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Strategic optimization of large-scale vertical closed-loop shallow geothermal systems

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Vertical closed-loop geothermal systems or ground source heat pump (GSHP) systems with multiple vertical borehole heat exchangers (BHEs) are attractive technologies that provide heating and cooling to large facilities such as hotels, schools, big office buildings or district heating systems. Currently, the worldwide number of installed systems shows a recurrent increase. By running arrays of multiple BHEs, the energy demand of a given facility is fulfilled by exchanging heat with the ground. Due to practical and technical reasons, square arrays of the BHEs are commonly used and the total energy extraction from the subsurface is accomplished by an equal operation of each BHE. Moreover, standard designing practices disregard the presence of groundwater flow. We present a simulation-optimization approach that is able to regulate the individual operation of multiple BHEs, depending on the given hydro-geothermal conditions. The developed approach optimizes the overall performance of the geothermal system while mitigating the environmental impact. As an example, a synthetic case with a geothermal system using 25 BHEs for supplying a seasonal heating energy demand is defined. The optimization approach is evaluated for finding optimal energy extractions for 15 scenarios with different specific constant groundwater flow velocities. Ground temperature development is simulated using the optimal energy extractions and contrasted against standard application. It is demonstrated that optimized systems always level the ground temperature distribution and generate smaller subsurface temperature changes than non-optimized ones. Mean underground temperature changes within the studied BHE field are between 13% and 24% smaller when the optimized system is used. By applying the optimized energy extraction patterns, the temperature of the heat carrier fluid in the BHE, which controls the overall performance of the system, can also be raised by more than 1 °C.