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Seasonal performance for Heat pump with vertical ground heat exchanger in Riga

S Jaundālders[1], P Stanka[1] and D Rusovs[1,2]

[1]Riga Technical University, Department of Heat and Power Engineering Systems, Kalku Str. 1, Riga, LV-1658, Latvia

E-mail: dmitrijs.rusovs@rtu.lv

Abstract. Experimental measurements of Seasonal Coefficient of Performance (SCOP) for heating of 160 m^2 household in Riga were conducted for operation of brine-water heat pump with vertical ground heat exchangers (GHE). Data regarding heat and electrical power consumption were recorded during three-year period from 2013 to 2016. Vapor compression heat pump has heat energy output of 8 kW. GHE consists of three boreholes. Each borehole is 60 m deep. Data regarding brine temperature for borehole input and output were presented and discussed. As far as house had floor heating, there were presented data about COP for B0/W35 and its dependence from room and outdoor temperature during heating season. Empirical equation was created. Average heat energy consumption during one year for heating was 72 kWh/m^2 measured by heat meter. Detected primary energy consumption (electrical energy from grid) was 21 kWh/m^2 which resulted in SCOP=3.8. These data were compared with SCOP for air-to-water heat pump in Latvia and available configuration software for heat pumps operation. Good agreement between calculated performance and reported experimental data were founded.

1. Introduction

The heat pumps efficiency is represented by its coefficient of performance (COP). Heat pumps manufacturer provide COP data within technical documentation. However, during heating season total performance of the heat pumps is affected by combination of heat energy demand curve and temperature profile for environmental energy source (ground or air). Energy Related Products (ErP) Directive and EcoDesign Directive requires calculation of Seasonal Coefficient of Performance (SCOP) according to standard EN 14825. SCOP or Seasonal Performance Factor (SPF) is ratio of heat energy supplied for heating divided by electrical energy consumed by heat pump during average annual heating season.

Experimental measurement of Air-to-Water Heat Pump in Latvian climate give average value of SCOP from 2.93 to 3.2 during 2011-2014 heating seasons [1]. Our research devoted to Brine-to-Water Heat pump SCOP measurement for heating season 2015 and 2016 in Riga.

For ground heat exchangers, specific heat collection capacity depends on ground condition and design – for example single or double loop, trench/spiral collectors, vertical or horizontal etc.

According to this article experimental results specific heat collection capacity remained constant, but temperature of the outlet brine flow from the boreholes had described below fluctuation.

[2] To whom any correspondence should be addressed.

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The ground heat source limitation of capacity was investigated in article and should be considered.

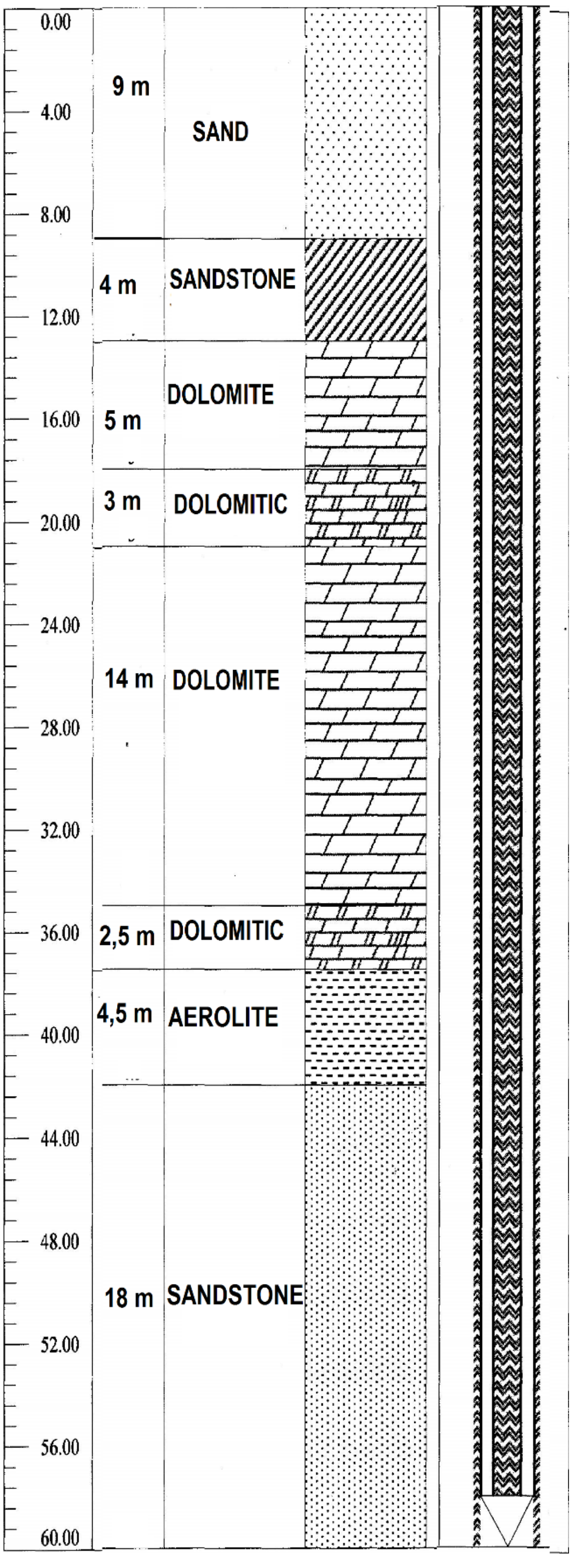

Figure 1. Borehole geological structure.

2. Experimental setup

The SCOP measurement were carried for detached two storey house with heating area of 160 m^2 with ceiling height 2,9 m. Walls of the house were built from perforated ceramic blocks (thickness 250 mm with thermal conductivity of 0.220 W/mK) with stone wool insulation outside by PAROC FAS3 thickness 150 mm with thermal conductivity of 0.040 W/mK.

Heating inside the building were provided by radiant floor system with snail layout. Due to that heat pump performance test was done according to DIN B0/ W35 (normally in test ground heat source brine temperature were from -1.0^{0}C to +10^{0}C) and heating water used in floor was warmed up to 35^{0}C. Ground heat exchangers analyzed in this paper consist of three vertical borehole each 60 m depth. Geological analysis give indication of underground layers presented in figure 1. The borehole diameter is 0.15 m. Empty space in borehole between wall and loop by U-pipes was filled by grout.
Horizontal distance between boreholes were around 6 meters.

Each borehole contains a loop of single U-tubes from polyethylene PE-HD 40x2 mm with an inner diameter of 0.036 m and an outer diameter of 0.04 m. The circulating fluid consists of a 25% monoethyleneglycol water solution.

Brine-to-Water Heat pump SI 8TU was installed in series with 200 litrs buffer storage tank. Heat pump had nominal heat output capacity of 8 kW at B0/W35.

The buffer tank ensures constant, sufficient water flow in floor heating system and also prevents frequent on/off switching of the compressor.

Heat energy generated by heat pump was measured by Sonometer 1100 installed after buffer tank. Electrical energy consumption by compressor and circulation pumps was measured by electricity meter ADDAX type NP73E.2-11-1.

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3.SCOP measurement results for year 2015 and 2016

Starting November 2013, heat pump was providing heat for described house. Heat meter and electrical energy meter were installed. After that, since end of 2014, systematic performance data collection was started. Therefore, in paper are presented experimental data of heating season for 2015, 2016 and partly 2017.

In this period house stayed empty without residents and domestic hot water function was switched off. Heat and electrical energy reading were recorded for each month together with average month temperature according weather data website http://www.meteo.lv. Overall electrical energy consumption consists of electricity consumed by heat pump compressor and by two circulation pumps: for brine (95 W) and for floor heating water (40 W).

Duration of heating season was seven months. Monthly average COP was calculated based on heat generation and electrical energy consumption. These results are presented in figure 2 and table I.

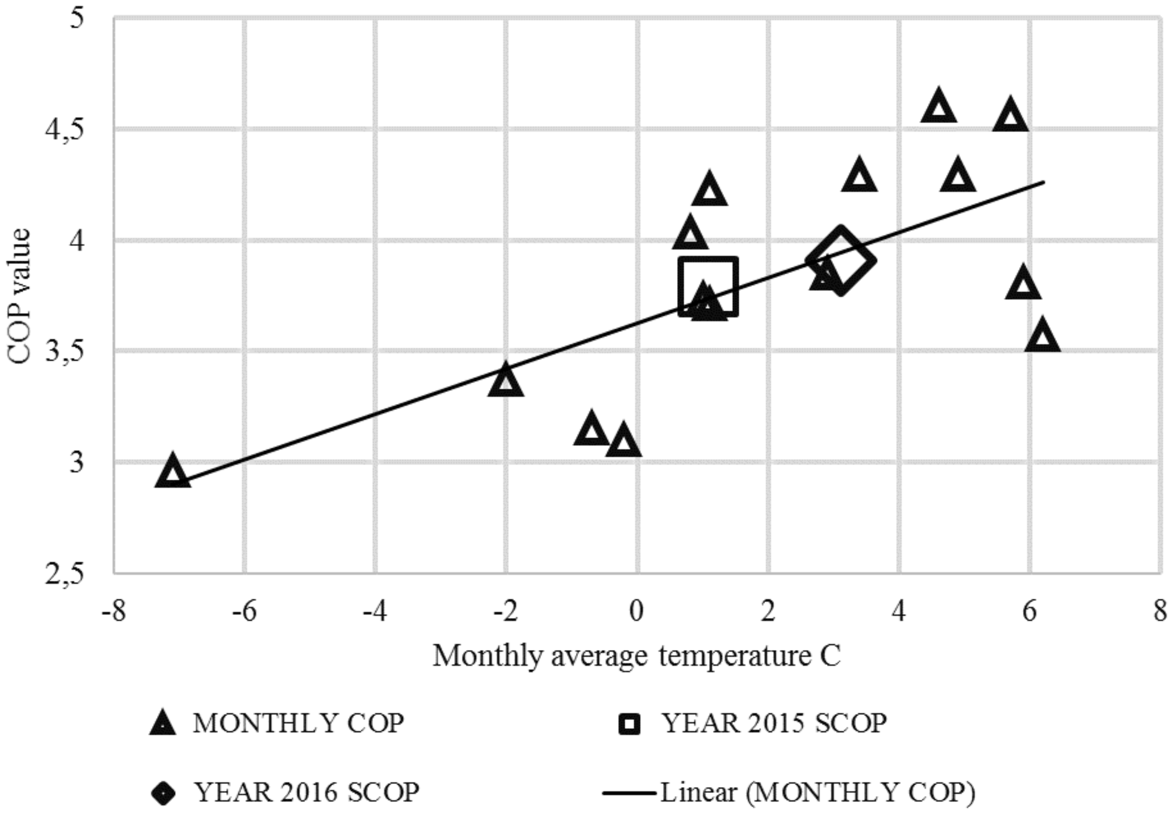

Figure 2. Monthly average COP and SCOP for heating seasons of 2015 to 2016 depending from average outside temperature.

Presented data shows that COP depends from outside temperature. This can be explained if floor heating uses big difference in temperature for cold and warm weather. In fact, temperature inside stayed almost constant: inlet water temperature for heating was about 32^{0}C and outlet water temperature was around 25^{0}C. This is average values because the buffer tank was used and heat pump generated heat in on/off cycling regime. Heat demand profile was supported by heat pump operation time during heating period.

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Experimental results in figure 2 can be represented by linear equation for monthly COP dependence from T_{av} average outside temperature

$$COP = 0.1022\ T_{\mathrm{av}} + 3.63 \tag{1}$$

Seasonal values SCOP for 2015 and 2016 are in good agreement with proposed equation. Such relationship (1) could be predictable for air-to-water heat pump. But for brine-to-water heat pump based on ground heat exchanger is not obvious why COP decrease with drop of average temperature. Therefore, is important to consider temperature of brine from ground source.

Table 1. Heat pump performance data in 2016 and 2015.

Year and month	Heat output, kWh	Electrical energy consumption, kWh	Monthly average temperature T_{av}, ^{0}C	Monthly average COP EN 14825
2017 January	2530	750	-2	3.37
2016 December	2001	536	1	3.73
2016 November	1991	494	0.8	4.03
2016 October	1386	323	4.9	4.29
2016 April	958	268	6.2	3.57
2016 March	1562	369	1.1	4.23
2016 February	1729	466	1.1	3.71
2016 January	2708	916	-7.1	2.96
Average temperature and SCOP for 2016			**1.1**	**3.79**
2015 December	1715	446	2.9	3.85
2015 November	1420	309	4.6	4.60
2015 October	1194	262	5.7	4.56
2015 April	1059	278	5.9	3.81
2015 March	1576	367	3.4	4.29
2015 February	1919	620	-0.2	3.10
2015 January	2301	731	-0.7	3.15
Average temperature and SCOP for 2015			**3.1**	**3.91**

4.Vertical ground heat exchangers seasonal performance

For vertical loop heat collector operation in borehole, where temperature at depth of about 15 m considered to be almost constant during all heating season, we made number of temperature measurement of brine flow for loop inlet and outlet.

The supply and return pipe of three ground loops were parallely collected in vault. Brine circulation pump provide a mass flow rate of 0.2 kg/s for each loop. That give average brine flow velocity in loop 0.7 m/s. Temperature difference for brine inlet and outle was always from 2^0C to 2.5^0C that means almost constant heat capacity of ground heat exchanger about 6.5 kW during heating season. As far as, total loops length was 180 m (three borehole each of 60 m depth) average power output from U-tubes loops were 36 W/m. This value is in good agreement with heat collection capacity for dry sediment ground given in [2]. However, the value of specific heat collection capacity can be up to 80-100 W/m for ground with high thermal conductivity at intensive underground flow or high grounwater level.

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Inlet and outlet brine flow temperature were measured by temperature transmitters installed in the heat pump and recorded every 5-10 minute during brine circulation cycle. Brine circulation normally started 2 minute before heat pump compresor switched on. The duration of compressor operation and brine circulation time depend on temperature in return line for floor heating loops connected to heat pump through buffer tank. When return line temperature reaches preset value compressor would stop operation and brine circulation pump also would be switched off after 2 minutes.

In this paper Fig. 3 we present results only for two measurments done in October 19, 2016, when average day temperature was +5^{0}C and February 5, 2017 with average day temperature of -8.1^{0}C.

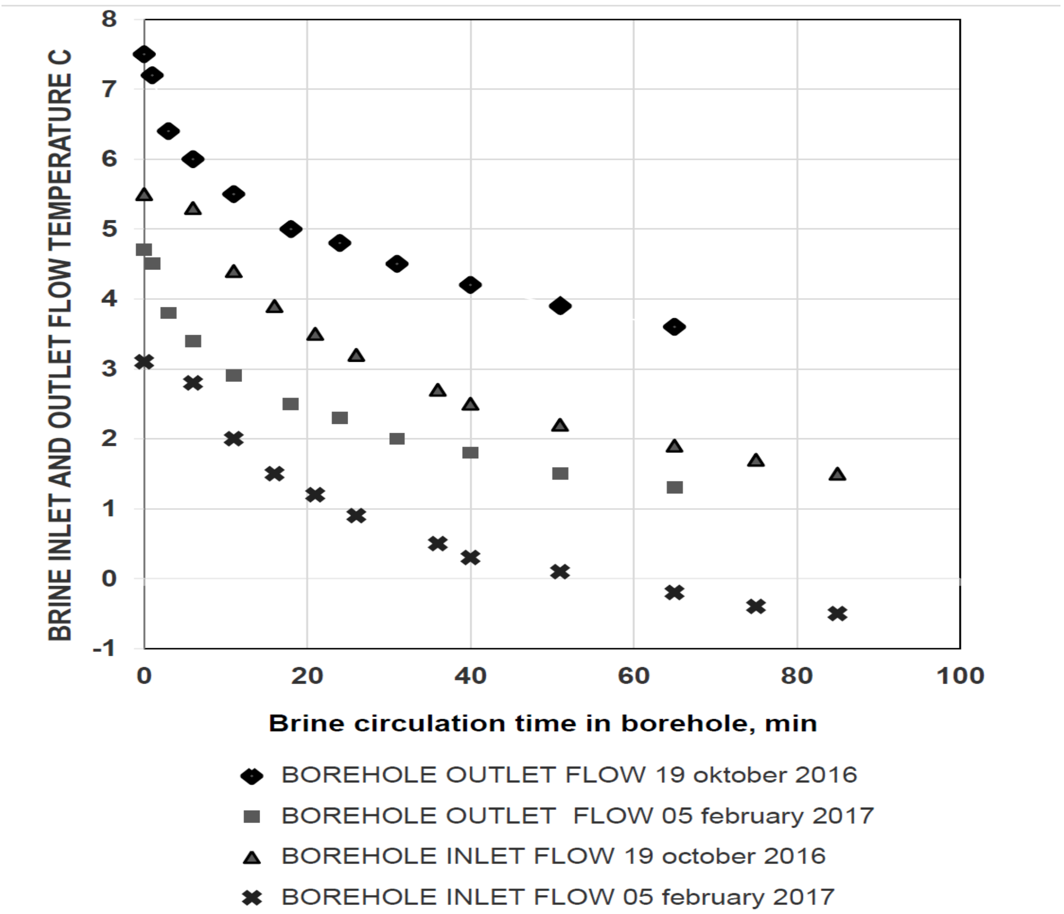

Figure 3. Brine flow temperature dependence on circulation time.

Duration of brine circulation in October 19 was 65 min, but for February 5, 2017 this duration become longer - up to 85 minute. This is due to bigger heat consumption inside the house heating system during cold period. The borehole outlet flow temperature (brine enter in heat pump evaporator) droped down from 4.4^{0}C (in October) to only 2.5^{0}C (in February). Evaporation of freon R410 A in the heat pump is going at average brine temerature (outlet and inlet of flow) and this pressure will affect heat pump coefficient of perfomance. Lower temperature and evaporating pressure will request more compression energy and COP will decrease.

Also during brine circulation flow inlet and outlet temperature drop down for around 4^{0}C in 65 minutes. Temperature of flow decreased because of grounds became cooler when heat was extracted from loops. This process definitely influenced COP of heating for various weather conditions. The question of how quick temperature of ground will recover between two heat extraction cycles needs to investigated more.

5.Results and discussion

Presented experimental results show that Seasonal Coefficient of Performance SCOP for brine-to-water heat pump with vertical ground heat exchangers is about 3.8-3.9 for average temperature of heating season +1..+3^{0}C. Air-to-water heat pumps in similar condition work at SCOP with value of 2.9-3.2[1].

The presented SCOP value for both types of heat pump can be used for selection purposes and economical calculation. There are known number of configuration software for heating systems with heat pumps.

In this article, we consider simulation result of investigated system by configuration software from website http://www.vpw2100.com. The configuration software offers two possibilities – to make selection for new building or for existing consumption. If we start from new build for described house (160 m^2) than configuration software proposes value for entered energy for heating 23020 kWh per year, which is around 143.9 kWh/m^2 per season. This value represents mean statistical heat losses for house heating. Considered configuration software has no function to calculate heat losses for heating taking in account wall heat insulation, windows area and design. However, house described in this paper consume average amount of energy for heating 70 kWh/m^2 in 2015 and 77 kWh/m^2 in 2016. That means total heating consumption of 11184 kWh/year in 2016 and 12335 kWh/year in 2015. Difference between configuration software suggested and considered house heat consumption is due to good level of heat insulation described above in section Experimental setup. Configuration software suggested heat consumption is higher and that will allow to keep safe margin for heating using heat pump. As far as our target is to evaluate SCOP calculation we will continue to consider configuration software's suggested set of consumption. According to configuration software requested electrical energy for selected Carrier 30NQC9H heat pump operation is 5730 kWh per year and recommended depth of borehole is 131 m with total collector pipe length of 460 m for operation in normal rock soil. In our measurement, electrical energy consumption were 3012kWh for 2015 and 3372 kWh for 2016 for used total length 180 m (three borehole each 60 m with total collector pipe length of 360 m). SCOP from configuration software data was around 4, which is close to our measurement in range of 3.8 to 3.9 during 2015-2016. In configuration software and in real measurements of described house heat consumption for domestic hot water preparation was switched off.

The presented value of SCOP corresponds to results of the heating season metrics of COPs value from 3.75 to 3.49 for house in Oak Ridge, Tennessee (USA), 36.01 ^{0}N 84.26 ^{0}W described in paper [3,4].

6. Summary

Performance of borehole ground heat exchanger requests more description than only recommendation for heat capacity collection in W/m for vertical loop. In our measurements, we find out that GHE heat capacity is 36 W/m of bore length, but for described configuration case it was around 50 W/m. Generally GHE power calculation is complicated function of geological structures and became in focus of recent research articles [5-8]. The proper design of GHE and alignment of its output with heat pumps operation will provide best possible SCOP value. The configuration software for heat pump selection present good agreement for prediction of SCOP with experimental results. However, heating energy consumption and desing of GHE evaluation by configuration software request more consideration and input information.

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