# Air–water heat pump applied as water boiler in single-family house, coefficient of performance analysis under the real conditions

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**Abstract**
The subject of the research was an air-water heat pump, model PCUW 2.5kW from HEWALEX, installed in a single-family house. The pump is only used for heating water. The research was carried out from 25-08-2017 to 18-09-2017 in the village of Zborowice, in Malopolska region, Poland. The data were recorded from the heat pump system: temperature of the lower heat source (external air), temperature of the upper heat source (water temperature in the tank), time of heat pump was calculated during the analysed cycle of work and electrical energy consumption. The Coefficient Of Performance (COP) of the analysed air-water heat pump was determined. The analysis of the results was carried out using the MATLAB and EXCEL statistical tools. The correlation between COP coefficient and external air temperature is strong: 0.67.

**Keywords:** Heat pump, air-water, coefficient of performance, COP

## Introduction

In spontaneous processes occurring in nature, energy is dissipated and entropy increases. The heat pump is a device that takes heat energy from a lower temperature environment and gives heat energy to an environment with a higher temperature. Entropy of the system grows (1), because energy is accumulated [1, 2].

$$\Delta S = -\frac{Q_0}{T_0} + \frac{Q_H}{T_H} \geq 0 \qquad (1)$$

where:

$\Delta S$ – entropy of the system
$Q_0$ – heat energy taken in evaporator
$Q_H$ – heat energy given in condenser
$T_0$ – temperature of low energy source
$T_H$ – temperature of high energy source

The total energy supplied to the system with heat pump, may be measured as energy increase in the high energy source (2), (3). Water is the high energy source at the system heated with the air-water heat pump. The temperature of the water in tank increases. The energy ($Q_H$) comes from: environment (from external air; counted as heat energy taken in evaporator ($Q_0$) that makes about 75% of total, and from the electrical energy (amount of energy consumed by the compressor; $Q_{El}$) that makes about 35% of total [1, 2].

$$Q_H = Q_0 + Q_{El} \qquad (2)$$

where:

$Q_{El}$ –amount of energy consumed by the compressor (electrical energy).

The energy accumulated in the upper source of heat (water) is directly proportional to the mass, the coefficient of specific heat and the temperature increase (3). Water is an excellent energy absorber due to its high specific heat coefficient.

$$Q_H = c_{pw} \cdot m \cdot \Delta T_H \qquad (3)$$

where:

$c_{pw}$ – water specific heat 4190 [J/(kg·K)]
m – water mass [kg]
$T_0$ – temperature of low energy source [°C]
$\Delta T_H$ – temperature increase, measured for high energy source [K]

The most important values characterizing the heat pump as the device are: the heating power ($Q_H$), and amount of energy consumed by the compressor ($Q_{El}$). The coefficient of performance (COP coefficient) of the heat pump is a ratio of these values (4). [2, 3]

$$COP = \frac{Q_H}{Q_{El}} \qquad (4)$$

The efficiency of the compressor heat pumps is the higher the lower temperature difference between the upper and the low-

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er heat sources. Typically, the coefficient of performance COP reaches a value of 3 to 4.5. Heat pumps have the highest efficiency among commercially available heaters. Traditional heating systems have an efficiency of 0.5 to 0.99 with respect to primary energy of fuel [3, 4]. Heat pumps are strongly recommended for house heating due to their effectiveness, and are treated as renewable energy source [4, 5]. The heat pumps might be on-line controlled and the data are registered, many parameters might be optimized by the user [6, 7].

## Materials and Methods

The subject of the research was an air-water heat pump, model PCUW $P_{QH}$=2.5kW from HEWALEX, installed in a single-family house. The pump is only used for heating water in the tank of capacity 300 l. The research was carried out from 25-08-2017 to 18-09-2017 in the village of Zborowice, in Malopolska, Poland. The following measurement data were collected and recorded from the heat pump system: temperature of the lower heat source (external air), temperature of the upper heat source (water temperature in the tank). Pt100 sensors were applied to measure the external air ($T_0$) and the water in the tank temperature ($T_H$). The system of monitoring and data acquisition was used [7]. Additional measurements were registered: the temperature of the working medium (R134a), the water temperature at several points in the installation (inlet to the heat pump, outlet from the heat pump, upper sensor in the water tank, lower sensor in the water tank), working time of the heat pump (as electrical energy consumption).

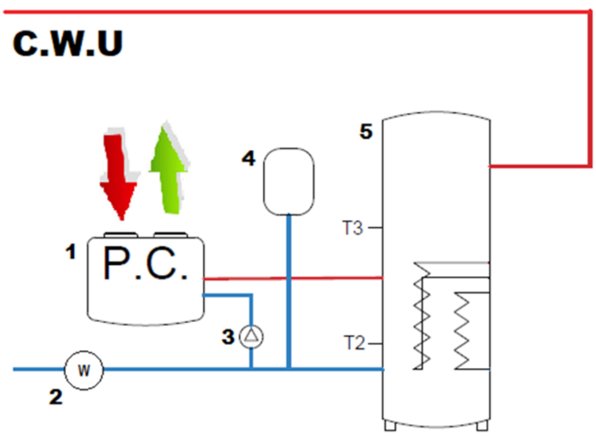


**Figure 1.** Heat pump installation diagram 1 – heat pump + air temperature sensor (T1), 2 – flow water meter, 3 – circulation pump, 4 – equalizing tank, 5 – hot water tank, T2, T3 – water temperature sensors [6]

Before the first heating cycle the water in the tank temperature was about 40 degrees Celsius. Some of the hot water was consumed. The tank was then supplied with water which temperature was 10 degrees Celsius. At that time, the heat pump did not work yet.

The heat pump worked 3 or 4 cycles a day, for each day the data collected only during the first cycle were analysed. The first cycle of work was set from 10.00 a.m., regardless of the temperature in the tank. It was the longest work period, not significant water outflow from the tank were noticed. The water in the tank was heated up to 42 degrees Celsius (as indicated by the sensor at the lower part in the water tank), and after that the device was automatically turned off. It were also analysed: the heat pump operating time, average air temperature (as the lower heat source), and the inflow water temperature. The heat energy given in condenser and warming the water in the tank was calculated, as well as the electrical energy consumed by the heat pump. The coefficient of performance (COP coefficient) of the heat pump was determined. Every day the outside air temperature, amount of heated water in the tank as well as electrical energy consumption varied. The analysis of the results was carried out using the MATLAB tools and EXCEL statistical analysis tools.

## Results and Discussion

For the period from 25-08-2017 to 18-09-2017 altogether 23 working cycles of the air-water heat pump were analysed. The external air temperature during the whole cycle was stable. External temperature during the work of the pump (External air temperature MV) as it is presented in the table 1st, varied every day from about 12.65 °C up to 28.55 °C . The heat pump worked during the analysed cycles (the first cycle during the day) for 141–161 minutes to warm up the water in the tank up to the 42 °C, when the temperature outside was high: 26–28 °C.

Working time rapidly increased when the weather conditions were worse. It took 153–297 minutes to achieve the same temperature in the tank when the external air temperature ranged between 12.6–14.0 °C. The heating time was longer when the beginning temperature of the water in the tank was lower (the water temperature increase in the tank, as delta). That happened when the water consumption before 10.00 o`clock a.m. was high. The electrical energy consumption was stable during work of the heating pump.

The COP coefficient during work of the heat pump in the experiment was quite high: from 2.23 to 4.50. Similar achievements were presented by the other authors [1–3, 5]. The results show that highest efficiency of the heating pump, determined as the COP coefficient, depends on the external air temperature. The correlation between these variables is strong: 0.67. There is no correlation between the COP and the beginning water temperature in the tank (or water temperature increase). Correlation coefficient is only 0.13.

The energy accumulation increases rapidly during the first 20–40 minutes of the air-water heat pump work. The temperature measured by the sensor in the lower part of the water tank (Fig. 1.) corresponds with the energy accumulation. The curves are exponential. At the end of the heating cycle the water heating

**Table 1.** Outside air temperature, data characterizing system operation and coefficient of performance of the analysed air-water heat pump

| External air temperature (MV) [deg C] | Time to warm up water in the tank, to 42 deg C [minutes] | Water temperature increase in the tank (delta) [K] | COP coefficient | Date |
|---|---|---|---|---|
| 28.55 | 161 | 22.60 | 4.39 | 27/08 |
| 26.18 | 141 | 19.60 | 4.35 | 26/08 |
| 25.63 | 181 | 21.50 | 3.71 | 31/08 |
| 25.19 | 261 | 25.50 | 3.05 | 10/09 |
| 24.57 | 185 | 22.40 | 3.79 | 01/09 |
| 24.09 | 141 | 20.30 | 4.50 | 25/08 |
| 23.76 | 149 | 18.30 | 3.84 | 30/08 |
| 22.68 | 197 | 20.40 | 3.24 | 11/09 |
| 22.67 | 297 | 26.70 | 2.81 | 09/09 |
| 21.40 | 289 | 24.20 | 2.62 | 14/09 |
| 20.53 | 165 | 22.50 | 4.26 | 29/08 |
| 20.41 | 157 | 18.30 | 3.64 | 28/08 |
| 18.81 | 221 | 17.70 | 2.50 | 13/09 |
| 17.78 | 177 | 16.50 | 2.91 | 07/09 |
| 16.31 | 233 | 19.50 | 2.62 | 06/09 |
| 16.26 | 193 | 17.60 | 2.85 | 05/09 |
| 16.17 | 185 | 17.30 | 2.92 | 15/09 |
| 14.97 | 157 | 15.70 | 3.13 | 02/09 |
| 14.72 | 245 | 23.50 | 3.00 | 17/09 |
| 14.42 | 177 | 17.90 | 3.16 | 04/09 |
| 14.06 | 205 | 14.50 | 2.23 | 12/09 |
| 13.73 | 153 | 16.30 | 3.33 | 03/09 |
| 12.65 | 297 | 24.40 | 2.57 | 16/09 |

rate is almost linear.

The results show that the heating time depends on the outside air temperature (Fig. 2.). The water temperature, at the later stage of work of the heating pump may be approximated with equation (5) for the outside air temperature 25 °C:

$$T_{H(25\,^{o}C)} = 0.10t + ß \quad (5)$$

where:

$T_{H\ (outside\ air\ temperature)}$ – temperature of high energy source: water temperature in tank [°C].

t – time [min].

The same for air temperature 21 °C: $T_{H(21\,^{o}C)} = 0.09t + ß$ (6)

The same for air temperature 13 °C: $T_{H(13\,^{o}C)} = 0.08t + ß$ (7)

When the external air temperature is high, about 25 °C, the water temperature measured in the tank increases about 0.10 K per every minute.

The water heating rate at the final stage of heating is much lower when the external air temperature is decreasing: for 0.09 K per every minute when the external air temperature is about 21 °C (6), as accordingly to 0.08 K per minute for 13 °C (7).

## Conclusions

The coefficient of performance for the analysed air-water heat pump installed in the single-family house was quite high: COP coefficient ranges between 2.2 and 4.5. Similar efficiency might be expected for the heat pump working under similar external air temperature conditions (between 12.7 °C and 28.6 °C) as well as the device and installation parameters (2.5kW, 300 l water for heating).

The correlation between COP coefficient and external air temperature is strong: 0.67.

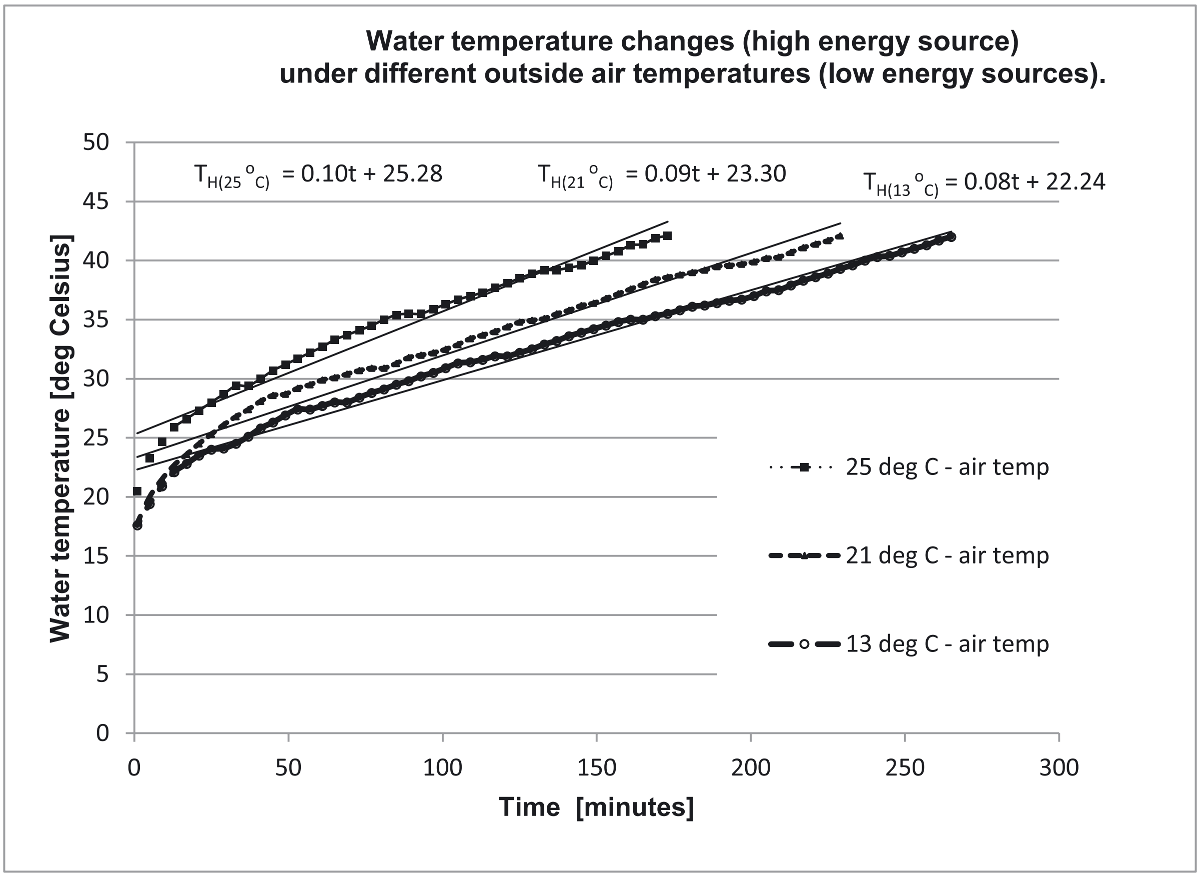


**Figure 2.** Water temperature changes (high energy source) under different outside air temperatures (low energy sources) for the analysed air- water heat pump

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