Analysis of impact of heat extraction from soil with low thermal conductivity

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Abstract

The impact of thermal energy extraction from closed-loop borehole heat exchangers on the long-term temperature response in a soil with low thermal conductivity is examined through numerical simulation. In- and outlet temperatures from the borehole heat exchangers, recorded during the first three years of operation, form the basis for calibrating a finite element model of the heat exchange process. The calibrated model was used to predict the minimum temperature in the borehole after 10 years of operation. Initial simulation indicates that the borehole temperature decreases with 4 °C over the course of ten years signifying a lack of thermal regeneration during the summer months.

This study investigates the effect of long-term heat extraction on ground temperature in a clayey soil with low thermal conductivity. The study is based on a ground source heat pump (GSHP) system at a single family house located in Glud, Denmark. The GSHP system consists of two vertical closed-loop borehole heat exchangers (BHE) that stand approximately 22 m apart. Each BHE is 100 m deep and is installed with a single U-tube.

The GSHP system has since June 2011 supplied the house with space heating and domestic hot water. A monitor and data logging system was installed to monitor the operation of the system. It records the flow together with the in- and outlet temperature of the refrigerant in the BHEs, the electricity consumption of the GSHP system, and the amount of heat generated by the heat pump. The measurements are recorded at 10 minutes intervals.

The geological and hydrogeological conditions at the site are characterised by lean to fat clay with negligible groundwater flow. The clay's thermal conductivity was estimated to be 1.4 W/m/K on the basis of a thermal response test (TRT). The soil's low thermal conductivity limits the rate of heat transfer in the ground. As a result, the ground temperature is slow to recover after a period of heat extraction, which means that the temperature may not be fully regenerated to its initial state during the summer seasons. The result is a significant temperature decrease in the vicinity of the BHEs that in the long-term may deteriorate the performance of the BHEs. The extent of the temperature decrease is examined by simulating the heat exchange process between the two BHEs and the ground using the finite element code FEFLOW. The BHEs are modelled as one-dimensional line elements within a three-dimensional finite element mesh representing the ground.

The model domain is assigned a constant temperature boundary at the top with a temperature of 8.4 °C, which is the annual mean temperature in the coastal areas of Denmark. At the model base a constant heat flux boundary condition is specified with a heat flux of 35 mW/m^2. An initial temperature field was assigned to the model domain. This background temperature was defined on the basis of undisturbed ground temperature measurements conducted in May 2011.

The daily power extraction for the first three years is calculated on the basis of the recorded measurements using the following equation:

$$H = \sum_{i=1}^{144} (T_{i\,out} - t_{i\,in}) \times \rho_r c_r \times Q_{i\,r} \times \Delta t_i$$

where H is heat energy extracted [J] per day, $(T_{i\,out} - t_{i\,in})$ is the temperature difference [K] as the refrigerant enters (inlet) and exits (outlet) the heat pump, $\rho_r c_r$ is the volumetric heat capacity [J/m^3/K], Q_r is the flow [m^3/s] of the refrigerant, and Δt is the time interval of the recorded measurements [s].

Time series of the daily power extraction [MJ/d] and the average flow of the circulating refrigerant [m^3/d] are used as input data. The daily power extraction is estimated for the first *c*. 8 months of operation, as no measurements were recorded during this period because of technical problems with the data acquisition system.

The simulation time is set to 1123 days corresponding to the first three years of operation. Calibration of the model is performed by comparing the simulated inlet and outlet temperatures with measured values. The resultant simulation is validated by comparing the computed ground temperature with ground temperature measurements assembled during the summer 2014.

The calibrated and validated model is then used to predict the minimum temperature in the borehole after 10 years of operation. Initial simulation indicates that the borehole temperature drops 1°C within the first 3 years of operation. It drops additionally *c*. 3°C after ten years of operation, which suggests that the ground temperature does not fully regenerate during the summer seasons.

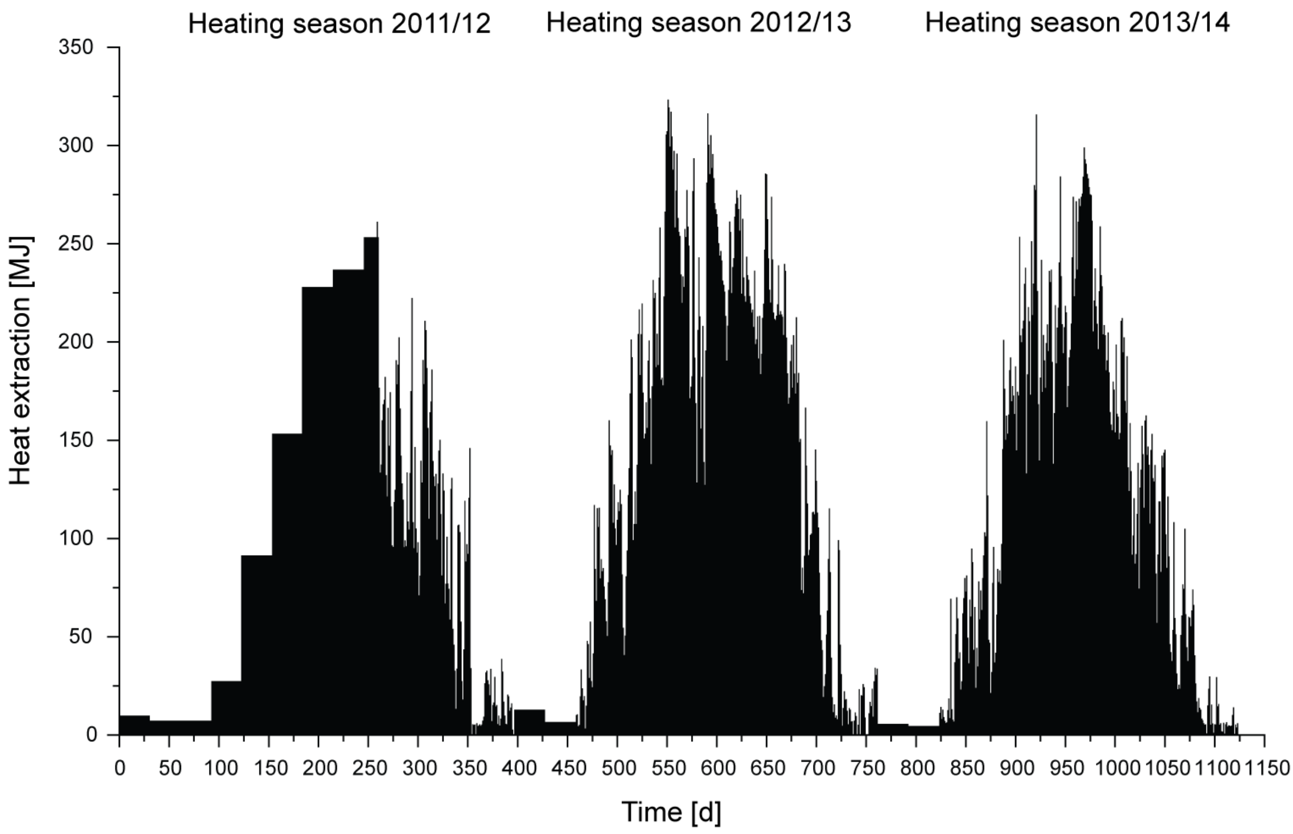

Figure 1. The calculated heat extraction from the ground during the first three years of operation. The first 8 months of heat extraction is estimated.