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RESULTS OF EXPERIMENTAL STUDIES OF A HEAT PUMP WITH COMPRESSOR SELF-COOLING

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ABSTRACT

In modern heat pumps, as well as in refrigerators, the chamber principle of placement of the main components continues to be applied, where the evaporator is isolated from the compressor by separate placement on different sides of the chamber. Meaning, the evaporator is inside the chamber, and the compressor is outside. The article experimentally explores the hypothesis of self-cooling of a heat pump compressor by providing heat exchange between the surface of the compressor housing and the surface of the evaporator. The author assumes that the circulating external heat flux from the compressor surface to the evaporator will act in parallel with the main internal heat flux, which will lead to a general positive effect. Particular attention is paid to the variant of the mutual concentric positioning of the compressor housings and the heat exchanger's evaporator. The assumption of the influence on the heat transfer processes of compressor placement in the center of the evaporator cavity or with an offset from the center is substantiated. For this purpose, the design of the evaporator is made in the form of a hollow cylinder with the compressor in the inner cavity of the evaporator body. Thermal measurements showed that the evaporator absorbs excess compressor heat and decreases the heating temperature of the housing and head of the compressor compression chamber. Studies have confirmed the increase in heating and cooling power output of the heat pump and the possibility of providing compressor self-cooling.

KEYWORDS: Heat Pump, Compressor, Evaporator & Condenser

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1. INTRODUCTION

Heat pumps (HP) are the only economically and environmentally acceptable alternative to traditional sources of thermal energy [1]. For comparison, for a gas heater to provide a conditional consumer with 100 units of energy it will consume 105 units of the primary energy source, meaning 5 units are lost. HP will consume 25 units of electrical energy [2]. Heat pump systems and devices are improved for the use of solar energy, soil heat, and secondary excess heat of technological processes. HPs can simultaneously serve heat and cold energy, cool products, and condition air [3–9].

The results of the literature review show that in modern HPs, as in refrigerators, the chamber principle of placement of the main elements continues to be applied. Processing systems, which are widespread and consume large amounts of low-efficiency energy, have significant potential for reducing energy consumption [4]. The concept of energy consumption level is presented to describe the different types of energy consumption procedures for machining parts in the same way [5] to study the effect of energy consumption on grinding and the parameters of chips, a power consumption model was developed and the model was validated and analyzed [6]. The main components are separated and placed on opposite sides of the camera. Evaporator is inside the refrigerator cabinet, compressor and condenser outside the chamber, at a distance from each other, so as not to overheat each other. In HP, this approach leads to an increase in the dimensions and metal consumption of heat exchangers. The compressor, the main element of the HP, is cooled by blowing a fan. Meaning, the excess heat is released into the environment. Although in HP, this heat can be used beneficially.

The most widely used are air heat pumps (ASHPs), which are mainly used for air conditioning. Some ASHP models can provide room heating even at outside air temperatures of minus 25 ° C, while maintaining a KPI value above 1. Mitsubishi Electric ZUBADAN Inverter series HP maintains the nominal value of heat output up to an outdoor temperature of –15 ° C. With a further decrease in temperature, operability remains up to –25 ° C. At the same time, remains the advantage both over conventional systems and over energy-efficient similar heat pumps of the POWER Inverter series [10].

The compressor is one of the most important parts of the refrigeration cycle. The power of cooling or air conditioning completely depends on the power of the compressor [11]. Replacing the compressor AC motor with DC motors and the subsequent use of magnets based on rare-earth materials solved the problem of flexible regulation and control of the motor speed [12]. A qualitative leap was achieved after the transition to hermetic scroll compressors and inverter control of refrigerant flow (VFR variable flow refrigerant) [10, 13].

An important parameter of the compressor is the temperature regime [14]. During operation, the temperature of the working winding of the electric motor reaches 120 ℃, the temperature of the suction vapor in the cylinder is 145 ÷ 155 ℃, and the temperature of the compressed vapor is 170 ÷ 190 ℃. Obviously, the use of these compressors without an additional cooling system is not acceptable, since overheating of the motor windings over 130 may occur, which is undesirable. In practice, hermetic compressors are cooled by suction vapors of the refrigerant, heat removal from the casing surface by external blowing by a fan, heat removal by cooling of oil with liquid refrigerants from the pre-condenser or a heat pipe, two-phase injection of refrigerant into the compressor, vapor-liquid injection, which ensures stable heat output of the heat pump [10]. Widespread is the cooling of the oil in the compressor, which implements "tropical" temperature conditions. In them, cooling is achieved by evaporation of the liquid freon coming from the pre-condenser into the coil, which is placed in an oil bath at the bottom of the compressor casing [15]. Moreover, the cooling capacity can be increased to 3 ÷ 4.5%, the efficiency coefficient by 3 ÷ 4%, and to reduce the temperature of the motor winding by 15 ÷ 20 ℃ [16].

There is a known method of cooling the head of a compressor cylinder block, in which the temperature of the working winding and the sound power levels are lower by 17% and 11%, respectively. Accordingly, the temperature of the working winding did not exceed 100 ℃, at a temperature of the working medium 32 ℃. There is an electronic cooling system, which has the official designation CIC System, i.e. Controlled Injection Cooling. The main purpose of this system is controlled injection by continuously monitoring the temperature of the injected gas [17].

Based on the carried on analysis, a new design of HP has been developed (Figure 1).

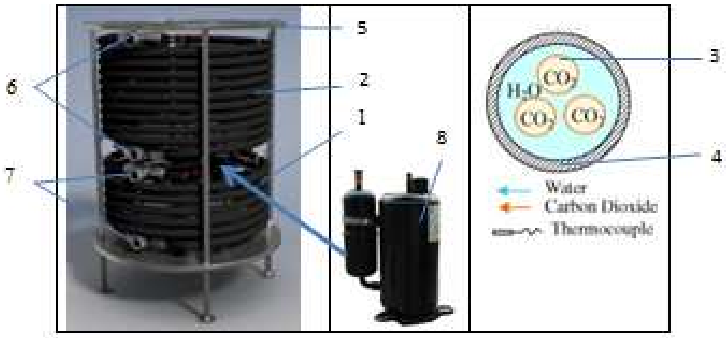


Figure 1: Design of the Proposed Heat Pump.

In the proposed HP, the heat exchangers of the evaporator 1 and the condenser 2 have the same design, made of the "pipe in pipe" type, where the coolant (CO2) passes through the inner tubes 3 (three parallel tubes are shown in the diagram) and the coolant (H2O) through the main pipe 4 and flows around the inner tubes 3, providing adiabatic supply or intake of heat from the inner tubes. At the same time, the tubular heat exchangers of the evaporator and condenser are laid in a spiral, forming a hollow cylindrical structure. Cylindrical heat exchangers are placed one above the other (bottom evaporator) in a common frame housing 5. The ends of the tubes 3 are connected to the inputs and outputs of the compressor according to the corresponding schematics. Through the pipes 6 and 7, the coolant is circulated through the pipes 4. The compressor 8 is installed inside the spiral case of the evaporator for cooling by absorbing its excess heat by the evaporator [18]. The proposed constructive solution also allows for replacement of expensive, dimensional and metal-intensive plate heat exchangers with lightweight flexible tubular heat exchangers.

2. RESEARCH METHODOLOGY

Analysis of HP characteristics is carried out for 3 options:

1st Option: the evaporator is protected from the compressor by separate placement of them on different sides of the partition. Meaning, there is no heat transfer between them. For this, a shielding cylindrical partition is installed between the side wall of the compressor and the walls of the evaporator.

2nd Option: the compressor is located in the center of the evaporator. In this case, heat exchange by radiation and convection between the heated compressor wall and the internal cold walls of the evaporator will occur.

3rd Option: the compressor is located with offset from the center, closer to the evaporator wall. It is assumed that in such an arrangement - the approach of the compressor side wall to the evaporator wall will affect the heat transfer by radiation and, in general, the cooling process.

Each experiment records temperatures at the corresponding points of the HP. The arrangement of temperature sensors on the elements of the HP is shown in figure 2.

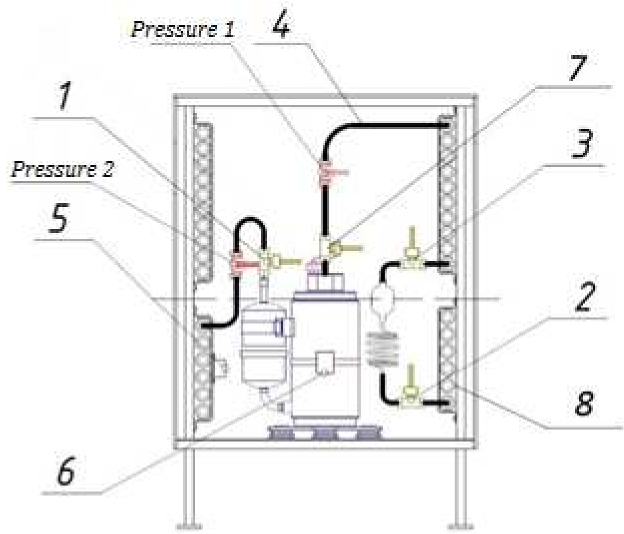


Figure 2: The Arrangement of Sensors in the HP.

Sensors: 1: refrigerant temperature at the outlet of the evaporator; 2: temperature of the refrigerant at the inlet to the evaporator; 3: refrigerant temperature at the outlet of the condenser; 4: refrigerant temperature at the inlet to the condenser; 5: air temperature around the compressor; 6: temperature of the side surface of the compressor, the area of the electric motor; 7: temperature of the compressor head; 8: surface temperature of the tubes of the evaporator heat exchanger. Also, on the diagram are shown refrigerant pressure sensors that are installed at the inlet and outlet of the compressor.

The temperature mode of the condenser is characterized by four sensors: 3 and 4, as well as sensors installed at the inlet and outlet 6 of the condenser heat exchanger, shown in Figure 1. They also show the temperature of the water in the storage tank.

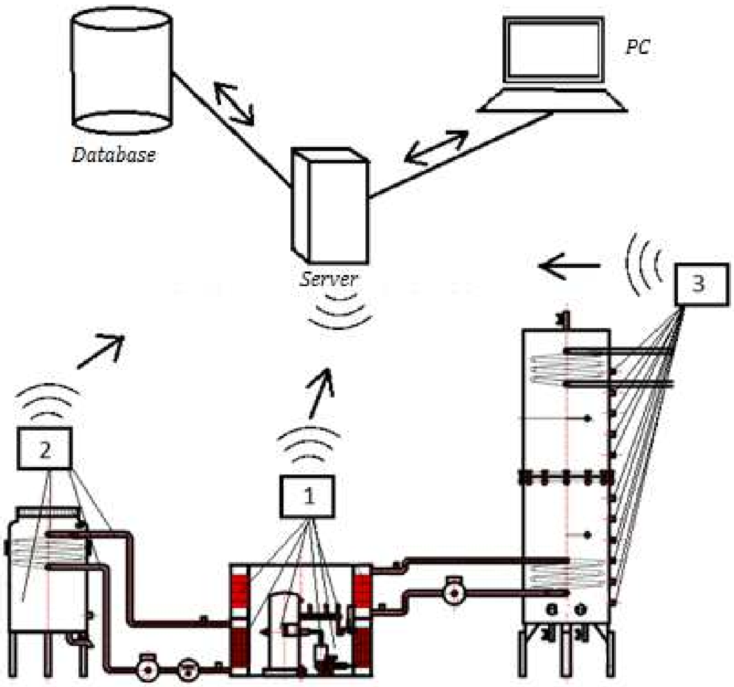
The temperature condition of the evaporator is characterized by four other sensors: 1 and 2, as well as sensors installed at the inlet and outlet 7 of the evaporator heat exchanger, also shown in Figure 1. They also show the temperature of the milk in the milk cooler (Figure 3).

The temperature regime of the compressor is shown by sensor 6 attached to the side wall, as well as a sensor 7 attached to the compressor head. At the same time, sensor 6 indirectly characterizes the temperature state of the electric motor, which is located inside the compressor, opposite of point 6. Sensor 7 characterizes the temperature in the compression zone of the refrigerant. Sensors 5 and 8 show the temperature state in the space between the compressor and the evaporator.

Figure 4 shows a diagram of a laboratory stand and measuring system, where a milk cooler (2) is used as a source of thermal energy for a HP (1), and a storage tank (3) is used as a load.

The stand diagram schematically shows the process of collecting, transmitting, processing and storing data during research. Records of pressure and temperature are kept synchronously in time, by a microcontroller with appropriate software. The information system is based on a central unit (server), a database, personal computers with software, as well as data collection modules from the heat pump (1), milk cooler (2) and storage tank (3).

The heat pump module collects data from the following sensors from 12 temperature sensors (encapsulated DS18B20), 2 liquid flow sensors (G1WFM) and 2 pressure sensors (Wika-R1). The milk cooler module is connected to 4 temperature sensors (DS18B20) and one liquid flow sensor (G1WFM). The battery module collects data from 15 temperature sensors (DS18B20), sequentially located vertically.



1: Heat Pump Module, 2: Milk Cooler Module, 3: Storage Capacity Module.
Figure 3: Diagram of the Laboratory Stand and Measuring System.

The information collecting process is initiated by the central unit, sending a request to each module, separately. After receiving a request, each module starts polling sensors and collects data in one packet, which is subsequently sent back to the central unit. Having received packets with raw data, the server processes them according to appropriate algorithms for easy storage. Next, the server sends data to the database for storage. From the user's personal computer, can be viewed the current values using special software.

3. ANALYSIS OF RESEARCH RESULTS

Figure 4 shows the comparative refrigerant temperatures of the condenser for the 3 options. The top 3 graphs show the refrigerant inlet temperature (sensors 3), and the bottom 3 graphs of the refrigerant temperature at the outlet of the condenser (sensors 4).

As can be seen, the temperature of the refrigerant at the inlet to the condenser is lower by 7-8^0 C when the compressor is located near the evaporator than in the other 2 variants. At the exit, after the removal of heat from them, the temperatures of the options are aligned.

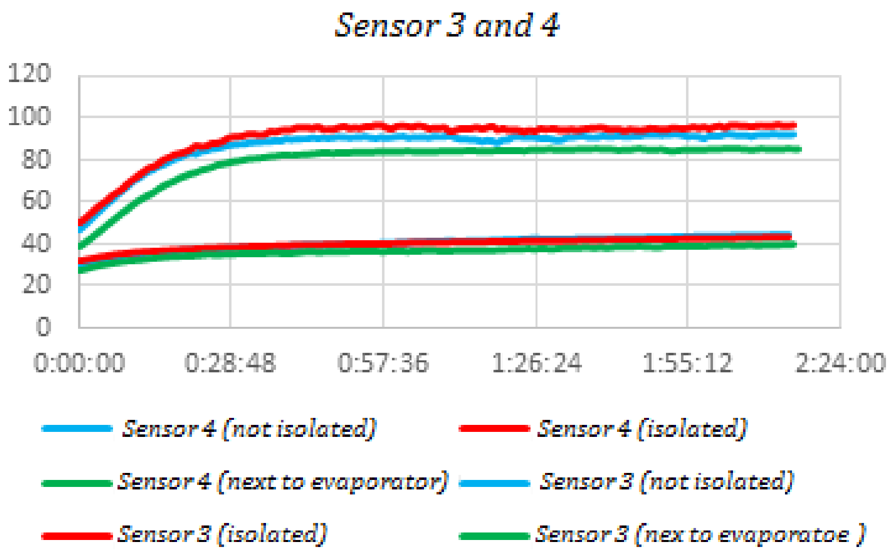


Figure 4: Comparative Condenser Refrigerant Temperatures in the 3 Versions - at the inlet (upper graphs) and Output (lower graphs).

Figure 5 shows the comparative evaporator refrigerant temperatures for 3 options. As can be seen, the average temperatures at the entrance to the evaporator (lower graphs) are: 0^0C (option 1), -2^0C (option 2) and -5^0C. The average temperature at the outlet of the evaporator (upper graphs) is + 25^0C (option 1), + 23^0C (option 2) and + 20^0C. The average temperature of the evaporator is + 10^0C.

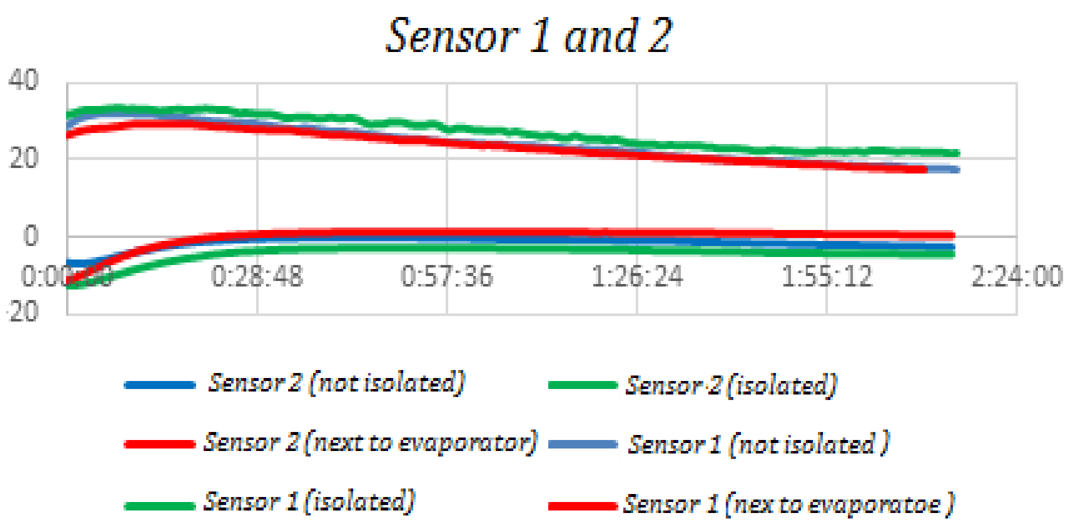


Figure 5: Comparative Evaporator Refrigerant Temperatures in the 3 Versions - inlet (Lower Graphs) and Outlet (upper Graphs).

Figure 6 shows the comparative temperatures of the side wall of the compressor with the 3 options. The graphs show that in the case of the separated arrangement of the compressor and the evaporator on different sides of the partition - when there is no heat exchange between them, it is 90 ^{0}C. In options with compressor cooling, the average temperature was 75-80 ^{0}C.

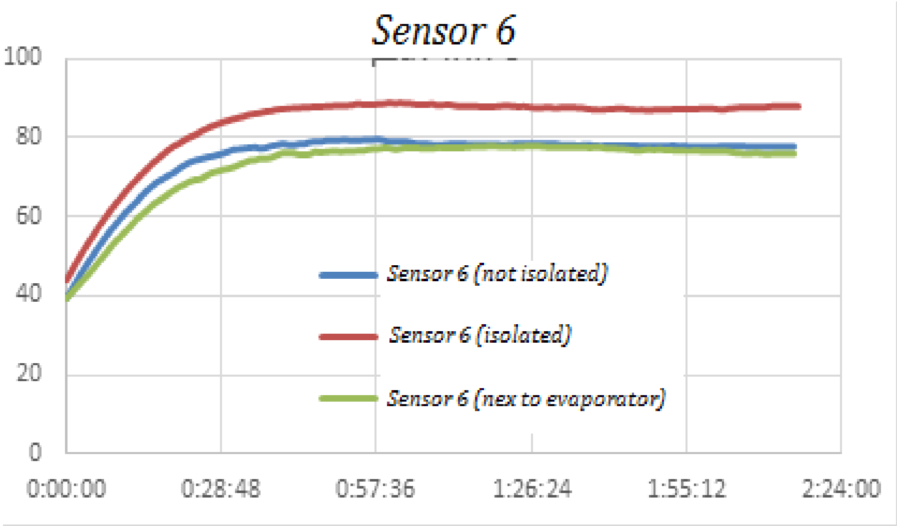
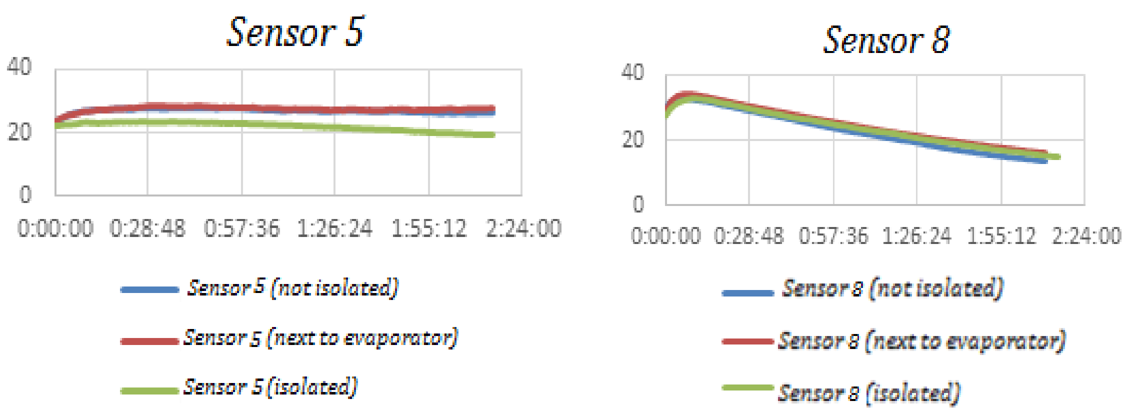


Figure 6: Comparative Temperature of the side Wall of the Compressor for the 3 Options.

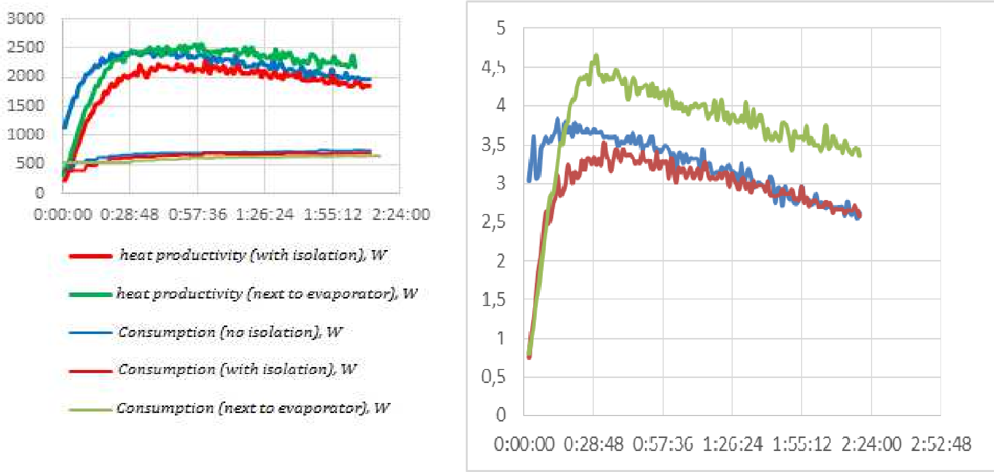
Figures 7(a) and 7(b) show comparative air temperatures in the space between the evaporator and compressor (sensor 5) and the surface of the outer pipe of the evaporator (sensor 8). As can be seen, it is at a level of about 20^{0}C. When the compressor is located near the evaporator, it is lower by 10^{0}C. This indicates that with this arrangement, the compressor heats the surrounding air less. Meaning, the evaporator more intensively absorbs the heat released from the compressor surface.



(a) **(b)**

Figure 7: Comparative Air Temperatures in the Space between the Evaporator and Compressor (a) and the Surface Temperature of the Evaporator for the 3 Options.

Figure 8 shows comparative indicators: a) the heat output and the power consumed by the compressor and b) the energy conversion coefficients (KPIs) of the studied options.



(a) (b)

Figure 8: Comparative Graphs: (a) Heat Production, (b) The Values of the Energy Conversion Coefficients of the 3 Options.

The results show that with a general equality of the consumed electricity, which is shown in the lower graphs of Figure 8(a), the heat production of the studied HP variants is different. The average heat output of the separated compressor and evaporator placement on different sides of the partition, the compressor location in the center and near the evaporator, with an offset from the center, are respectively 2.0; 2.3 and 2.4 kW. As can be seen, the productivity of the first option is smaller than the other two options, respectively, by 15% and 20%.

The graphs of the energy conversion coefficient figure 8(b) correlate with the graphs of heat production. KPI values in the options are on average from 2.5 to 4.5 units.

The obtained results suggest that in the proposed design of the HP, the effect of self-cooling is realized. Between the surfaces of the compressor and the evaporator, a circulating external heat flow is generated, which removes excess heat from the surface of the compressor. Considering the fact that the temperature difference between the compressor wall (about 80°C) and the evaporator (about 10°C) is about 70°C, it can be assumed that heat exchange by radiation, heat transfer and convection occurs between the surfaces. In this case, in the first option, the compressor does not overheat, since its convective cooling is maintained.

4. CONCLUSIONS

The article describes a new design of a heat pump, and develops a methodology for its experimental research. The goal is to confirm the hypothesis of compressor self-cooling due to the absorption of its excess heat by the evaporator. The studies are based on obtaining comparative information on the temperature dynamics of the main components involved in the studied heat transfer processes with three design options - when the evaporator is isolated from the compressor by installing a partition between them, and two options - when the excess heat of the compressor is returned to the system by transferring it to the evaporator, and the compressor itself is cooling. The basic temperature characteristics of the evaporator and compressor condenser are established and the heat production of the compared options is determined on their basis. Studies show that placing the compressor in the evaporator zone helps to reduce its temperature by 10–150C, increase the heat output of the heat pump by 15–20% by returning excess compressor heat to the system, as well as improving the temperature regime of the compressor and the drive electric motor.

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