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Non stationary combination for the simulation of time-varying flow rates in closed-loop ground heat exchangers

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Ground source heat pump systems are among the most energy-efficient heating and cooling technologies. Their performance is strongly related to the accuracy of the ground heat exchanger sizing, hence requiring the forecast of the system's temperature evolution in response to the anticipated thermal loads. Through this process, simulation techniques that make use of the superposition principle are commonly used to reduce the computational burden. In their current state, these techniques are however only suitable for addressing linear and stationary problems and do not apply to fundamental non stationary situations related to ground source heat pumps operation that involve time-variant parameters.

The present work addresses this issue by introducing a novel method based on the principle of superposition that tackles the fast evaluation of the temperature of a closed-loop ground heat exchanger operating with a dynamic heat load as well as time-variant circulation flow rates. The developed method relies on the non stationary combination, a technique borrowed from the field of seismic data processing. This technique achieves discontinuous transitions of convolution products that can be smoothened near transition times by realizing a linear interpolation over the duration of the fluid residence time.

The accuracy and efficiency of the proposed method are verified by comparing its results with those provided by reference 3D finite-elements models developed in the Comsol Multiphysics environment. For this purpose, comparative simulations representing the non stationary operation of a closed-loop system having time-variant circulation flow rates are conducted. The case of a single well is first investigated, followed by a borefield of eight wells to demonstrate the validity of the method in both scenarios.

Findings indicate that the proposed method can reproduce the reference results with a mean absolute error that is lower than 0.02 °C, and that it is faster than the numerical models by several orders of magnitude. These findings suggest that a broader range of operating scenarios can be handled by highly efficient simulation tools based on the superposition principle, which could foster the development of optimal operating strategies and lead to enhanced overall performances of ground source heat pump systems.