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Numerical Analysis of Changes in Ground Temperature Caused by Ground Source Heat Pump System using HYDRUS

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Ground source heat pump systems (GSHP) that use ground or groundwater as a heat source can achieve much higher coefficient of performance (COP) than conventional air source heat pump systems because the temperature of the ground is generally much more stable than that of the air. Heat energy in the ground is then viewed as one of the renewable energy sources. GSHP has been receiving great interests among countries in North America and Western Europe, as well as some developed countries in Asia because it can potentially reduce energy consumption and greenhouse gas emission. While GSHP can inject heat from the buildings to the ground for cooling during the summer, it can pump heat stored in the ground for heating during the winter. Although it is rarely considered, installing too many GSHP systems nearby and/or running GSHP systems for long time may disturb the ground heat source. As some physical, chemical, and biological properties of the ground and groundwater are temperature dependent, this can eventually affect groundwater quality.

The effect of heat injection and pumping on the ground and groundwater temperatures therefore needs to be accurately quantified for assessing environmental impacts. Although there have been a number of studies predicting GSHP heat injection and pumping rates, their goals were usually to design optimum GSHP systems. The main objective of this study was to develop a model that allows predicting not only ground and groundwater temperatures but also changes in physical, chemical, and biological properties with GSHP under operation.

In this particular study, we used HYDRUS software to simulate heat exchange and transfer processes in the ground for a vertical-loop closed GSHP system. HYDRUS allows one to simulate variably-saturated water flow and solute and heat transport in porous media numerically in two- and three-dimensional domains with great flexibility in defining boundary conditions. At first, for model verification, changes in ground temperatures measured at every 5-m in the 50-m observation well installed 3.7 m from the 50-m long heat exchange boreholes, in which polyethylene heat exchanger tubes had been installed, were predicted in response to Thermal Response Test (TRT) conducted at our study site. Then, heat exchange and transfer processes for the vertical closed-loop GSHP systems were simulated to predict changes in ground and groundwater temperatures using three-dimensional domains. In this simulation, inside the polyethylene heat exchanger tube and the tube itself were assumed to be porous media. Very high hydraulic conductivity was assigned to the former, while very low hydraulic conductivity was assigned for the latter so that there would be only negligible water exchange between the ground and the heat exchange tube. This study demonstrated that HYDRUS was a very effective tool to assess the environmental impact, especially the temperature changes, when GSHP systems were used for injecting heat to the ground and pumping heat from the ground.