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INTEGRATION OF HEAT PUMPS WITH HEAT EXTRACTION FROM THE SOIL AND AIR INTO BUILDING HEATING SYSTEMS

Ю. Рєпін, М. Сергеєв. **Інтеграція теплових насосів із відбором теплоти від грунту та повітря в системи теплопостачання будівель.** В роботі проведено огляд сучасного стану систем теплозабезпечення житлових будівель та будівель громадського призначення. Показано необхідність застосування альтернативних джерел енергії для теплозабезпечення житлових будинків та будівель громадського призначення. Виконано аналіз різноманітних теплонасосних систем та джерел теплоти. Визначено найбільш поширені джерела теплоти для систем теплопостачання із застосуванням теплових насосів, а саме грунт та зовнішнє повітря. Для теплонасосних систем із відбором теплоти з грунту проаналізовано різні підходи, щодо відбору теплоти. Охарактеризовані переваги та проблеми застосуваня теплонасосних систем із відбором теплоти від зовнішнього повітря та грунту. Показано, що заходи з економії енергоресурсів потребують комплексного підходу. Використання теплонасосних систем в комбінованих системах теплопостачання повинна вирішуватися спільно з питаннями теплових режимів експлуатації будівель. Доведено, що для підвищення процесу впровадження теплонасосних систем необхідно підвищити їх рентабельність за рахунок збільшення частки заміщення традиційних енергоресурсів відновлювальними джерелами енергії. Для дослідження ефективності роботи теплових насосів із різним видом джерел теплоти в роботі наведена математична модель роботи теплового насосу із відбором теплоти від зовнішнього повітря та грунту. Для будівель зі схожими технічними даними проведено дослідження роботи комбінованих систем теплопостачання із використанням теплових насосів з відбором теплоти від зовнішнього повітря та грунту впродовж року. За отриманими даними побудовано порівняльні графіки роботи теплових насосів, та проведено аналіз ефективності режимів експлуатації основного обладнання. За результатами аналізу зроблені висновки, які показують зони ефективної роботи теплових насосів різних типів. Отримані результати дозволили оцінити ефективність роботи теплонасосних систем з різними джерелами теплоти, та надати можливість подальшого дослідження у напрямку напрацювань рекомендацій застосування теплових насосів в комбінованих систем теплопостачання.
Ключові слова: теплові насоси, комбіновані системи теплопостачання, відновлювальні джерела енергії

Y. Riepin, M. Serheiev. **Integration of heat pumps with heat extraction from the soil and air into building heating systems.** The paper reviews the current state of heat supply systems for residential and public buildings. The need to use alternative energy sources for heat supply in residential and public buildings is shown. Various heat pump systems and heat sources are analyzed. The most common heat sources for heat supply systems using heat pumps are identified, namely the soil and outside air. For heat pump systems with heat extraction from the soil, various approaches to heat extraction are analyzed. The advantages and problems of using heat pump systems with heat extraction from the outside air and soil are characterized. It is shown that energy saving measures require an integrated approach. The use of heat pump systems in combined heat supply systems should be addressed together with the issues of thermal operating modes of buildings. It is proven that in order to improve the process of implementing heat pump systems, it is necessary to increase their profitability by increasing the share of replacing traditional energy resources with renewable energy sources. To study the efficiency of heat pumps with different types of heat sources, the paper presents a mathematical model of the operation of a heat pump with heat extraction from the outside air and the soil. For buildings with similar technical data, a study of the operation of combined heat supply systems using heat pumps with heat extraction from the outside air and the soil throughout the year was conducted. Based on the data obtained, comparative graphs of heat pump operation were constructed, and an analysis of the efficiency of the operating modes of the main equipment was conducted. Based on the results of the analysis, conclusions were drawn that show the zones of effective operation of heat pumps of different types. The results obtained allowed us to assess the efficiency of heat pump systems with different heat sources, and provide an opportunity for further research in the direction of developing recommendations for the use of heat pumps in combined heat supply systems.
Keywords: heat pumps, combined heat supply systems, renewable energy sources

1. Introduction

Energy security of the country is based on the use of the internal potential of generation, transport and transformation of energy resources. Recent events have shown how important it is to have internal reserves to counteract external challenges. The rising cost of fossil fuels, the impossibility of importing them and the political factor of energy independence have increased interest in the use of renewable energy sources to ensure the rational consumption of energy resources of the housing and communal sector [1]. In conjunction with these problems, there is also a solution to the issue of improving the ecological state of the country.

As you know, the housing and communal sector of our country consumes about 30% of fossil fuels for heat supply, and in large cities the share of fossil fuels for heat supply is more than 80% [2].

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This highlights the path of modernization of existing heat supply systems. First of all, it concerns the introduction of renewable energy sources into existing or projected heat supply systems [3, 4].

Calculations show that when transferred to autonomous alternative heat supply ~10% of consumers in the southern regions of Ukraine, it is possible to achieve annual savings of 0.17 million tons of conventional fuel. [5]. The most mobile in this case are private buildings, offices, small and medium-sized businesses. Integration of heat pump systems into their heat supply systems is the most likely and productive.

Despite the fact that heat pump systems, like other renewable energy sources, are widely used by many countries of the world (for example, Israel, USA, Denmark, Germany, Sweden, Belgium, Brazil, Spain, etc.), it should be noted that the development of alternative heat supply is due to state support and subsidy policy [6]. In Ukraine, this process is inhibited by the current state of the state [7].

To increase the process of introducing heat pump systems, it is necessary to increase their profitability by increasing the share of replacement of traditional energy resources with renewable energy sources [8, 9, 10].

At the same time, however, another selection problem arises – for heat pump systems which heat source to choose for integrated heat pump systems. This issue is associated with both capital costs and operating costs.

2. Analysis of literary data and formulation of the problem

Energy saving measures require an integrated approach [11]. The use of heat pump systems in combined heat supply systems should be solved in conjunction with issues of thermal modes of operation of buildings.

Integrated heat supply systems that combine traditional heat pump systems are increasingly used in the design or modernization of heat supply systems. The use of such systems allows, first of all, to significantly reduce the consumption of fossil fuels at peak loads of heat supply systems and completely replace it both during the heating period and in the demi-season period.

For residential buildings and small and medium-sized businesses, the most common main source of heat can be either outdoor air or soil. In this case, the extraction of heat from the soil can be either due to the installation of horizontal systems, or vertical collectors [12, 13]. Soil is a natural energy accumulator. The natural qualities of the soil as a source of renewable energy are evidenced by its physical properties – thermal conductivity, density, heat capacity, depending on the rock and location [14].

From the point of view of investment, a system with heat extraction from external air is less costly. However, it is very frequent is less effective and not able to provide standardized parameters of the heat supply system.

A less costly system with horizontal collectors requires developed areas of land and less efficiency due to close proximity to the surface of the earth. On the other hand, the use of vertical collectors (depth can reach 100 m), requires significant capital investment in the system of heat extraction and coordination with the departments of the country. Moreover, such a system is more effective in terms of heat extraction.

On the other hand, the soil is quite inertial and takes some time to regenerate. Therefore, when the air temperature has already increased significantly enough, the soil temperature in the area of heat exchangers remains unchanged for a long time.

At the same time, the air temperature is less inertial and is able to fluctuate during the day in the region of 10 C. this is able to provide a fairly smooth transition to new parameters of heat carriers. The outside air temperature changes throughout the year. To determine the total need for energy during the year use the data of climatology [15].

Over the past decade, there has been a change in the temperature of the outside air in the cold season, which is associated with general trends on the planet.

Given that the efficiency of heat pump systems depends on two temperatures - the temperature of the heat source and the temperature of the coolant in the building, it becomes a question to determine the range of efficiency of using heat pump systems for combined heat supply systems with heat extraction from external air and soil heat for climatic factors of the middle natural zone of Europe.

3. The purpose and objectives of the research

The main purpose of this study is to determine the characteristics of heat pumps under the same climatic conditions through the use of different sources of heat (outdoor air and soil).

To solve the goal you need to solve the following problems:

– based on existing research, choose a mathematical model of the heat pump;

– conduct a study of the operation of heat pumps from different heat sources for the same climatic conditions;

– based on the experimental data obtained, analyze the use of heat pumps from various heat sources for communal infrastructure facilities.

4. Methods of conducting research and processing experimental data

We will use the technique of numerical simulation of the heat pump cycle [16] to analyze the energy efficiency of the application of the three studied schemes of the heat pump facility for Southeast Europe in the winter (t_0 = –18 °C).

The evaporation temperature of freon t_0, by which the enthalpy h_1 and the pressure of freon P_0 after the evaporator can be determined:

$$t_u = t_{n2} - \Delta_{tu}\,, \tag{1}$$

where t_{n2} – temperature of low-potential heat source, °C;

Δt_u – temperature difference at evaporator outlet, K.

The condensation temperature of freon t_k, by which the enthalpy h_3 and P_k pressure of freon after the condenser can be determined:

$$t_k = t_{w2} - t_k\,, \tag{2}$$

where t_{w2} – low potential heat source temperature at evaporator outlet, °C;

Δt_k – temperature difference at the condenser outlet, K.

Compressor adiabatic efficiency:

$$\eta_a = \frac{0.98(273 + t_0)}{273 + t_k}\,, \tag{3}$$

where t_0 – ambient air temperature, °C.

Freon enthalpy after compressor:

$$h_2 = h_1 + \frac{h_{2a} - h_1}{\eta_a}\,, \tag{4}$$

where h_{2a} – enthalpy after adiabatic compression, kJ/kg.

Specific heat load of condenser:

$$q_k = h_2 - h_3\,, \text{ kJ/kg.} \tag{5}$$

Specific heat load of the heat pump facility is:

$$q_{hp} = h_k\,, \text{ kJ/kg.} \tag{6}$$

Compressor compression operation is defined as follows:

$$l_k = h_2 - h_1\,, \text{ kJ/kg.} \tag{7}$$

Specific energy consumed by the electric motor:

$$W = \frac{lk}{\eta_{em} - \eta_e}\,, \text{ kJ/kg,} \tag{8}$$

where η_{em} – electromechanical efficiency of the compressor;

η_e – Efficiency of the electric motor.

Transformation ratio:

$$\mu = \frac{q_{hp}}{l_k}\,. \tag{9}$$

Compressor compression ratio:

$$\varepsilon = \frac{P_k}{P_u}\,. \tag{10}$$

Freon mass flow rate:

$$G_f = \frac{Q_{hp}}{q_{hp}}\,, \text{ kg/s,} \tag{11}$$

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where Q_{hp} – heat load of the heat pump facility, kW.

Power consumption for compressor drive:

$$N = WG_f \text{, kW.} \quad (12)$$

Specific primary energy consumption:

$$\text{PER} = \frac{1}{\eta_{em}\eta_e\eta_{eu}\eta_{per}\mu}, \quad (13)$$

where PER – primary energy;

η_{eu} – facility efficiency factor;

η_{per} – efficiency factor of the power supply system.

5. Results of experimental bench research

To solve the research tasks, two typical residential buildings with star-dimensional thermal characteristics were selected. Moreover, in one building, a heat collector with heat extraction from external air was used (Fig. 1, 3), and in another building, a heat collector with heat removal from the soil with vertical collectors was used (Fig. 2, 4). Both heat pumps are installed on these buildings of Viessmann, Germany.

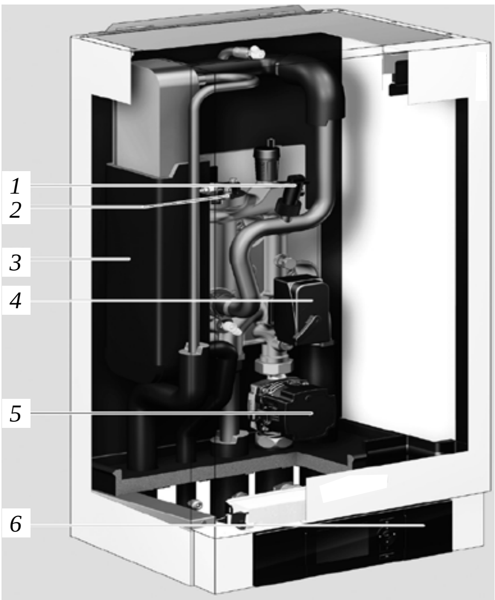

Fig. 1. Installation of the inner unit of heat pump with heat extraction from outside air:
1 – Flow relay, *2* –Coolant flow heater, *3* – condenser, *4* – 3-way valve, *5* – secondary pump, *6* – heat pump controller

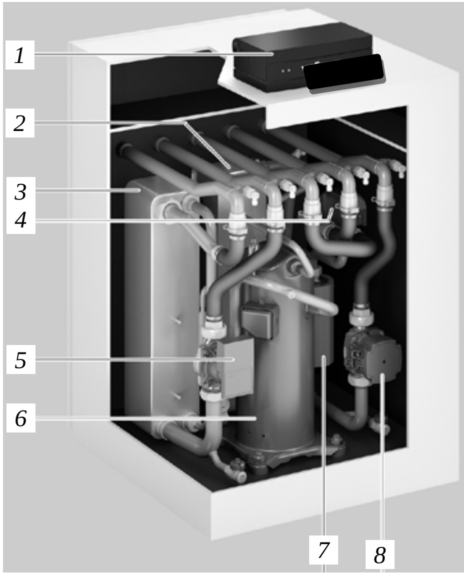

Fig. 2. Installation of the internal unit of the heat pump with the extraction of heat from the soil:
1 – Weather-dependent digital heat pump controller, *2* – Condenser, *3* – Evaporator, *4* – 3-way valve, *5* – Primary pump, *6* – Compressor, *7* – Coolant flow heater, *8* – Secondary pump

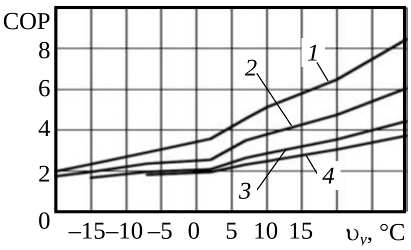

Fig. 3. Heat pump characteristics with heat extraction from outside air, °C:
35 (*1*); 45 (*2*); 55 (*3*); 60 (*4*)

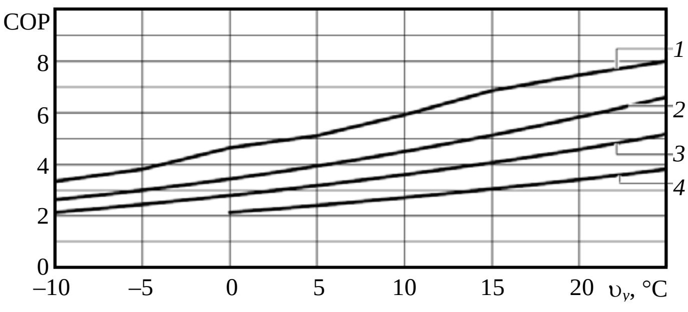

Fig. 4. Characteristics of the heat pump with the extraction of heat from the soi, °C:
35 (*1*); 45 (*2*); 55 (*3*); 60 (*4*)

During 2023 – 2024, a study of the main parameters of the operation of heat pump systems at public housing facilities was conducted (Fig. 5 – 9).

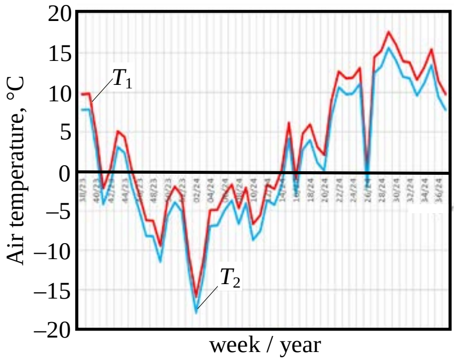

Fig. 5. Graph of primary coolant temperature change (T_1 – supply line, T_2 – return line) during the reporting period for heat pump with heat extraction from outside air

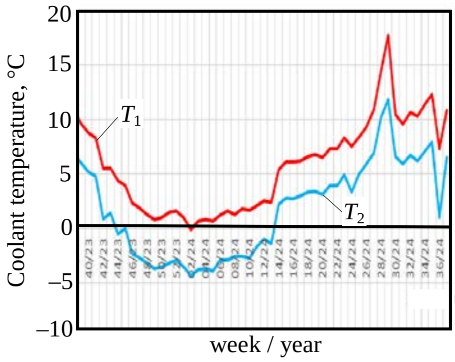

Fig. 6. Graph of the temperature change of the primary coolant (T_1 – supply line, T_2 – return line) during the reporting period for the heat pump with the extraction of heat from the soil

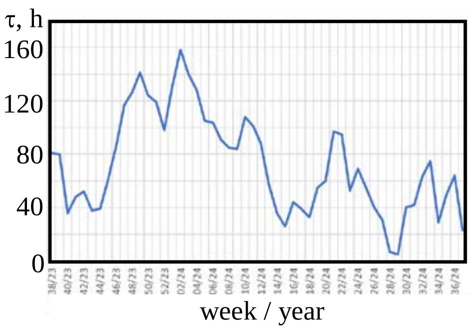

Fig. 7. Schedule of operating time of the heat pump with heat extraction from outside air during the reporting period (hours)

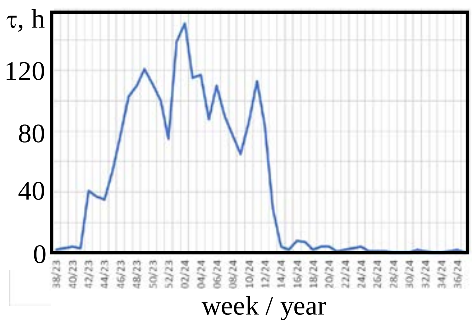

Fig. 8. Schedule of operating time of the heat pump with the extraction of heat from the soil during the reporting period (hours)

The analysis of the obtained results of pilot projects of heat pumps operation with heat extraction from external air and soil allows to assess the efficiency of these heat pump systems as part of combined heat supply systems (existing or projected) for the conditions of the average climate in Europe. The use of heat pump systems for conditions with an air temperature of less than 0 °C over a long period constitutes the conditions for the effective use of soil heat. However, when the air temperature changes during the day from 0 °C to 10 °C, it becomes more attractive to use heat pumps with heat extraction from outside air, as less inertial. It should be noted the positive contribution of the use of soil heat for passive cooling. Specified air conditions for cooling systems are not possible.

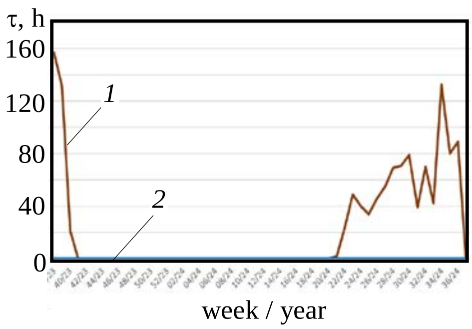

Fig. 9. Operating time schedule of the heat pump in passive cooling mode. For conditions of heat extraction from soil and outside air (*1* – ground source heat pump, *2* – air source heat pump)

Conclusions

The paper analyzes heterogeneous sources of thermal energy for heat pump systems.

In accordance with the tasks, the following studies were conducted:

– on the basis of the conducted research, a mathematical model describing the operation of heat pump systems under various operating conditions was chosen;

– experimental studies of the operation of heterogeneous heat pump systems in variable climatic factors for similar objects of the housing and communal sector;

– on the basis of the obtained experimental data, an analysis of the use of heterogeneous heat pumps for residential and communal infrastructure facilities was carried out.

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It is shown that the use of heat pumps with the use of heat from external air have a lower efficiency coefficient, but in distinction they have the property of less inertia.

However, heat pumps with the extraction of heat from the soil have greater energy efficiency, and are also able to provide passive cooling (due to the cold of the soil), but have greater inertia in the transition period.

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