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Energy Efficient Modular Block Diagram of an Air Heat Pump Heat Supply System

Svetlana A. Loginova*[a] and Vadim N. Fedoseev[b]
[a]Yaroslavl State Technical University
Yaroslavl, Russian Federation
[b]Ivanovsk State Polytechnic University
Ivanovo, Russian Federation

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Abstract. The use of air source heat pumps, together with other renewable energy devices and high efficiency heating equipment, together with digital control systems, is a promising European trend that continues to grow in the face of rising costs of traditional energy carriers. The article presents a number of technical energy-saving solutions, such as a mixing chamber for HHP, built into the heat supply system and the use of a supply and exhaust ventilation system, which is based on the principle of recuperation. A digital modular-functional-structural diagram of heat generation of a coolant from the environment is proposed. Based on the energy efficiency of the circuit solution with an electric boiler, a buffer tank and a patented mixing chamber, the authors achieve a rationally controlled heat and air exchange of a combined heat pump space heating system. Automation of the joint work of rationally selected elements of the heat pump air system is one of the Smart Home technologies that improve the efficiency of heat supply, create comfortable living conditions and security due to the digitalization of the control algorithm for this system.

Keywords: air heat pumps, energy efficiency, heat supply, digitalization.

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* Corresponding author E-mail address: sl79066171227@yandex.ru

Энергоэффективная модульная блок-схема системы теплообеспечения воздушного теплового насоса

С. А. Логинова[а], В. Н. Федосеев[б]
*[а]Ярославский государственный технический университет
Российская Федерация, Ярославль
[б]Ивановский государственный политехнический университет
Российская Федерация, Иваново*

Аннотация. Использование воздушных тепловых насосов вместе с другими устройствами на возобновляемых источниках энергии и высокоэффективным отопительным оборудованием вместе с цифровыми системами управления является многообещающей европейской тенденцией, которая продолжает расти в условиях увеличения стоимости традиционных энергоносителей. В статье представлен ряд технических энергосберегающих решений, таких как смесительная камера для ТТН, встроенная в систему теплоснабжения, и использование приточно-вытяжной системы вентиляции, в основе которой лежит принцип рекуперации. Предложена цифровая модульно-функционально-структурная схема тепловыделения теплоносителя из окружающей среды. На основе энергоэффективности схемного решения с электрокотлом, буферной емкостью и запатентованной смесительной камерой авторы добиваются рационально регулируемого тепло- и воздухообмена комбинированной системы теплонасосного отопления помещений. Автоматизация совместной работы рационально подобранных элементов воздушной системы теплового насоса является одной из технологий умного дома, позволяющих повысить эффективность теплоснабжения, создать комфортные условия проживания и безопасность за счет цифровизации алгоритма управления этой системой.

Ключевые слова: воздушные тепловые насосы, энергоэффективность, теплоснабжение, цифровизация.

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Introduction

In recent years, the demand in the market of air heat pumps (AHP) has increased tenfold in European and Scandinavian countries, the climate of which can be called moderately cold. In the official rating of countries with a relatively cold climate, Russia occupies the first place. Therefore, the question of the possible and effective use of air source heat pumps in climatic conditions on the territory of most of the Russian Federation remains relevant.

It should be noted that in the practice of building energy-efficient buildings, issues of energy-saving technologies, microclimate and air exchange in domestic science and engineering research were dealt with by such well-known Russian scientists as: RAASN, professor.d.t.s. Yu. A. Tabunshchikov, Professor, Doctor of Technical Sciences G. P. Vasiliev, professor Brodach M. M., professor Shilkin N. V. [1, 2].

In modern conditions, continuing the traditions of resource and energy saving, the development and practical solutions for the use of high-voltage transformers based on digital computer control become relevant.

A distinctive feature of the use of VTH is that ambient air is used as a source of low-grade heat. If such a VTH device is installed outdoors, its use becomes less effective, especially at low outdoor temperatures.

Research methodologies

The authors of this work, using an experimental scientific laboratory, on the basis of which they studied and applied modern technological solutions and a patented device – a mixing chamber built into the boiler room [3, 4], which made it possible to increase the efficiency and productivity of the heat pump system, in particular due to the mixing chamber, which includes an air exchange scheme with recuperation. Implementing the experiment in a low-rise residential building, a combined heat pump [5] was installed, built into the room, with the function of a warm floor (Fig. 1).

The experimental combined heat supply system consists of an air-water heat pump [6], an electric heating element, a storage buffer tank with a volume of 200 liters, and an air duct system with a heat exchanger.

Electric heating element with continuously adjustable electric power from 0.1 kW to 5 kW based on PWM (pulse-width electronic) – a controller built into the VTH controller to maintain the operating temperature in the buffer tank on the coldest days at temperatures from – 15 °C to – 30 °C.

The buffer storage tank in such a combined heating system performs the function of hydraulic decoupling of the volumetric flows of the heat source and heating, equalizes the moment of the difference

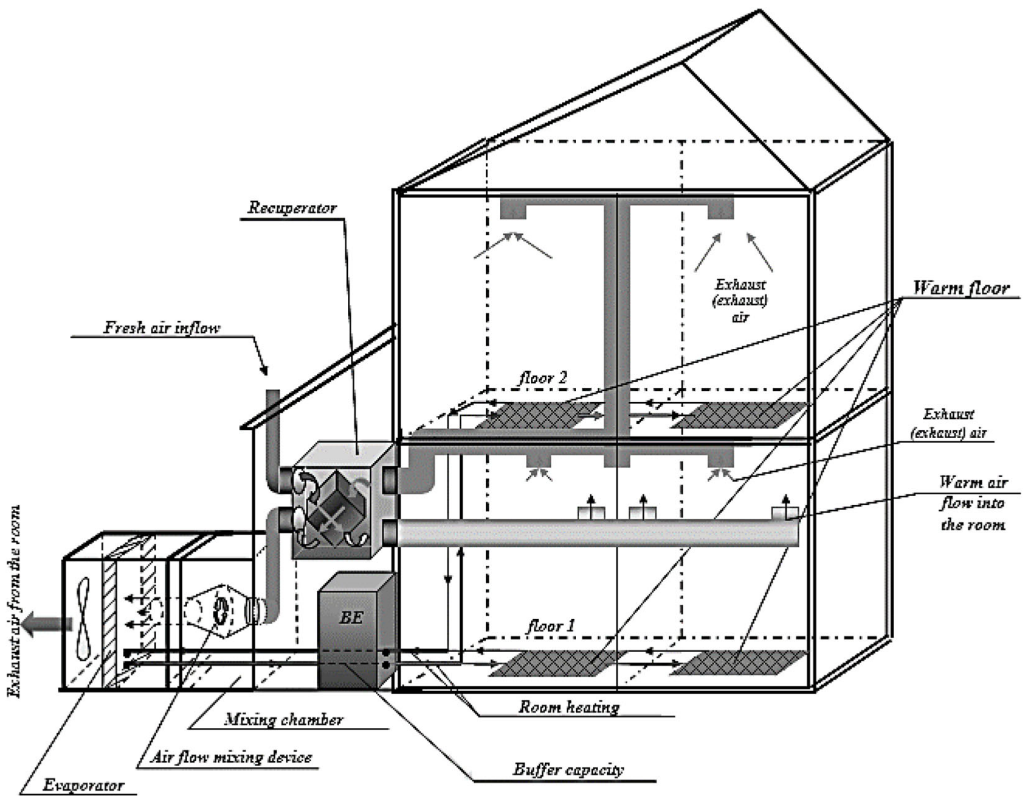

Fig. 1. Combined heat pump heat supply system

in turning on / off the electric energy, starting the electric motor of the compressor, compensating for the hysteresis of the heat output of the heat generator and the heat consumer, and at the same time performs a partial overlap of the tariff periods of electricity.

An important technically useful solution of the authors was the development of a mixing chamber for the HHP, built into the HHP – boiler room system (Fig. 2) [7], the operation of which ensures the supply of the equilibrium pressure of the air mixture to the heat exchanger – the HHP evaporator.

The air flow mixing device itself (Fig. 3) works as follows. The air flow, when moving through the inlet pipe of the air duct 1, enters a chamber made in the form of a capsule in the form of a hemisphere

Fig. 2. Photo of the mixing chamber (patent No. 185689) and VTH installed in a low-rise residential building

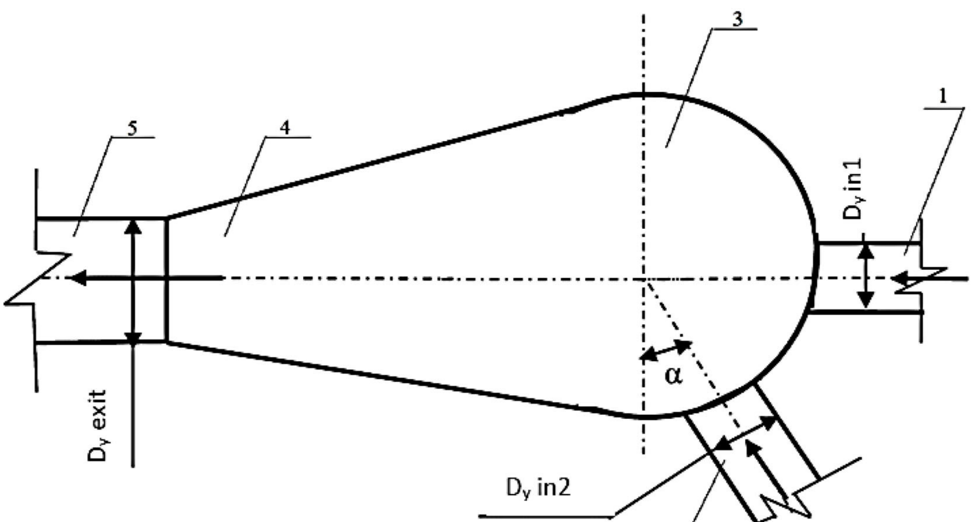

Fig. 3. Device for mixing gas streams

3, connected to the large base of the truncated cone 4. Where, when it enters the hemisphere 3, the transition of the flow from a laminar air flow to a turbulent flow is ensured and changes speed with a greater to a smaller one. Then there is a supply through the pipe for supplying additional air flow 2 at an angle within $0° \leq \alpha \leq 90°$ to the vertical. Due to the ingress of air through the branch pipe for supplying additional flow 2 into the turbulence zone, the intensity of mixing of the flow from the inlet pipe of the air duct 1 and the flow from the branch pipe for supplying additional flow 2 increases.

The proposed tool allows you to increase the equilibrium intensity of mixing, improving the conditions of heat transfer.

Another important energy-saving solution for the joint operation of the mixing chamber and the boiler house was the proposal to use a supply and exhaust ventilation system, which is based on the principle of recuperation, that is, a process in which part of the heat is returned from the exhaust air.

Interpretation and discussion of research results

Considering such specifics of the air exchange mode of the HPU with a recovery element, we determine the functionality of the heat exchange system operating through the boiler room and the air ducts of the room. Structurally, the heat exchanger is located in a closed room of the heating unit (boiler room) with air ducts connected to the evaporator on one side, and on the other hand it provides the room with slightly heated fresh air through the air ducts. The technology of using such a configuration of air ducts with recuperation makes it possible to additionally ensure an effective increase in the thermal power of the VTH in the mode of space heating in a moderately cold climate.

For practical calculation of the effective temperature of the mixed air supplied to the heat pump evaporator, we use an engineering calculation method based on the influence of the percentage of temperatures according to the formula “street – room”. Let us use the solution for a particular case from the heat balance conservation equation to determine the temperature relative to the warm air flow removed from the room and supplied to the VTH evaporator [8].

That is, as an example, choosing a heat exchanger with η (efficiency) = 50 %, we obtain the temperature of the mixed air flow supplied to the evaporator:

$$\frac{\eta \times t_1 + \eta \times t_2}{100} = \frac{50 \times 24°C + 50 \times (-10°C)}{100} = \frac{(1200 - 500)°C}{100} = 7°C$$

where:

$t_1 = 24$ °C is the room temperature;

$t_2 = -10$ °C – outdoor air temperature.

Under such conditions, based on the main goal of creating energy-efficient heating, we obtain an air exchange system that is economically beneficial for a VTH heat generator.

Leaving the room, the warm air partially heats the oncoming cold flow in the heat exchange system and, according to the configuration of the device, exits, as exhausted along the air duct guides, into the mixing chamber to the evaporator and then through the VTH to the street, and partially already heated recuperation air enters the room.

Using the efficiency values of the heat exchanger in Russia, according to climatic conditions, they are closest to the Finnish climate. In Finland, before commissioning a duct with recuperation after testing, they operate with an annual regeneration coefficient, which is maintained for the cities of Helsinki and Lapland.

In the real conditions of the experiment, long-term volumetric studies were carried out to develop this technological process. Under these conditions, the “threshold” of savings (losses) does not occur until the outdoor air temperature is – 15 °C with the coolant (water) from +30 °C to +45 °C.

Recirculating air heat pump with an electric boiler with forced control of the dampers and a buffer tank with a hydraulic arrow, which ensures the supply and distribution of the coolant, heating the room at the same time through a warm floor or fan coil unit in the switching mode (on / off). The heat carrier temperature sensor installed in the buffer tank, which receives a signal from the room temperature thermostat, sends a signal to enable/disable the VTH control module (Fig. 4).

The operation of the equipment of this combined heat supply system is controlled by a single automated control module [9–11], a digital circuit solution that is acceptable for various climatic conditions with a relatively cold climate.

The installed digital control module reads data from all temperature sensors analyzes the information and reacts accordingly.

Sensor 1 – D/t_1 – Installed in a buffer tank. The signal enters the VT control module (MUTN) when the boundary values of the set temperature and the output heat power of the VTN change. VTN turns on or off.

Sensor 2 – D/t_2 – Installed on the evaporator. The signal enters the MUTN when the set values of the parameters are changed. The fan blowing the evaporator changes the rotation speed according to the parameters.

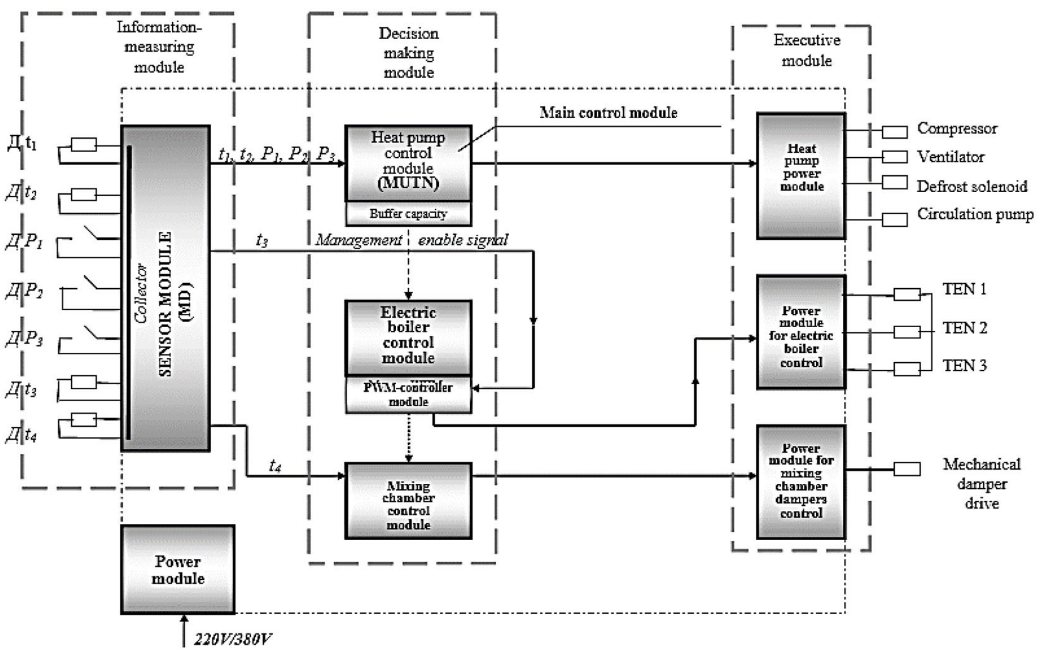

Fig. 4. Digital technological model of heat exchange control through an air source heat pump in a low-rise building

P_1, P_2, P_3 – Compressor protection sensors. In normal working condition, the contacts are closed. When the set parameters are exceeded or decreased, the contacts of the sensors open, which leads to the compressor stop.

Sensor 2 – D/t_3 – Installed outdoors and gives a signal of the temperature status to the PWM module – the electric boiler regulator. The PWM module – the regulator has its own program – setting the control of the electric boiler.

Sensor 2 – D/t_4 – Installed in a volumetric mixing chamber and gives a signal to the mixing chamber control module. Software setting, which is protected by 10 °C by reacting to temperature changes inside the mixing chamber. The purpose of the damper mechanism is to react to a change in the percentage ratio of incoming air from the street and from the room, ensuring that the desired temperature is obtained for the evaporator.

Depending on the change in the outside air temperature, the digital control system, the computer-controller, will respond in a program-set sequence through the appropriate sensors and the controller to the system to ensure the set temperature remains constant inside the storage buffer tank [12, 13].

Summary and Conclusions

Thus, the operation algorithm of the combined heat pump unit determines the optimal conditions for heat supply in order to ensure the best heat output with minimal own power consumption.

Using modern information and digital solutions, there are wide functionality of technological control and management of the temperature and humidity state in the premises of the building. The digital module for recognizing the parameters of this technological process VTH allows for the regulation of the variable flow of warm air, implementing this process through a computer-controller to the actuators of the air exchange system, both manually and automatically. Such digitalization, when making a decision by the contractor, allows reducing excessive heat and electrical load, as well as minimizing the volume, area of the boiler room and air exchange communications. As a result of making such decisions, the cost and dimensions of the premises are reduced.

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