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Using thermal recycling to optimise short-term high-temperature aquifer thermal energy storage for demand-side management applications

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Coupling electrically-driven heating, ventilation, and air-conditioning (HVAC) systems with thermal energy storage (TES) in building is seen as a promising tool for demand-side management (DSM) in the low-voltage grid, mainly thanks to the ability to decouple electricity and heating demand. So far, TES strategies consider the thermal envelope of a building or a water tank or both as buffers for thermostatically-controlled load-shifting. Thermal energy is then stored during off-peak periods and recovered during peak periods. With this study, we further assess and optimise aquifer thermal energy storage (ATES) to improve the overall energy efficiency of an open-loop geothermal system connected to a building and a smart-grid with a groundwater heat pump (GWHP). If we only consider space heating, two ATES strategies can be developed. The first one considers the preheating of the aquifer to improve the coefficient of performance of the overall system, which includes a GWHP. Such ATES system is known as a low-temperature (LT) one with a ΔT (difference of temperature between initial and heated groundwater) mainly ranging between 3 and 11 K. The second strategy considers a direct use of the stored heated water, using only a heat exchanger for space heating. Such ATES system is known as a high-temperature (HT) one and the main goal is to retrieve a minimal absolute groundwater temperature of 45°C (space heating systems operate at this temperature).

To assess and optimise such ATES strategies, we first conceptualised, constructed, and calibrated a 3D groundwater flow and heat transport model in FEFLOW that represents a typical productive shallow alluvial aquifer of Wallonia, Belgium, where ambient groundwater flow is slow (~12 m/year). This model was calibrated with PEST and the pilot points method with the help of data coming from an experimental design mimicking a 72 hours ATES cycle. A previous study demonstrated that single ATES cycles (at real time, intraday, and interday frequencies) already presented suitable energy recovery rates ranging between 78 and 87 % for LT-ATES, but only sufficient rates ranging between 53 and 71 % for HT-ATES. Obviously, higher energy recovery rates correspond to shorter storage periods. In terms of exergy, it was impossible to recover an absolute temperature of 45°C with a single ATES cycle, demonstrating the need for better control strategies.

With this study, we consider the joint use of thermal recycling and consecutive ATES cycles at typical DSM frequencies to improve both energy recovery rates and exergy for HT-ATES. The use of a production well close enough to the injection well favours thermal recycling and as a consequence, the local increase of groundwater temperature. Thanks to an adequate design of the well doublet, taking into account the local hydrogeological conditions, and thanks to adequate control strategies, a training phase of less than 10 weeks allows for an optimal exergy since groundwater can be maintained at 45°C and for energy recovery rates of at least 80 %. This study shows that considering ATES in shallow alluvial aquifers for DSM applications is feasible for both LT- and HT-ATES.