An Ecological Profitability Assessment of the Heat Pumps in Poland †

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Abstract: Indirect greenhouse gases emissions due to electricity production for powering heat pumps are compared in all Polish climatic zones. The different meteorological conditions are defined by the typical meteorological year. The comparison is made for air-to-water, brine-to-water and water-to-water devices. It starts from determining electrical energy consumption and coefficient of performance value in every hour of a heating season. The determination algorithm takes into consideration a buffer tank or separating heat exchanger when one is required. Subsequently the emissions estimations are done for the present Polish energy mix and assumed one in “Energy policy of Poland until 2040”.

Keywords: heat pump; greenhouse gasses emission; ASHP; GSHP; WSHP; nuclear power

1. Introduction

Due to the current continuously temperature increase which is supposably caused, inter alia, by excessive greenhouse gasses emissions the European Union took numerous measures to decarbonize its energy system being one of the largest sources of emissions. These measures ensure supply of energy and competitiveness of this system [1]. Hence, Polish authorities undertook the actions aimed at modernizing the current structure of the domestic electrical energy generation. This structure is modernized on a regional and national scale. The former involves, for instance, photovoltaic micro-installations, while the latter includes a construction of new nuclear power plants [2]. Also the inhabitants are encouraged in applying modern devices in the designed or existing heating systems, which would reduce or even eliminate emissions from small buildings. The Polish Organization for the Development of Heat Pump Technology (PORT PC) forecasts that by 2030 a heat pumps share in single-family buildings will be 10% in the likely scenario, and 22.8% in the optimistic one [3].

The aim of the study is comparison of two scenarios for reducing harmful substances emissions during a heating system operation in all the Polish climatic zones. Indirect emissions of carbon dioxide, nitrogen oxides and sulfur oxides for the current Polish energy mix are determined in the first scenario. The second scenario assumes 32% share of renewable energy sources in the future Polish energy mix.

2. Material and Methods

A proposed system provides heat to a commercial building with 46 kW of the design heat load; its heat generator is the considered heat pumps whose the lower temperature sources are as follows: outdoor air, ground, and groundwater basin; they are named...
as: air-to-water (ASHP), brine-to-water (GSHP), and water-to-water (WSHP). To avoid continuous operation each heat pump must be equipped with a buffer tank. Moreover a separating heat exchanger (SHE) is needed to protect WSHP against salty groundwater. In the case of installations equipped with ASHP, to avoid the device operation out of the allowed temperature range of the lower source, the system was additionally equipped in an auxiliary heat source, so this hybrid system is called the bivalent system. There are assumed two variants of the system operation control; in the first one the water temperature in the buffer tank equals to the maximum supply temperature of the central heating system, and in the second variant water temperature in the buffer tank results from the heating curve.

The study compares emissions among the five climatic zones in Poland, each zone is represented by one city: Szczecin, Poznań, Łódź, Białystok, Zakopane. The different climatic condition are expressed by typical meteorological year (TMY) [4]. While temperature profile along ground heat exchanger is determined using the Baggs formula modified for the northern hemisphere by a team led by Oleśkowicz-Popiel [5]. Whereas groundwater temperature is obtained from the Kowalski monograph [6]. Consequently an algorithm which satisfies the standards [7,8] enables computation of hourly power demand, coefficient of performance (COP), and seasonal coefficient of performance (SCOP). Then the current fuels shares, efficiencies of electrical energy production and transfer [9], and hourly power demand, are the input data in the indirect pollutants emissions estimation, which describes the first scenario. The second scenario assumes 32% share of renewable energy sources in Polish power industry, which is a goal of Energy Policy of Poland until 2040 [10]. Other goals of energy policy [10] are the heating all households by 2040 from system heat and zero or low-emissions individual heat generators as well as 30% reduction of greenhouse gases emission by 2030 in comparison to 1990.

3. Results

The heat generators characterized by a constant temperature of the heat source (GSHP, WSHP) consume less energy and achieve higher SCOP than a generator which takes heat from the outside air (ASHP) where temperature varies rapidly, which results from the non-linear thermodynamic properties of the refrigerants. Regardless of the heat source, a heating systems operating at a constant temperature of water in the buffer tank yields lower SCOP values and consumes more electricity than a system whose the supply temperature changes along the heating curve. In the former case the temperature in a condenser is maintained at the design value which is the maximal operating one, hence a compressor increases pressure up to the maximal value in all the heating season. Whereas compression up the lower temperature and pressure in the latter case needs less energy, for the design temperature value occurs infrequently.

In the second part of the analysis, the emission values of the selected air pollutants: carbon dioxide, nitrogen oxides and sulfur oxides are obtained in relation to the current and forecast energy market structure, taking into account direct emissions resulting from the operation of an additional heat source, e.g., an oil boiler in a system equipped with an ASHP heat pump. The results related to carbon dioxide emissions are presented in Figure 1a,b.

Both charts in Figure 1 show that the planned activities for increasing the share of renewable energy sources in the production volume and the efficiency of electrical energy generation may almost halves the carbon dioxide emissions; it concerns other greenhouse gas emissions, for they are correlated.

The comprehensive results analysis will be presented in the full text. The outcomes will be compared with the suitable EU regulations. Also the differences between each scenario will be discussed in detail.
Figure 1. Carbon dioxide emissions for specific locations: (a) at a constant temperature in the buffer tank; (b) with changed temperature in the buffer tank.

4. Conclusions

Since the estimated CO$_2$ emissions reduction is 45% it will be a significant share in 30% greenhouse gases reduction by 2030.
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