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ANALYSIS OF THERMOTECHNICAL PARAMETERS OF AIR-WATER HEAT PUMP AS A PART OF THE RADIATOR SYSTEM OF HEAT SUPPLY OF THE ADMINISTRATIVE BUILDING

Abstract: *The description of original technical decision of using heat pump for heating part of administrating building is described. The hydraulic connection scheme has been developed and selection of heat devices was made for it. The energy efficiency for using heat pump in heating season is analyzed. Based on the obtained experimental data, the coefficient of performance of the heat pump was calculated for the above mode of operation of the heat supply system. With such indicators, a significant saving of thermal energy is achieved in comparison with the use of a centralized heat supply system.*

Keywords: *heat pump, heat supply, coefficient of performance (COP)*

Introduction

According to statistics, people spends up to 90% of the total time in buildings, the climatization of which is comparable to the largest part of the final consumption of all types of energy. In Ukraine, the housing and communal sector uses for more than 40% of this volume, and the efficiency of possible energy-saving measures in this direction, on a national scale, exceeds the possible savings in such technologically energy-intensive industries as metallurgy, chemical industry, etc. [1].

The use of heat pump systems based on renewable energy sources is a real alternative to the use of fossil fuels. More and more attention in the literature has been paid to the issues of efficiency assessment and implementation of heat pump technologies in customer's heat supply systems.

Literature review

Thus, in [2], the peculiarities of the schematic diagrams of such systems are considered (Fig. 1). The main advantages of using heat pump technologies for heating compared to centralized heat supply are described.

The works [3, 4] describe the concepts and give specific examples of the effectiveness of the use of heat pumps. It is noted that when using heat pump heating systems, the use of energy obtained from fossil carbon fuel is reduced by 2-3 times and the comfortable thermal conditions of a person's stay indoors are significantly improved. Also, at the same time, heat pump systems have less inertia of operation than centralized heat supply systems.

In works [5] it is stated that the higher the coefficient of thermal resistance of enclosing structures, the more profitable the use of heat pump technologies for heating, ventilation and hot water supply of buildings. This is due to the low temperatures of the heat carrier at the output of the heat pump, the transition from radiator heating to water floor heating, as well as the use of accumulator tanks in hot water supply systems.

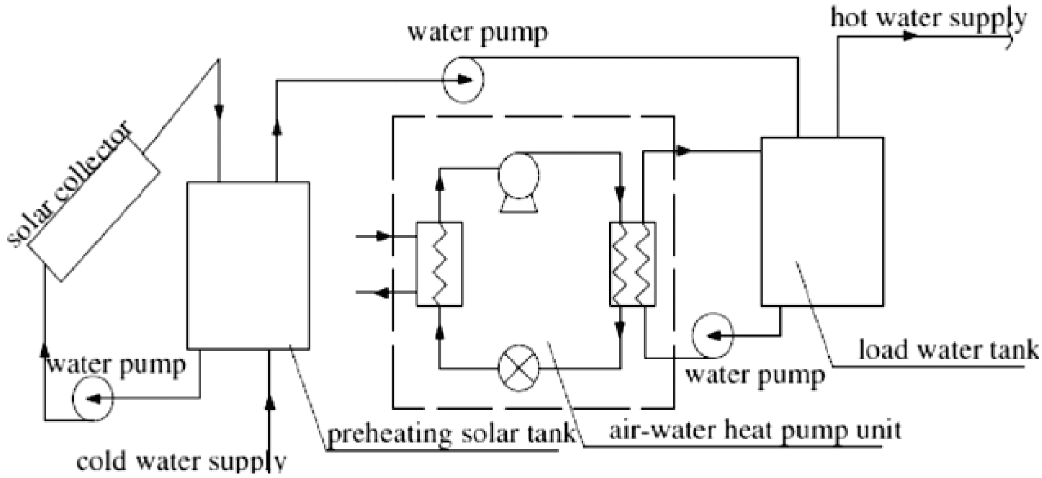

FIGURE 1. *Schematic diagram of the combined heat supply system [2]*

Problem formulation

The high energy consumption for the full cycle of building operation in Ukraine is, on average, more than 300 kWh/(m^2·year) for the heated area, and should be significantly reduced in the future thanks to the widespread implementation of energy-saving measures in the housing and communal economy and increasing energy efficiency of heat supply engineering systems.

Object, subject, and methods of research

The Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine has implemented a number of projects aimed on reducing the consumption of thermal energy for the needs of heating of the administrative buildings. Among such projects is the modernization of part of the heating system of building No. 1 of the Institute with the installation of an air-water heat pump [6].

In Figure 2 presents the basic hydraulic scheme of the modernization of the existing centralized heating system of the three-story administrative building of building No. 1 of the Institute using an air-water heat pump. The improvement of the heating system was carried out by integrating the heat pump 7 IVT Optima 1700 (made in Sweden) with an output heat capacity of 16 kW into the existing system of centralized heating of the building [7, 8]. At the same time, the modernized heating system can be operated both from an individual heating station, using heat from the district boiler house, and from a heat pump.

When operating the system according to the first option, in order to avoid contamination of pipelines and heating devices from the heat carrier coming from the heating network, a bubble separator for dirt and gases Spirovent was installed 2.

During the operation of the system from the heat pump, part of the circuit of a typical one-pipe heating system is disconnected from the individual heating station with the help of a shut-off valve. Balancing valves 1 are provided for hydraulic balancing of the circulation along the circuits and prevention of redistribution of the heat carrier in the heating system. Regulation of thermal parameters is carried out according to the temperature of the return water. At the same time, as a result of cutting off part of the heating system, the thermal regime of the building was not disturbed and the maximum effect of energy saving was achieved due to the reduction of the use of heat from the centralized heating network.

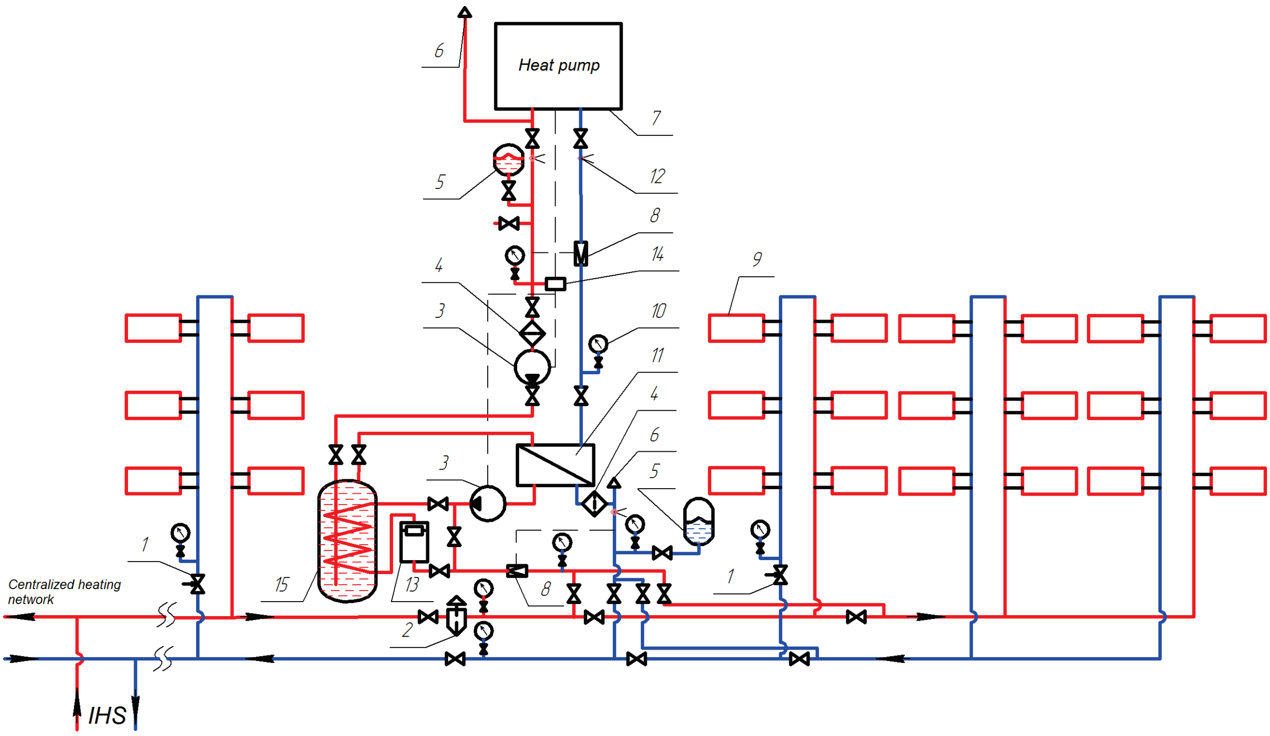

FIGURE 2. Schematic diagram of a heating system based on an air-liquid heat pump: 1 – balancing valves; 2 – bubble separator; 3 – circulation pumps; 4 – mesh filters; 5 – membrane expansion tanks; 6 – air vents; 7 – heat pump of the "air-water" type; 8 – heat meters; 9 – radiators of the heating system; 10 – manometer; 11 – plate heat exchanger, 12 – temperature sensor; 13 – electric boiler; 14 – pressure sensor, 15 – accumulator tank; IHS – is an individual heating station

In order to avoid the negative impact of the heat network on the heat pump, hydraulic separation of the heat pump circuit from the heating system circuit through a plate heat exchanger was provided Alfa Laval 10 with the use of an intermediate heat carrier – 20% aqueous solution of ethylene glycol.

At the same time, with the help of the shut-off valves, the fittings of six or four heating circuits (depending on the mode of operation of the heat supply system based on the heat pump) with radiators 9 are disconnected from the centralized heating system.

When filling the circuits and their further operation, air is removed with the help of air vents installed in the highest places of the circuits.

Circulation in both circuits with a given flow rate is provided, respectively, by pumps 3 Wilo-Star-RS 25/6 and Wilo-Top-S 25/10 with heat carrier cleaning by mesh filters 4.

Automatic shutdown of circulation and heat pumps with the help of pressure sensor 14 is provided in case of depressurization of circuits and loss of pressure. To compensate for the volumetric expansion of the heat carrier during its heating, two expansion tanks 5 with a volume of 4 and 50 liters are used, respectively. The volume of the tanks is calculated according to the volume of the heat carrier in the circuit, its coefficient of thermal expansion and the temperature schedule of the heating system. The amount of heat consumed for space heating is measured separately in each of the circuits by heat meters 8 Apator LQM – III – K, which makes it possible to estimate the heat losses in the main pipelines and the efficiency of the heat exchanger. Electric boiler 13 "Eco-Compact" K-6/6-380 with a heat capacity of 6 kW is intended for backup (emergency) and peak heat supply in the event of the heat pump not being able to work or its insufficient heat output.

To conduct research on the effectiveness of the heat pump, the temperature of the heat carrier in the forward and return pipelines of both circuits is measured by TSP-002k type thermal sensors and recorded by secondary control devices. To automate the operation of the heat pump, following temperature sensors are used:

- heat carrier in the supply and return circuit of the heat pump with an intermediate heat carrier (supply and return heat carrier from the heat pump);
- heat carrier in the supply and return circuit of heating devices (supply and return heat carrier of the heating system);
- heat carrier in the supply and return circuit of the centralized heat supply system (supply and return heat carrier of the heating system);
- air inside the control room;
- external air.

Experimental studies, the results of which are presented, were conducted during the heating period in 2019 using different modes of operation of the heat supply system of a part of the administrative building using an air-water heat pump in different operating modes. The duration of the study of one of the modes was an average of 15 days.

With the help of the measuring complex, all the main heat supply parameters were determined and recorded automatically in real time at intervals from one to twenty minutes: the temperature of the heat carrier at the inlet and outlet of all circuits, the air in the control room and the environment, as well as the consumption of the heat carrier in each of the circuits.

Regulation of the heat pump operating modes was carried out using a temperature sensor installed on the return pipeline of the heat pump circuit. For a detailed analysis, time intervals of the heat supply system operation were chosen, during which the temperature of the surrounding air changed slightly and the process of heat transfer through the enclosing structures of the building was quasi-stationary.

Study results and their discussion

In Figure 3 shows the experimental data that were obtained on January 24, 2019 from 5:00 a.m. to 11:00 a.m. The heat supply system based on the heat pump worked in the mode of heating 4 circuits of the heating devices of building No. 1, the peak electric boiler was turned off.

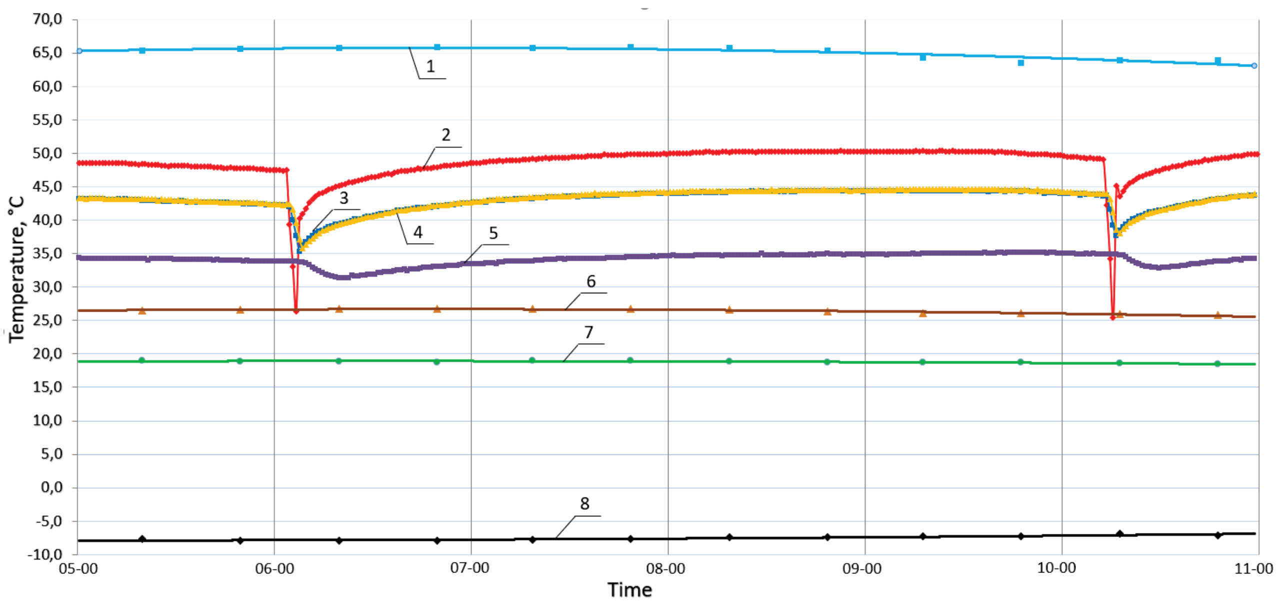

FIGURE 3. *Dependencies of internal air and heat carrier temperatures in the circuits of the heat supply system of a part of the administrative building 24.01.2019 (hours): 1 – heat carrier supply temperature from the centralized heat supply system; 2 – the temperature of the intermediate heat carrier at the outlet of the heat pump; 3 – the temperature of the intermediate heat carrier at the inlet to the heat pump; 4 – the temperature of the heat carrier on supply to the heating system; 5 – temperature of the return heat carrier from the heating system; 6 – the temperature of the return heat carrier of the centralized heat supply system; 7 – air temperature in the control room; 8 – outdoor air temperature*

The flow of the heat carrier was:

- heat carrier flow in the centralized heat supply system G_1 = 1.1-1.3 m^3/h;
- heat carrier flow in the circuit of the heat pump G_{TN} = 1.2 m^3/h;
- heat carrier flow in the G_{CO} heating system = 1.4 m^3/h.

As can be seen from Figure 3, the heat pump operates with an on/off interval of about 4 hours, indicating an excessive heat load on the heating system. The temperature of the heat carrier supplied to the heating system is on average 0.5°C lower than the temperature of the return heat carrier of the heat pump circuit. This indicates the insufficiency of the available heat exchange surface and the need to increase it. The outside air temperature ranged from -7.7°C to -7.1°C. The internal air temperature was within 19.0°C ±0.5°C.

Based on the obtained experimental data, the coefficient of performance (COP) of the heat pump was calculated for the above mode of operation of the heat supply system, which was COP_1 = 1.6.

In Figure 4 shows the experimental data obtained on February 25, 2019 from 17:00 to 23:00. The heat supply system based on the heat pump worked in the mode of heating 4 circuits of the heating devices of the building No. 1, the peak electric boiler heated up the heat carrier of the circuit of the heating system of the building. The flow of the heat carrier was:

- heat carrier flow in the centralized heat supply system G_1 = 1.2-1.3 m^3/h;
- heat carrier flow in the circuit of the heat pump G_{TN} = 0.95 m^3/h;
- heat carrier flow in the G_{CO} heating system = 1.75 m^3/h.

The heat pump operation interval in this mode decreased and the on/off period was 1.5 hours. In this operating mode, the temperature of the heat carrier that was supplied to the heating system is on average 3.0-3.5°C higher than the temperature of the return heat carrier of the heat pump circuit due to the operation of the electric boiler. The outside air temperature ranged from -5.3°C to -4.1°C. The internal air temperature was 19.5°C.

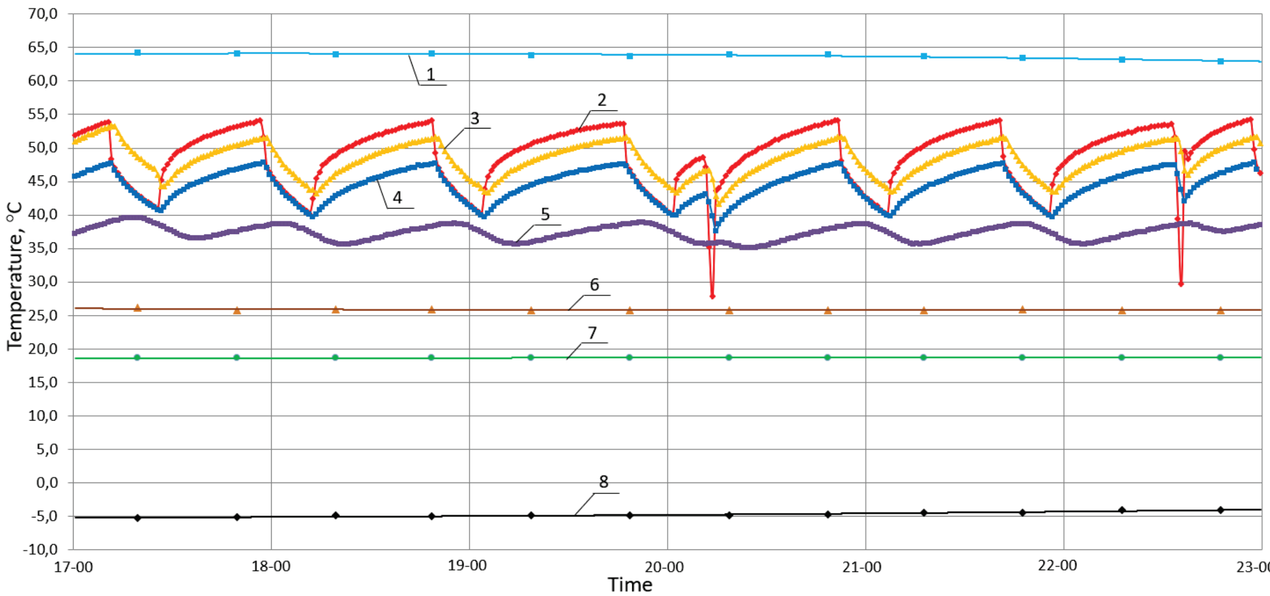

FIGURE 4. Dependencies of internal air and heat carrier temperatures in the circuits of the heat supply system of a part of the administrative building 25.02.2019 (hours): 1 – heat carrier supply temperature from the centralized heat supply system; 2 – the temperature of the intermediate heat carrier at the outlet of the heat pump; 3 – the temperature of the intermediate heat carrier at the inlet to the heat pump; 4 – the temperature of the heat carrier supply to the heating system; 5 – temperature of the return heat carrier from the heating system; 6 – the temperature of the return heat carrier to the centralized heat supply system; 7 – air temperature in the control room; 8 – outdoor air temperature

At 20: 15 and 22:40 there is a sharp decrease in the temperature of the supply heat carrier of the circuit of the heat pump, which is explained by icing of the surface of the evaporator of the heat pump.

The COP of the heat pump was calculated for the above mode of operation of the heat supply system, which was $COP_2 = 1.62$. A slight increase of the COP_2 is explained by a relatively high value of the outside air temperature.

In Figure 5 shows the experimental data obtained on March 4, 2019 from 12:00 to 18:00. The heat supply system based on the heat pump worked in the mode of heating 6 circuits of the heating devices of building No. 1, the peak electric boiler was turned off. The flow of the heat carrier was:

- heat carrier flow in the centralized heat supply system G_1 = 0.9-1.2 m^3/h;
- heat carrier flow in the circuit of the heat pump G_{TN} = 0.75 m^3/h;
- heat carrier flow in the G_{CO} heating system = 2.1 m^3/h.

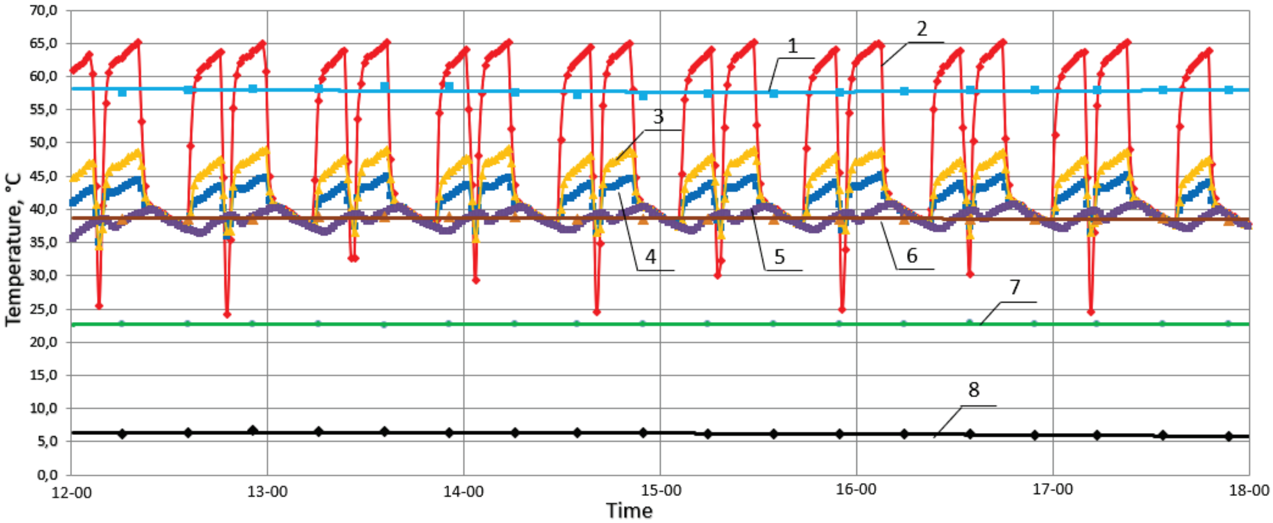

***FIGURE 5.** Dependencies of internal air and heat carrier temperatures in the circuits of the heat supply system of a part of the administrative building 03.04.2019 (hours): 1 – heat carrier supply temperature from the centralized heat supply system; 2 – the temperature of the intermediate heat carrier at the outlet of the heat pump; 3 – the temperature of the intermediate heat carrier at the inlet of the heat pump; 4 – the temperature of the heat carrier supply to the heating system; 5 – temperature of the return heat carrier from the heating system; 6 – the temperature of the return heat carrier to the centralized heat supply system; 7 – air temperature in the control room; 8 – outdoor air temperature*

The heat pump operation interval in this mode decreased and the on/off period was 45 minutes. In this mode of operation, the temperature of the heat carrier supplied to the heating system is on average 5.0°C higher than the temperature of the return heat carrier of the heat pump circuit due to the reduction of heat losses of the building and the increase of the heat carrier temperature. The outside air temperature ranged from 6.1°C to 6.5°C. The internal air temperature rose to 22.8°C.

In this mode of operation, icing of the surface of the evaporator occurs in almost every cycle of the heat pump, which negatively affects the resource of the heat pump and reduces the reliability of the entire heat supply system.

Based on the obtained experimental data, the COP of the heat pump was calculated for the above mode of operation of the heat supply system, which was $COP_3 = 1.94$. An even greater value can be explained by the increase in the temperature of the outside air and the decrease in the limit value of the coolant temperature in the circuit of the heat pump.

Conclusion

Average for the heating period, the COP of the air-water heat pump, when it was integrated into the existing heat supply system of the administrative energy building, was COP = 1.82, which is significantly less than the recommended 2.5-2.7 for proper implementation. However, even with such indicators, a significant saving of thermal energy is achieved, from 10% to 24%, in comparison with the use of a centralized heat supply system.

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