Karlsruhe Institute of Technology

Sponsored by the Scholarship Programme of the DBU Deutsche Bundesstiftung Umwelt

Residential heating and cooling with Aquifer Thermal Energy Storage (ATES) on city scale

Ruben Stemmle[1],*, Haegyeong Lee[1], Philipp Blum[1], Kathrin Menberg[1]

[1]Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences (AGW), Karlsruhe, 76131, Germany

*Corresepondence: ruben.stemmle@kit.edu

1. Research goal

- Aquifer thermal energy storage (ATES) enables seasonal storage of thermal energy in groundwater.
- This study quantifies the technical potential of shallow Low-Temperature (LT-ATES) in the city of Freiburg im Breisgau, Germany by means of spatially distributed power density [W m^{-2}].
- Possible heating and cooling supply rates of ATES are calculated by comparing power densities with existing heating and cooling demands.

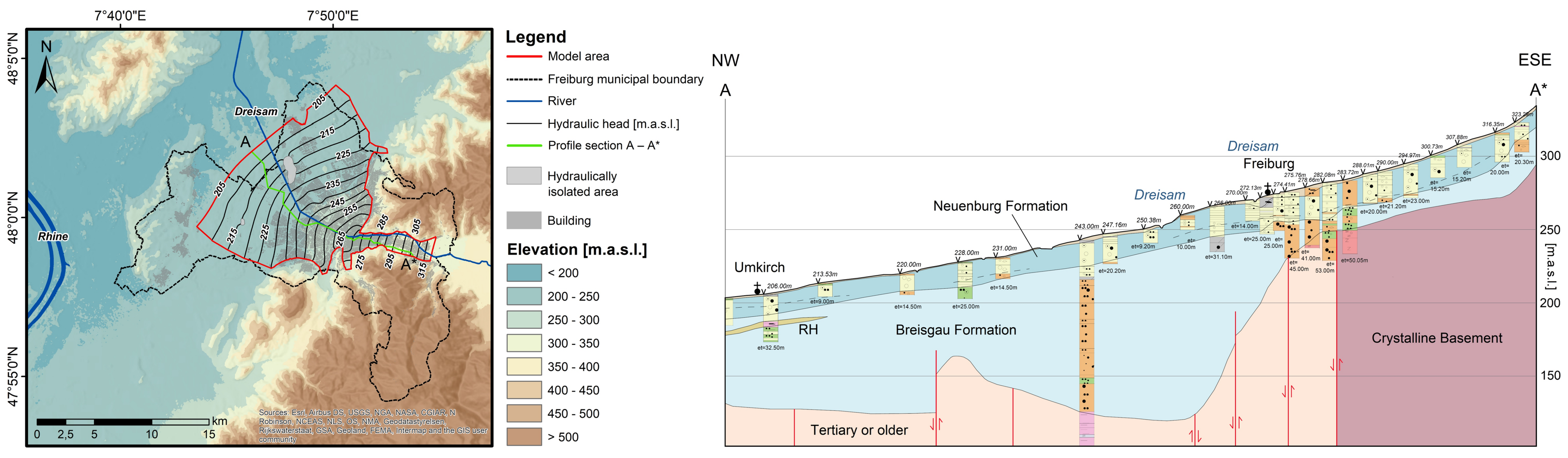


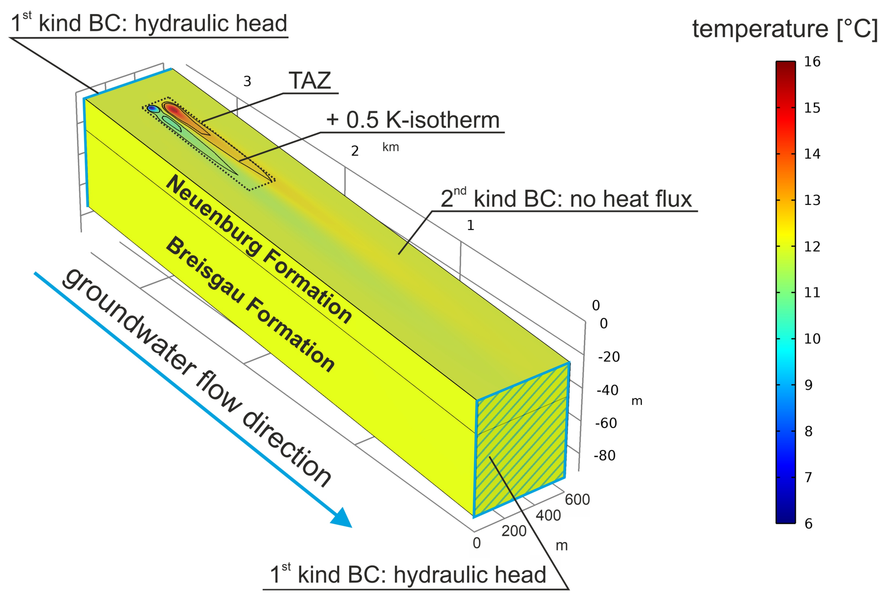
Fig. 1: Model area lcoated in the city of Freiburg im Breisgau: Map overview and profile section A – A* (modified from [1]).

2. Methods

- Simple and fast-to-compute 3D thermo-hydraulic numerical box models approximating the Freiburg subsurface conditions of three designated hydrogeological regions within the study area.
- Simulation of 1-, 2- and 3-doublet ATES systems dependent on groundwater flow in order to achieve highest thermal recoveries *TR*:

$$TR = \frac{E_{extr}}{E_{inj}} = \frac{\int_{extr\,start}^{extr\,end} \dot{V}_{extr} \cdot (T_{extr} - T_{amb})\,dt}{\int_{inj\,start}^{inj\,end} \dot{V}_{inj} \cdot (T_{inj} - T_{amb})\,dt}$$

- The power density relates the ATES heating and cooling power to the required horizontal Earth surface, i.e. the thermally affected zone TAZ (Fig. 2).



Simulated ATES operation:

- Pumping rate = 600 m^3 d^{-1}
- Injection temperature of warm water = 18 °C
- Injection tempeature of cold water = 6 °C
- 4 months heating and 4 months cooling per year
- Two 2-months pasive storage periods

Fig. 2: Exemplary box model of a 2-doublet ATES system in the Neuenburg Formation. The TAZ around the ± 0.5 K-isotherms after 30 years of operation is highlighted.

- Separate calculation of heating and cooling power densities *PD*:

$$PD_{heating} = \frac{\bar{P}_{heating} \cdot f_{ava}}{A_{TAZ} \cdot 0.5} \quad \text{with}$$

$$\bar{P}_{heating} = \dot{V}_{extr} \cdot \rho_f c_{p,f} \cdot [(T_{inj,warm} - T_{amb}) \cdot TR + (T_{amb} - T_{inj,cold})] \cdot \frac{COP}{COP - 1}$$

$$PD_{cooling} = \frac{\bar{P}_{cooling} \cdot f_{ava}}{A_{TAZ} \cdot 0.5} \quad \text{with}$$

$$\bar{P}_{cooling} = \dot{V}_{extr} \cdot \rho_f c_{p,f} \cdot [(T_{amb} - T_{inj,cold}) \cdot TR + (T_{inj,warm} - T_{amb})]$$

- Calculation of heating and cooling supply rates *SR* from power densities *PD* and energy demand *ED*:

$$SR = \frac{PD}{ED}$$

3. Results and discussion

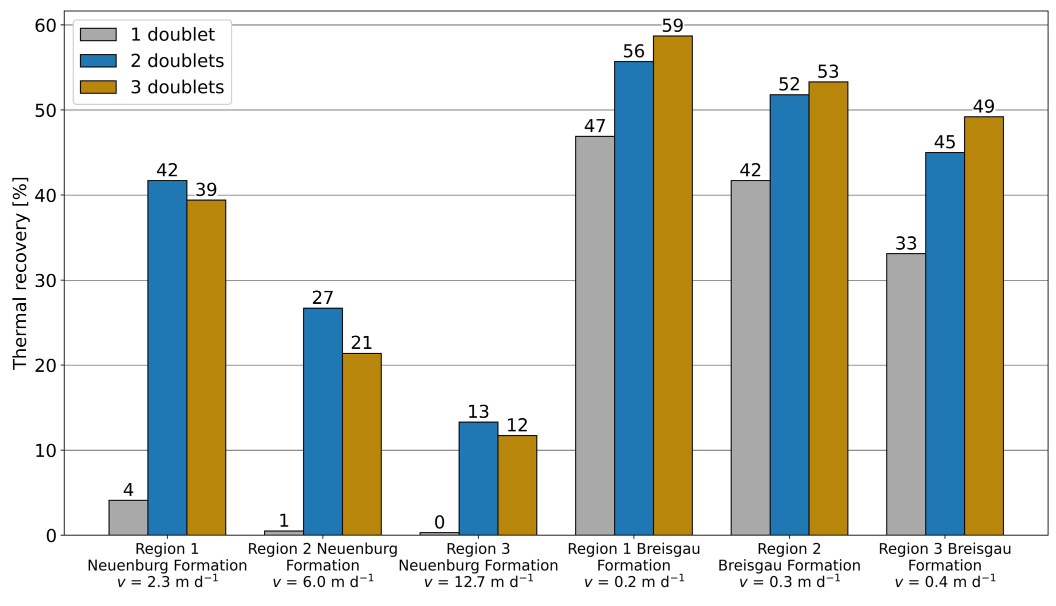


Fig. 3: Thermal recovery values for various ATES configurations in different groundwater flow regimes.

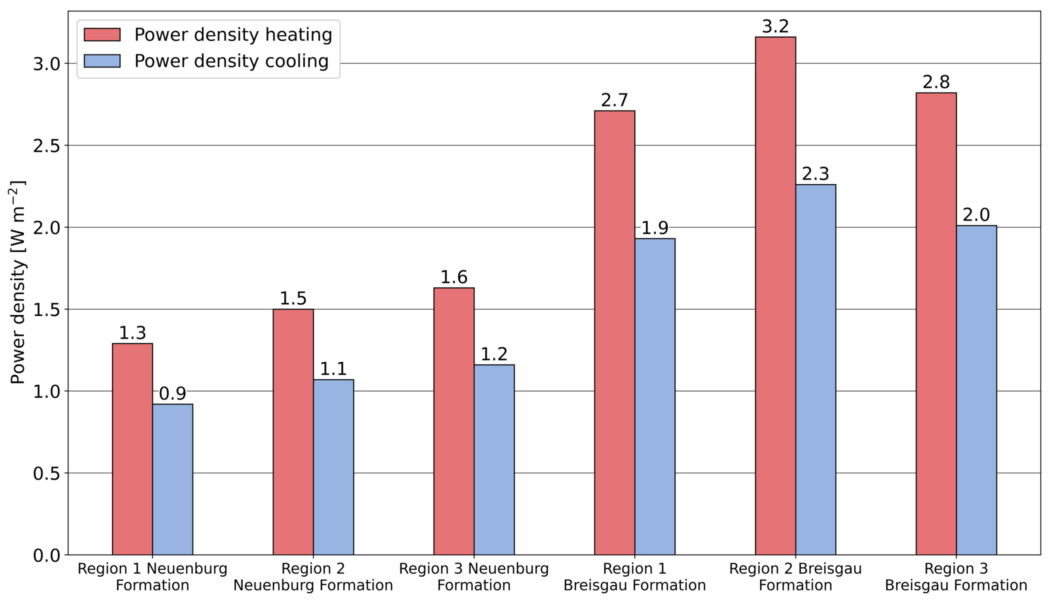


Fig. 4: ATES power densities for 2-doublet systems (Neuenburg Formation) and for 3-doublet systems (Breisgau Formation).

Thermal recoveries (Fig. 3) are consistently higher for ATES systems in the Breisgau Formation compared to systems in the Neuenburg Formation (Fig. 2). Accordingly, the highest ATES power densities (Fig. 4) are determined for 3-doublet systems in the Breisgau Formation. For these systems, Fig. 5 shows possible ATES supply rates of residential heating and cooling energy demands. The highest supply rates can be observed for suburban and commercial districts. Based on these supply rates, Fig. 6 shows possible greenhouse gas (GHG) emission savings calculated from a typical ATES heating emission factor and the current heating supply mix in Freiburg.

In this study, the ±0.5 K-isotherms are used for delineation of the TAZ (Fig. 2). This leads to lower, more conservative power densities than the smaller ±1 K-isotherms, which are more commonly used in previous, similar publications (e.g. [2,3,4]).

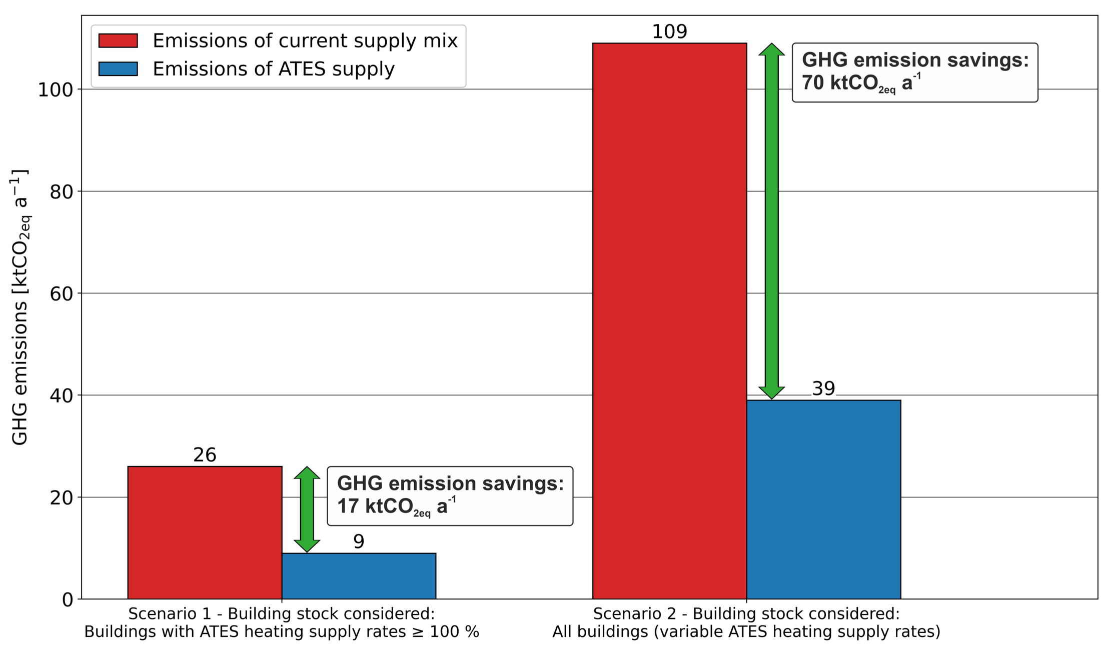


Fig. 6: Possible greenhouse gas (GHG) emission savings from ATES heating compared to the current heating energy mix in the city of Freiburg. Calculated for two scenarios based on data from [5,6].

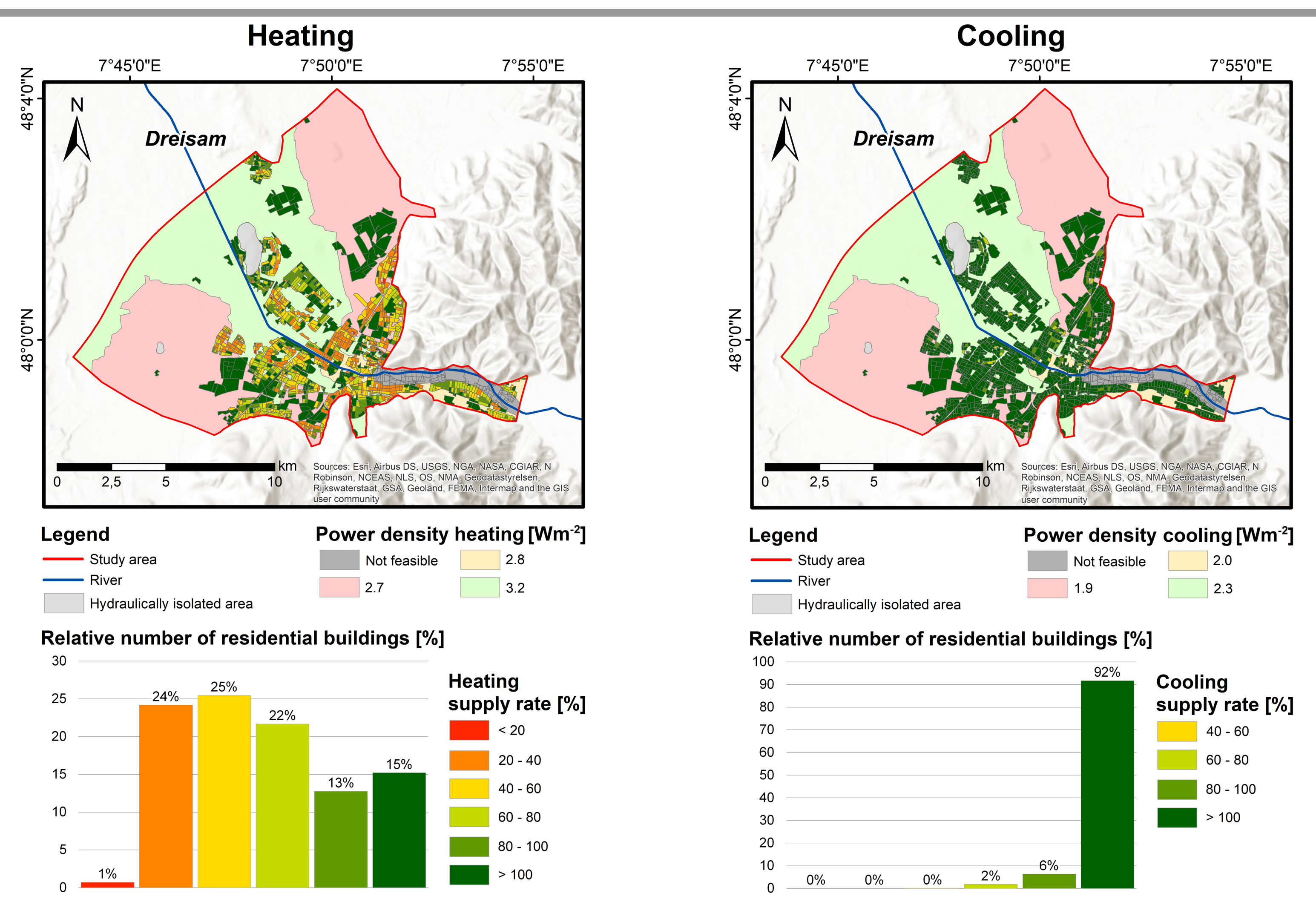


Fig. 5: ATES supply rates in the city of Freiburg for heating and cooling using the Breisgau Formation. The bar charts illustrate the share of the total residential buildings in each individual supply rate class.

4. Conclusion

- The technical potential of LT-ATES is quantified for the city of Freiburg by determining ATES power densities using numerical 3D heat transport models.
- Multi-doublet ATES designs reduce subsurface thermal energy storage loss.
- Thermal recoveries of up to 59 % can be obtained for ATES in the deeper aquifer with lower groundwater flow velocities.
- ATES power densities of up to 3.2 W m^{-2} are determined.
- Residential ATES heating supply rates of more than 60 % are determined for about 50 % of all buildings. 100 % ATES cooling supply is possible for 92 % of the buildings.
- GHG emission savings of up to 70,000 tCO_2eq a^{-1} resulting from ATES heating alone are estimated.

References

[1] Wirsing, G., Luz, A. (2005): Hydrogeologischer Bau und Aquifereigenschaften der Lockergesteine im Oberrheingraben (Baden-Württemberg). Regierungspräsidium Freiburg, Abteilung 9 Landesamt für Geologie, 775 Rohstoffe und Bergbau (LGRB), Freiburg i. Br.
[2] Gizzi, M., Taddia, G., Abdin, E. C., Lo Russo, S. (2020): Thermally Affected Zone (TAZ) Assessment in Open-Loop Low-Enthalpy Groundwater Heat Pump Systems (GWHPs): Potential of Analytical Solutions. Geofluids; 2020:1–13.
[3] Lo Russo, S., Taddia, G., Verda, V. (2012): Development of the thermally affected zone (TAZ) around a groundwater heat pump (GWHP) system: A sensitivity analysis. Geothermics; 43:66–74.
[4] Piga, B., Casasso, A., Pace, F., Godio, A., Sethi, R. (2017): Thermal Impact Assessment of Groundwater Heat Pumps (GWHPs): Rigorous vs. Simplified Models. Energies; 10:1385.
[5] GEF Ingenieur AG, ifeu - Institut für Energie- und Umweltforschung gGmbH, badenova-Gruppe (2021): Masterplan Wärme Freiburg 2030.
[6] Stemmle, R., Blum, P., Schüppler, S., Fleuchaus, P., Limoges, M., Bayer, P., Menberg, K. (2021): Environmental impacts of aquifer thermal energy storage (ATES). Renewable and Sustainable Energy Reviews; 151:111560.