# HORIZONTAL GROUND HEAT EXCHANGERS – LOW-TEMPERATURE ENERGY SOURCE

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***Abstract***
*The aim of this paper is to analyse and compare the temperatures of heat carrier fluids, thermal resistances, specific outputs and extracted energies for horizontal ground heat exchangers used in the function of low-temperature energy source for heat pumps. Linear and Slinky type horizontal ground heat exchangers, the most commonly used ones in Europe, were verified. The temperatures of the heat carrier fluids did not reach negative temperatures in the two horizontal exchangers throughout the monitored period. The results of the verification indicated that, in terms of the monitored parameters, the linear horizontal exchanger seemed to be more effective than the Slinky type. The temperatures of the heat carrier fluid were on average higher at the linear exchanger by 1.43±2.12 K, with a specific output of 5.76 W per 1 m$^2$ of the heat exchange surface. The thermal resistance was higher at the Slinky than at the linear exchanger by 50%.*

**Key words:** *heat exchanger; temperature; heat carrier fluid; energy accumulation; energy extraction; thermal resistance.*

## INTRODUCTION

According to *Stefánson (2000)*, low-temperature heat pump energy sources should be renewable and sustainable. The author specified the term "renewable" as a feature of energy source and "sustainable" as a way of using energy. *Wei et al. (2013)* considered the ground mass as a renewable energy source. However, as mentioned by *Kupiec et al. (2018)*, given the time intervals between accumulation and energy extraction, the ground mass can lose its sustainability due to long-term, unbalanced extraction. The temperatures of the ground mass, temperatures of heat carrier fluids in the heat exchangers, extracted outputs and energies are important parameters that affect not only the efficiency and performance of the heat pump, but also the recoverability and sustainability of the low-temperature energy source.

*Kayaci, Demir (2018)* paid attention to modelling inlet and outlet temperatures of horizontal ground heat exchangers (HGHEs) and its verification. The temperatures of heat carrier fluid in the mode of heat extraction from the ground mass during heating and its supply during cooling a building was monitored by *Gyu et al. (2015)*. The HGHE simulation model was developed and successfully verified in long-term experiments by *Fujii et al. (2012)*. They presented specific outputs of HGHEs depending on the volume flow of the heat carrier fluid. *Verda et al. (2016)* studied the dependence of the depth of HGHEs deposition in the ground mass on its specific output value. *Kupiec et al. (2015)* described the relationships between the energy accumulated in the ground mass during the summer season and the possibilities of its extraction during winter. *Bottarlli et al. (2015)* verified the possibilities of accumulation of energy in the ground mass during summer using PCM materials operating on the principle of phase change. They also analysed the effect of this accumulation on heat carrier fluid temperatures and HGHEs outputs. A series of experiments to determine the specific resistances of HGHEs was carried out by *Zeng et al. (2013)*.

The aim of this contribution was to analyse and compare the temperatures of the heat carrier fluids delivered to the heat pump evaporator, the HGHEs thermal resistances, their specific outputs and energies extracted by HGHEs from the ground mass during a heating season.

## MATERIALS AND METHODS

The verification was conducted at the experimental workplace of VESKOM s.r.o. based in Prague, Dolní Měcholupy, during the heating season 2012/2013 from 17 September 2012 to 22 April 2013 (218 days, 5 232 hours). The workplace is located at 50°3'32" north latitude and 14°33'31" east longitude at an altitude of 266 m. Linear and Slinky type HGHE were the subjects of the verification. Linear HGHE consisted of 330 m (41.47 m$^2$) piping PE 100RC 40 x 3.7 mm (LUNA PLAST as, Hořin, Czech Republic) deposited at 1.8 m depth in 3 loops with a length of 54.6 m and pipe spacing of 1.0 m. For Slinky HGHE, the total length of piping PE 100RC 32 x 2.9 mm was 220 m (20.11 m$^2$). This exchanger consisted of 53 loops with a spacing of 0.38 m, deposited at a depth of 1.5 m. *Adamovsky et al. (2015)* presented a detailed scheme of HGHEs installation. Tested HGHEs, along with vertical ground exchangers, were low-temperature energy sources for 3 heat pumps (Industriell Värme Teknik, Tnanas, Sweden) – one PremiumLine EQ E13 (heat output of 13.3 kW at 0/35 °C) and two GreenLine HT Plus E 17 (heat output of 2x 16.2 kW at 0/35°C). The temperatures of the heat carrier fluids were measured by Pt100 sensors at quarter-hour intervals and recorded by the ALMEMO 5990 measuring station (AHLBORN Mess-und Regulungstechnik GmbH, Holzkirchen, Germany). Volume flows of heat carrier fluids were recorded by MTW 3 electronic meters (Itron Inc. Liberty Lake, USA). Ground mass reference temperatures were measured at installation depth at a distance of about 14m from HGHEs. They were measured by GKF 125 and GKF 200 sensors (GREISINGER electronic GmbH, Regenstauf Germany) and recorded at half-hour intervals by the ALMEMO 5990 measuring station. Ambient temperatures were measured by ATF 2 KTY 81.210 sensor (S + S Regeltechnik, Nürnberg, Germany) at a height of 2.5 m above the mass surface. The STATISTICA program (StatSoft, Inc. 2013) and MS Excel 2016 were used to evaluate and analyse the measured values.

## RESULTS AND DISCUSSION

### 1. Heat carrier fluid temperatures

The average daily temperatures of the heat carrier fluids exiting the exchangers, $t_L$, $t_S$ and the ambient temperatures throughout the heating season are shown in Figure 1. The reaction of the average daily temperatures of the heat carrier fluids to the ambient temperatures is evident. With the exception of the beginning and the end of the heating season, the temperatures of the heat carrier fluid, $t_L$ were higher at linear HGHE than the temperatures, $t_S$ at Slinky HGHE. The quadratic equations of the trend lines of the HGHEs heat carrier fluid temperatures have the form of (1) and (2). Determination coefficients $R^2$ indicate very good data-curves matching. In equations (1) and (2), $\tau_d$ is the duration of the heating season from its beginning, expressed in days.

$$t_S = 0.0007\tau_d^2 - 0.2105\tau_d + 18.74 \quad (R^2 = 0{,}970) \tag{1}$$
$$t_L = 0.0005\tau_d^2 - 0.1784\tau_d + 19.185 \quad (R^2 = 0{,}980) \tag{2}$$

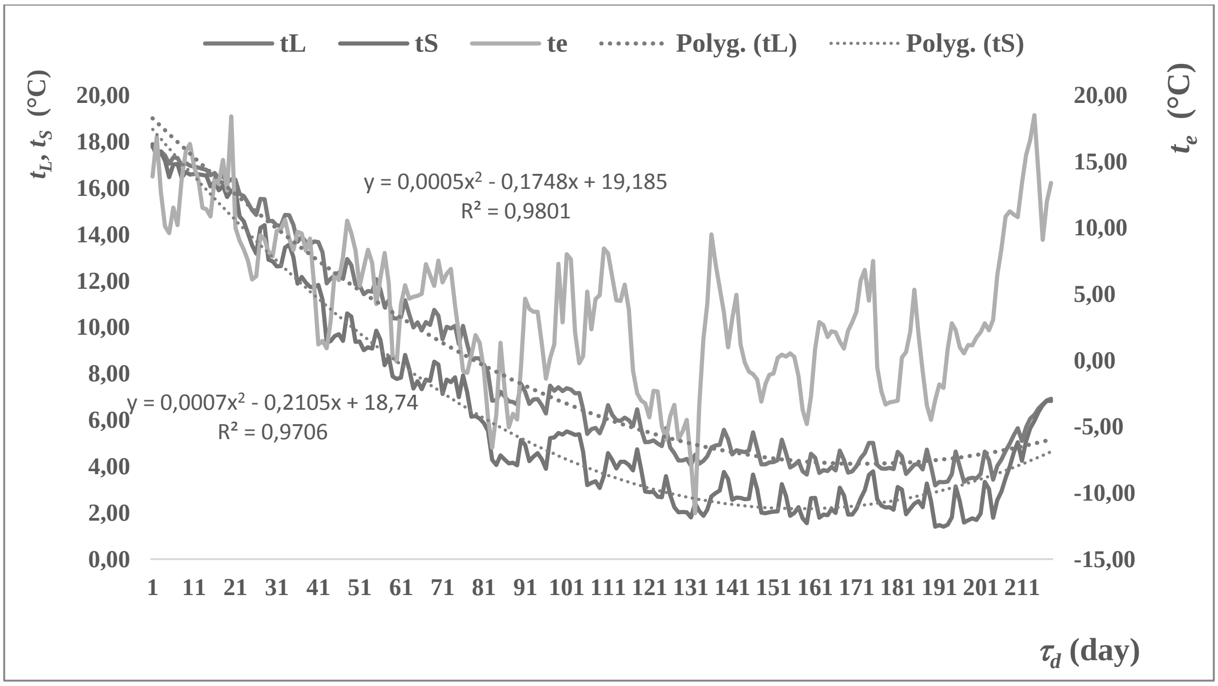
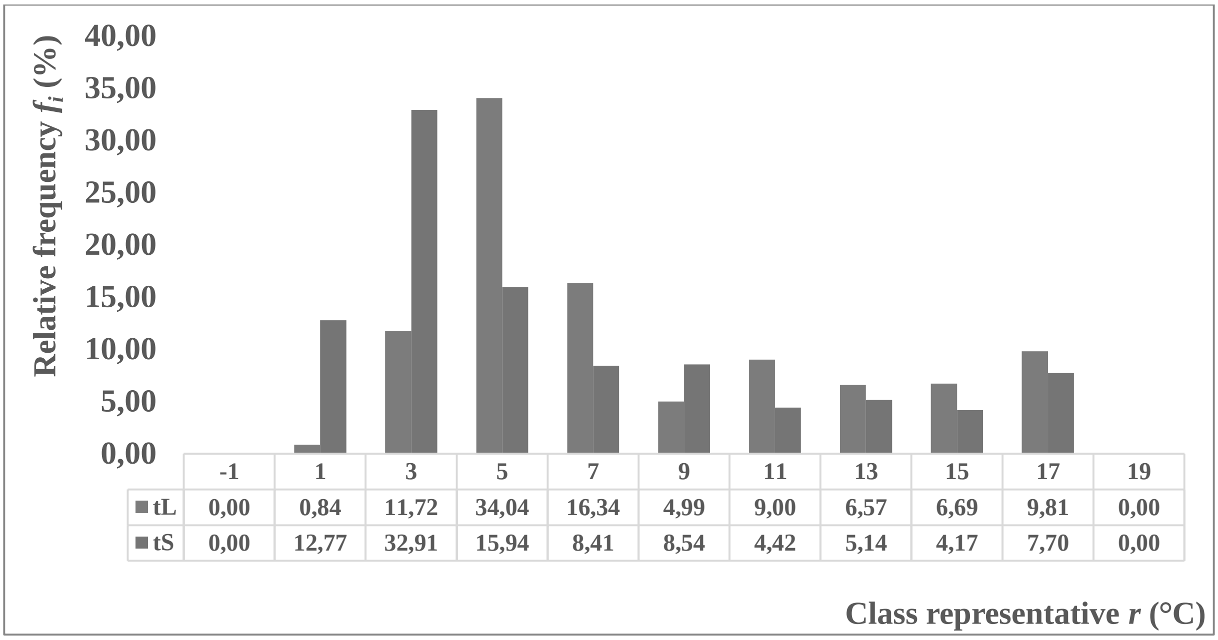



**Fig. 1** Average daily temperatures of heat carrier fluids from Slinky HGHE, $t_S$ and from linear HGHE, $t_L$ and ambient temperatures, $t_e$.

The distribution of the heat carrier fluid temperatures during the heating season is better described by the histogram in Figure 2. It shows the frequency of average hourly temperatures, $f_i$ (5232 values) and temperature modes, *Mod(t)* (the most frequent temperatures) at 2 K intervals throughout the heating season. The horizontal axis of the histogram shows the temperatures defining the interval, the so-called class representative *r* in the range of <-1.0; 19.0> ° C.
The histogram indicates that *Mod*($t_S$) of Slinky HGHE occurred in a temperature range of <2.10; 4.00> ° C (*r* = 3 ° C) with relative frequency $f_i$ = 32.91%. The mode of linear HGHE, *Mod*($t_L$) had higher relative frequency $f_i$ = 34.04% at higher interval <4.10; 6.00> ° C (*r* = 5 ° C). The temperatures $t_S$ occurred with quite high relative frequency $f_i$ = 12.77% in an interval as low as <0.10; 2.00> ° C (*r* = 1 ° C). Since the higher frequency of the heat carrier fluid temperatures at higher temperature intervals indicate the advantage of a low-temperature energy source, the linear HGHE can be considered more advantageous in terms of temperatures of heat carrier fluids. This conclusion is based on the reversed Carnot cycle. At a constant condensation temperature, an increase in the evaporation temperature, influenced by the temperature of the heat carrier fluid supplied to the evaporator, will increase the heat pump's heating factor. The distribution of heat carrier fluid temperatures in HGHEs is closely related to the distribution of temperatures in the ground mass mentioned in publication by *Adamovsky et al. (2015)*.




| | -1 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| tL | 0,00 | 0,84 | 11,72 | 34,04 | 16,34 | 4,99 | 9,00 | 6,57 | 6,69 | 9,81 | 0,00 |
| tS | 0,00 | 12,77 | 32,91 | 15,94 | 8,41 | 8,54 | 4,42 | 5,14 | 4,17 | 7,70 | 0,00 |

**Fig. 2** Relative frequencies of average hourly temperatures of heat carrier fluids from HGHEs, $t_L$ and $t_S$

## 2. Heat outputs and extracted energies

The specific heat outputs ($q_{\tau,a}$, $q_{\tau,max}$) and the energy extractions ($q_a$, $q_{max}$) were determined on the basis of the difference between the temperatures and the flow rates of the heat carrier fluid ($V_\tau$), the specific heat capacity and the density corresponding to the mean temperature of the heat carrier fluid.
Table 1 presents the average and maximum hourly flow rates of the heat carrier fluids, $V_{\tau,a}$ and $V_{\tau,max}$, respectively, the overall volume of heat carrier fluid, $V_\Sigma$ flowing through the exchangers during the heating season, the average and maximum specific outputs, $q_{\tau,a}$ and $q_{\tau,max}$, respectively, recalculated to 1 m pipe length and 1 m$^2$ of the exchanger's heat transfer surface, average and maximum specific energies, $q_a$ and $q_{max}$, respectively, transferred from the ground mass by 1 m$^2$ of the exchanger in 1 day of the heating season, the overall energy, $q_\Sigma$ transferred from the mass and overall time of energy extraction by the exchangers, $\tau_\Sigma$ during the heating season.
The overview presented in Table 1 shows that both the specific powers and the extracted energies were higher for linear than for Slinky HGHE. However, the values are determined at different volume flows of the heat carrier fluid and different heat transfer surfaces of the HGHEs. But if the volume

flows of the heat carrier fluids are converted to 1 m$^2$ of heat exchanger surface, this value is higher for HGHE Slinky. The values of the recorded average specific outputs of HGHEs correspond to those reported by *Rosen et al. (2006)*. At a heating factor of 3.5, they indicated the heat pump's specific output 13 W/m for linear HGHE with a pipe diameter of 40 mm and 7 W/m for Slinky HGHE. The HGHEs outputs and extracted energies were certainly influenced by the special character of the operation of the production halls and administrative building, such as interrupted operation and required low outputs of the heating system, especially at the beginning and end of the heating season.

**Tab. 1** Heat carrier fluid flows, heat outputs and extracted energies

| Parameter | Linear HGHE | Slinky HGHE |
|---|---|---|
| $V_{\tau,a}$ (m$^3$/h) | 0.47±0.22 | 0.35±0.12 |
| $V_{\tau,max}$ (m$^3$/h) | 0.89 | 0.72 |
| $V_\Sigma$(m$^3$) | 1 183.70 | 592.82 |
| $q_{\tau,a}$ (W/m) | 4.92±3.60 | 3.35±2.42 |
| $q_{\tau,max}$ (W/m) | 15.25 | 12.48 |
| $q_{\tau,a}$ (W/m$^2$) | 39.14±28.67 | 33.38±24.11 |
| $q_{\tau,max}$ (W/m$^2$) | 121.42 | 124.20 |
| $q_a$ (kJ/m$^2$.day) | 1 614.15±1 076.40 | 938.31±677.70 |
| $q_{max}$ (kJ/m$^2$.day) | 4 407.73 | 4 258.86 |
| $q_\Sigma$ (MJ/m$^2$) | 351.88 | 204.55 |
| $\tau_\Sigma$ (h) | 2 497 | 1 703 |

Figure 3 presents the course of specific energies extracted by HGHEs during the heating season. As in the case of the heat carrier fluid temperatures, there is a clear dependence of the extracted energy values on the ambient temperatures. The extracted energy values are lower for Slinky HGHE than for linear HGHE due to lower heat carrier fluid temperatures. The reported values of the energy extracted from the ground mass are in accordance with the limit values recommended in the publication by *Kyriakis, Michopoulus (2006)*.

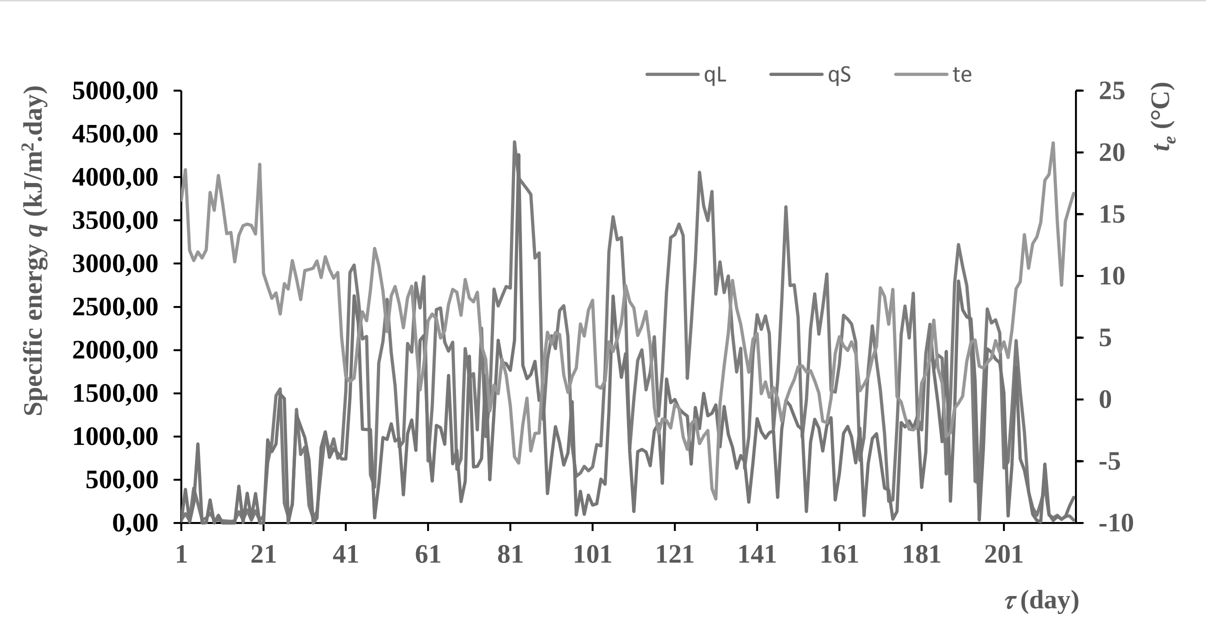



**Fig. 3** Energies extracted from the ground mass by HGHEs

## 3. HGHEs Thermal resistances

The process of heat transfer between ground mass and heat carrier fluid can be evaluated by the relationship published by Z e n g at al. (2003). They relate specific thermal resistance to 1 m length of vertical ground borehole. In terms of HGHEs comparison, it seems to be more advantageous to specify the specific thermal resistance per 1 $m^2$ of the heat exchanger surface according to the relation:

$$R = \frac{t_{r.m.} - t_a}{q_\tau} \tag{3}$$

where:
$t_{r.m.}$ – temperature of reference ground mass (°C);
$t_a$ – temperature of heat carrier fluid (°C);
$q_\tau$ – specific heat output of HGHEs ($W/m^2$).

The average thermal resistance value $R$ ranges from 0.07±0.02 $m^2.K/W$ for linear HGHE and 0.14±0.06 $m^2.K/W$ for Slinky HGHE. The maximum $R$ value for Slinky HGHE is more than double the value for linear HGHE. A lower thermal resistance value indicates a higher intensity of heat transfer between the ground mass and the heat carrier fluid.

## CONCLUSIONS

The above analysis and comparison of the verification results indicate that linear HGHE appears to be more advantageous than Slinky HGHE in terms of the evaluated parameters. This conclusion is confirmed by the courses of the average daily temperatures of the heat carrier fluids, equations (1) and (2) and by the intervals of the modes of the average hourly temperatures and their relative frequencies. Specific heat outputs and energies extracted from the ground mass were also higher at the linear HGHE than at Slinky HGHE. The thermal resistance of linear HGHE was approximately half the resistance monitored at HGHE Slinky.
However, these conclusions are based only on the results of the verification in one heating season. Further measurements will show whether the trends of the monitored parameters do not change under other climatic conditions.

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