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TEMPERATURE CHANGES IN HEAT PUMP HORIZONTAL GROUND SOURCE

Summary

The paper deals with assessment of thermal fields and temperature changes in ground massif with horizontal heat exchanger used as a heat source for a heat pump. Temperatures in the zone of the horizontal ground exchanger are compared with temperatures in a reference land. Changes of heat potential of the soil during the heating period are also assessed. Possibilities of recovery of thermal potential of the ground massif when utilizing vertical and horizontal exchangers are analyzed in the opening part of the paper. The results of the first verification indicated that average temperatures in the horizontal planes of the ground massif did not differ considerably with distance from the exchanger tube. Differences in average temperatures in reference and experimental lands confirmed sufficient heat potential of the ground massif even at the peak of the heating period. The differences in average temperatures reached up to 6.51 K in the end of the heating period while at the beginning of the heating period, the differences in average temperatures dropped to 1.35 K. The differences between maximum and minimum temperatures in the zone of the ground exchanger reached up to 1.9 K at the peak of the heating period and rose to 3.9 K at the beginning and end of the heating period. The first results of our measurements indicate the necessity of accumulation of thermal energy in the soil massif in the summer period like in case of the vertical exchangers.

Key words: Ground heat exchanger; Parallel pipe hozizontal ground heat exchanger; Ground source heat pump; Ground temperature; Temperature distribution; Heat transfer; Energy conservation.

INTRODUCTION

Heat pumps used to heat the premises of agricultural farms and residential and civil buildings are classified according to a heat source for evaporator and heat transfer medium classified to the water – water, air – air, air – water, water – air, ground – water and ground – air types. The ground – water and ground –

air types are implemented either as vertical heat exchangers or as horizontal heat exchangers.

The vertical heat exchangers utilize in particular so called internal power of the Earth in depths of up to 100 or even more meters by means of U-shaped polyethylene tubes through which a heat transfer medium flows. The horizontal ground heat exchangers utilize prevailingly thermal energy accumulated as a result of incident solar radiation. This energy is utilized by means of polyethylene tubes with diameter of 35 – 50 mm buried in the depths of 0.5 – 3 m with spacing between tubes of 0.5 – 1.8 m. A mixture of ethylene glycol and water is mainly used as a heat transfer medium.

Incident solar radiation on the earth surface after passing through atmosphere is partially reflected and partially absorbed. Jakeš (1984) states that 47 % of solar radiation is converted directly to thermal power 159 $W.m^{-2}$ on the earth surface. The internal power of the Earth called also the Earth's thermal flow represents approximately 0.065 $W.m^{-2}$. The above mentioned facts are also confirmed by the publication of the Oklahoma State University (1988) where it is claimed that a proportion of solar radiation on accumulation of thermal energy in the subterranean layers of the Earth amounts to 97 – 98 % and the rest comes from internal sources of the Earth. Layers up to the depth of 20 m are probably considered to be the subterranean layers here.

The equation (Drbal, 1969) $Q_a = Q_p + Q_s$. applies to the thermal regime of the earth surface. Heat Q_a is the heat accumulated. Heat Q_s is the heat conveyed or transferred in the ground massif through radiation of the earth surface, cooling of soil with adjacent atmosphere, cooling by water evaporation, conveying of heat in leaking gravitational water, conveying of heat in the layers with lower temperature, by endothermic chemical and biological reactions and heat consumption for melting of snow and ice. Heat supplied in the ground massif Q_p is the heat obtained by effects of solar radiation, heating of soil with adjacent atmosphere, adsorption of gases and water vapour and their condensation, heating of the massif with artesian water, conveying of heat from the layers with higher temperatures, by exothermic chemical and biological reactions, conveying of internal latent heat at phase change to ice and heat conveyed by the Earth's thermal flow.

It follows from the above mentioned that when utilizing thermal energy of the vertical drill wells exceeding the depth of 20 m, in particular the Earth's thermal flow is extracted, i.e. much higher output than the internal output of the Earth even in case of a small heat pump. This fact should be reflected in an increase of power consumption in the heat pump system and also in reduction of a thermal potential of the adjacent massif that was depleted for a long period and is recovered only slowly during the summer period. For that reason, thermal energy has been accumulated from the condensers of air conditioning systems in the ground massif in the summer period and is reused in winter in countries with

a tradition of application of air conditioning plants such as the USA since 1974. The horizontal ground exchangers the issues of which we intend to address in this paper seems to be more promising for us from the viewpoint of restoration of thermal potential of the ground massif, investment costs for exchanger implementation and effects upon adjacent environment (disturbance of underground water circulation).

Demir, Koyun, Tenor (2008) dealt with comparing the results of experimental verification and the results of modelling thermal fields in the ground massif with a horizontal heat exchanger. The horizontal heat exchanger consisted of three tubes with diameter of 20 x 2.7 mm and length of 40 m installed in the depth of 1.8 m with spacing of tubes of 3 m. The heat conductivity coefficient of the ground massif was 2.18 $W.m^{-1}.K^{-1}$. The results of calculations of thermal fields in the MATLAB program and experimentally measured values differed by 10.3 %.

One-dimensional and two-dimensional models of the thermal fields in the ground massif in the surroundings of the tubes of both horizontal and vertical ground exchangers are analyzed in the publication of Florides and Kalogirou (2007). The effect of thermal characteristics on distribution of temperatures is also assessed here. The authors also present an interesting design of a horizontal ground exchanger installed in three layers over one another. This solution has a practical meaning and has not been verified experimentally.

Tarnawski et al. (2009) dealt with simulation of utilization of a horizontal ground exchanger for heating and cooling a house. The aim was also to analyze the possibilities of an increase of the thermal potential of the earth massif in the summer period. The simulation was carried out for a house with the total floor area of 200 m^2, thermal power required for heating of 5.5 kW and power required for cooling in the summer period of 3.3 kW. Ground exchangers consisting of tubes with outer diameter of 20 mm, length of 100 to 1,000 m, installation depth of 0.5 to 1 m and spacing of tubes of 0.5 m were analyzed. The ground exchangers were positioned on the same level or on two levels over one another. The results of the analysis indicated that the horizontal ground heat exchanger positioned on the same level with length of tubes of 300 m buried in depth of 0.5 m was the optimum solution from the viewpoint of electric power consumption for system operation. With average COP of the heat pump of 3.26, electric power consumption for house heating and cooling amounted to 19.7 $GJ.year^{-1}$. Even in case of a different required heating and cooling power, the thermal potential of the ground massif increased considerably after the summer period.

The results of verifications and analyses of utilization of heat exchangers in both greenhouses (Adamovský 1982) and open planting areas (Adamovský, Bartoloměvev 1982) indicated that the differences in temperatures in the horizontal plane range in the zone of the tubes of the ground heat exchanger between 1 and 3 K. They are reduced in higher layers and the temperature differences in

the depth of 0.3 under the ground surface can be considered to be statistically unimportant.

Already in the first publications focused on thermal fields and temperature changes in the ground massif with a horizontal heat exchanger (Rouvel 1975; Heinrich, Najork, Nestler 1982), the authors ask themselves questions with respect to a drop of temperature in the place of heat discharge, low thermal potential of the ground massif in the coldest months of the year, changes in thermal potential of the ground massif and their potential irreversibility. However, these questions have not been answered successfully till today according to our opinion. For that reason, we would like to continue finding answers to them.

The aim of our work is to analyze temperature changes and their distribution in the ground massif in the zone of the horizontal heat exchanger used as a source of heat for the heat pump. We also intend to compare temperatures of the ground massif with the horizontal heat exchanger in a reference land.

METHODS

The verification took place in a family house in the village of Hlinice (480 m above sea level) that is situated nearby the town of Tábor (Southern Bohemia). The ambient air temperature used for calculating thermal losses of premises achieving to -15 °C in this region.

The horizontal ground heat exchanger consisted of polyethylene tubes of 40x3.7 mm, PN 6 bar. The tubes are installed in the depth of 1 m below ground surface with spacing of 1.5 m. The ground floor area of the land is 27 x 25 m. The total length of tubes is 400 m. A mixture of ethylene glycol (40 %) and water (60 %) is a heat transfer medium flowing in the tubes. Grundfos UP 25-80 heat transfer medium circulation pump supplies heat carrying medium with a mass flow of 1.1 $kg.s^{-1}$ in Thermia Villa Classic 105 heat pump evaporator (condenser thermal power of 10.5 kW). The ground exchanger was operated for approximately 4 years before the verification.

Instruments supplied by Ahlborn, měřící a regulační technika, s.r.o. (Measuring and Control Equipment, ltd.) Praha were used for measurements: data loggers Almemo 5990.2 and Almemo 2890-9 with FH A646AG and T 123-30 sensors.

Temperatures of the ground soil were measured according to Fig. 1. The temperatures were recorded in 1 hour time step within the period between April 24, 2008 and April 30, 2009.

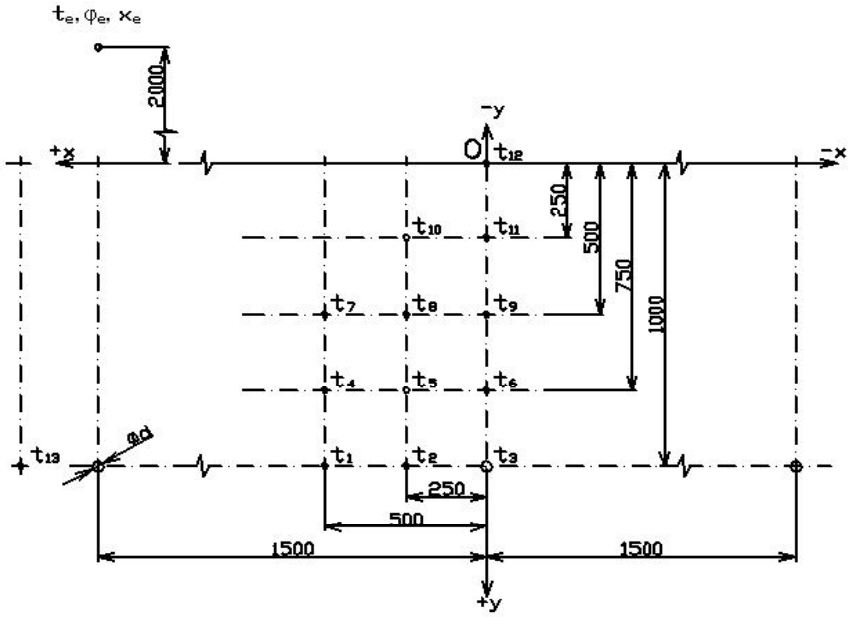


Figure 1. Diagram of temperature measuring in ground massif

ISOMET instrument supplied by Applied Precision, Bratislava, the Slovak Republic, was used to determine thermal characteristics of the ground. It is a microprocessor controlled manual apparatus intended for direct measuring of volume specific heat capacity c_o [J.m^{-3}.K^{-1}], heat conductivity coefficient λ [W.m^{-1}.K^{-1}] and thermal conductivity coefficient a [m^2.s^{-1}] of compact, bulk and liquid materials using exchangeable needle or flat probes.

RESULTS AND DISCUSSION

Monitoring average temperatures in the depth of 1 m, i.e. in the horizontal plane of the ground heat exchanger, showed that the relation $t_1>t_2>t_3$ applies in case of all measurements at temperature differences of 0.71 to 2.91 K. The temperatures of the ground massif close to a tube of the heat exchanger dropped to the lowest values in January t_3 = -1.10°C, t_2 = 0.00°C and t_1 = 0.30°C. Diffusion of water with variable intensity takes place in the places of installation of the ground exchanger tubes with a drop of ground temperature in dependence upon physical properties. This water will freeze on the external surface of the tubes during operation of the heat pump and melt when it is idle in case of freezing temperatures of the heat-carrying medium. This process may affect thermal flow accepted with the ground exchanger considerably. The temperature differences t_1, t_2 and t_3 were reduced in the depths of 0.75 m and 0.5 m under the ground

massif surface, however, the relation $t_1 > t_2 > t_3$ still continued to apply. It showed only at the depth of 0.25 m that temperatures in the horizontal plane were not affected by pumping of heat energy with the ground exchanger any more.

The results of measurements of temperatures in the zone of the horizontal ground exchanger, temperatures in the reference land and temperatures of ambient environment are illustrated in Fig. 2. The differences between maximum and minimum temperatures in the reference land were unimportant.

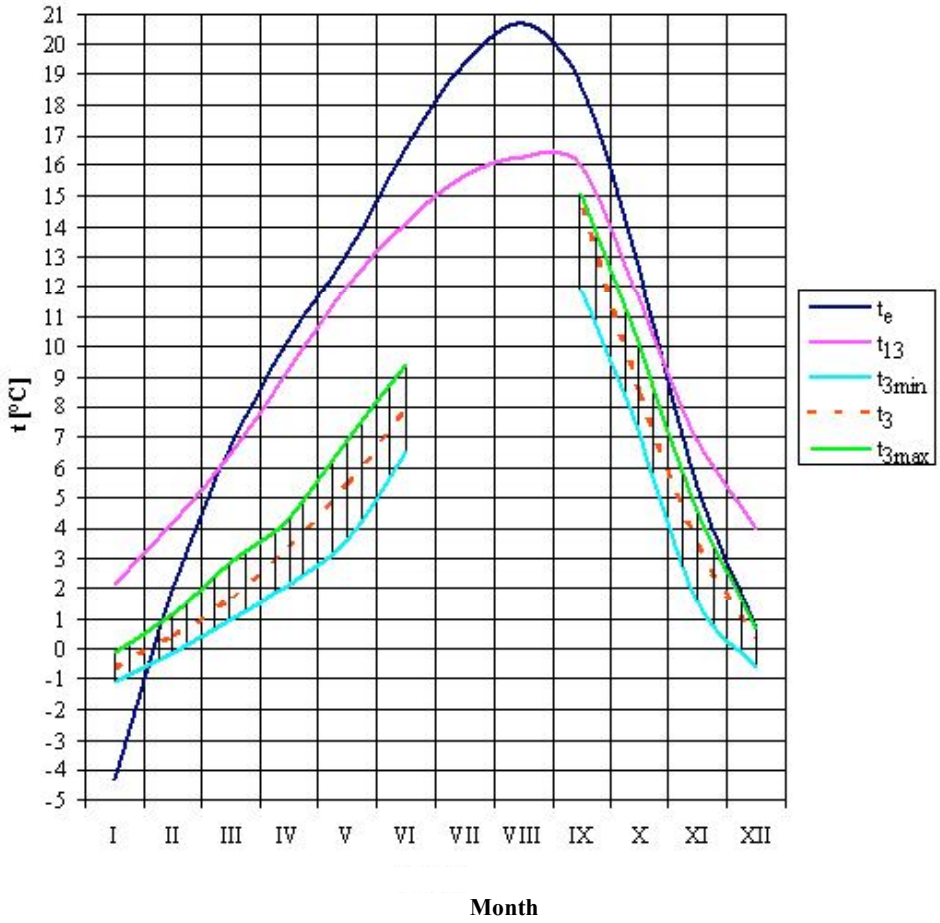


Figure 2. Results of temperature measurements. $t_{3,min}$ – minimum temperature of the ground massif in the zone of the horizontal exchanger; $t_{3,max}$ – maximum temperature of the ground massif in the zone of the horizontal exchanger; t_3 – average temperature of the ground massif in the zone of the horizontal exchanger; t_{13} – average temperature of the ground massif in the reference land; t_e – average temperature of ambient air

The difference of temperatures t_{13} and t_3 was probably the most significant parameter for assessment of the differences in the thermal potential of the ground massif with a horizontal heat exchanger and the reference land potential. Average temperature in the reference land, t_{13}, was lowest in January, t_{13} = 2.17 °C, and highest in August, t_{13} = 16.32 °C. The differences in temperatures t_{13} - t_3 ranged between 1.35 K and 6.51 K in the course of yearly monitoring. The maximum temperature differences were measured in March – June, namely in the range of 4.83 – 6.51 K. This fact results partially from increasing of solar radiation activity during this period but in particular from depletion of thermal energy of the ground soil in the end of the heating period. Temperature differences t_{13} - t_3 within the range between 2.79 and 3.80 K were measured in the critical period of the heating season in December to February. Smaller differences in temperatures indicate a sufficient thermal potential of the ground massif.

The finding that the temperature in the zone of the horizontal exchanger is by 1.35 K lower than that in the reference land at the beginning of the heating period in September is an important result of the first verification. As the ground exchanger has been operated for 4 years, it cannot be specified credibly whether the reduction of temperature occurred progressively or suddenly during the last year.

With respect to the fact that heat consumption from the ground massif is almost continuous in the peak of the heating period from December to March, the temperature differences $t_{3,max} - t_{3,min}$ range between 1.0 and 1.9 K. The differences $t_{3,max} - t_{3,min}$ increase to 2.2 – 3.9 K at the beginning and end of the heating period as a result of interrupted operation of the heating system.

The following findings have resulted from analyses of the first measurements of temperatures of the ground massif with the installed heat exchanger fulfilling a function of a source of energy for the heat pump:

– Average temperatures in the horizontal planes of the ground massif did not differ considerably with increasing distance from the exchanger tube;

– Temperatures of the ground massif in the zone of exchanger tubes reached even negative values;

– Differences in average temperatures in the reference and experimental lands confirmed a sufficient thermal potential of the ground massif even in the peak of the heating period;

– Differences in average temperatures reached up to 6.51 K in the end of the heating period;

– Differences in average temperatures dropped to 1.35 K at the beginning of the heating period;

– Differences in maximum and minimum temperatures in the zone of the ground exchanger reached to 1.9 K in the peak of the heating period and increased up to 3.9 K at the beginning and end of the heating period.

The first results of our measurements indicate the necessity of accumulation of thermal energy in the ground massif in the summer period like in case of the vertical exchangers. However, the period necessary for thermal potential increasing will be considerably shorter when compared with the vertical ground exchangers and the necessary thermal power will also be lower. The aim of our next research in this field will be verification of the possibility of an increase of natural accumulation of heat within the ground massif and the possibility of an increase of heat contents of the ground massif using reverse operation of the heat pump in the summer period.

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