Investigations into the influence of functional parameters of a heat pump on its thermal efficiency

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Summary. The paper presents some issues related to the selection criteria of a heat pump based on the published research results. The experimental research conducted on a single family house with a floor heating allows an assessment of the influence of individual functional parameters on the heat pump energy performance coefficient.
Key words: ground source heat pump, vertical collector, scroll compressor, evaporator, condenser, lower heat source, coefficient of performance.

1. BACKGROUND INFORMATION

Heat pumps have practically been used in Europe for 25 years now but recently we have been observing a rapid growth in their sales. This partly results from the requirements set by the EU directives whose main aim is to increase the use of RSE in the final energy consumption to 15% in 2020.

According to the data obtained from the Polish Organization for the Development of Heat Pumps (PORT PC) we can state that in 2011 in Poland approximately 10 000 heat pump units were sold [18, 23].

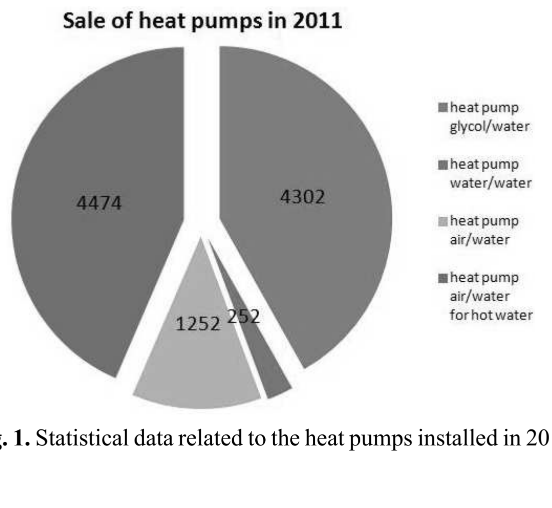

Fig. 1. Statistical data related to the heat pumps installed in 2011

The technology of geothermics, known and developed in the world for over 50 years has gained an increased interest in Poland, too. Unfortunately, it still is a consequence of the efforts of the manufacturers and fans of this type of technology who try to show the invaluable advantages this technology has despite relatively high investment costs. A group of satisfied users also contributes to the growing popularity.

Out of all the installed heat pumps the main share constitute the ground source heat pumps that, due to the cold climate, are preferred by Polish users. In Poland in the sector of ground source heat pumps (41-43% in the years 2008-2009) the most frequently installed are the ones of the power output of up to 10 kW. They are fitted in new single-family houses of the usable area of 150 ÷ 200 m². Such houses constitute 80% of all newly built houses. In recent years a growth in the demand for high power heat pumps has also been observed for the purposes of heating of multifamily houses, office buildings, hotels and buildings undergoing modernizations [7,16].

A dynamically evolving market is the market of air heat pumps used exclusively for the production of hot water. It is mainly caused by their low price and simplicity of fitting. Because of their function they most often compete with solar thermal collectors. Compared to solar thermal systems heat pumps are more cost efficient, capable of producing hot water throughout the year and provide additional ventilation, dehumidification and air conditioning of rooms.

2. CHARACTERISTICS OF THE RESEARCH STAND

INTRODUCTION

At the Institute of Mechanical Engineering of Warsaw University of Technology in Płock for some years now works have been continued in the area of renewable sources of energy (RSE). Due to a constant decrease of the costs of the installation of renewable sources of energy (RSE) in recent years the interest in these systems has grown significantly. In the current energy-related situation the development of RSE as complementary sources of energy to traditional solutions is a must. To this end, the university team has undertaken to optimize the operating processes of mechanical systems in terms of selected RSE installations. An idea was created to explore fundamental relations between the heat pump parameters in the aspect of minimization of energy consumption. To this end the authors designed and developed a research stand of a ground source heat pump and vertical collectors.

CHARACTERISTICS OF THE RESEARCH STAND

The heating system utilizing a ground source heat pump (brine/water) was installed in a two story single-family house of the total area of **156 m²**. Minding the application of the heat pump a low temperature floor heating system was installed on both stories. The heating circuits on the ground and first floors were supplied independently with circuit pumps, which allowed an easy control of the supply of the heating power to the rooms on the ground and fist floors.

In the blueprint documentation of the building an annual demand for energy of **E=16400 kWh/year** is given. Assuming an average operating time of the heat pump on the level of **1800 h** we can obtain an estimate thermal load of the building on the level of **9.1 kW** [14. 24].

CONSTRUCTION OF THE RESEARCH STAND

The realization of the adopted scope of experimental research and the fulfillment of the basic guidelines as to the construction of the research stand practically excluded serially manufactured heat pumps. The authors decided to build a heat pump basing on generally available construction subassemblies of renowned manufacturers in the refrigeration industry.

It was assumed that the refrigerant would be the widely applied CFC free **R407C.** In the condenser and evaporator plate heat exchangers by WTK were applied and the supplier of the control systems was Danfoss.

Due to an even load of the individual phases of the electrical installation and the experimental research performed using an inverter, the authors decided to use a three-phase power supply for the compressor. From the catalogue the authors selected the smallest of the available three phase compressors of the heating power of **9 kW.** For the assumed working parameters (**B0/W35)** it has the coefficient of performance of **COP=4,4.** The catalogue compressor number is C-SBN263H8A.

Tab. 1. An excerpt from the catalogue data for the C-SBN263H8A compressor

C-SBN263H8A 400V/3f/50Hz / 400В/3ф/50Гц						R407C
Temperatura skraplania / Condensing temperature / Температура конденсации [°C]	Temperatura odparowania / Evaporating temperature / Температура кипения [°C]	-10	-5	0	+5	+10
30	Wydajność / Capacity / Производсть, [W] [Вт]	6638	8081	9846	12005	-
	Moc / Power consumption / Потр.мощн. [W] [Вт]	1889	1890	1885	1873	-
	Pobór prądu / Rated current / Потр. ток, [A]	3,7	3,8	3,8	3,8	-
	Współczynnik efektywności / COP / КПД	3,51	4,28	5,22	6,41	-
35	Wydajność / Capacity / Производсть, [W] [Вт]	6127	7473	9123	11146	13614
	Moc / Power consumption / Потр.мощн. [W] [Вт]	2079	2080	2076	2064	2044
	Pobór prądu / Rated current / Потр. ток, [A]	4,0	4,1	4,2	4,2	4,2
	Współczynnik efektywności / COP / КПД	2,95	3,59	4,39	5,40	6,66
40	Wydajność / Capacity / Производсть, [W] [Вт]	5645	6901	8442	10338	12660
	Moc / Power consumption / Потр.мощн. [W] [Вт]	2310	2313	2309	2298	2279
	Pobór prądu / Rated current / Потр. ток, [A]	4,5	4,5	4,6	4,6	4,5
	Współczynnik efektywności / COP / КПД	2,44	2,98	3,66	4,50	5,56
45	Wydajność / Capacity / Производсть, [W] [Вт]	5192	6365	7805	9580	11762
	Moc / Power consumption / Потр.мощн. [W] [Вт]	2583	2587	2584	2574	2556
	Pobór prądu / Rated current / Потр. ток, [A]	5,0	5,0	5,0	5,0	5,0
	Współczynnik efektywności / COP / КПД	2,01	2,46	3,02	3,72	4,60

From the presented catalogue data it results that in the range of evaporation temperatures (-10ºC ÷ +10ºC) the power consumption is on the same level but the compressor efficiency grows, hence the coefficient of performance (COP) is also proportionally higher for higher temperatures. Thus, we need to maintain the highest possible refrigerant evaporation temperature values. The increase in the temperature of the condensation causes significant drops in the coefficient of performance (COP).

Due to limited possibilities related to the organization of the plot and disadvantageous ground conditions (on the depth of 1÷2 m sand deposition was discovered) a lower heat source was performed using a vertical collector.

For the selection of the vertical collector the authors used dedicated **Energeo** software recommended by Aspol – the supplier of the probes of the vertical exchanger. Upon entering of the parameters of the pump to the Energeo software for the assumed coefficient of ground thermal power on the level of **38 W/m** a total required length of the vertical exchanger of **186 m** was calculated (dual pipe probes were applied, filled with a 20% solution of ethylene glycol. Three probes **62 m** each were connected to the wall distributor located in the heater room [8, 12].

Upon installing of the research stand the circuit of the lower heat source was filled with a solution of ethylene glycol of the concentration of 20% (fluid known as Henock 20E15). The circuit of the upper heat source was filled with water. Upon breathing individual circuits, lower heat source circuit pumps were activated for two hours to obtain an even fluid concentration in the whole circuit.

Next, a calibration was performed of the individual measurement chains and a verification of the correctness of the installation of the control circuits was carried out.

3. RESULTS OF THE PRELIMINARY TESTS

The preliminary tests were carried out in November and December in the heating season 2012/2013. For economic reasons the experimental research was carried out in the G12 off peak time of day (night rates applied) [6, 20].

During the tests the basic operating parameters necessary for the determination of the heat balance were recorded.

Symbols adopted in the graphs:

– Tgin – glycol temperature at the inlet from the lower heat source,

– Tgout – glycol temperature at the outlet from the evaporator,
– Thin – return water temperature from the heating circuit,
– Thout – heating circuit water temperature,
– Tco –condensation temperature of the refrigerant,
– Tev – evaporation temperature of the refrigerant,
– Tcwu – water temperature in the hot utility water tank,
– Tcoin – refrigerant temperature at the inlet to the condenser,
– Tevout – refrigerant temperature at the outlet from the evaporator.

Fig. 2 clearly shows that at constant chilling power of the heat pump the increase in the temperature in the hot utility water tank forces an increase in the temperatures of the upper heat source.

From the presented graphs (Fig. 3 and Fig. 4) it results that for a constant temperature difference in the glycol circuit of the lower heat source for the higher preset evaporation temperature, the capability of the takeoff of the refrigerating power by the heat pump decreases.

Additionally, maintaining a higher inlet temperature to the upper heat source causes a much lower value of the coefficient of performance.

Fig. 4 shows that within the first 15 minutes from the pump activation a significant increase in the temperature of the return water was observed in the upper heat source for the floor circuit pump on the ground floor set to speed I. Switching the pumps to speed II causes an abrupt drop in the temperature of the inlet water to the upper heat source. Fig. 5 shows the changes in the temperatures for

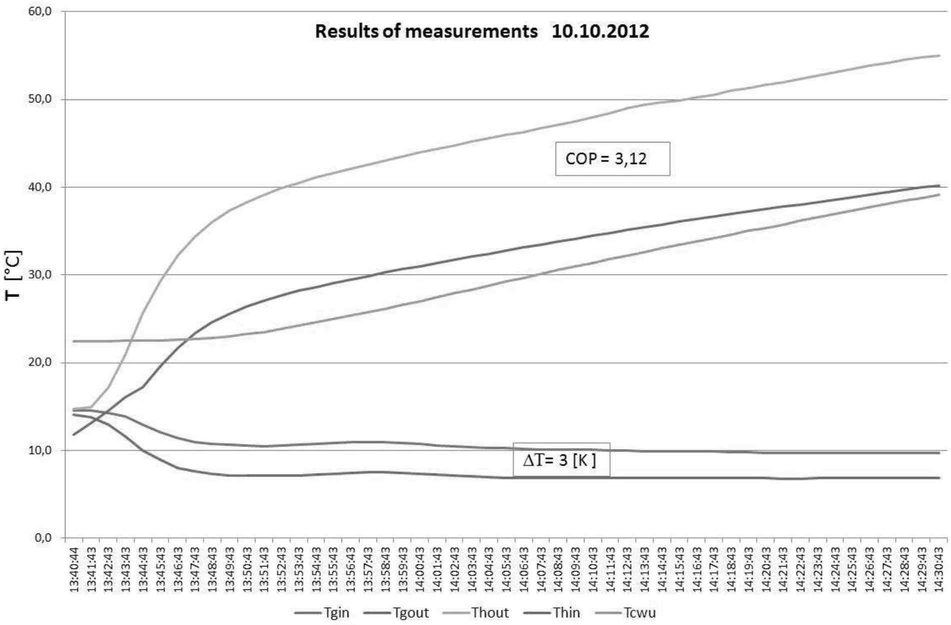

Fig. 2. Changes in the temperatures in the hot utility water tank circuit

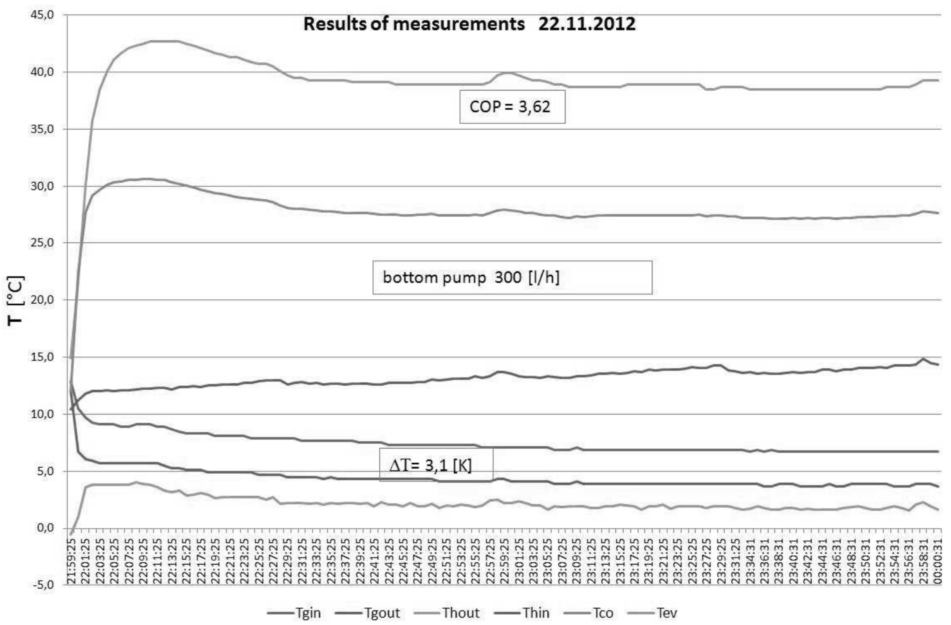

Fig. 3. Changes in the temperatures in the floor circuit for the evaporation temperature of 2°C

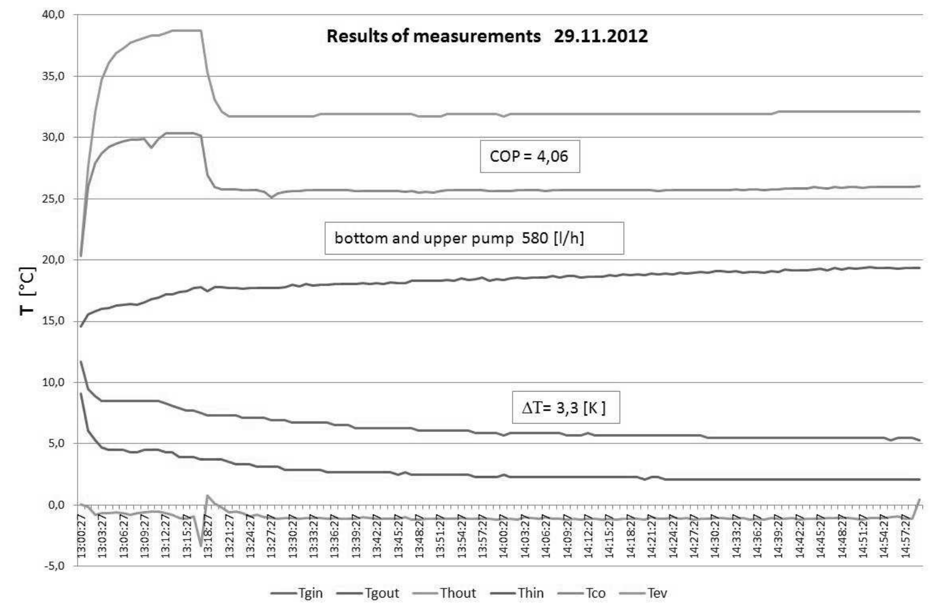

Fig. 4. Changes in the temperatures in the floor circuit for the evaporation temperature of -1°C

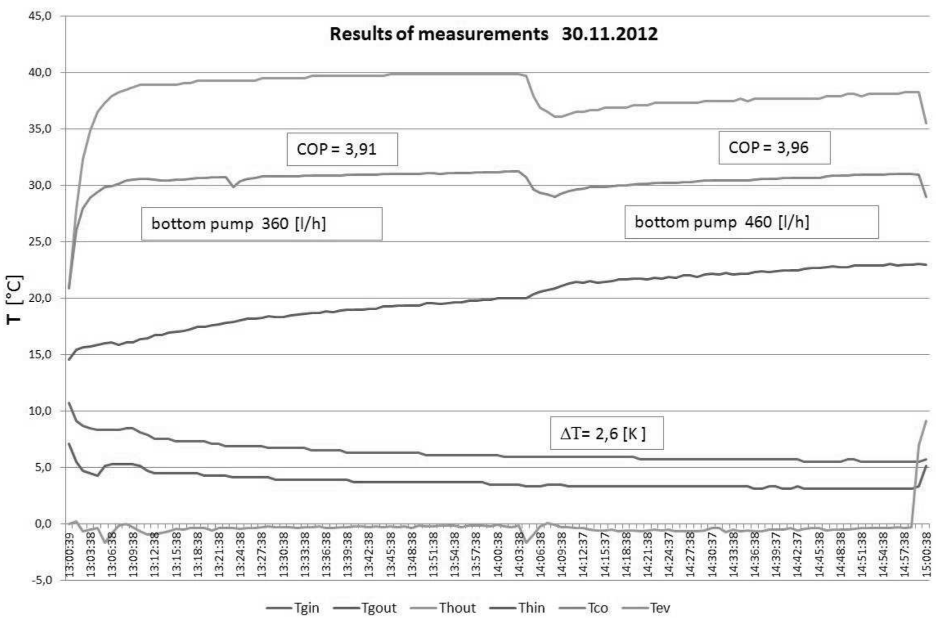

Fig. 5. Changes in the temperatures in the floor circuit for the evaporation temperature of 0°C and circuit pumps in the glycol circuit set to speed II

the case when in the upper heat source circuit only the floor circuit was on and the circuit pumps of the lower heat source were set to speed II. At a constant heat transfer rate in the ground for given conditions, changing the glycol flow rate results in a decrease in the difference in the glycol temperature at the inlet and return of the evaporator.

When only the floor circuit on the ground floor is on, setting the pump to speed II does not result in such a large decrease in the temperature of the inlet water in the upper heat source anymore, as was the case in the example shown in Fig. 4.

In the graph (Fig. 6) we can additionally see the course of the temperature changes in the condenser and evaporator for the CFC circuit.

The temperature of the refrigerant at the outlet from the compressor remains on the level of 60°C irrespective of the operating parameter changes of the upper heat source in the floor heating.

4. CONCLUSIONS

The research was carried out in a single-family house that is not yet in regular use. For purely economic reasons the room temperature was maintained on the level of 16°C, as generated by a heat pump operating in the off peak time of day when night rates for electricity applied. Hence, the pump during the research did not operate under optimal conditions. Nevertheless, from the prelimi-

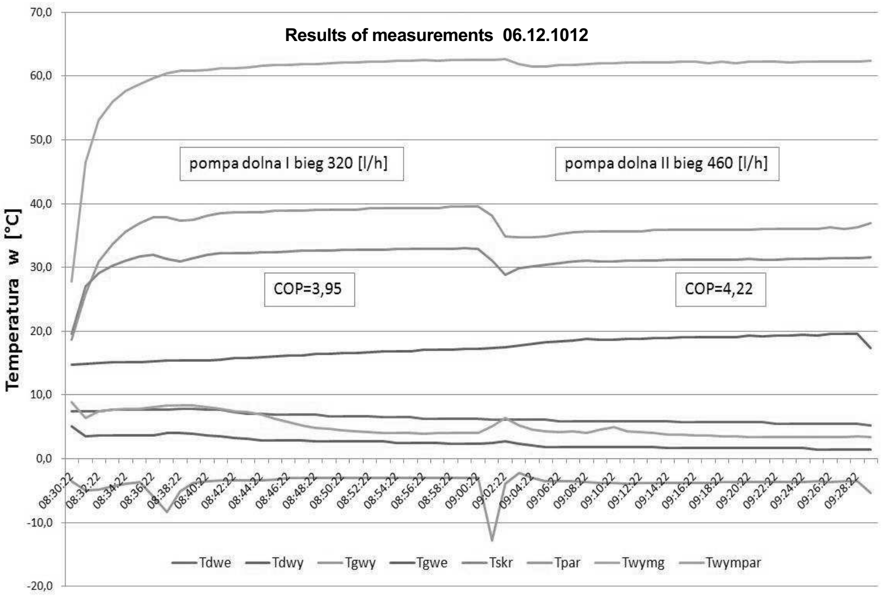

Fig. 6. Changes in the temperatures in the floor circuit for the evaporation temperature of -3°C

nary investigations we were able derive which operating parameters have a significant impact on the heat pump energy performance.

Determining of the fundamental relations of the influence of the operating parameters of the heat pump on the heat pump coefficient of performance will become possible upon a completion of research on the entire range of changes of the operating parameters. A detailed analysis of the obtained results will allow a determination of which of the subassemblies significantly block the possibility of obtaining a better coefficient of performance. The effect of this analysis will be a validation of the correctness of the methodology of selection of the individual heat pump subassemblies.

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BADANIE WPŁYWU PARAMETRÓW FUNKCJONALNYCH POMPY CIEPŁA NA WYDAJNOŚĆ CIEPLNĄ

Streszczenie. W pracy zostały zaprezentowane wybrane zagadnienia dotyczące doboru gruntowej pompy ciepła na podstawie publikowanych wyników badań. Przeprowadzone badania eksperymentalne na stanowisku badawczym (domek jednorodzinny z ogrzewaniem podłogowym) pozwolą oszacować wpływ poszczególnych parametrów funkcjonalnych na współczynnik efektywności energetycznej pompy ciepła.
Słowa kluczowe: gruntowa pompa ciepła, kolektor pionowy, sprężarka spiralna, parownik, skraplacz, źródło dolne, współczynnik efektywności energetycznej.