

Operation analysis of a spiral ground heat exchanger functioning as a lower heat source in a pressurizing heat pump

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Abstract. The main aim of the study is to identify functioning of a ground, spiral heat exchanger co-functioning with a pressurizing heat pump. The heat pump is connected with a heat battery and works periodically during the heating period. The analysis was made by means of numerical modelling and using the finite element method.

1 Introduction

A common solution for lower heat source in low-power, pressurizing heat pump installations are horizontal, ground heat exchangers. Horizontal exchangers are usually installed at the depth of 1.5-1.6 metre in relation to the ground level. The main limitations connected with using such solutions are:

- the efficiency is strongly dependant on the degree of base ground moisture;
 - there is strong influence of atmospheric air temperature on the efficiency of a ground heat exchanger;
 - large ground area is required in order to provide appropriate efficiency of the exchanger;
 - there is a possibility of freezing the ground surface layers, which leads to hindering plant vegetation;
 - high investment costs connected with laying pipes of the exchanger in the ground.
- The so-called spiral ground heat exchangers are free from these disadvantages.

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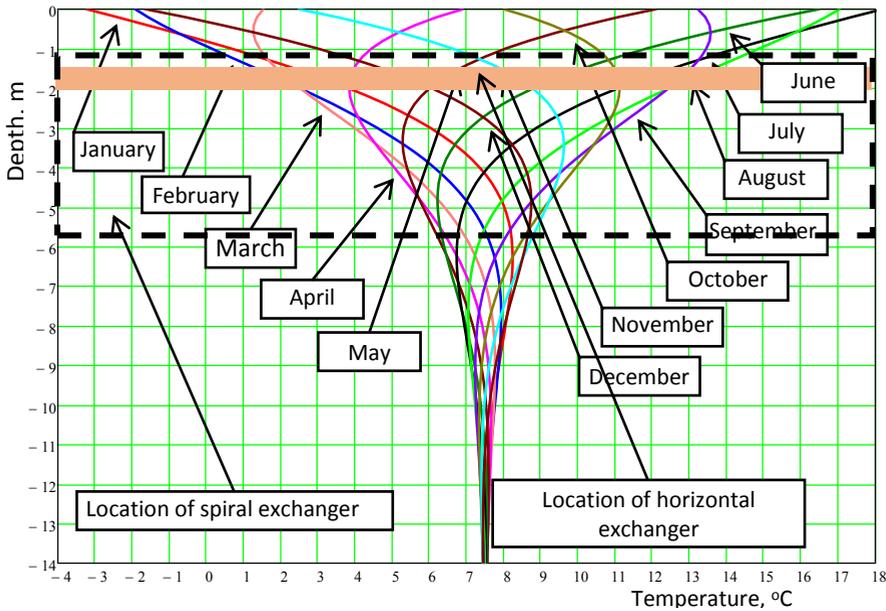


Fig. 1. Ground temperature distribution.

Figure 1 shows temperature distribution in ground for particular months. The closer to the surface the higher amplitudes of temperature changes in the ground can be observed. It is the effect of temperature wave penetrating the ground, which results from seasonal changes of atmospheric temperature. In the case of a spiral exchanger, which is installed at the depth of 1.8-5.5 m beneath the ground level, one can observe a significantly lower amplitude of temperature change than in the case of a horizontal exchanger. This enables to provide much more stable working conditions of a spiral exchanger during whole year and its smaller influence on temperature in the area just below the ground surface. It has significant influence on plant vegetation. Apart from that, in deeper parts grounds have lower moisture, which has positive impact on heat transfer from the ground to the working medium in the ground heat exchanger [6, 8].

2 Model

In order to conduct the analysis of a ground heat exchanger in the conditions of non-determined heat exchange, the measurement data were approximated to average monthly temperature of atmospheric air on the basis of many-year meteorological research of Rzeszów [10], Table 1, by using Hillel's model, fig. 2:

$$T(x, t) = T_a + A_o \cdot \exp \left[-\frac{(x+x_{gr})}{d} \right] \cdot \sin \left[\frac{2 \cdot \pi \cdot (t-t_o)}{d} - \frac{(x+x_{gr})}{d} - \frac{\pi}{2} \right] \quad (1)$$

where:

x -depth, m

$$x_{gr} = \frac{k_{gr}}{h}$$

k_{gr} - coefficient of ground conductance , W/mK,

h -heat transfer coefficient, W/m²K,

$d = \sqrt{\frac{2 \cdot D_{gr}}{\omega}}$ – penetration depth,
 D_{gr} - ground thermal diffusivity, m²/day
 $\omega = \frac{2 \cdot \pi}{T}$
 $T=365$ days,
 t - time, h
 t_o - phase shift, h
 A_o - amplitude, K

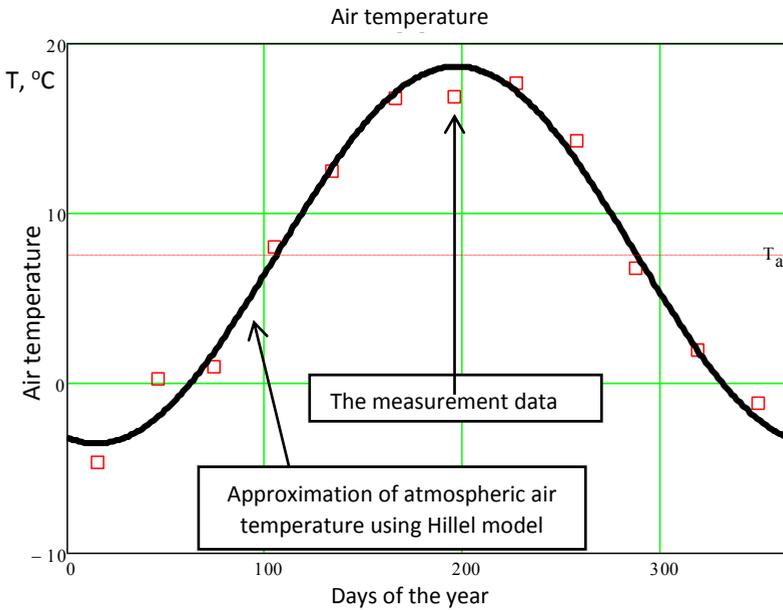


Fig. 2. Approximation of atmospheric air temperature.

The amplitude of atmospheric air was determined on the basis of meteorological data [10]. Constant values of specific heat, density and ground conductance coefficients were assumed for the analysis of lower heat source operation. Boundary conditions at the ground surface were also determined on the basis with Hillel’s model, assuming the coefficient of atmospheric air transfer of 16 W/m²K.

Table 1. Meteo data for Rzeszów [10].

Month	Average monthly temperature of external air, °C
1	-4.6
2	0.3
3	1
4	8
5	12.5
6	16.8
7	16.9
8	17.7
9	14.3
10	6.8
11	2
12	-1.2

Table 2. Thermal properties of ground.

Ground heat transfer, W/mK	Ground density, kg/m ³	Specific heat, J/kgK
1.5	1742	1175

The data for December were assumed as an initial condition for numerical calculations. On this basis, as well as by using Hillel’s model, the initial profile of temperature in ground was determined, fig. 3.

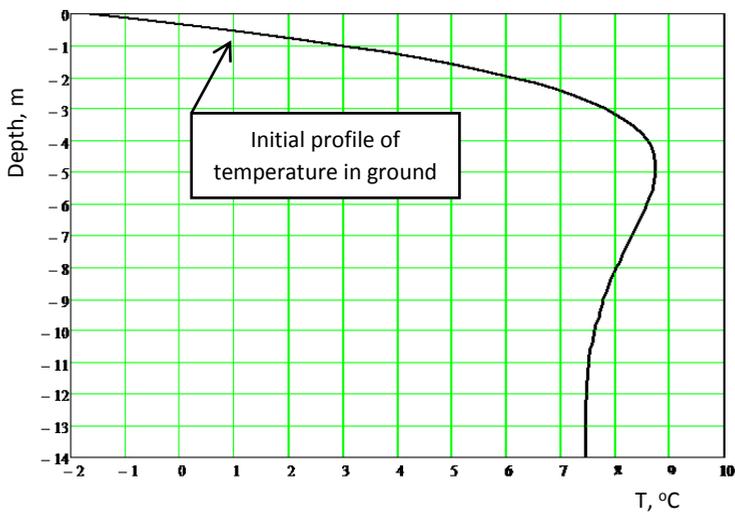


Fig. 3. Ground temperature profile for December.

The calculation model consisted of two spiral coils placed in the ground. The calculation domain was the ground area together with the exchanger, the dimensions of which were 15 m x 24 m x 14 m.

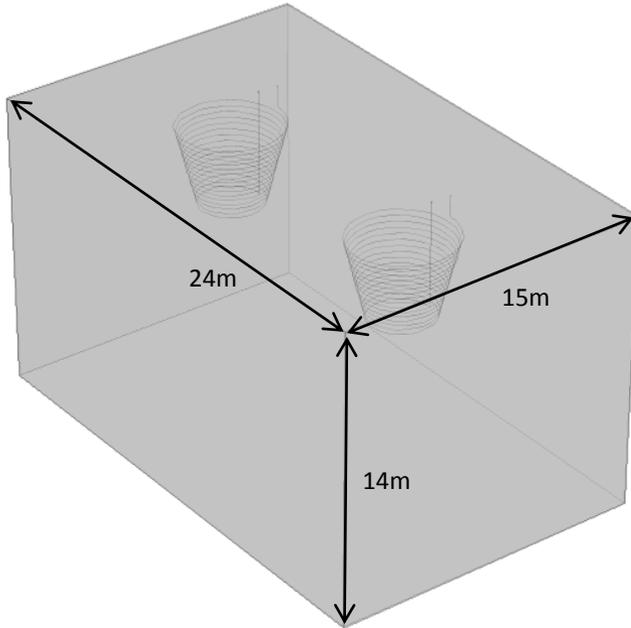


Fig. 4. Calculation domain.

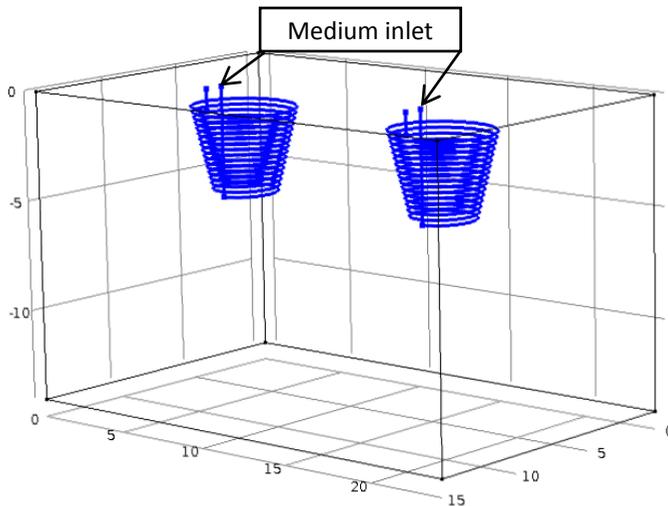


Fig. 5. Spiral exchangers.

The exchangers were placed at the depth of 5 m below the ground surface, in the distance of 12 m from each other. The height of the exchangers was 4 m, and minimal and maximal diameter amount, respectively, 3 m and 5 m. The scale of coils was 25 cm. The

coils were made of a pipe made of polymer with the conductivity coefficient of 0.4 W/mK and the external diameter of 36 mm and wall thickness amounting 3 mm. The working medium flowing through the coils is water solution of propylene glycol of the concentration of 20%. The flow of the medium through each coil is constant and amounts 0.25 l/s. The exchangers are connected with the heat exchanger of the power of 3 kW. The exchanger works periodically, due to the fact that the heat pump is integrated with a pop tank, fig. 6.

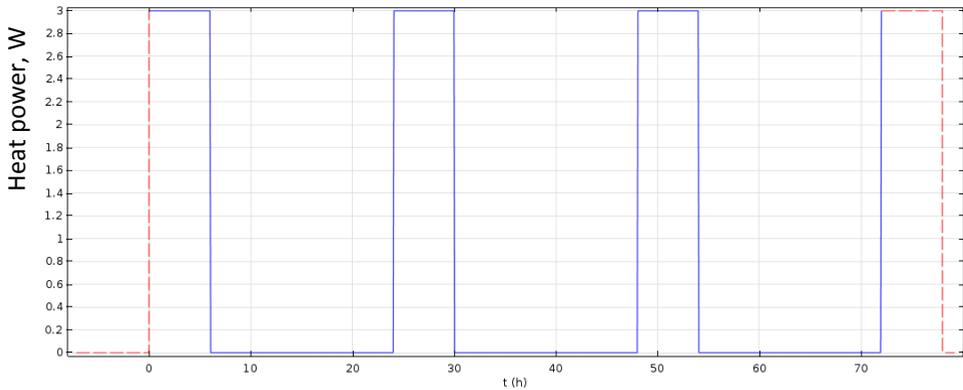


Fig. 6. Duty of a heat exchanger.

3 Numerical model

The computational domain was divided into: 148774 3D prismatic elements, 6296 triangular elements of 2D surface and 940 boundary elements. The numerical calculations encompassed the analysis of the unsteady temperature area in the ground, the temperature of the working medium flowing in coils of ground heat exchangers. The flow of the medium and the unsteady heat exchange in coils were analysed by using 1 D-time models, and in the ground by means of the 3D-time method. Comsol Multiphysics software was used for calculations [1,7].

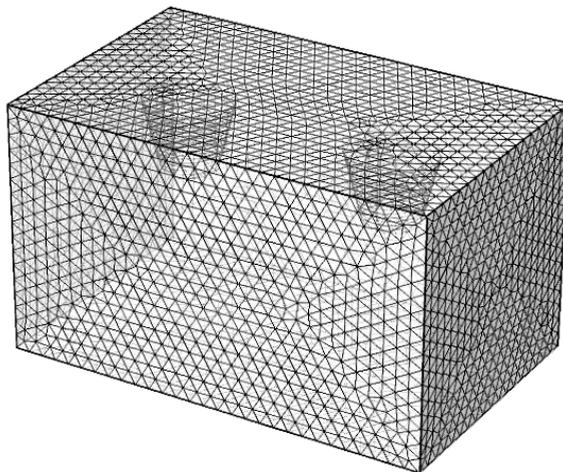


Fig. 7. Finite element grid.

4. Results

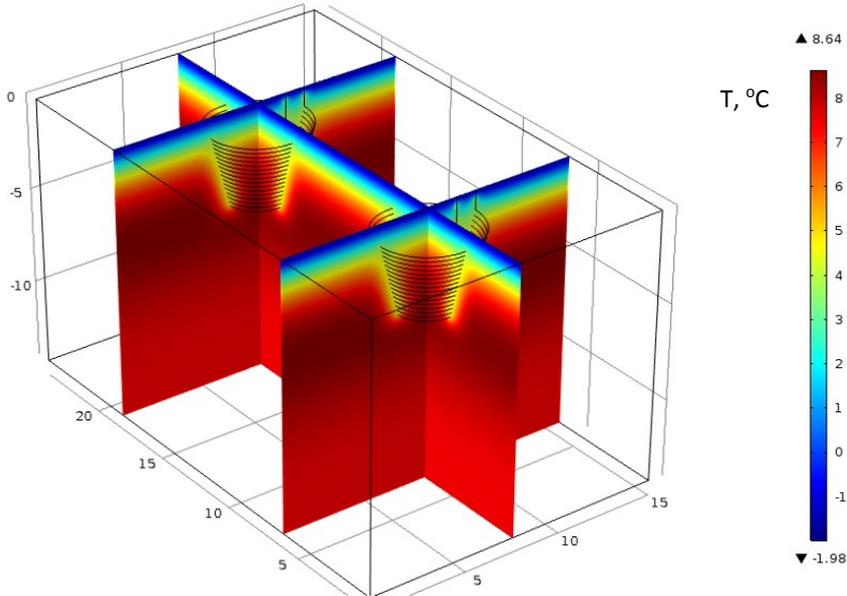


Fig. 8. Temperature distribution in the ground on the 5th day of operation.

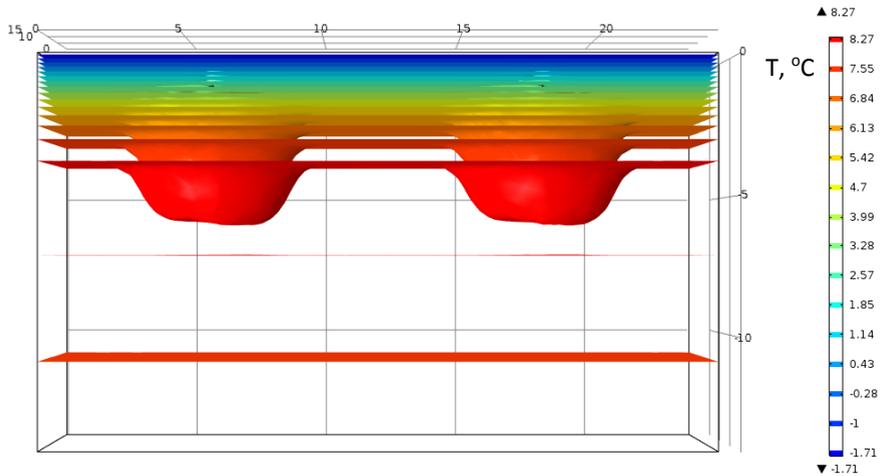


Fig. 9. Isotherms around the ground heat exchanger on the 5th day of operation from its start.

Figures 8 and 9 show the temperature field in the ground around coil-spiral heat exchangers. As one can notice, the area of the influence of heat exchanger on the temperature field encompasses a small area around the exchanger. Additionally, heat is transported to the medium from deeper parts of the ground [3]. It provides the possibility to increase condensation of coils in the given area. It enables to increase unit heat power when comparing to horizontal ground heat exchangers. Additionally, absorption of heat from

deeper parts of ground by spiral heat exchangers allows for lower cooling in the surface layers of soil and hence improvement of plant vegetation.

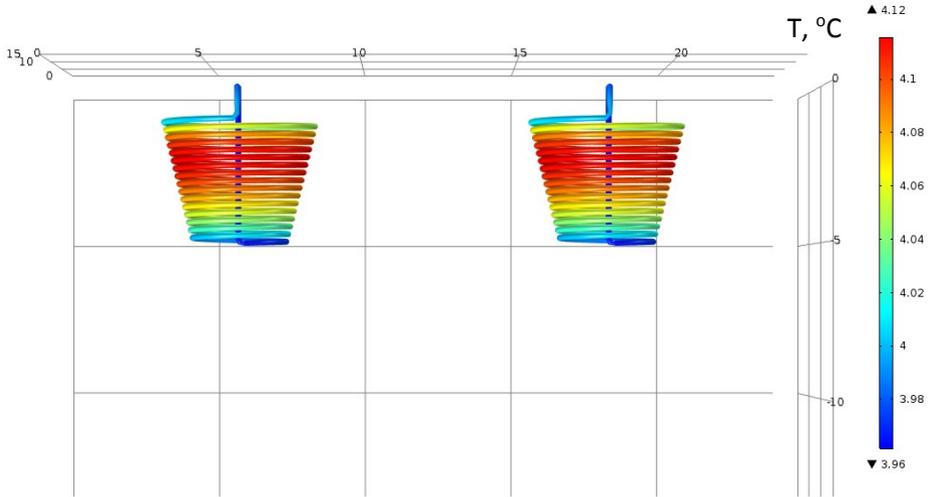


Fig. 10. Temperature distribution of the working medium in coils on the fifth day of operation.

Figure 10 presents temperature distribution of the working medium in the coil. Cold working medium flows in at the lowest point of the coil and then is transported upwards. As one can notice the medium gradually heats up, but in the upper part of the coil that is placed below the ground surface it is cooled down. It is due to lower ground temperature than the temperature of the medium. It causes deterioration of the efficiency of heat exchanger performance [2, 5]. Therefore, in order to improve the efficiency of operation one should apply an exchanger with variable scale so that it is smaller in the lower part and bigger in the upper part. It enables to increase the efficiency of heat exchangers as the difference between the ground and the medium becomes bigger.

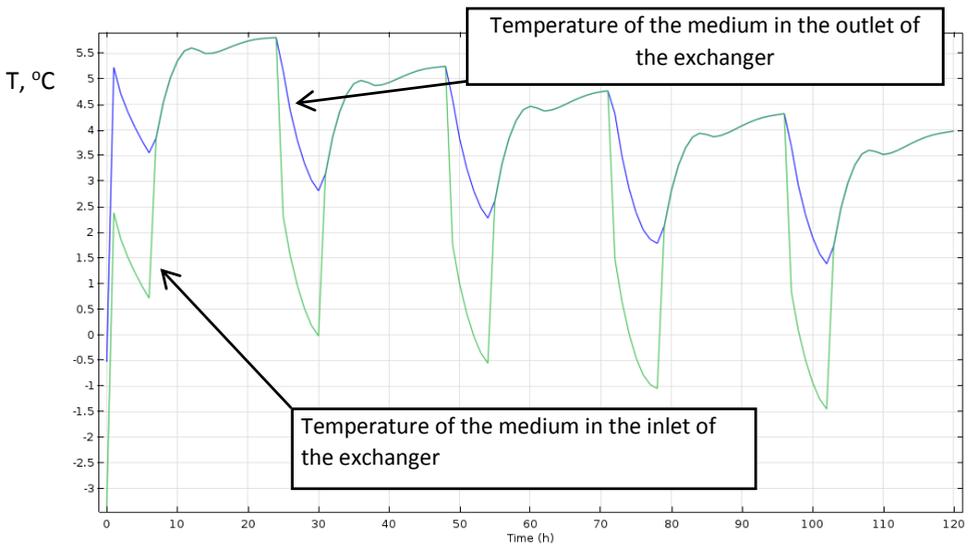


Fig. 11. Working medium temperature waveform.

Figure 11 presents temperature of the medium in the inlet and outlet of the coil heat exchanger. As it can be seen, after some time the waveform of temperature is stabilised and almost reaches a quasi-static state. One can notice a small amplitude of the working medium changes, about 2°C, as well as that temperatures above 0°C that are maintained at the outlet of the exchanger. It has positive influence on the conditions of heat exchanger operation as it improves the thermal coefficient of performance.

5. Conclusion

Final effects of the R&D studies in the context of the research results will allow for quantitative and qualitative analysis of the influence of coupling photo-thermal collectors with a heat pump in the lower part of the heat pump on the energy output, as well as productivity and general efficiency of the installation [4, 9]. The economic analysis together with the what-if analysis will enable to consider the influence of control algorithms and characteristics of energy receivers, which should allow to optimize the choice of technological installation scheme selection to the building where it is to be installed.

The result of the R&D research in the implementation aspect will be preparation of the offer for energy system working on the basis of photo-thermal collectors with a heat pump that uses the effect of synergy of their coupling in the lower part of the pump and component elements of such a system.

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