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Changes in energy and temperature in the ground mass with horizontal heat exchangers—The energy source for heat pumps

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ABSTRACT

This article addresses soil temperature analysis, heat flows and energy transferred from the soil massif via a linear horizontal heat exchanger and horizontal heat exchanger of Slinky type. Heat exchangers are used as low-potential sources of thermal energy for heat pumps. Both exchangers were compared in terms of their influence on the soil massif temperature in the exchanger area, and on the exchanger power output. The exchangers were evaluated in the heating periods of 2011–2012, 2012–2013 and in the exchanger stagnation period of 2011. The linear heat exchanger seems to be more suitable as a low-potential power supply for heat pumps. The average temperatures of the soil massif in the exchanger areas were positive in both heating periods and the temperature was higher at the linear exchanger. The temperatures of the heat-transfer fluid exiting the exchangers were positive and the linear exchanger temperature was higher. The temperatures of the heat-transfer fluid entering the exchangers were identical, and were negative only in exceptional cases. The natural energy recovery capabilities of the ground massif during the exchanger stagnation period were confirmed. The specific heat transferred from the ground massif was significantly lower with the linear exchanger than with the Slinky type.

1. Introduction

Limited natural energy resources for heating as well as environment quality requirements force people to utilise renewable energy resources. Preference should be given to particular energy systems that utilise energy that is non-exploitable in terms of the 2nd law of thermodynamics, so called "anergy". This requirement is fulfilled by heat pumps.

From the regular statistical report of the European Heat Pump Association [1] it is observed that there are more heat pumps of the air/water type than the ground/water type in the 21 monitored European countries. In the 2010–2012 periods there was a difference of 50–65 thousands units in favour of the air/water heat pumps. There were slightly more ground/water heat pumps used before 2006. Currently, more than 65 % of the ground/water heat pumps are located in the Netherlands, Poland and Lithuania.

The higher number of implemented air/water heat pumps is definitely affected by lower investment costs and easier installation compared to ground/water heat pumps. The situation may change with the new methodology evaluating the efficiency of energy systems with heat pumps according to EN 14825 [2] defining SCOP (Seasonal Coefficient of Performance). The advantages of ground/water heat pumps consisting in the temperature stability of the energy source will then become clearly visible. An indisputable advantage of using the ground massif as the energy source for the heat pumps is the fact that the ground temperature is higher than the ambient air temperature for most of the winter period. In the summer period, the opposite is true [3]. The ground massif temperature can therefore be utilised for heating in winter periods and/or cooling in summer periods.

Ground source heat pumps (GSHPs) use horizontal ground heat exchangers (HGHE) and vertical ground heat exchangers (VGHE). The VGHE work with a high efficiency and require a minimum site area. They are, however, more expensive than HGHE, which present a compromise between the high efficiency and initial costs of the heat exchanger. They are installed in three basic configurations [4]: Linear, spiral and Slinky type. The exchanger pipes with a diameter of 30–50 mm are installed in the ground massif at a depth of 1.0–2.0 m, based on the thermal characteristics. The exchanger loop diameter can be in the range of 0.5–2.0 m with a span of 0.1–0.5 m. The pipe span of the linear exchanger is 1.0–1.5 m.

Petit and Meyer [5] presented a comparison of the low-potential energy sources for heat pumps. They observed the performance and economical parameters of the air, HGHE and VGHE. The results of their analyses showed that the maximum output can be achieved by

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Nomenclature

d	pipeline diameter (m)
I	determination index of non-linear regression (-)
L	exchanger pipeline length (m)
Nu	Nusselt number (-)
Pr	Prandtl number (-)
q	specific heat transferred from the ground massif (Wh/(m^{2}day))
r	exchanger loop radius (m)
Re	Reynolds number (-)
t	temperature (°C)
$\bar{t}$	mean temperature (°C)
Δt_A	oscillation amplitude around the temperature $\bar{t}$ (°C)
α	heat transfer coefficient (W/(m^{2}K))
ε	pipe curvature coefficient (-)
λ	thermal conductivity of the fluid (W/(mK))
τ	number of days from the start of measurement (day)
φ	initial phase of oscillation (rad)
Ω	angular velocity (2π/(365 rad day))
Subscript	
02	temperature sensor installed at a depth 0.2 m above the heat exchanger
1	the ground heat exchanger output
2	the ground heat exchanger input
e	ambient air
h	hydraulic (diameter)
i	inlet pipeline from the heat pump evaporator
o	output pipeline to the heat pump evaporator
L	linear horizontal ground heat exchanger
R	regression function
S	slinky-type ground heat exchanger

using VGHE technology. HGHE technology achieved a better heating coefficient and the best economy indicators of all three energy sources. The air was evaluated as the worst energy source for heat pumps. Benli [6] performed an evaluation of the Coefficient of Performance (COP) using HGHEs and VGHEs. He validated the COPHP values for standalone heat pumps and COPsys of the complete system used for heating a greenhouse. The HGHE results showed that the COPHP was in the range of 3.1–3.6 and COPsys in the range of 2.7–3.3. When validating the VGHE the COPHP was in the range of 2.9–3.5 and COPsys in the range of 2.7–3.3.

Congedo et al. [7] dealt with an analysis of the main parameters and configurations of the pipelines that influence the HGHE output, temperatures and heat flows in the ground. They analysed operating conditions at the HGHE installation depth (from 1.5 m to 2.5 m), the heat-transfer fluid flow speed (from 0.25 m/s to 1.0 m/s) and the ground heat conductivity (from 1.0 to 3.0 W/(mK)). It was determined that the most important parameters influencing HGHE performance were the ground heat conductivity and the heat transfer coefficient between the exchanger pipe wall and the heat-transfer fluid. The installation depth and exchanger configuration did not play an important role. Šedová et al. [8] performed an analysis of the influence of the ground massif, the thermal resistance (conduction) of the heat exchanger piping and the thermal resistance (convection) between the exchanger pipe wall and the flowing heat-transfer fluid. Svec et al. [9] dealt with the influence of the HGHE plastic piping heat resistance. They point out the results of verification of various HGHE configurations that displayed a negative influence of the exchanger pipeline resistance, which was usually neglected in the calculations and systems modelling. The importance of the piping material is emphasised by a verification of using the aluminium ribbed pipelines in HGHE [10], which proved an increased heat transfer per volume unit of the heat-transfer fluid by 26%. This resulted in a reduction of both HGHE pipeline length and the parcel area.

The influence of the ground moisture content on the thermal power of HGHE and COP was investigated by Leong et al. [11]. They discovered that the HGHE output strongly depends on the moisture content and mineralogical composition of the soil. They also verified that the COP is up to 35% lower in dry soils than in the soils with a optimum moisture content. Moisture content in the range of 25% to 50% is considered to be optimum in terms of HGHE performance. Moisture lower than 12.5% significantly reduces both HGHE and COP performances. It was found that frozen ground around the HGHE pipeline creates an almost constant temperature of the heat-transfer fluid and constant HGHE and COP performance. Song et al. [12] analysed the most important parameters that influence the heat conductivity coefficient of the ground. They quote that with an increased moisture content the heat conductivity coefficient rises to a certain value. Above this value, the heat conductivity coefficient remains almost constant. Their experiments showed that the heat conductivity coefficient in regular ground at temperatures of 10 °C to 40 °C reaches values in the range of 0.55 to 0.6 W/(mK) in dry ground, 2.3 W/(mK) at a regular moisture content, and 2.7 W/(mK) in wet ground. It confirms the high heat conductivity coefficient of frozen ground in line with the work of Leonga et al. [11]. The performed measurements show the heat conductivity coefficient of clay is 1.616 W/(mK) at temperatures above zero and 2.454 W/(mK) in frozen ground.

Rezaei et al. [13] verified the influence of different surface coverage of ground with HGHE on the temperature distribution and heat flow in the ground. The verification results showed a positive influence of the ground coverage. For example, when the ground massif was covered by an insulating layer of recycled tyres the heat flow from the ground massif was increased by 17% in the winter period.

The effects of heat-transfer fluid influence on heat flow in heat exchangers were studied by Guo et al. [14]. They showed that if the heat-transfer fluid is not properly selected the heat transmission and heat exchanger performance are reduced. Tarnawski et al. [15] verified the influence of heat-transfer fluid flow in HGHE on heat transfer in heat exchanger pipelines. They realised simulations of various HGHE configurations. The results show that the heat transfer rate in HGHE is dependent on the flow speed of the heat-transfer fluid, pipeline diameter, density, heat conductivity, and specific calorific capacity of the heat-transfer fluid. They also illustrated that the heat flow between the liquid and the exchanger pipe wall is stronger with a lower content of anti-freeze concentrate and shorter heat exchanger pipes. The verification results prove that HGHE cause only a slight change in ground temperature. Similar conclusions were also drawn by Neuberger et al. [16], who state that the differences between the temperatures in the ground massif in the area of the Slinky-type heat exchanger and at the distance of 1 m from the exchanger were negligible both in the heating and stagnation periods. The issue of concentration levels of antifreeze in the heat-transfer fluid is also engaged by Xu and Spitler [17]. They verified the influence of the concentration and temperature of the heat-transfer fluid on the Reynolds number Re.

The goal of further verifications was to:

- Monitor temperature values and analyse ground temperature changes with linear and Slinky HGHE based on the exchanger operation;
- Determine the specific heat flow and energy drawn from the ground massif by HGHE's during the heating period;