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SEASONAL COEFFICIENT OF PERFORMANCE OF ASHP, GSHP, AND WSHP HEAT PUMPS IN DIFFERENT CLIMATIC ZONES IN POLAND

Abstract

The observed global warming phenomenon has induced European Economic Area (EEA) to promote heat pump as a heat generator in the member states. According to European Union (EU) directive 2009/28/EC each heat pump must be energetically viable. To do it, seasonal coefficient of performance (SCOP) is calculated in the five climatic zones in Poland for three different heat sources. The algorithm, which satisfies an EU standard, is extended to take into account a separating heat exchanger which is needed by water-water heat pump. The heating degree-days depicts the different temperature conditions. Underground temperature profile is averaged in each climatic zone separately. Groundwater temperature is estimated using Kowalski formula. Other important factors are average electrical energy production efficiency and low voltage electricity transfer efficiency in Poland. Then it is concluded that air-water heat pump cannot be applied in Poland as it fails the EU requirements and only ground-water or groundwater-water heat pump may be applied in Polish climatic and energy market conditions.

Keywords

heat pump, seasonal coefficient of performance (SCOP), air to water heat pump (ASHP), ground to water heat pump (GSHP), groundwater to water heat pump (WSHP)

1. INTRODUCTION

As a solution of the global warming problem, many international organizations, including EU, look for the more effective energy generators to reduce greenhouse gas emissions, especially carbon dioxide. For this purpose EEA states [1] increasingly invest in a technology development based on alternative energy sources. However, EU [2] requires the use of heat pumps that provide significantly more energy than primary energy used to drive them. Gajewski

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et al. [3] obtained minimal coefficient of performance (COP) value at 3.5 in the Polish energy market conditions. The exchange of heating devices which consumes coal to heat pumps is prompted EU action [2]. Instead of fuel combustion, heat pump converts heat from source at lower temperature and supplied work to heat, which is transferred to a heating system at higher temperature. Heat pump dissemination may diminish both carbon dioxide and PM_{10} dust emissions to atmosphere, which improve outdoor air quality eventually. Moreover, such policy have a pragmatic effect, which will allow avoiding the financial penalty resulting from unexecuted EU's standards [4].

2. THE COMPUTATION ALGORITHM

Assessment of heat pumps suitability as the only heat generator for a building is the aim of the study, in which SCOP value is the criterion of reasonableness. Estimation is done in each Polish climatic zone using devices of Alpha Innotec company: ASHP (LW 121), WSHP (WWC 130H/X) and GSHP (SWC 122H/K3). Every device generates heat for a detached house for which the design heat load for a building equals 12 kW. Their technical characteristics provided by the producer are used in an algorithm. The locations selected for a comparison are as follows: Szczecin, Poznań, Łódź, Białystok, Zakopane.

SCOP magnitude estimation is preceded by COP values ascertainment at each temperature that the designed devices work at. COP value depends on both outdoor temperature and temperature of the lower source. Since, heating degree days (HDD) and monthly averaged outside temperature as the climatic factors are used in the analysis, it must be assumed that outside temperature is constant all the month. Inasmuch as, COP depends on outdoor temperature and the dependence is not linear, such averageness may seem too far. Thus, the authors of the paper weigh up the second option with medium minimal temperature that is a difference of mean month temperature and the half of the monthly amplitude. The results of these two options are denoted with "I" and "II" respectively hereinafter. The study has been started from finding a relation between outside temperature values and the operating temperature range of the device. All the considered pump models are controlled with the same model of a weather compensator, which leads to one heating curve that the heat pumps are adjusted along. So as to apply the curve in the algorithm it is approximated by a quadratic polynomial. Forasmuch as, heat delivered to a heating system is a sum of heat taken from the heat source and supplied work, the lower amount of heat is taken the more work must be done. Moreover, the amount of heat taken from the heat source depends on one's temperature, which means the lower source temperature value affects COP significantly. For that reason, the lower source temperature magnitude is determined in the second step.

Since ASHP uses the outside air as a heat source, temperature in its evaporator changes continuously. Therefore, ASHP operation at low outside temperature is less efficient than at higher temperature. Heat, from the underground resources, is taken by WSHP or GSHP. Although underground temperature does not change below a shallow zone significantly, a heat source depth is one of the independent values in the algorithm, another argument is a geographic location. Temperature profile in ground is obtained from Baggs formula adopted by Oleśkowicz-Popiel et al. [5] for the Northern Hemisphere:

$$t(z,\tau)=(t_a+\Delta t_m)-1.07k_v A_s \exp\left(-0.00031552za^{-0.5}\right)\cos\left[\frac{2\pi}{365}\left(\tau-\tau_o-0.018335za^{-0.5}\right)\right] \quad [°C] \qquad (1)$$

where τ is a day number in the year, z is the depth [m], other variables are defined in Table 1.

Table 1. Data to the mean underground temperature determination

Parameter	Symbol	Unit	Data
A difference between ground temperature below the shallow zone and average annual air temperature [5]	Δt_m	[deg]	9.4
A vegetation coefficient [5]	k_v	[–]	0.85
The amplitude of annual air temperature in every climatic zone respectively	A_s	[deg]	9.3; 10; 10; 10.9; 9.3
The soil thermal diffusivity [5]	a	[m²/s]	5.50E-07
The phase of the air temperature wave [5]	t_o	[d]	24
Average annual air temperature in each climatic zone respectively	t_a	[°C]	8.27; 8.03; 7.56; 6.67; 5

The temperature value, which is obtained from Equation (1), is integrated along the borehole depth up to 100 m and in respect of time to obtain monthly averaged underground temperature. The temperature value in groundwater basin t_H is evaluated using Kowalski relation [6]:

$$t_H = t_a + A + g_g (H-h) \ [°C] \qquad (2)$$

where the variables are defined in Table 1 and Table 2.

Table 2. Data to groundwater basin temperature ascertainment in every climatic zone respectively

Parameter	Symbol	Unit	Data
A correction factor due to true altitude [6]	A	[–]	0.81; 0.83; 0.86; 0.84; 1.19
A geothermal gradient [7]	g_g	[deg/m]	0.023; 0.0216; 0.024; 0.013; 0.0188
A depth of a groundwater basin level [8]	H	[m]	22.5; 81.4; 66.5; 75.7; 1010.7
The depth of the shallow zone [6]	h	[m]	15; 15; 15; 15; 15

If chemical composition of groundwater, which supplies the WSHP evaporator, does not meet the manufacturer's requirements, the separating heat exchanger (SHE) must be installed in the primary circuit to avoid a failure. Thus, the brine temperature value after SHE is lower at 2°C according to the manufacturer's data. If the brine after SHE is out of the temperature range of WHSP then GSHP must be applied instead of WSHP. It is because GSHP can be supplied with the colder brine than WSHP, as ground has lower temperature than groundwater, usually. In the case such situation exists, hence GSHP is used, instead of WSHP, in the variant with SHE.

Part load for heating $P_h(t_j)$ is ascertained following EN 12831 [9]:

$$P_h(t_j) = \Phi_i \frac{(t_i - t_j)}{(t_i - t_e)} \left[\mathrm{kW}\right] \tag{3}$$

where:

- Φ_i – the total design heat loss [kW],
- t_i – internal design temperature, assumed 20°C,
- t_j – external air temperature [°C],
- t_e – external design temperature [°C].

COP value at the particular outside temperature value is denoted as COP_{bin}. COP_{bin} is determined as a function of outside temperature and supply temperature in the heating system basing on the manufacturer data. $SCOP_{net}$ value is determined according to the guidelines in the norm PN-EN 14825:2016 [10]:

$$SCOP_{net} = \frac{\sum_{j=1}^{n} h_j \left[P_h\left(t_j\right) \right]}{\sum_{j=1}^{n} h_j \left[\frac{P_h\left(t_j\right)}{COP_{bin}\left(t_j\right)} \right]} \left[\mathrm{kW}\right] \tag{4}$$

where:

- h_j – the number of the bin hours occurring at external temperature t_j in the heating season [h/a],
- $COP_{bin}(t_j)$ – COP value of the unit for external temperature t_j [–].

3. RESULTS

The results of the COP values distribution with regard to the four kinds of heat pump are presented in each Polish zone (Figs. 1–5).Regardless of the type of the device used, it is possible to observe an increase in the COP value as the outside air temperature magnitude rises. In the case of an ASHP pump, there is a clear leap between 3.2°C and 7.5°C. It is caused by the fact that in the temperature range given above, the device achieves the best proportion of efficiency increase to the external source temperature increase. It simultaneously causes a disturbance in the linear character of the function describing changes in the value of the analysed factor. Because the SCOP value of ASHP pumps is lower than 3.5, they should not be applied in Poland. The GSHP pump meets the EU requirements in all the climate zones because the minimum SCOP value is 4.67. It is the best solution for four of the five climatic zones that have been analysed. Only in the fifth climatic zone the water heat pump works more efficiently than a ground pump. WSHP heat pumps meet the requirements set by the EU in each zone also with additional equipment (SHE). In addition, their energy efficiency does not correlate with the climatic conditions. It is because their SCOP value is affected by the local geological conditions.

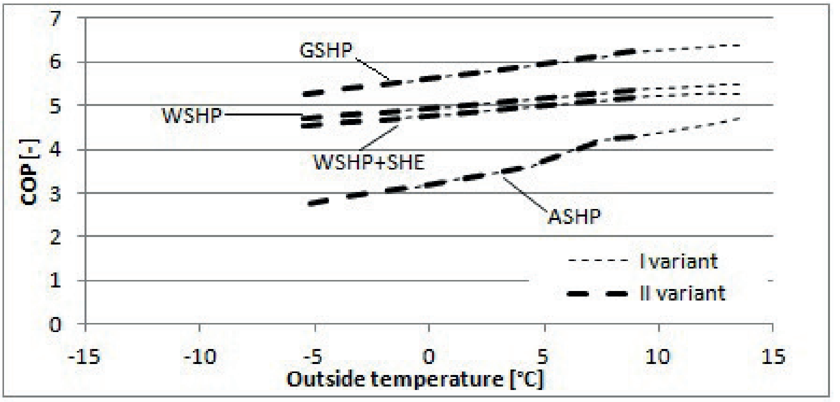

Fig. 1. Results for Szczecin

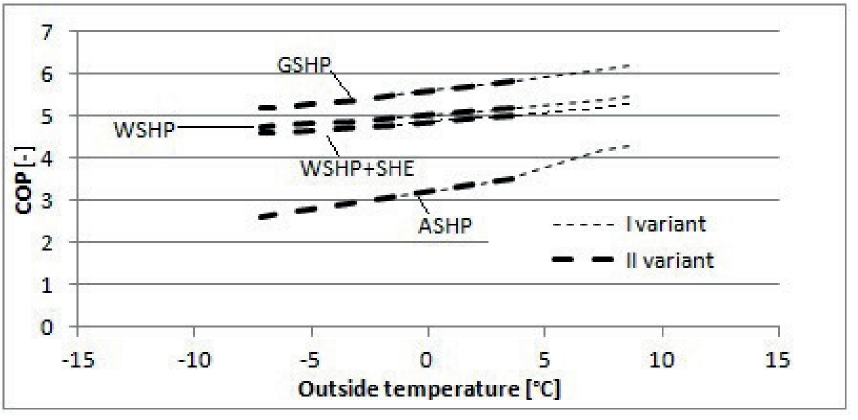

Fig. 2. Results for Poznań

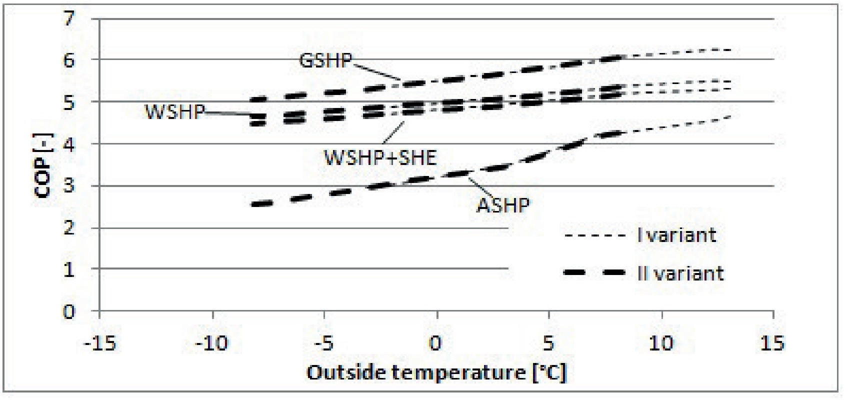

Fig. 3. Results for Łódź

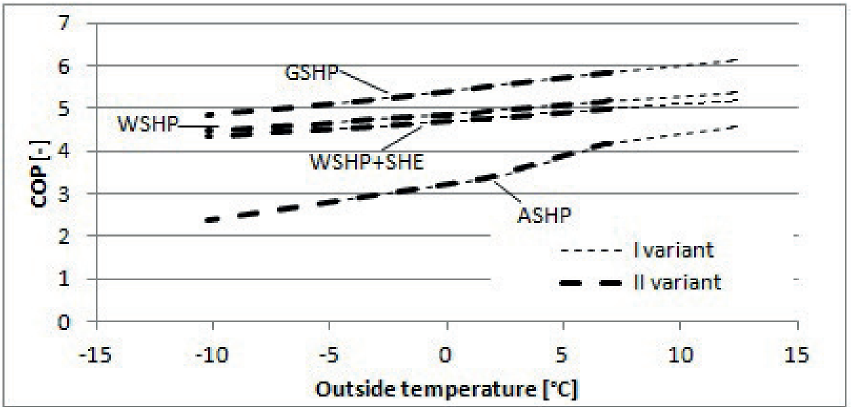

Fig. 4. Results for Białystok

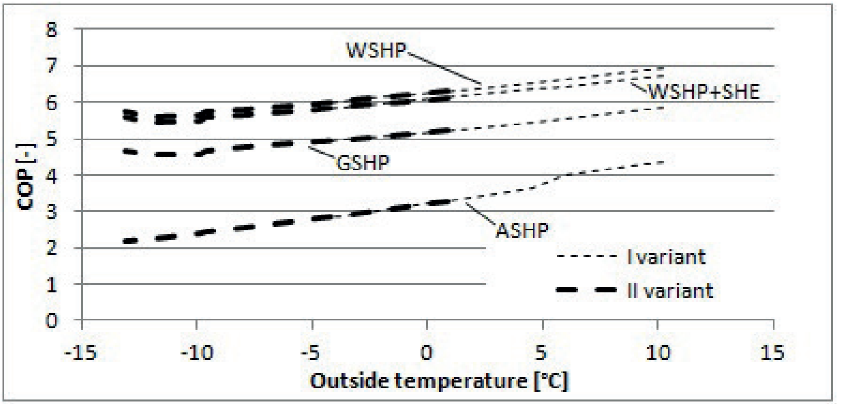

Fig. 5. Results for Zakopane

In the above analysis neither investment costs nor running expenses were included, as it is out of research's scope. Nevertheless, each heat pump selection should be preceded by capital expenditures and running costs analysis. The analysis should include the accurate SCOP values which are achieved in the paper.

4. CONCLUDING REMARKS

Heat pumps that use geothermal heat may be considered as an ecological source of heating in Poland. Regardless of the climate zone heat pumps which use low geothermal temperature reservoir are more effective that those which use atmospheric air. Inasmuch as, air-to-water heat pumps' SCOP values fail EU requirements they may not to be applied in Poland amid all heating season duration. Therefore, only GSHP and WSHP should be weighed up in the Polish climate and energy market conditions. However, economic analysis, which includes all the expenditures in respect to a local climatic and geological case, is necessary before a final decision.

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