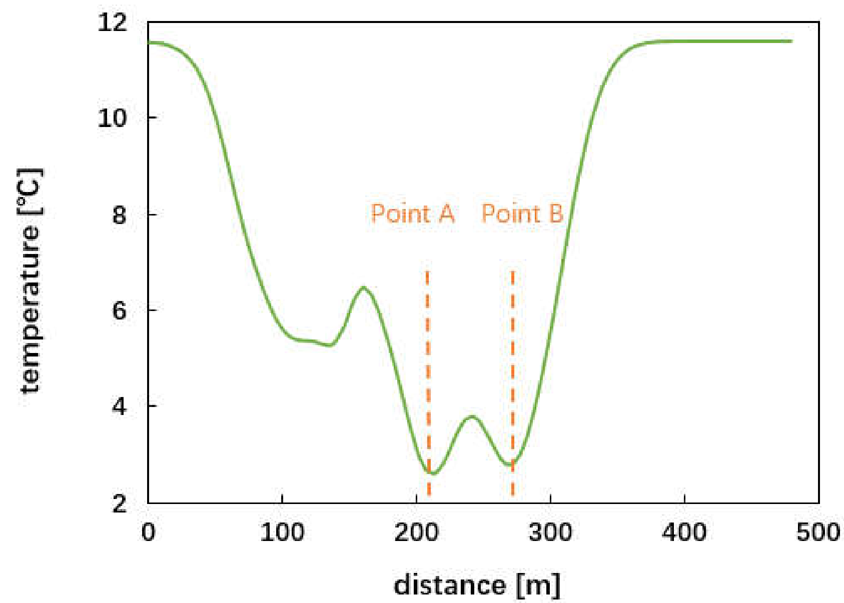


HELMHOLTZ
CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Impact of the low temperature zone produced by long-term operation



temperature distribution of the worst-case scenario at the beginning of the 26th heating season



two points with the lowest temperature on the outflow boundary

A series of GSHPs along the flow direction adds to downstream cooling!

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Summary

- What are the influencing factors for BHE efficiency?

  GW Flow, Specific Thermal Load, Soil Thermal Conductivity

- How much energy can be sustainably extracted from shallow subsurface?

  About 2-4 dC of equivalent Temperature Drop

- What will be the potential impacts on downstream groundwater temperatures?

  In general not much. In places where GSHP systems are lined along with the GW direction, this will cause lower efficiency.