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Combined simulation-optimization of borehole heat exchanger fields

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Currently, far more than one million ground-source heat pump systems are installed in Europe for space heating of buildings. Most of these are single, closed, vertical systems, with borehole heat exchangers (BHEs) that penetrate shallow aquifers down to a depth of about 100-200 m. Multiple BHE fields that are implemented for large-scale geothermal energy supply of buildings or district heating systems are of increasing importance. In comparison to the straightforward design of single BHE systems, concerted operation of several BHEs is more challenging. Multiple adjacent BHEs can interact and affect each other. Large-scale, non-uniform thermal anomalies are potentially generated in the ground. Mutual interaction among BHEs could have an influence on the overall system's performance and therefore, should be either circumvented or integrated in the operation strategy. However, so far strategic tuning of energy extraction rates of the individual BHEs in space and time has not been considered in practice. In our presentation, a combined simulation-optimization approach is presented to regulate the individual operation of BHEs. The BHE field is simulated analytically, by temporally and spatially superimposed line source equations, as well as in more detail in numerical models. Both conditions with and without horizontal groundwater flow are studied. Groundwater flow means an additional advective energy supply, which is advantageous but also complicates apposite multiple BHE adjustment. The optimization task is formulated in an objective function to minimize the thermal impact in the ground, to avoid extreme temperature anomalies, and by this, enhance heat pump performance. We select linear programming to optimize the time-dependent loads in a computationally efficient way. Evolutionary algorithms are utilized when the BHE positions are adjusted. In different hypothetical applications with given seasonal changing load profiles and variable BHE configurations we show that either individual BHE heat extraction or position optimization is sufficient, and that only little improvement potential exists for joint optimization of both aspects. It is also demonstrated that groundwater flow direction and velocity has substantial influence on the identified ideal BHE operation patterns. Increase of groundwater flow velocity means more energy supply, and thus a better thermal recovery for given energy extraction rates. As a consequence, this mitigates the benefit from optimized BHE operation.