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Selected Issues of the Technical Analysis of a Heating System Using the Direct Evaporation Heat Pump

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Summary. The article describes selected issues falling within the scope of the technical analysis of a detached building's heating system with a direct evaporation ground source heat pump installation. This paper covers the characteristics of modernized facility as well as calculations to determine the heat demand. What is more, the article describes the manner in which heat pumps shall be selected, its installation components as well as the receiving installation.

Key words: heat pumps, renewable energy sources, energy management, environment.

INTRODUCTION

Currently, providing for energy security for the country poses one of the Poland's greatest challenges. The task is difficult and shall also be fully met in terms of the logistics. In view of the prolonging deadline for launching the gas port and nuclear power plant construction, taking into consideration instability in the East, as well as strict emission standards implemented within the EU, renewable energy sources provide one of the ways to improve the country's energy potential. Such installations, supported by the EU, may possibly be extremely successful. During the recent years, micro-installations and prosumer energy systems have become particularly popular. The solution consisting in providing independent heat or energy sources with the sales of the production surplus to the network seems highly sensible in terms of the above-mentioned difficulties. Surely, heat pumps, which are more and more common in industrial and warehousing facilities, constitute such installations [1, 10].

HEAT PUMP OPERATION PRINCIPLE

Heat pumps are devices, whose operation do not contribute to the emissions of harmful dust, nitrogen oxide, sulphur and carbon, hence they improve the human health [21]. The pumps use the heat accumulated in the ground, air and water [7]. The structure of the devices allows for collecting the low temperature heat and increasing the temperature for the purpose of central heating of warm water installations [2]. Some types of heat pumps are additionally capable of cooling the rooms [4]. The installation comprises a bottom heat source, the heat pump unit and the top heat source – the receiving installation. It operates based on the cooperation of the following components: condenser, compressor, evaporator and expansion valve. The low temperature heat is collected from the bottom source (water, ground, air) through the working agent circulating within the system, which is also the heat carrier. The heat carrier is phase transitioned in the evaporator, in the low temperature. In the next step, the working agent in the form of low pressure vapour is compressed in the compressor, with the external power consumption. The temperature and the pressure increase here. Then the agent reaches the condenser, where the heat is conveyed to the receiving installation and the working agent's vapour is condensed. In the extension valve the agent's pressure changes by extending the condensation pressure to the evaporation pressure [23]. What is more, it regulated the working agent's stream depending on the evaporator's load. All the thermodynamic transition occurring in the system is compliant with the left-hand Linde's circulation principle.

The heat pumps available on the Polish and foreign markets are classified based on their top and bottom heat sources [25]. The following types of pumps may be distinguished: air/water, air/air, water/water, water/air, ground/water, ground/air [16]. The heat collected from the bottom source is conveyed to the receiving installation with air or water circulating in it. The heat source cooperating with the heat pumps may include: floor heating, warm water system, fan coil units, and radiators [18, 27]. The air heat pumps, as suggested by their name itself, collect the heat from the air. Other devices, of the water/water type, operate in the locations with ground water resources, wells or open water reservoirs [29]. The ground water pumps are divided based on the manner of installing the heat exchanger in the ground – into the horizontal or vertical heat exchanger systems, as well as depending on the device's operation principle into heat pumps with indirect or direct evaporation system. The indirect evaporation heat pumps with horizontal heat exchangers are used more commonly, since they are cheaper and easier in installation.

In the indirect evaporation system one may distinguish three circulation systems, while the direct evaporation system may operates in two various circulation systems [9, 24] In the case of system A presented on Figure 1, the first circuit is the bottom circuit with a brine, namely the mixture of propylene glycol and water. The middle circuit is a circuit with the cooling agent, while the third one is the top heat source circuit. The direct evaporation heat pumps reach better performance coefficients, compared to those with the indirect evaporation system. This is possible thanks to the elimination of the losses on the additional heat exchangers and circulation pumps. The horizontal heat exchanger shall be placed at least 30 cm below the freezing zone. The depth depends on the distance between them of no less than 5 m. The distance is based on the 2.5 m heating radius of the heat exchanger. Vertical heat exchangers reach various depths of 30 up to more than 200 m. The heat is stored in the ground from the solar radiation and from the ground water. The thermal conductivity of the ground depends on its humidity and mineral composition. The higher the humidity of the ground, the higher the thermal conductivity is [31]. The conducted experiments suggest that in various types of the ground, the thermal performance of the vertical heat exchanger varies from 30 and 70 W/lm [12]. In the case of dry soils, a water jet is generated in result of the water steam diffusion, surrounding the heat exchanger and conveying the heat to the surface. The probe's efficiency in this case is estimated to reach 50 W/lm [8]. The ground may be iced if the ground's heat recovery is not provided for. The process brings also the decreased pump efficiency. There are heat pump units available on the market, that provide for both the heating in the winter and comfortable temperature in the summer [32]. They operate in the reverse system, meaning that they have the cooling option [30]. This happens with the four-port valve, reversing the flow direction of the cooling agent [22, 28]. The condenser takes the role of the steamer and receives heat from the rooms. The working agent evaporates, flows through the four port valve and reaches the compressor. Then it is conveyed to the heat exchanger receiving the heat in order to heat the water, and finally it is conveyed to the ground heat exchangers, where it losses the heat. One shall note here, that in this operation system, the water heating is only provided when the compressor is working [13, 27].

DESIGNING A HEATING INSTALLATION WITH A HEAT PUMP

Designing the heating installation operating with heat pumps requires the analysis of the the data of the building, for which the devices are being selected [20]. One shall take into consideration its location, construction technology, ventilation type, and purpose [3]. With the above information one may start selecting the heat pump. Selecting high quality construction materials and insulation materials significantly influence the building's heat demand and the cost of its heating. The next component is the ventilation type used. For example, gravitational ventilation requires 20% more heat demand for the building compared to the heat recovery ventilation system. The next analysis component is the building's location. The territory of Poland is divided into five climate zones. Each zone has been estimated in terms of the freezing depth, the lowest and average annual outdoor temperatures. For example, Warsaw is located in the third climate zone, where the freezing depth is 1.20 m, the lowest design outdoor temperature is -20 °C, and the average annual outdoor temperature is 7.6 °C. Defining the manner of using the rooms within the building requires the application of standardised temperatures [16, 19]. For living rooms where people are to be spending time without jackets, the selected temperature is 20 °C, while in the bathrooms the temperature selected is 24 °C [26]. The next step in designing the heating installation is to determine the heat demand. Therefore, energy efficiency audit is being performed, but applying the simplified method detailing the information on the building's area, location, and design temperatures is also possible. The peak heat demand of the building is determined as the product of the building's heat demand coefficient and the building's area. The coefficients are presented in Table 1. The annual heat demand is provided in equation 1 [17].

$$Q_h = 24 * P * Sd / (t_i - t_e) \text{ [kWh]}, \quad (1)$$

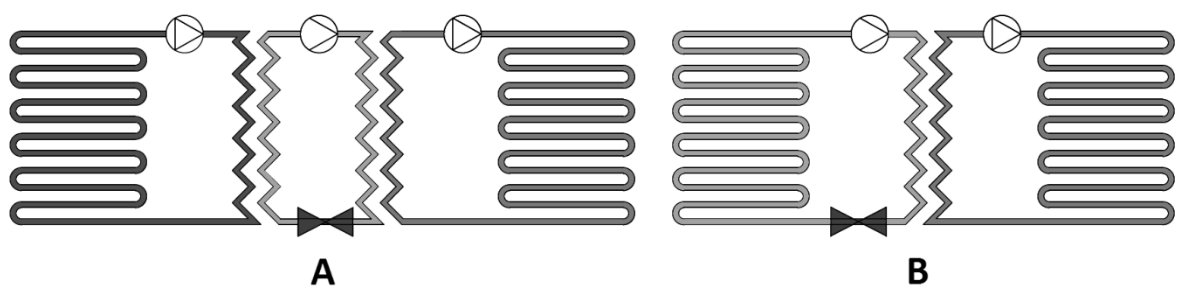

Fig. 1. Heat pump operation principle A) pump with the indirect evaporation system, B) heat pump with the direct evaporation system [Own elaboration]

where:
P – building's peak heat demand [kW],
Sd – number of the day degrees [-],
t_i – indoor temperature [ºC],
t_e – outdoor temperature [ºC].

Table 1. The building's heat demand coefficients for rooms 2.5–2.7 [m] high

Type of the building	Demand depending on the building's area	Demand depending on the building's cubature
	W/m²	W/m³
Old housing, uninsulated building	90–100	33–37
Old housing, insulated building (approx. 5 cm thick insulation)	65–75	25–28
New housing, standard insulation (approx. 10–15 cm thick insulation)	45–65	17–25
New housing, increased insulation	30–40	11–15

[Own elaboration based on 23]

The second dependency determines the average daily demand for hot water in the building [14]:

$$qdśr = n * qc \ [dm^3], \quad (2)$$

where:
n – number of people in the building [-],
qc – water consumption per person [dm³].

The average hourly demand for warm water is determined with dependency 3 [14]:

$$qhśr = qdśr / \tau \ [dm^3/h], \quad (3)$$

where:
τ – number of hours during which the installation is used during the day [h].

Eventually, the thermal input necessary to heat 200 litres of warm water is determined with dependency 4 [15]:

$$Q=0{,}001*m*1{,}163*\Delta T \ [kWh], \quad (4)$$

where:
m – water amount [kg],
ΔT – difference between the temperature of the heated water – output and the temperature of the installation water – input [K].

With the information on the peak heat demand within the building one can select the heat pump out of the abundant group of manufacturers offering a wide range of products. Two methods of installation designing are common. Installations with heat pump providing for one hundred percent of the heat demand, namely a monovalent system, or cooperation between the heat pump and another heat source, i.e. a boiler, electric heaters, namely a bivalent system. Catalogues with individual models present their heating efficacy described together with two working parameters. On the example of the Fonko Sp. z o.o.'s catalogue, the first parameter (W35/W45/W55/W65) defines the temperature of the heating installation, while the next one (E4/E0/E-4) defines the ground temperature [18]. The receiving installation shall be designed so that the temperature of the heating installation is as low as possible. Then the power consumption is low and the thermal efficiency of the heat pump is high. High ground temperature is most wanted. If there are no information on the ground conditions, assuming the lowest temperature possible of -4 °C is recommended. The heating installation shall be divided from the heating circulation system with a batch tank, acting as the heat storage, as well as with the hydraulic coupling. It also provides for the proper water flows, excluding the possibility that the receiving installation might affect the operation of the heat pump.

The next designing step consists in the selection of heating devices. Low-temperature radiators, floor heating, wall heating as well as fan-coil units are most commonly used. Jacket heating system is highly efficient and provides low energy consumption. Fan coil units may be used for heating or cooling. This choice requires a form of a compromise, since the device selected for cooling purposes will be oversized in terms of the heat demand and, the other way round, the heating demand will be oversized compared to the cooling demand. While selecting the fan coil units for heating purposes, application of the simplified method, analysing only the area and wall structure, is allowable. While estimating the cooling demand, one shall consider many variables. The analysis shall include heat gains by glazing the partition walls, solar access, intensity of the electric lighting, number of the people present in the building and electric devices. The simplified method in this case is limited to the analysis of the building's area as well as the purpose of the rooms. Low-temperature radiators are dedicated exclusively for heating the rooms. Selecting that option also requires the need to oversize, since they have to provide heating with the supply of 35-45 degrees [5].

ANALYSIS OF THE SELECTED HEATING INSTALLATION WITH THE HEAT PUMP

The research undertaken by the authors presents the technical and economic analysis of a heating system based on the joint operation of three direct evaporation heat pumps. The installation was operating to supply for the central heating and heating the warm water in a detached house with the total area of 826 m². The facility was located in the third climate zone, where the designed outdoor temperature is – 20 ºC, while the average annual outdoor temperature is 7.6 ºC. The designed temperature in the offices is 20 °C, while in the manufacturing rooms the temperature is 16 °C. The heated area was 785 m². Having in mind the above-mentioned conditions, the peak heat demand for the building with the average insulation was estimated to reach 55 kW. The annual heat demand is 129 302 kWh. It has been estimated that the average daily consumption of warm water in the building was 375 dm^3, assuming that one employee uses in average 15 dm^3 of water. The consumption provided for above has been oversized. The installation was supplement with a warm water reservoir with the volume of 200 litres, equipped with 2 kW electric heater. The heating energy of 10.5 kWh is required to heat the water in the reservoir, this value was omitted in determining the peak heat demand. Three direct evaporation heat pumps operating with 30 meter vertical heat exchanger were selected. The aggregate power of the devices was 52.05 kW. With the ground temperature of 0 °C and the installation temperature of 45 ºC, the thermal efficiency of a single pump was 17.35 kW, the electricity consumption was 4.51 kW, and the coefficient of performance COP was 3.85 [6, 11]. During the summer the installation was operating in the cooling mode. With the output temperature of 7 °C and the input temperature of 35 ºC, the cooling efficacy was 18.15 kW, the electricity consumption was 3.79 kW, and the coefficient of performance EER was 4.79 [6]. A 1500 litre batch tank was selected. The bottom heat source was provided by 15 vertical ground heat exchangers, 30 metres each. Five ground probes were entering each heat pump directly, without collector pipes. The receiving installation was composed of 35 ceiling and wall fan coil units of various power performance. Each device was equipped with a controller to set up the required temperature. Although the heat demand to heat the water was omitted and the selected devices provide the aggregate power not completely meeting the determined heat demand, the building's tenants declare that the installation operating provides comfortable temperature both in winter and in summer.

CONCLUSIONS

Heat pumps as a part of renewable energy sources are widely used in the heating systems of both newly constructed and modernized facilities. It is forecasted that by 2020 more than half of the new facilities will be equipped with heat pumps.

The survey on the detached office building situated near Warsaw with the total usable area of 785 m^2 provided in this article proved that having modernized the thermal insulation of the building by installing new windows and insulating the walls, the annual heat demand of the building was 129 302 kWh. The peak heat demand was estimated to reach 55 kW. The 25 individuals working eight hours a day were provided with a 200 litre reservoir of warm water and it was stated that 10.5 kWh were required to heat the water in the reservoir.

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WYBRANE ASPEKTY ANALIZY TECHNICZNEJ SYSTEMU GRZEWCZEGO Z ZASTOSOWANIEM POMP CIEPŁA BEZPOŚREDNIEGO ODPAROWANIA

Streszczenie. W artykule omówiono wybrane zagadnienia z zakresu analizy technicznej systemu ogrzewania budynku wolnostojącego instalacją z gruntowymi pompami ciepła bezpośredniego odparowania. Opracowanie obejmuje charakterystykę zmodernizowanego obiektu oraz obliczenia prowadzące do wyznaczenia zapotrzebowania na ciepło. Ponadto, w artykule dokonano opisu sposobu doboru pomp ciepła, elementów jej instalacji oraz instalacji odbiorczej.

Słowa kluczowe: pompy ciepła, odnawialne źródła energii, gospodarka energetyczna, środowisko.