Impact factors on the long-term economic efficiency and environmental sustainability of borehole heat exchanger systems for the use of shallow geothermal resources

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In recent years, Borehole Heat Exchanger (BHE) based Ground Source Heat Pump (GSHP) systems have been increasingly applied around the globe, providing heating and cooling to buildings. Some GSHP systems are experiencing a gradual decrease of BHE outflow temperatures and thus finally be shut down due to low temperature protection. In this work, a comprehensive numerical model was established, to quantitatively prognoses the flow and heat transport processes in and around a BHE, together with the dynamic change of heat pump efficiency. Model parameters, including the local geothermal gradient, soil temperature and surface weather conditions were adopted for simulation over 30 years. It is found that the recovery of subsurface temperature only accounts for about 89% of the energy extracted after the first year of operation. Yet, over the following years, the outflow and soil temperature will gradually drop until reaching a quasi-steady-state. Because of a stronger thermal gradient around the BHE, more thermal energy will be conducted from the neighboring soil and balances the amount of energy extracted. It is also found that lateral groundwater flow and applying BHE for cooling will be beneficial to the recovery process, along with the efficiency improvement of the heat pump. Among all influencing parameters, the soil heat capacity and thermal conductivity are considered to have minor impact on the long-term sustainability, while the application of thermally enhanced grout material will always be financially beneficiary. In contrast, it is very likely that undersized systems and improper grouting are the causes of strong system degradation. Therefore it is especially important to consider soil thermal conductivity as a key parameter for the determination of BHE installation length. Hence, a detailed knowledge about the geological subsurface and hydrogeological regime can greatly contribute towards a sustainable intensive thermal use of the shallow subsurface.