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A field study of the performance of a heat pump installed in a low energy house

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HIGHLIGHTS

- An efficiency field test of a heat pump was performed.
- The thermodynamic cycle of the heat pump was controlled by an electronic expansion valve.
- A high COP of the heat pump was obtained for underfloor space heating.

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ABSTRACT

The experimental studies of the thermal performance of a ground source heat pump (GSHP) described in this paper were conducted in a single-family house. These studies were aimed at performing a field test for the heating capacity of a heat pump. The studies were conducted for 3 cases of variable demand for heat: when space heating was used on the ground floor (75 m^2); when space heating was used on the ground and first floors (140 m^2) and with the additional heating of domestic hot water mode on (hot water tank 250 L). During the measurement cycle the evaporation temperature of the R407C refrigerant was maintained at a constant level using an electronic expansion valve. Series of measurements were conducted for the evaporation temperature ranging from −5 °C to 2.5 °C.

The COP increases along with the evaporation temperature of the R407C refrigerant, yet in the case of the heat pump the maximum COP value was obtained for the evaporation temperature about −2.5 °C. The obtained results were considerably influenced by the temperature of glycol in the secondary circuit of the low temperature source. The heating performance of the heat pump within the investigated period ranged from 8.4 kW to 9.2 kW. While heating domestic hot water, the system could heat the water in the storage tank to a temperature of 45 °C. The control system of the heat pump should enable keeping the condensation temperature as low as possible thus maintain a high COP value.

The heating capacity can be adjusted to match the heat demand for space heating by controlling the duration of compressor operation.

1. Introduction

Heat pumps have been used in Europe for 25 years, yet there has been a sudden increase in their sales recently. This results mainly from the EU Directives whose principal objective is to increase the share of Renewable Energy Sources (RES) in the final energy use up to 15% by 2020 [1]. The forecasts of the RES market development in Poland indicate that low temperature geothermal energy (heat pumps) may play a significant role in meeting the requirements of the said Directives.

Heat pumps are fitted in popular heating systems in leading European countries (Sweden, Germany and France). These countries have the highest energy saving rates and ecological indexes [2]. These results from the effective promotion of heat pump technologies based on special electricity charge rates dedicated to such units and various forms of subsidies or tax incentives.

Theoretical and experimental studies have confirmed that ground source heat pump (GSHP) offer the highest energy performance [3]. Advanced studies of vertical collectors with inclined boreholes were performed by Cui et al. [4]. The numerical and experimental analysis of horizontal collectors is available in the

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work by Esen et al. [5]. Literature also provides results of experimental studies concerning the performance analysis of heat pumps e.g. Nagano et al. [6], where the ground exchanger was used as ground heat source.

The use of heat pumps for home heating, owing to its low maintenance costs, is also on the increase in Poland [7].

Because of moderate climate in Poland, GSHP are used with vertical and horizontal collectors. Recently, there has also been an increasing demand for high heating capacity heat pumps for heating multi-family buildings, offices, tourist and leisure facilities that are to undergo thermal upgrades.

The market for air source heat pumps used only for producing domestic hot water has also been developing rapidly (Fig. 1). This mainly results from their relatively low price and easy of fitting. Compared to solar systems, they are cheaper and domestic hot water is available throughout the year.

The use of an appropriate heat pump technology ensures the most advantageous economic indexes depending on the local climate and terrain conditions [8]. In Europe, heat pumps are equipped with two separate circuits for the heating system and production of domestic hot water. In the U.S. systems with an additional desuperheater are popular enabling a use of domestic hot water DHW and space heating simultaneously [9]. Experimental studies on hybrid ground source heat pumps (HGSHP) have been conducted. These studies aimed at obtaining a higher COP [10].

The demand for heating changes throughout the heating season. The results of experimental studies on heat pumps with variable volume [11] and variable speed compressors [12] are also available.

Advanced research studies on various heat pump configurations are supported by experimental research conducted on prototypical research stands. In the literature, there is little information on energy efficiency analyses of heat pumps obtained in field tests [13]. Therefore, this paper describes a field test of a heat pump. The object under study was a single-family house equipped with a heat pump configuration commonly used in Poland.

2. Research station

2.1. Description of the research station

A two-story single-family house with a total living area of 156 m^2 was investigated. The building was constructed to use low energy technology. A low temperature floor heating system was used on the ground and first floors. In individual rooms, a heating system with 0.15 m spacing between the pipes was fitted with the exception of the bathrooms where the spacing was 0.1 m. The average length of individual circuits was 60–65 m. Separate manifolds powered by independent circulation pumps were used for heating circuits on the ground and first floors. The applied configuration made it possible to conduct a study of the heat pump for variable demand for the mass heat flow. In the first case only the underfloor space heating was attached only on the ground floor (75 m^2 of 0.07 m thick concrete underlayment). In the second case was also attached underfloor space heating on the ground and first floors simultaneously (140 m^2 of 0.07 m thick concrete underlayment).

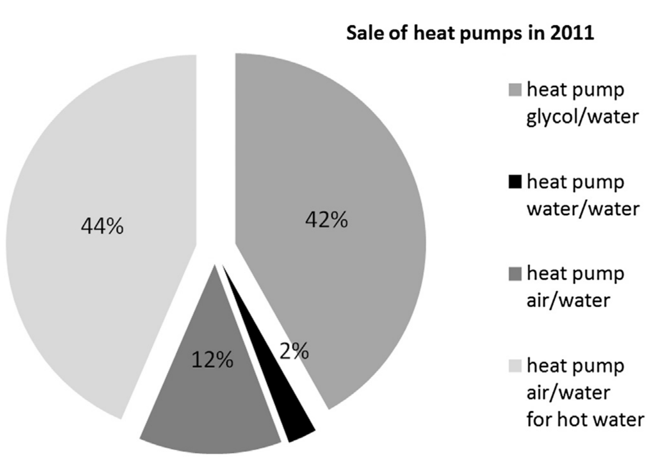

Fig. 1. Statistical data related to heat pumps installed in 2011 in Poland.

Design documentation and specifications give the yearly power requirement at a level of E = 16,400 kWh. Assuming that, on average, the pump works for 1800 h, an approximate heat load of the building at a level of 9.1 kW was obtained.

According to data available in relevant literature, the demand for heat energy for new low-energy single-family buildings amounts to 40–50 W/m^2 [8]. Assuming the unit heat load of 50 W/m^2 and 156 m^2, an average heat load of the building amounting to 7.8 kW was obtained. If the heat pump also produces DHW, then, for a 4-person family, an additional 1 kW needs to be added [14]. Finally, for a 156 m^2 house, a heat load of 8.8 kW was obtained.

In round figures, for further calculations, it should be assumed that the required heating capacity of a heat pump amounts to 9 kW.

2.2. Basic components of a heat pump

Heat pumps used for heating low energy houses are controlled by thermostatic expansion valves. Examining the assumed scope of experimental studies requires the use of a heat pump controlled by an electronic expansion valve. Therefore, a mass-market heat pump was not an option. Instead, components produced by reputable manufacturers from the refrigeration industry were used for its construction.

Following the guidelines given in Ref. [15], R407C was used as a refrigerant and in the circuit of the condenser and evaporator, plate heat exchangers by WTK (Italy, www.wtk.it) and a spiral hermetic compressor made by SANYO were used.

Because of an even load of individual phases of the electrical installation and following the experimental studies using a frequency inverter, a three-phase compressor was applied. A compressor was selected of a heating capacity of 9 kW reaching a COP = 4.39 for the assumed conditions of B0W35 as specified in the manufacturer data given in Table 1.

The data shown in Table 1 indicate that a change in the evaporation temperature practically does not result in a change of the motor power consumption. The compressor performance increases along with the evaporation temperature, therefore the COP is also proportionally higher for higher evaporation temperatures. This means that the evaporation temperature of the refrigerant should be maintained at the highest possible level. On the other hand, if the condensation temperature is increased, COP is significantly reduced.

The applied R407C refrigerant is a three-component mixture. Each of these components has a different evaporation temperature. In order to ensure 100% evaporation of each of the components, a super-heater of drawn-in gas was used, following guidelines included in the manual [14].

Table 2 includes basic GSHP data, whereas Fig. 2 shows a concept diagram of the applied GSHP system.

The plate heat exchangers were selected through Avogadro2 rev. 2.0. software. The standard working parameters for a brine heat pump are B0/W35, which denotes the refrigerant evaporation temperature (0 °C) and the condensation temperature (35 °C).