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A case study on the intensive shallow geothermal usage in a German neighborhood

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Ground source heat pump (GSHP) systems has become a renewable technology to provide space heating and cooling. An evident trend is the intensive exploration of shallow geothermal heat within a limited area, e.g. residential quarters. In such context, thermal interaction among nearby installations is often expected, which leads to concerns about the subsurface environment and the system performance.

This talk presents a case study to evaluate the thermal impacts and predict the long-term sustainability of intensive geothermal use in a typical urban neighborhood in Germany. Within this site, 50 GSHPs have been applied since around 2008 and are operating mainly for heating. Site investigations and monitoring campaigns have been carried out, while an unsaturated groundwater flow has been confirmed. In addition, a declining trend of the groundwater temperature was detected in the downstream direction.

A 2D numerical model was built using the OpenGeoSys program to simulate the coupled groundwater flow and heat transport processes at the study site. In particular, the individual GSHP systems are represented as thermal/hydraulic source terms which become active during the operating seasons. In order to determine the key model parameters such as hydraulic conductivity, thermal conductivity and heat extraction rates, a calibration procedure was performed until the numerical model was able to reproduce the monitored groundwater temperatures with sufficient accuracy.

Following the model validation, a long-term prognosis of the induced thermal impacts and feedback on the energy efficiency was performed on a 24-year basis. The predictive results of subsurface temperature indicate limited thermal impacts as the minimum temperature will maintain above 3 ℃ and that the area undergone severe temperature drop is less than 1% size of the neighborhood. Based on the temperature predictions, the evolution of the Coefficient of Performance (COP) of the individual installations was extrapolated using a novel estimation approach. The results showed that the energy performance of all installations will be quite robust since seasonal COPs are at least 3.8. Nevertheless, it is worthwhile to note the exacerbated ground cooling near the downstream installations as well as the associated deterioration of their COP factors with time. As a consequence, downstream installations consume more power than the upstream ones, leading to a maximum 92 EUR difference in annual expenditure on electricity.

Furthermore, a sensitivity analysis on the effect of groundwater flow velocity was also performed in which a bandwidth of one order of magnitude was considered. The results revealed that the temperature distribution and the GSHP performance rely strongly on the groundwater flow regime depending on the geometrical layout of installations. Particularly, for the conduction-dominating scenario, the groundwater temperature reaches ~0 ℃ after eight years, which is unsustainable in the long run.

To conclude, this study demonstrates that intensive utilization of geothermal heat is generally sustainable in refurbished living quarters, provided that sufficient groundwater flow exists. As a prerequisite for the optimal planning of such projects, site-specific information on the groundwater flow direction and magnitude needs to be accounted for especially when allocating the GSHPs. In addition, site-wise parameterized models should be applied more to support optimized development and management.

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