Experimental based determination of SCOP coefficient for ground-water heat pump

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Abstract. The paper presents research related to the operation of an ground-source heat pump with a thermal output of 16.85 kW and an electrical power of 3.72 kW in various conditions, both from the mechanical and thermodynamic perspective. The publication contains the results of research on a selected heat pump model with an R410a refrigerant carried out in an accredited laboratory in the Czech Republic. Detailed analysis of the data in terms of changes in the COP coefficient for two heating water temperatures was carried out (35°C and 55°C) and in the range of outdoor air temperature from -10°C to 15°C every 1°C. The analysis was also carried out to determine the efficiency of the heat pump depending on the parameters of the heat source. Devices of this type, enabling effective use of environmental available thermal energy with low operating costs, meet increasingly stringent environmental protection requirements. Significant costs of heating buildings are one of the main reasons for the need to look for alternative energy sources. The heat resources contained in water, air and land are huge. Due to the fact that heat pump prices dropped significantly, and their efficiency has increased over the last few years, these devices are a real competition for conventional ways of supplying buildings with heat. Heat pumps do not require daily maintenance, are fully automated and have intuitive control. These features allow to use them as components in the system of a modern and intelligent household. It was shown that the SCOP of the tested device increased by 1% on average reaching SCOP = 4.71 for a typical external calculation temperature and for a low-temperature heating system (35°C).

1 Introduction

Heat pumps are devices in which various processes occur, including condensation and evaporation at different pressures. In order to optimize the operation of these devices in the design process, it is necessary to measure many variable parameters, often under difficult conditions [1]. In industrial practice, the measurements are subject to additional uncertainties when analysing the obtained results [2]. The heat pump is a device that extracts energy from renewable heat sources such as ground, air or groundwater. Heat is taken from a source with a lower temperature, and then it is directed to a source with a higher temperature (heat sink).

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A source with a lower temperature should be understood as the ground characterized by temperature variability depending on the season, in the range of +5°C to +14°C, or air heated by solar radiation, with a temperature ranging from +8°C to +12°C. The heat sink for household purposes is the installation of central heating and hot utility water. In Poland the heat pump, despite many years of its use in construction, is still considered an unconventional source of energy. Providing heat in an ecological way with a relatively low energy input used to power the compressor. Recently there are many different experimental researches conducted to determine the best operating conditions for the HP. For example the influence of variable speed compressor, variable speed water pumps and variable speed fans in the coils [3], quality of a borehole heat exchanger [4] or regeneration of borehole heat source [5]. Another approach is the comparison of different types of HP [6] or study to optimize the injection-port geometries of a vapour injection asymmetric scroll compressor operating under various climatic conditions [7]. Also the changes in the stability of indoor air temperature and power consumption is a subject of investigations [8], along with the numerical models to simulate the transient and steady state behaviour of a vapour compression refrigeration system [9]. The objective of this study is to investigate SCOP depending on variable weather conditions.

2 Measurement setup

With the purpose of determining the SCOP of the examined HP, a measurement system was developed with the layout presented in Fig. 1. The analyzed HP contained a number of the design upgrades, which offered the achievement of greater SCOP compared to other equipment with a similar capacity. The principal element that forms a novelty in the analyzed HP applies the use of a spiral compressor, whose description is found below. The heat sink is the household heating system in the form of a buffer tank, central floor heating installation and installation of water radiator system. Tested ground-water HP is designed for cooperation with a glycol ground exchanger. The HP is equipped with compressor, in which the compression process takes place in cooperation with two brand new designed spiral compressors. This allows to achieve higher efficiency, increase the service interval, as well as to obtain low noise and vibrations. The device is equipped with electronic circulating pumps, with modulated power adapting to the system operation, with low power consumption. The electronic expansion valve maximizes the energy recovery accumulated in the soil. The tested HP is also equipped with a switching valve that allows the circulation of hot utility water. In addition, the device has the ability to control the hot tap water circulation pump and set the schedule of its operation. The heat pump controller also allows controlling the heating circuits of the central floor heating system [10] and the central heating installation, or the additional heater of the hot water storage tank [11].

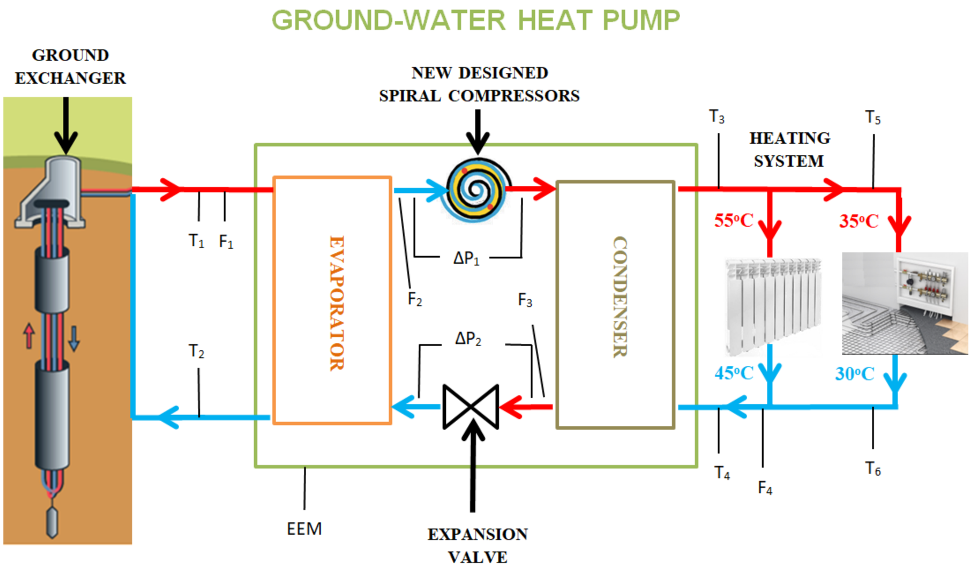

Fig. 1. Schematic view and the layout of measurement system: T_1, T_2, T_3, T_4 – thermometers; F_1, F_2, F_3, F_4 – flowmeters; ΔP_1, ΔP_2 – differential pressure transducer; EEM – electric energy meter.

The HP evaporator has the form of a plate heat exchanger, where the heat supplied from the ground via glycol is received. In the exchanger there is evaporation of refrigerant R410A via heat from the ground. The flow of glycol through the exchanger is driven by the circulation pump. The refrigerant in the gas form is directed to the compressor where the compression process is increasing its temperature and pressure. Then it goes to the condenser, where the heat is given back. The condenser has the form of a plate exchanger. The refrigerant in the condenser transfers the heat to the water. Then the medium is subjected to a process of expansion in the expansion valve, where its pressure and temperature are reduced, after which it is again directed to the evaporator and the whole process is repeated [12]. Table 1 presents the measurement values of indicators needed to determine the SCOP.

Table 1. Measurement values of indicators needed to determine the SCOP.

Indicator	Measured Value	Unit
H_{HE}	2066	[h]
H_{TO}	178	[h]
H_{SB}	0	[h]
H_{CK}	3850	[h]
H_{OFF}	3672	[h]
P_{TO}	42.2	[kW]
P_{SB}	9	[kW]
P_{CK}	0	[kW]
P_{OFF}	9	[kW]
P_{design}	18.81	[kW]
$SCOP_{ON}$	4.65	[-]

3 Results

Coefficient Of Performance (COP) is an indicator of the efficiency of heat pumps. This coefficient relates to the temperature of the medium from which the heat is taken (the heat source) and the medium to which the heat is given off (the heat sink). The COP is a temporary value, variable with outdoor temperature. The Seasonal Coefficient Of Performance (SCOP) coefficient determines the efficiency of heat pumps at several temperature points, not taking into account the diversity of temperature changes in Europe, which is in the area of three climatic zones (Average, Warmer, Colder) and hence other operating temperatures as well as the SCOP coefficient. In addition, there are heat pump subassemblies that consume a significant amount of electricity per year, which should be taken into account when determining the efficiency of the entire heating device. The determination of the SCOP coefficient consists in determining the ratio of the heat pump's demand for electricity throughout the heating season in a given climate zone to the amount of energy consumed by all heat pump devices in different work cycles, in which the compressor breaks after the set parameters are taken into account [13].

The SCOP coefficient can be described by the formula (1):

$$SCOP = \frac{Q_h}{Q_{HE}} \, \mathrm{SCOP} = \frac{\mathrm{Q_H}}{\mathrm{Q_{HE}}} \, \mathrm{SCOP} = \frac{\mathrm{Q_H}}{\mathrm{Q_{HE}}} \tag{1}$$

where:

Q_H – annual demand for heat, Q_{HE} – annual electricity consumption

$$Q_H = P_{desigh} \cdot H_{HE} \tag{2}$$

where: P_{desigh} – computing power, H_{HE} – number of hours of heating determined by the climate zone.

$$Q_{HE} = \frac{Q_H}{SCOP_{on}} + H_{TO} \cdot P_{TO} + H_{SB} \cdot P_S + H_{CK} \cdot P_{CK} + H_{OFF} \cdot P_{OFF} \tag{3}$$

where:
H_{TO} – quantity of hours in the season when the thermostat is turned off, H_{SB} – quantity of hours in the season in heat pump standby mode, H_{CK} – quantity of hours of compressor crater heating in the season, H_{OFF} – Number of hours when the compressor does not consume electricity, P_{TO} – the amount of energy collected in the season, P_{SB} – the amount of energy taken in standby mode, P_{CK} – the amount of energy taken to heat the compressor crater, P_{OFF} – the amount of energy consumed when the compressor itself does not work.

Research on a selected ground source HP was carried out in an accredited laboratory in Brno in the Czech Republic. The device efficiency analysis was carried out for the heat sink temperature of 35°C and 55°C. Table 2 presents the results of the HP tests, characterizing the tested ground heat pump for two set temperatures of heating system water (35°C and 55°C) and variable outdoor temperatures. The tests were conducted for the outside temperature in the range of -10°C to 15°C. It is clear that SCOP is dependent on outdoor temperatures in a large extent.

Table 2. Results of the determined SCOP for the measured values of the tested HP for given domestic hot water temperatures of 35°C and 55°C for different outdoor temperatures.

Item	**Outdoor temperature [°C]**	**Load indicator [%]**	**Temperature of hot water 35°C**		**Temperature of hot water 55°C**	
			Electricity consumption [kW]	**Coefficient SCOP [-]**	**Electricity consumption [kW]**	**Coefficient SCOP [-]**
1	-10	100.00	18.81	4.40	17.68	2.87
2	-9	96.15	18.09	4.43	17.00	2.93
3	-8	92.31	17.36	4.47	16.32	3.00
4	-7	88.46	16.64	4.51	15.64	3.06
5	-6	84.62	15.92	4.52	14.96	3.12
6	-5	80.77	15.19	4.54	14.28	3.17
7	-4	76.92	14.47	4.56	13.6	3.23
8	-3	73.08	13.75	4.57	12.92	3.29
9	-2	69.23	13.02	4.59	12.24	3.35
10	-1	65.38	12.30	4.61	11.56	3.41
11	0	61.54	11.58	4.63	10.88	3.46
12	1	57.69	10.85	4.64	10.20	3.52
13	2	53.85	10.13	4.66	9.52	3.58
14	3	50.00	9.41	4.68	8.84	3.65
15	4	46.15	8.86	4.71	8.16	3.71
16	5	42.31	7.96	4.73	7.48	3.78
17	6	38.46	7.23	4.76	6.80	3.85
18	7	34.62	6.51	4.78	6.12	3.92
19	8	30.77	5.79	4.78	5.44	3.97
20	9	26.92	5.06	4.77	4.76	4.02
21	10	23.08	4.34	4.76	4.08	4.07
22	11	19.23	3.26	4.75	3.40	4.12
23	12	15.38	2.89	4.74	2.72	4.17
24	13	11.54	2.17	4.74	2.04	4.23
25	14	7.69	1.45	4.73	1.36	4.28
26	15	3.85	0.72	4.72	0.68	4.33

Changes in the percentage ground load of the heat pump, electric energy consumption and the SCOP coefficient depending on the outside temperature (in the range from +15°C to -10°C) are presented in the Figures 2, 3 and 4.

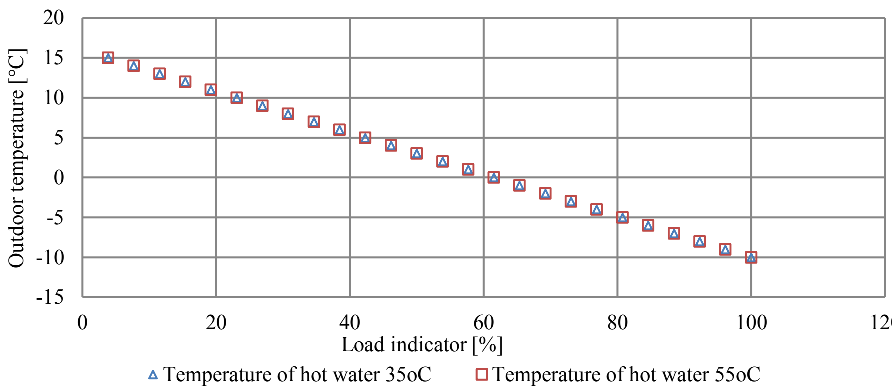

Fig. 2. Relation of the outside temperature to the HP load indicator.

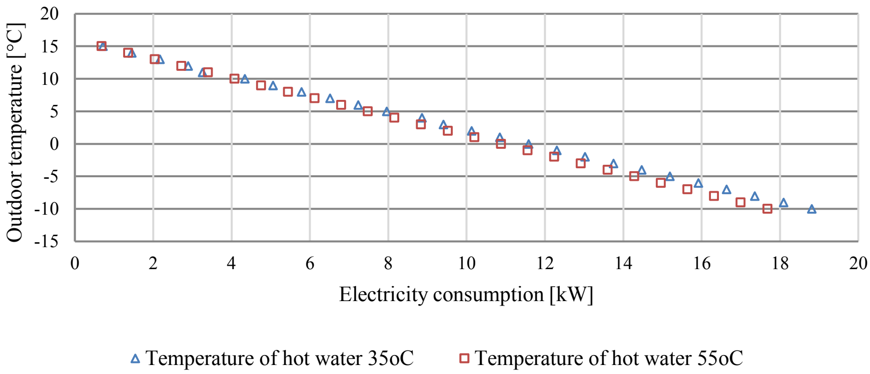

Fig. 3. Relation of the outside temperature to HP electricity consumption.

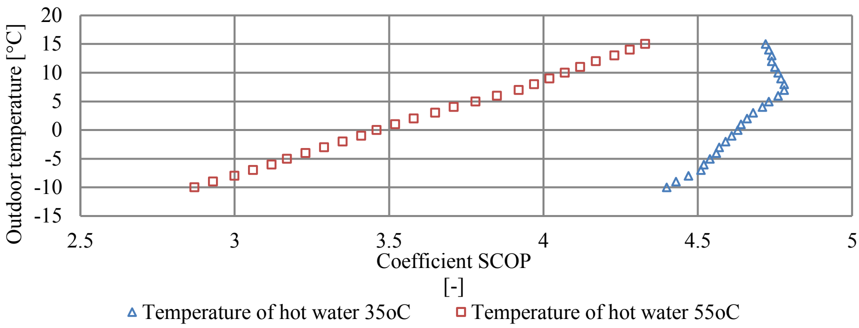

Fig. 4. Relation of the outside temperature to the HP SCOP coefficient.

The completed studies show that HP performance depends on the outside temperature. The SCOP coefficient of the tested heat source reached the value of 3.59 for the hot water temperature 55°C and 4.63 for 35°C. The research shows that as the outside temperature drops, the efficiency of the heat pump decreases and its load and electricity demand increase. At an external temperature of -10°C and a hot water temperature at 55°C, the HP system operates at 100% load, taking approximately 18.81 kW of electrical power and SCOP reaches 4.4. At the same value of outdoor temperature (-10°C) and hot water temperature 35°C, the system works also at 100% load, however it consumes 17.68 kW of energy and reaches the significantly lower SCOP of 2.87. As the outdoor temperature decreases, the SCOP decreases, which is caused by the need to start the heater supporting the heat sink. At the temperature of +15°C the HP has very high efficiency, as well as low energy consumption. For a given temperature of the heating system 35°C the HP load is 0.72 kW. For the heating system temperature of 55°C the HP load is 0.68 kW.

4 Conclusion

The publication contains the results of research on a heat source of the ground heat pump manufactured by one of the Polish producers charged with the R410a refrigerant. The research was carried out in an accredited laboratory located in the Czech Republic. A detailed analysis of the data in the scope of SCOP changes for two heating system temperatures was carried out (35°C and 55°C) in the range of outdoor air temperature from -10°C to 15°C. The analysis was also carried out to determine the efficiency of the heat pump depending on the parameters of the heat source. The conducted research shows that the tested ground heat pump at a set temperature of 35°C achieved very high efficiency coefficients in relation to the outside temperature. Average SCOP = 4.65. For the most frequent temperature in Poland (t = 4°C) SCOP = 4.71. The results of measurements at 55°C are characterized by much lower efficiency values in relation to the outside temperature, and the same decrease in efficiency is more progressive than for the variant with a lower heating temperature. Average SCOP = 3.59. For the most frequent temperature in Poland (t = 4°C) SCOP = 3.71.

It is 1% higher than similar HP constructions available on the Polish market. According to the literature, modernizations of this type of compressor (e.g. the numerical optimized injection-port designs in the asymmetric scroll compressor were proposed to achieve the maximum SCOP at various climatic conditions, which increased the SCOP by 2%–6% relative to the baseline injection compressor [7].

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