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Experimental Study of the Air Heat Pump for Domestic Hot Water

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The article contains the results of the experimental research of the air heat pump for the preparation of domestic hot water (DHW). An installation consisting of a modular heat pump for hot water connected to two storage tanks with a capacity of 130 dm^3 each was the object of the research. The article presents the results of investigations on the influence of the supply air temperature in the evaporator cycle and the variable heat load of the condenser on the heating capacity of the heat pump and the coefficient of performance (COP). The tests were carried out for water heating cycles in the storage tank from room temperature to 50 °C. The research shows that heating water in a 130 dm^3 storage tank with ventilation or external air at a temperature above 15 °C takes an average of 2 h, and the heat pump consumes approx. 2.2 kWh of energy per heating cycle. Pump operation in winter is possible with the use of ventilation air, but with the discharge of air cooled outside the building. In order to ensure conditions for effective compressor operation, it is advisable to gradate heat load of the heat pump. The optimal solution is to use a circulating pump with smooth regulation of performance. The air source heat pump for DHW heating is an ideal solution for heating systems equipped with solid fuel boilers. It is a maintenance-free and economical system for producing domestic hot water outside the heating season.

1. Introduction

Water heating, as one of the major energy consumer in the world today, has become an inseparable part of modern life (Ibrahim et al., 2014). It accounts for a high proportion of all residential energy consumption, which is 14 % in European Union, 17 % in the United States, 22 % in Britain, and 27 % in China.
Heat pump technology helps reduce the consumption of electricity or fossil energy. Therefore, in comparison with traditional electric water heater (EWH) and gas water heater (GWH), air source heat pump water heater (ASHPWH) makes a better use of the energy from air. ASHPWH is energy-saving, low-cost, and safe in use, which provides a new energy-efficient way with a promising prospect in water heating.
One of the fastest growing heating technologies in Poland are currently air/water and air/air heat pumps (Piwowarczyk, 2014). It results from the obligatory use of energy classes of heating devices, class A+ and A++ introduced in 2015 (Lachman, 2014). The whole fits in with the European Union strategy regarding the reduction of CO_2 emissions and the development of Renewable Energy Sources (Wagener, 2017).
Maintaining high energy efficiency of the heating system in a wide range of ambient temperature changes in different seasons, is an important problem in installations with air heat pumps. That is why, the research is being carried out to optimize the structural solutions of the components.
The integration of new versions of condensers directly with water storage tanks increases efficiency of the heating system (Peng et al., 2016). New structural solutions of subassemblies, such as expansion valves, enable higher efficiencies, making air heat pumps economically attractive compared to other heating systems (Jiang, 2011).
Hybrid system solutions (He et al., 2017) or cascade systems (Jung et al., 2013) are increasingly being used in Europe. A good complement to such an installation are also integrated solar collectors (Dong et al., 2017) or photovoltaic panels (Anifantis, 2017). At the same time, simulation studies of hybrid solutions are also conducted (Walmsley et al., 2017). The main justification for the use of hybrid heating systems is the rising prices of traditional fuels or the lack of availability of cheaper heat energy carriers.

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2. Test stand

The Hewalex DHW heat pump for the construction of the test stand was offered in the version with an external hot water tank. This solution allows the use of tanks with different water capacity for testing. The method of installing a 2.5 kW DHW heat pump in the test stand is shown in Figure 1.

Figure 1: Installation of a DHW heat pump in a test stand

Characteristic for this heat pump is the connection of the upper source to the circulation circuit in the tank, not to the built-in coil. In the designed test stand, two tanks with a capacity of 130 dm^3 were used. This solution enables testing of a heat pump with variable heat load of the upper heat source (Szreder, 2014).
The designed test stand has been equipped with the EKONTROL system offered by Hewalex. The measuring equipment enables the heat flow to be measured in the heat pump's upper source circuit. During the laboratory tests, the measurement data were recorded on an ongoing basis in the EKONTROL system database. The test stand has been equipped with an additional G922-COP measuring module for testing the COP coefficient with access to the database at ekontrol.pl

3. Experimental results

The ventilation air of the laboratory room and outside air were used for the tests. The series of measurements were carried out for cases of heating water in containers 130 and 260 dm^3 from room temperature to a water temperature of 50 °C. The measurements were carried out for the 3 speeds of a standard 60 W circulation pump, getting an average water mass flow rate amounting to 0.17 kg s^{-1} on the 1st speed, 0.24 kg s^{-1} on the 2nd speed and 0.27 kg s^{-1} on the 3rd speed.
Figure 2 shows changes in registered temperatures in the heat pump cycle for the use of outdoor air at 17 °C for heating water in a 130 dm^3 storage tank to 50 °C (profile A17/W30-50) and setting the circulation pump to 3rd speed. The increase in the temperature of the water in the tank gradually forced an increase in the temperature of water in the heating circuit, so that the temperature of condensation also gradually increased. With the increase in temperature in the heating circuit, the heat load of the heat pump was successively reduced, which is evidenced by the recorded increase in the evaporating temperature of the refrigerant at a constant air temperature at the inlet to the evaporator (Szreder, 2013).

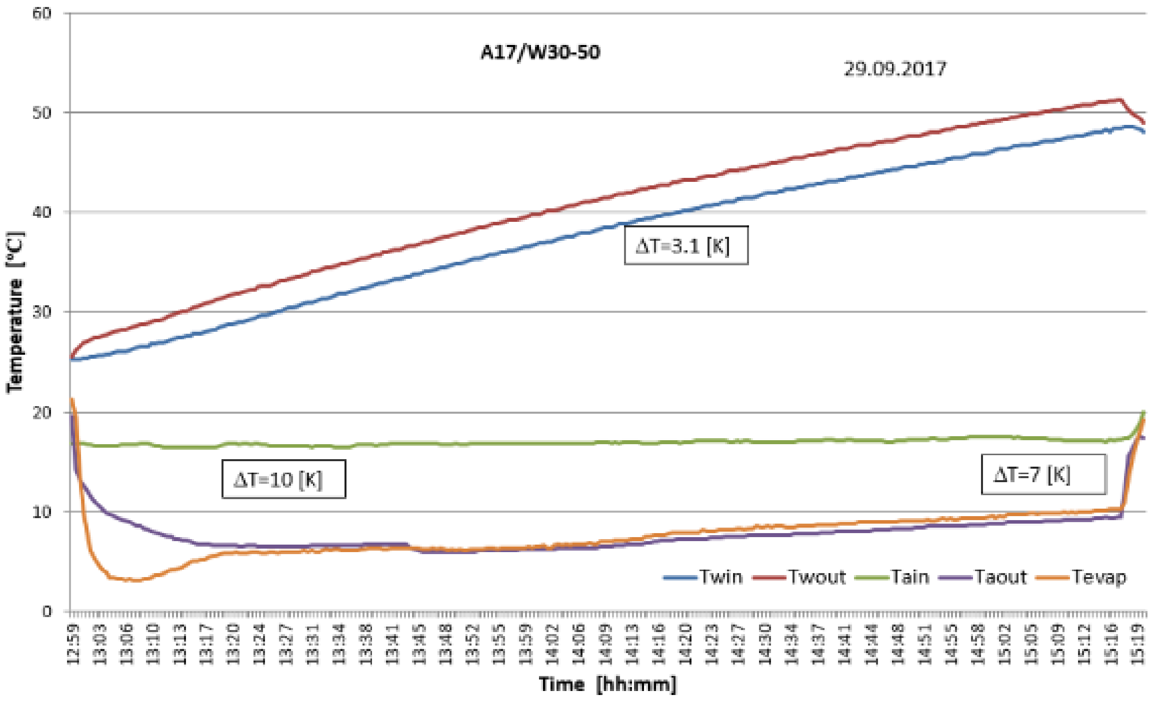

Figure 2: Diagram of temperature changes in the heat pump for outside air circulation of 17 °C and water mass flow of 0.24 kg s^{-1}

Temperature difference at inlet and outlet of the water in the heating circuit for the water mass flow 0.24 kg s^{-1} amounted on average to ΔT_w=3.1 °C, while in the evaporator circuit it has changed from ΔT_a=10 °C to ΔT_a=7 °C.

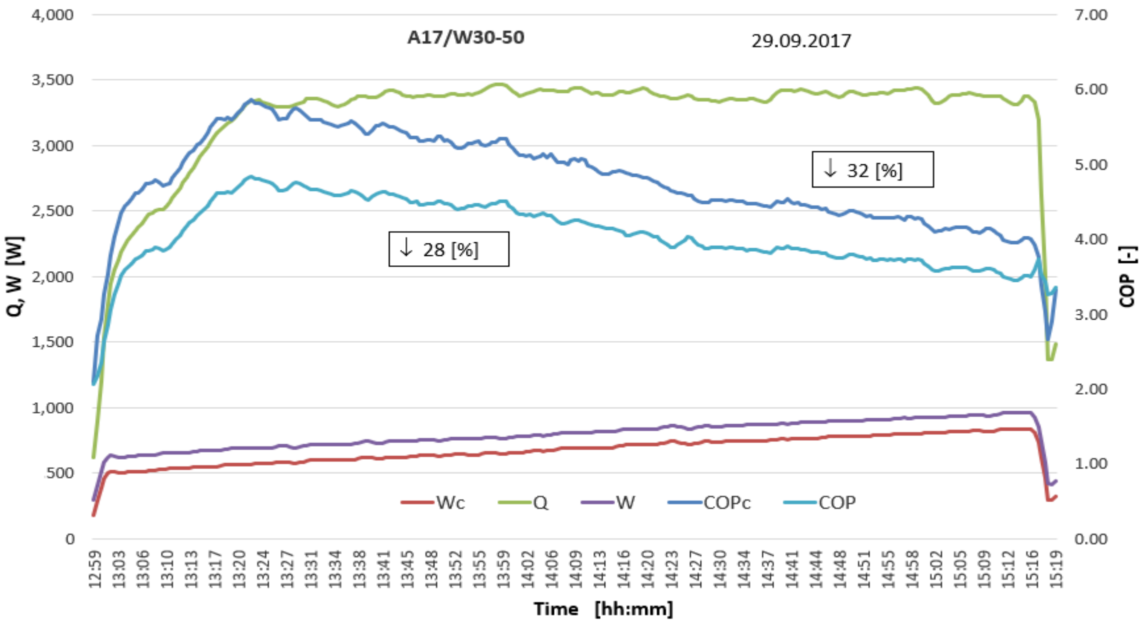

Figure 3: Graph of changes in the demand for electric power and registered heating power in a heat pump for the circulation of external air of 17 °C and water mass flow of 0.24 kg s^{-1}

On average, 20 min after the heat pump was switched on, the heat pump's operating conditions stabilized. In the presented example, the evaporating temperature of the refrigerant was maintained at 6 °C for 40 min and

then gradually increased to 9 °C. The registered measurement results show that the evaporating temperature of the refrigerant for stabilized operating conditions is close to the temperature of the air at the outlet from the evaporator.
Figure 3 presents data registered in the G922-COP module. The values of momentary COP and heating power were determined for each measuring cycle. The demand of a rotary compressor for electric power (W_c) varied in the range of 510 - 860 W depending on the condensing temperature.
In fixed conditions, the heat pump operated with an average heating power of 3,350 W. As a result, the COP coefficient values for the compressor (COP_c) were obtained in the range from 5.80 to 3.90 for stabilized heat pump operating conditions, calculated COP value for the A17/W30-50 profile was 4.80. The demand of the circulating pump and heat pump control system for electric power was 120 W. Thus, the heat pump COP for the A17/W30-50 profile decreased to 4.0 (Miara, 2011).

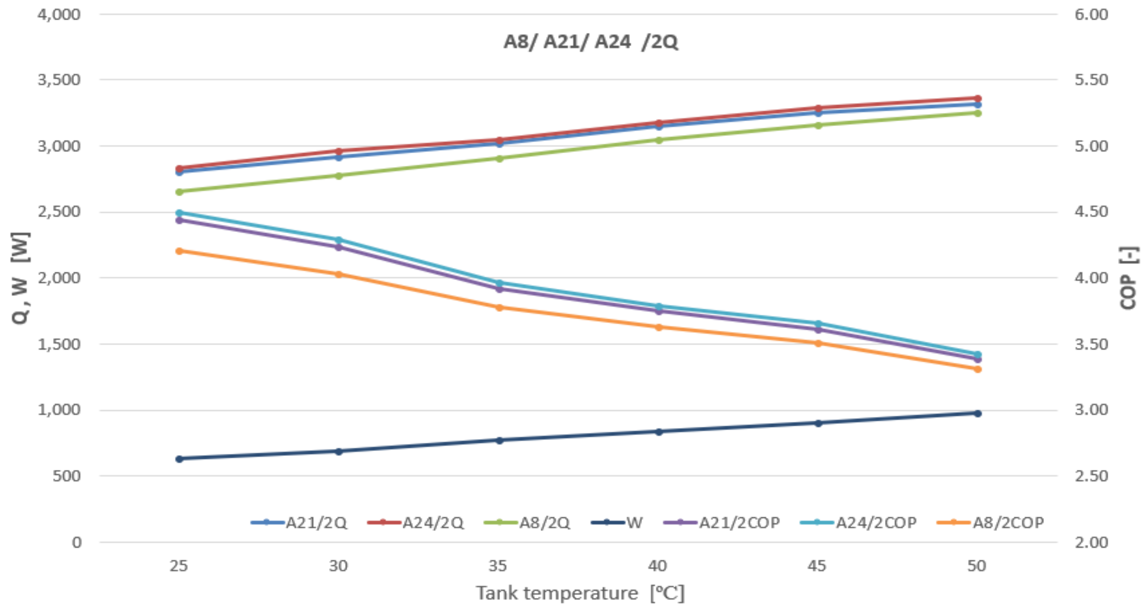

Figure 4: Graph of changes in the demand for COP and registered heating power in a heat pump for the circulation of external air of temperature: 8 ºC, 21 ºC, 24 ºC and water mass flow of 0.24 kg s^{-1}

Figure 4 presents a combination of heating cycles for 3 air temperatures supplying the evaporator (8 ºC, 21 ºC, 24 ºC), with a constant water mass flow rate in the heating circuit, 0.24 kg s^{-1}. In line with expectations, with higher supply air temperature, higher values of generated heating power and COP coefficient were obtained.
For example, for the A8 (8 ºC) supply air, the heat pump generated heating power in the range of 2,650 – 3,250 W (increase of 20 %). Accordingly, the demand for electric power varied in the range of 630 - 980 W (50 % increase). The COP value dropped from 4.20 to 3.30 (20 % decrease). During the heating cycle for the A8/W30-50 profile, the pump produced 8.6 kWh of heat energy using 2.3 kWh of power consumption, so averages were obtained COP of 3.70.
Figure 5 presents a comparison of heating cycles for 3 values of water mass flow and constant A8 air temperature feeding the evaporator. In the case of a circulation pump set in 1st speed, the heat pump generated heating power in the range of 2,740 – 2,960 W (increase of 8 %), the determined COP value varied from 4.35 to 3.0 (30 % decrease). During the heating cycle for the A8/W30-50 profile, the pump produced 7.9 kWh of heat energy using 2.2 kWh of power consumption, and the average COP was 3.60.
If the circulation pump was set to 3rd speed, the heat pump produced heating power in the range of 2,500 – 3,550 W (increase of 40 %), and the determined COP value varied from 3.95 to 3.60 (9 % decrease). During the heating cycle for the A8/W30-50 profile, the pump produced 8.65 kWh of heat energy using 2.3 kWh of power consumption, averages were obtained COP of 3.75.
It follows that in the initial stage of the heating cycle, it is recommended to set the circulation pump in 1st speed, while in the final cycle stage the heat pump works effectively if the circulation pump is set to run in 3rd speed. At the initial stage of the heating cycle, a large mass flow of cold water creates an excessive thermal load of the heat pump and the compressor operates outside the optimal range of effective operation (Guo et al., 2011).

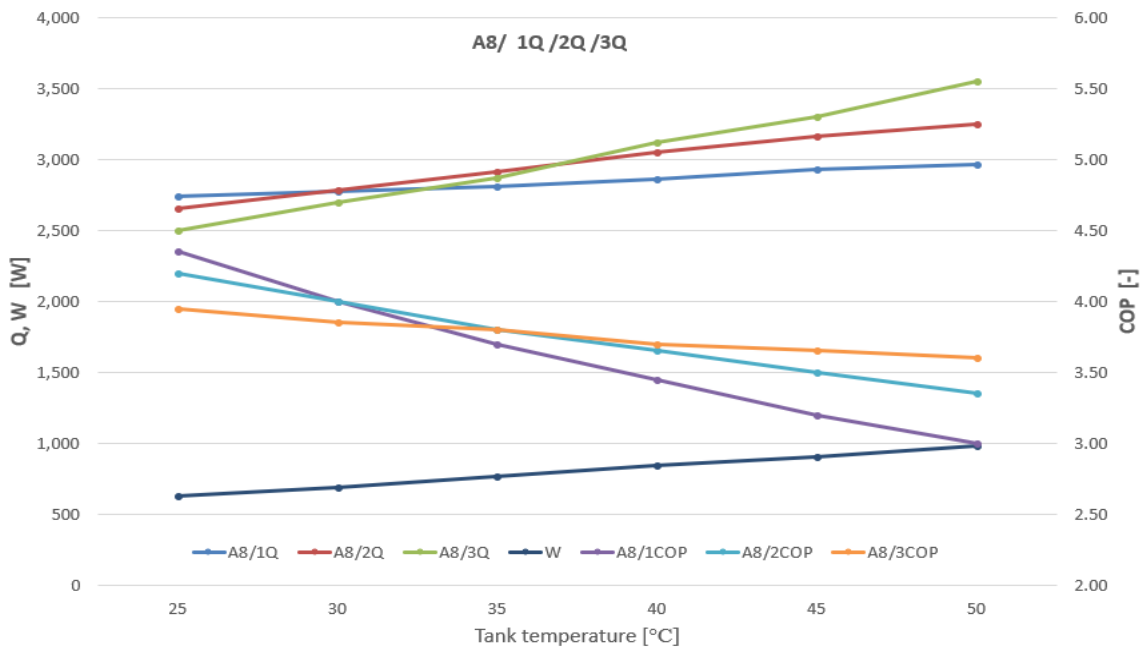

Figure 5: Graph of changes in the demand for COP and registered heating power in a heat pump for the circulation of external air of 8 ºC and water mass flows of: 0.17 kg s^{-1}, 0.24 kg s^{-1}, 0.27 kg s^{-1}

For comparison, Figure 6 presents an analogous comparison for measurements performed in the summer or using ventilation air (21 ºC). If the circulation pump is set to 1st speed, the heat pump's operating efficiency is maintained at a similar level to the measuring cycle with the A8/W30-50 profile.

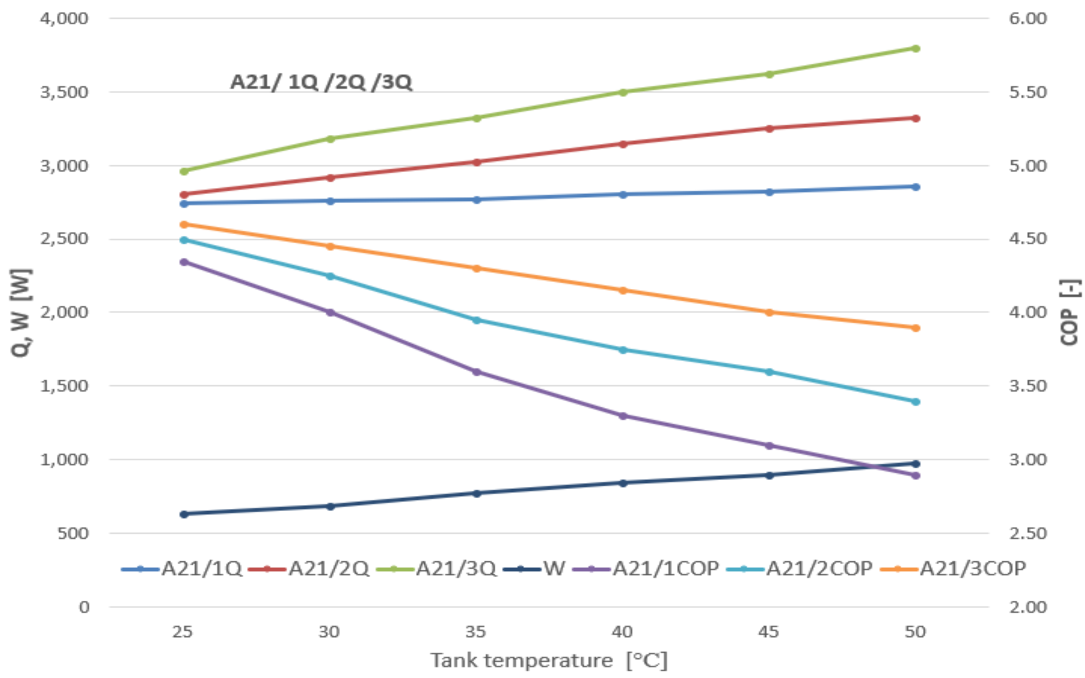

Figure 6: Graph of changes in the demand for COP and registered heating power in a heat pump for the circulation of external air of 21 ºC and water mass flows of: 0.17 kg s^{-1}, 0.24 kg s^{-1}, 0.27 kg s^{-1}

However, for the water mass flow rate of 0.27 kg s^{-1}, the heat pump's efficiency increased by 15 %.

During the measuring cycle for the A21/W30-50 profile, the pump produced 8.8 kWh of heat energy using 2.15 kWh of power consumption, thus obtaining the average COP of 4.10.
The measurements show that the air heat pump achieved for the A21/W30-50 profile the highest COP of 4.55 in the first phase of water heating in the storage tank for the water mass flow 0.27 kg s^{-1}, and the demand for electrical power was 630 W. In the final heating phase, the efficiency of the heat pump decreased to the value of COP of 3.95, and the demand for electrical power increased to 980 W. The average values for the entire measurement cycle were respectively: heating power generated at 3,440 W, with the demand for electrical power 840 W, one obtained COP of 4.10.

4. Conclusions

For negative ambient temperatures, operation of the pump with the use of external air is uneconomical (the compressor start-up block is automatically activated if the temperature of the air supplying the lower source falls below 0 °C). Pump operation in winter is possible with the use of ventilation air, but with the discharge of air cooled outside the building. Limiting the maximum refrigerant pressure in the freon up to 3.4 MPa allowed for heating the water in the tank to a maximum of 55 °C.
The research showed that heating water in the 130 dm^3 container conducted in the most appropriate conditions in the summer season, lasted an average of 130 min and the heat pump consumed about 2.2 kWh of energy per heating cycle. It must also be said that with a relatively constant heating power of 3,400 W, the energy efficiency of heat pump, was dropping from COP of 4.50 at the beginning of the measuring cycle, to COP of 3.90 in the final moment of the cycle. The average COP of 4.10 was obtained for the whole measuring cycle. On chilly days (air temperature: 3-5 °C) the efficiency of the heat pump drops about 15 % averagely.
During the measurement cycle the demand of the compressor for the power consumption grows along with the increase of the condensation temperature from 0.6 to 1 kW. With 1 kWh of electric energy collected by the compressor, the presented heat pump is able to produce 4.4 kWh of heat energy in 70 min.
In order to ensure the optimal range of effective compressor operation, it is advisable to grade the heat load of the heat pump by using a circulating pump with smooth capacity regulation. An air-to-water heat pump for DHW is an ideal solution for heating systems equipped with solid fuel boilers. It is a maintenance-free and economical system for producing hot utility water outside the heating season.

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