NUMERICAL SIMULATION OF THERMAL ENERGY STORAGE IN UNDERGROUND SOIL HEAT ACCUMULATOR

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Abstract

The alternative energy sources have been getting popular for last decades as a new way to obtain enough energy especially for countries which do not have rich natural reservoirs of fossil fuels. Gathering the thermal energy from the solar radiation seems to be as one of the cheapest alternatives of them. The disadvantage of it is the overflow of the heat energy during the summer and lack of them during the winter, when the demand for heat is on top. The underground thermal energy storage can be a good alternative for accumulating the heat energy and then offers it on demand. However, it is difficult to monitor the real physical condition in the soil. In the article, the results of numerical simulation are shown as a good way for a better identification of the process of accumulating the energy to the soil material.

Keywords:

Sub-surface heat accumulation;
Solar heat storage;
Soil mass thermal capacity;
Ground heat.

1. Introduction

The Sun is an unlimited energy source and harnessing of solar radiation is widely supported by government bodies in many countries across the world. Especially, solar thermal wavelengths have been used for practical solutions for years to get alternatives for common heating systems. Even though, the principle of collection of this type of energy is very simple, there are many difficulties to store the gained heat. Using a huge water tank for this purpose means that the final system is very expensive. The natural soil mass that surrounds each house and is pay-free seems to be a good alternative to water tank. The idea to create a cheap thermal energy storage system using ground mass is not brand new and these accumulation systems are successfully used in many countries (ISOMAX, Drake Landing Solar Community, Canada) [4], [5]. The efficiency also depends on the way, how the heat can be distributed throughout the borehole exchangers to the surrounding soil. Measuring of temperature combined with numerical simulation is a good way to identify this process. [1], [2], [3].

2. Description of the numerical model

A body of ground with the dimensions of 10 m x 10 m and depth of 5 m was defined to analyze the way how the thermal energy is distributed throughout the soil. Nine boreholes stretched to the depth of 2.5 m with 20 m^2 total contact area with surrounding soil are used to transfer heat from solar system to the ground via liquid medium (Fig.1). The soil accumulation volume is thermally insulated on top and sides only.
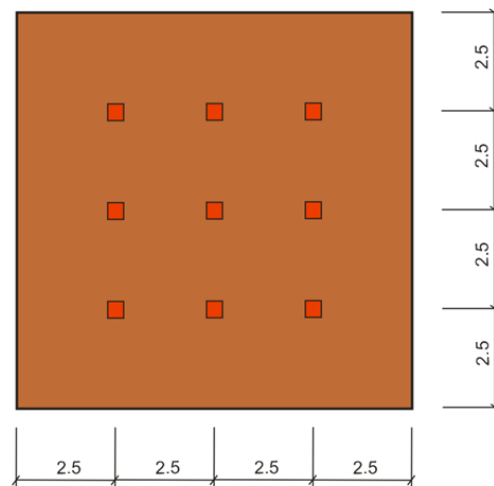
Fig. 1: Boreholes distribution.

The 3D hexahedral conduction elements are used to create FEM model, which can be degenerated into prismatic or tetrahedral elements by collapsing a face, or a face and edge respectively. The element matrices are integrated numerically by Gauss integration with orders of 2 in each local coordinate direction.

Material characteristics of the soil are defined by the thermal capacity of $c = 920$ J kg^{-1} K^{-1}, thermal conductivity of $\lambda = 0.7$ Wm^{-1}K^{-1} and the density is $\rho = 1800$ kg.m^{-3}. The theoretical capacity of the soil storage system is 138 kWh°C^{-1}, if the active height is 3 m.

The solar system is designed for the conditions in central Europe, where an average solar radiation is expected to be 1680 Wm^{-2} per day. The designed area of the solar collector is 20 m^{2} and the efficiency of collecting and transporting of the heat energy is assumed to only 50 percent. The intensity of heat flux per second is defined for a square meter as a loading for contact area between the surrounded soil and boreholes exchangers. The change of intensity of heat flux is shown in the Fig. 2.
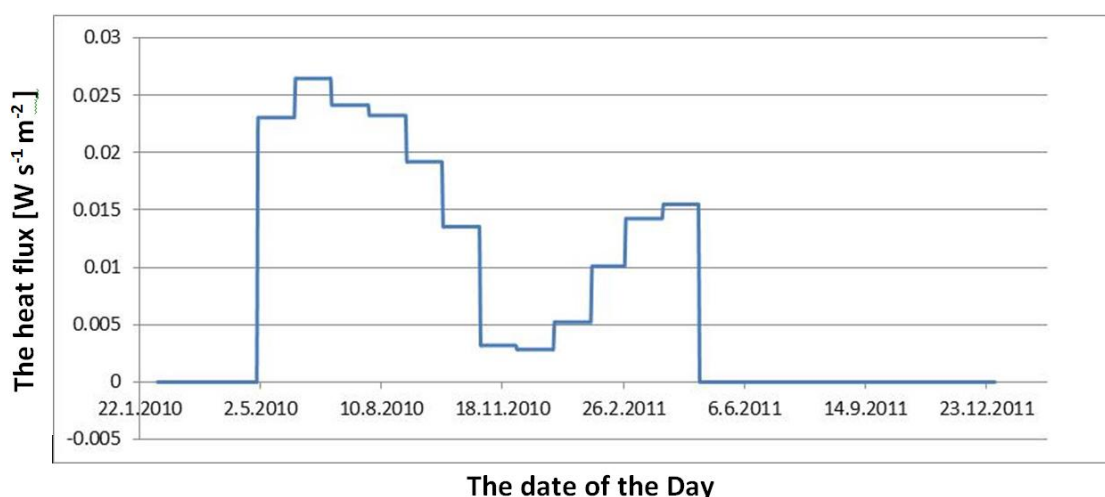

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Fig. 2: The heat flux loading defined for boreholes contact surface.

The boundary temperature along the top of an accumulator is 18 ^{0}C to simulate the placement of this accumulator beneath a house. The temperature defined at the edge of the soil simulates the real conditions reflecting the changes of open air temperature during the year. The boundary temperature also depends on depth. The real measured data was used for simulation (Fig.3).

The simulation starts in January with zero temperature in the whole modeled space. The beginning of the storage of the thermal energy starts in May. The time between January and May is defined for consolidation of the temperature distribution throughout the soil. Then, the charging of the system starts and continues till September. The whole simulation finishes in March of the following year, because the information about remaining temperature distribution is also important.
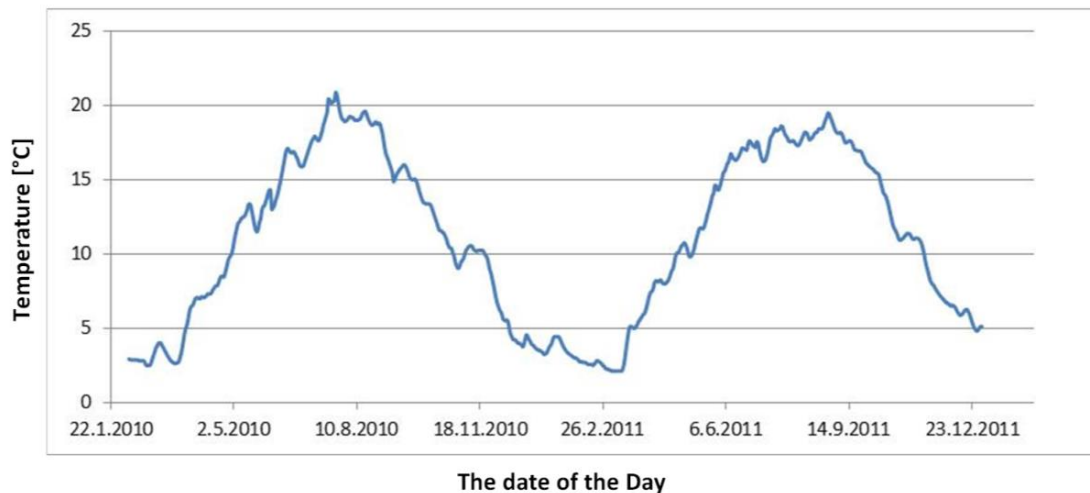

Fig. 3: The change of temperature in the 0.75 m deep soil under the surface per year.

3. Evaluation of results

The temperature distribution over the whole space is used to obtain results for comparison of changes between the state at the beginning of collection of thermal heat and at the end (Figs. 4, 5, 6). At the beginning, the maximum temperature is 18 °C. At the end of heat charging in September, the maximum temperature reaches 75 °C.
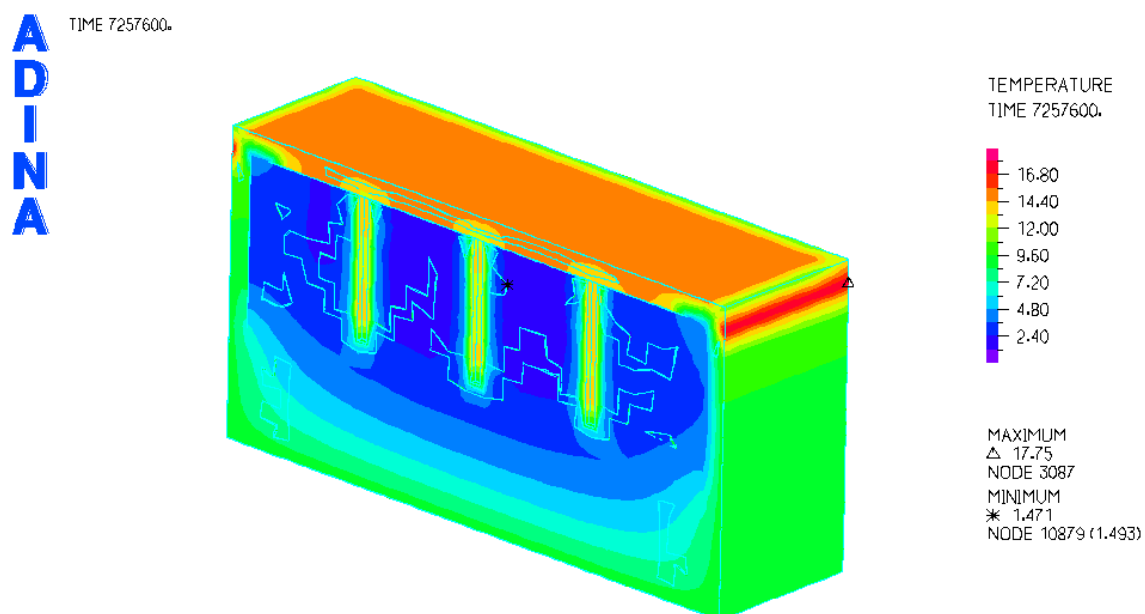

Fig. 4: The beginning of the collection of the solar thermal energy in May.
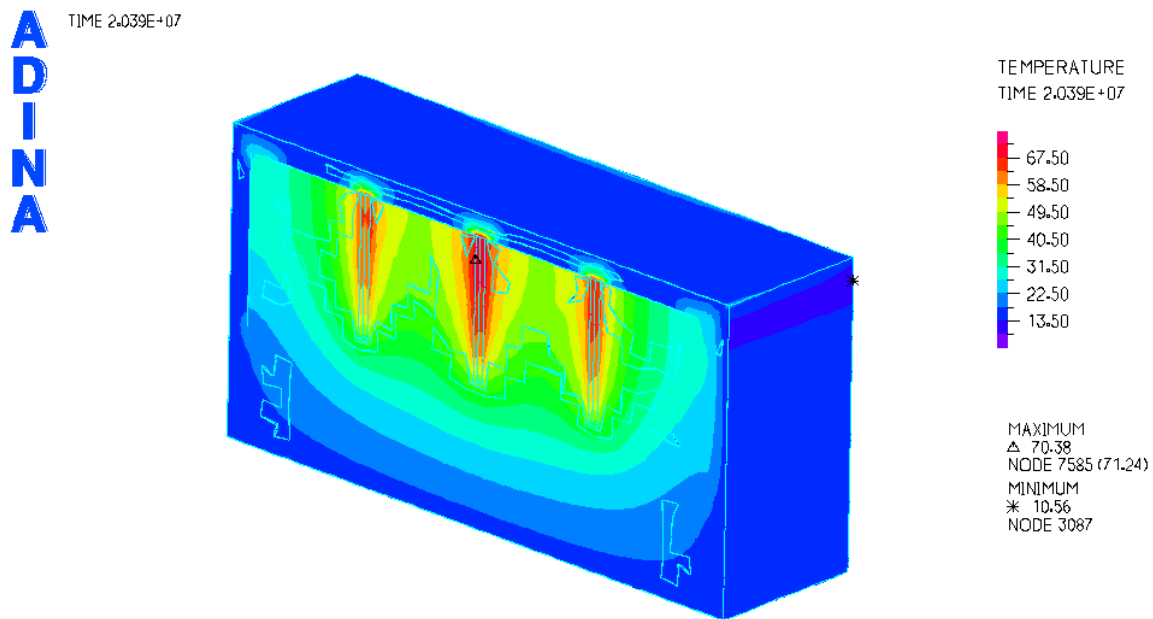
Fig. 5: The end of the collection of the solar thermal energy in September.

The average temperature in the system is 35 °C in January. It means that there is approximately 1380 kWh stored in the form of heat if the low temperature of 20 °C is expected as the boundary for the effective usage of the system.
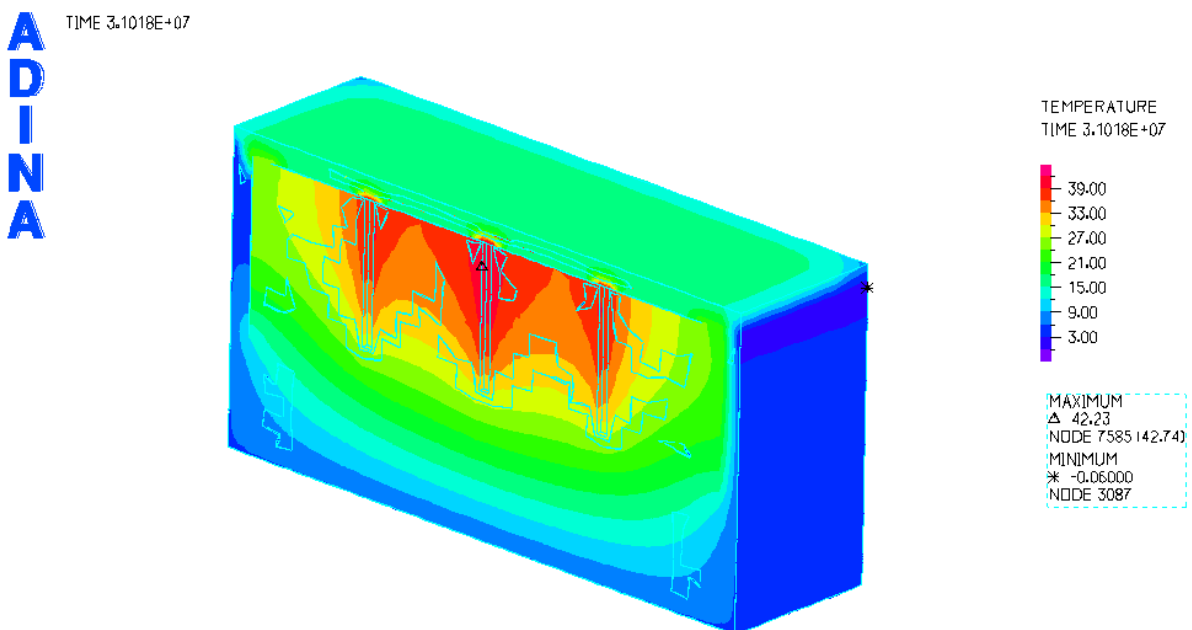

Fig. 6: The final state of the soil heat exchanger in the middle of winter season in January.

4. Conclusions

The results of the numerical simulation showed that the major part of collecting of thermal energy was successfully stored in the underground soil heat exchanger. The location of the nine boreholes seems to be good for equally distributed temperature across the modeled space.

Acknowledgement

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