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The potential of the ambient air and the functionality of heat and mass transfer of the freon circuit of the air heat pump

S.V. Fedosov[1], I.A. Zaitseva[2], V.N. Fedoseev[2], V.A. Emelin[2]

Sergey V. Fedosov
[1]National Research Moscow State University of Civil Engineering, Moscow, Russia
fedosov-cademic53@mail.ru

Irina A. Zaitseva
[2]Ivanovo State Polytechnic University, Ivanovo, Russia
75zss@rambler.ru

Vadim N. Fedoseev
[2]Ivanovo State Polytechnic University, Ivanovo, Russia
4932421318@mail.ru

Victor A. Emelin
[2]Ivanovo State Polytechnic University, Ivanovo, Russia
emelin.viktor@inbox.ru

Air is one of the most promising sources of extraction of scattered thermal energy from the surrounding space. An energy-saving and environmentally efficient technology for obtaining dissipated thermal energy from the ambient air and converting it into a form of energy convenient for use is an air heat pump (AHP), which can extract heat even at -30 °C. The heat pump does not create thermal energy, but pumps it from the environment for heating buildings, water or air. This process takes place only with the supply of external energy (usually electricity) to the heat pump. The electricity consumed by the AHP compressor is only used to move the freon in a closed circuit consisting of copper tubes with different cross sections. Determination of the volume of incoming air to the evaporator of the air heat pump is a particularly important parameter for controlling the processes of heat and mass transfer and improving the performance of the air heat pump system (AHPS). This knowledge allows us to substantiate the establishment of computational mathematical models for predicting the required thermal power (performance) of a heat pump.

Key words: air heat pump, heat energy transfer, air consumption

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НАУЧНАЯ СТАТЬЯ
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Потенциал окружающего воздуха и функциональные возможности тепломассообмена фреонового контура воздушного теплового насоса

С.В. Федосов[1], И.А. Зайцева[2], В.Н. Федосеев[2], В.А. Емелин[2]

Сергей Викторович Федосов
[1]Национальный исследовательский Московский государственный строительный университет, Москва, Российская Федерация
fedosov-academic53@mail.ru

Ирина Александровна Зайцева
[2]Ивановский государственный политехнический университет, Иваново, Российская Федерация
75zss@rambler.ru

Вадим Николаевич Федосеев
[2]Ивановский государственный политехнический университет, Иваново, Российская Федерация
4932421318@mail.ru

Виктор Александрович Емелин
[2]Ивановский государственный политехнический университет, Иваново, Российская Федерация
emelin.viktor@inbox.ru

Одним из наиболее перспективных источников извлечения рассеянной тепловой энергии из окружающего пространства является воздух. Энергосберегающей и экологически эффективной технологией получения рассеянной тепловой энергии из окружающего воздуха и преобразования ее в удобную для использования форму энергии является воздушный тепловой насос (AHP), который может извлекать тепло даже при температуре -30 °C. Тепловой насос не создает тепловую энергию, а перекачивает ее из окружающей среды в помещение для обогрева и нагрева воды или воздуха. Этот процесс происходит только при подаче внешней энергии (обычно электроэнергии) на тепловой насос. Электроэнергия, потребляемая компрессором AHP, расходуется только на перемещение фреона по замкнутому контуру, состоящему из медных трубок различного поперечного сечения Определение объема поступающего воздуха в испаритель воздушного теплового насоса является особенно важным параметром для управления процессами тепло- и массообмена и повышения производительности системы воздушного теплового насоса (AHPS). Эти знания позволяют нам обосновать создание вычислительных математических моделей для прогнозирования требуемой тепловой мощности (производительности) теплового насоса.

Ключевые слова: воздушный тепловой насос, передача тепловой энергии, расход воздуха

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INTRODUCTION

Improving the energy efficiency of heat pump technologies using alternative types of energy is now becoming the main task of implementing the strategy of energy, resource conservation and environmental safety. On the one hand, the development and application of innovative structural materials and devices allows to expand the range of power and scope of application of air heat pumps, on the other hand, to ensure their higher comprehensiveness design and increase operational productivity [1-4].

THE EXPERIMENTAL PART

The potential of the ambient air, which can be effectively used by an air heat pump into useful heat (heating, hot water supply), is inexhaustible.

It is known that the heat transfer coefficient in calm air ranges from 4 to 5 W/(m^2·K), and with intensive air blowing of heat transfer surfaces, it can reach up to 30-40 W/(m^2·K) [5].

The question arises: how this amount of thermal energy from the surrounding air could be achieved?

The authors formulated a scientific and practical task: to calculate the volume (flow rate) of air that comes from the surrounding space to determine the required amount of thermal energy at the outlet of an air heat pump.

However, the idea of the necessity of engineering calculations of the ambient air potential arose on the basis of the idea of energy conversion put forward by P.K. Oshchepkov, whose hypothetical method of obtaining energy based on the movement and concentration of heat energy scattered in the surrounding space[1].

The electricity consumed by the compressor of the air heat pump is not spent directly on heating, but is spent on "concentration" and "transfer" of scattered energy from a low-potential heat source. These physical phenomena are formed in the air heat pump, on the one hand, by a retracting fan, and using low-potential energy from the combination of electromagnetic waves of the surrounding air arising in this process and when the aggregate state of the working fluid (freon) of the freon circuit changes, which the compressor provides, giving some of its thermal energy [6-9].

As a rule, it is rather difficult to estimate how much the heat pump transfers "scattered" heat from the air.

Firstly, because of the inconstancy of the parameters of air itself, e.g. change of its heat capacity when the temperature changes, etc. Air, as a low-temperature heat source, has the following properties: high heat capacity; maximum high and constant temperature; easy availability of heat without disturbing the natural state of the source; absence of impurities that can damage the pump elements [10-12].

Secondly, the operation of the air-source heat pump is based on the thermodynamic cycle of the freon circuit, the efficiency of which is largely determined by a rational choice of working fluid (refrigerant) and the ratio of the thermal properties of the refrigerant, both in the liquid and in the vapour phase [13].

Thirdly, the hydromechanical characteristics of the flows of the liquid and gas (steam) phases, and the process of two-phase nonequilibrium flows in which the evaporation and condensation of the refrigerant occurs, are very important. Naturally, in order to realize the effective operation of the freon circuit, it is necessary to establish working conditions for its phase transition from a liquid state

1 Energy conversion [online]. Available at: https://ru.wikipedia.org/wiki

to a vapor state through the heat exchange process of the two–phase system of the working fluid "liquid - steam" located inside the evaporative pipes of the heat exchanger interacting with the ambient air enveloping the bundle of pipes of the evaporator of the air heat pump [14].

Heat pumps with an air source by "air-air" and "air-water" systems can be used to extract the dissipated heat energy of the ambient air, depending on which working medium is used to distribute heat in the building's communications - air or water (Table 1).

Table 1. Characteristics of VTN system types

Type of air heat pump system	**"air-air"**	**"air-water"**
Appointment	Heating (cooling) of indoor air, air purification	Heating, hot water supply
Coolant temperature (water)	+20 ... +35°C	+40 ... – 65°C
Coefficient of Performance(COP)	3.5 and more	2 and more

Considering the process of transferring the scattered thermal energy from the ambient air into the system of the air heat pump circuit, we found it technologically consisting of two circuits: the first circuit is the "ambient air – evaporator", the second circuit is the freon circuit – "ambient air – freon (working fluid)"(Fig. 1).

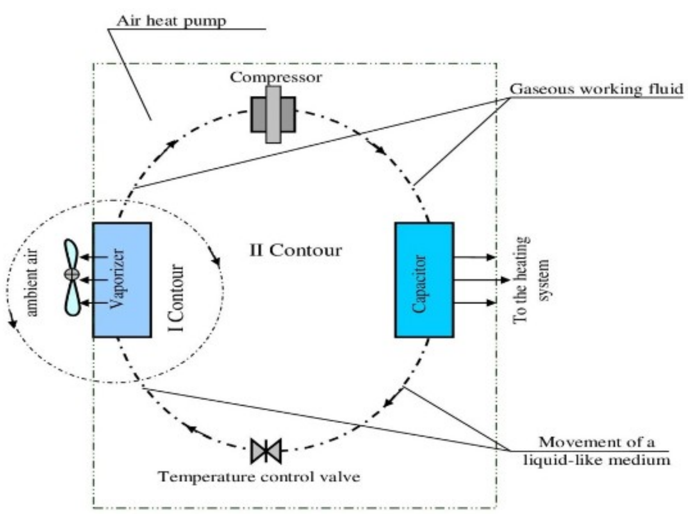

Fig. 1. The system of pumping (transferring) heat energy from the ambient air in the contour of the evaporative-condensing unit air heat pump

As an example, the passport characteristics and operating conditions of the Meeting MD20D monoblock air heat pump, with a power of 7 kW, with an operating mode of A10/W30 (Fig. 2) were taken, where A – atmospheric – ambient air with a temperature of +10 °C, W – the temperature of the coolant (water) +30 °C (for underfloor heating) [15].

In accordance with the graph in Fig. 2, we assume that the structure of the ambient heat energy flow affecting the evaporator will correspond to the following configuration shown in Fig. 3.

The heat pump has two energy sources – the energy of the electric motor of the compressor of the air heat pump ($Q_{el.motor}$) and the scattered thermal energy of the ambient air (Q_{air}).

Table 2 shows the technical characteristics and design parameters of the air heat pump and compressor.

<u>The first contour</u>

For the primary circuit, the calculation of the volume (V^1_{air}) of air drawn in by the fan and supplied to the evaporator of the freon circuit in air-source heat pump operating mode can be represented as follows:

1. The capacity or heat output of the air-source heat pump (Q_{COP}) is determined on the basis of a

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given conversion efficiency (COP) corresponding to the operating conditions of the A10/W30 air-source heat pump and the electricity consumption of the air-source heat pump (Q_{el}) according to the formula:

$$Q_{COP} = Q_{el} \cdot \text{COP}.$$

2. The difference between the required heat energy received by the air-source heat pump and its electrical power consumption will indicate how much energy needs to be taken from the dissipated air (Q_{air}) by the traction fan, feeding it to the evaporator:

$$Q_{air} = Q_{COP} - Q_{el}.$$

3. The temperature pressure (Δt) as the difference between the freon boiling point (t_{boil}) determined by the thermodynamic tables [16] and the operating temperature at the evaporator ($t_{ev.}$), calculated experimentally, is

$$\Delta t = t_{ev} - t_{boil}.$$

4. It is known [5] that when air with a volume (V_{air}) of 1 m^3 is heated by 1 °C, it gives off energy (Q_{air}) of 1kJ or 0.278 W/h. Then at a given temperature pressure (Δt), the heat flux energy density (q), W/h per 1 m^3, can be obtained from the air volume:

$$q = Q_{1м^3} \cdot \Delta t.$$

Table 2. Technical characteristics of the air heat pump and compressor and calculation of their performance

Indicator	Meaning
1. Operating mode of the air heat pump	A10/W30
2. Thermal power of the air heat pump according to the technical characteristics, kW	7
3. Electric power consumption of the air heat pump (Q_{el}), kW/h	1.84
4. Conversion factor (COP)	3.5
5. Evaporator temperature (t_{vap}), °C	+10
6. Compressor	Lanhai QXR – 44
7. The rotation speed of the compressor electric motor (n), tur/min	2480
8. The volume described by the compressor piston in one revolution (V_{pis})	44.2cm^3=44.2·10^{-6}m^3
9. Performance of the air heat pump (Q_{COP}), kW/h (=*l*.3×*l*.4)	1.84·3.5=6.44
10. The energy of the scattered air, (Q_{air}), W/h (=*l*.9–*l*.3)	6.44 – 1.84= 4.6kW/h=4600W/h
11. Hourly compressor capacity (*P*c), l/h (=*l*.8×*l*.7×60)	44.2·10^{-6}·2480·60=0.109616 m^3/min= =109616 cm^3/min =109.616 l/min·60 min= =6577 l/h

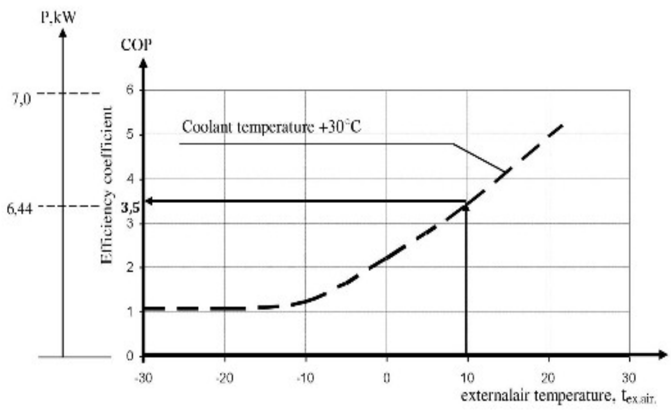

Fig. 2. Dependence of the efficiency coefficient (COP) of the air heat pump – 7 kW on the ambient temperature according to the technical characteristics

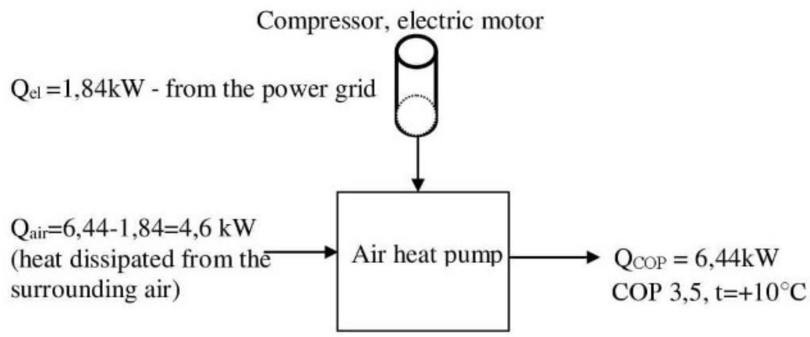

Fig. 3. Configuration of energy flows affecting the thermodynamic process of an air heat pump

5. At a given ambient temperature of +10 °C, the amount of ambient air required to produce (pumping) the heat output (Q_{air}) of the air-source heat pump (in our example 4.6 kW (see Table 2) through the air-evaporator circuit will be ($V^1{}_{air}$), m^3/h:

$$V^1{}_{air} = Q_{air}/q.$$

<u>The second contour</u>

The system of influence of the energy of the freon contour under considering consist of evaporator, compressor, condenser, thermostat. Here is an algorithm for calculating the volume (flow rate) of air in the operating mode of a freon circuit, with the compressor as the main energy carrier. On the basis of the initial data (area, volume of the building, heat loss value and heat output of the air-source heat pump) we select the tabulated acceptable compressor with a capacity of 7 kW.

1. Within one hour, the compressor capacity (P_c), capable of pumping the refrigerant circuit from the evaporator to the condenser through the mains at the given compressor nameplate parameters, motor speed (n, rpm) and volume described by the piston per revolution (V_{pis}), will be the actual volume of gaseous freon drawn in per compressor motor revolution:

Hourly compressor capacity (the actual volume of the sucked-in gaseous freon per revolution of the compressor motor (V_c) per hour, l/h (=*l.8*×*l.7*)

$$P_c = V_{pis} \cdot n \cdot 60 \text{ min}.$$

2. The volume of vaporous freon (V^f), m, with a mass (m) of 1 kg, with a vapor saturation density (ρ), kg/m^3, is taken according to thermodynamic tables [16] at its boiling point and can be determined by the formula:

$$V_f = m/\rho.$$

3. The mass of freon (m_f, kg/h) can be represented as the ratio of the hourly capacity of the compressor (V_{hf}) and the volume of vaporous freon (V_f):

$$m_f = P_c/V_f.$$

4. Based on the values of the latent heat of vaporization (r) of freon, taken according to thermodynamic tables [16] at the boiling point, the mass of freon (m_f), we determine the amount of heat (Q_f, W/h) released by the freon main on the superheated steam line, according to the formula:

$$Q_f = r \cdot m_f \cdot 0.278.$$

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5. The volume (flow rate) of air in the second circuit, m^3/h, is:

$$V^2_{air} = Q_f/q.$$

6. The total volume (flow) of air, m^3/h, is equal to:

$$V_{tot} = V^1_{air} + V^2_{air}.$$

The scheme for calculating the indicators of the volume of air in the I and II contours is shown in Fig. 4.

The results of air volume calculations for various refrigerants used in an air source heat pump are presented in Table 3.

Table 3. Air flow rates for various refrigerants

Indicators	R22	R32	R143a	R404a	R407c	R410a	R507a	R290
1. t_{boil}, °C	–40.8	–51.7	–47.6	–46.5	–43.6	–51.6	–46.7	–42.2
2. Δt, °C	50.8	61.7	57.6	56.5	53.6	61.6	56.7	52.2
3. q, W/m^3 (=0.278*l.2)	14.12	17.15	16.01	15.71	14.90	17.12	15.76	14.51
4.V^1_{air}, m^3 (=4600 W/h / l. 3)	325.72	268.18	287.27	292.86	308.71	268.62	291.83	316.99
5. ρ, kg/m^3	4.704	2.988	4.769	5.415	4.574	4.526	5.586	3.000
6. V_f, m^3 (=1kg/.5)	212.59	334.67	209.69	184.67	218.63	220.95	179.02	250.00
7. m_f, kg/h (6577 l/h /l.6)	30.94	19.65	31.37	35.61	30.08	29.77	36.74	26.31
8. r, kJ/kg	234	391.60	233.1	204	252.9	264.3	199.8	406.0
9. Q_f, W/h (= c.7*c.8*0,278)	2012.59	2139.42	2032.55	2019.77	2115.04	2187.18	2040.65	2227.00
10. V^2_{air}, m^3/h (l. 9/l. 3)	142.53	124.75	127.14	128.57	141.95	127.76	129.48	153.48
11. V_{tot}, m^3/h (=(l. 4+ l. 10)	468.25	392.93	414.41	421.43	450.66	396.38	421.31	470.47
12. Q, kW/h (=l.3*l.8/1000)	6.61	6.74	6.63	6.62	6.71	6.79	6.64	6.83

The diagram of indicators of air volume by refrigerants is shown in Fig. 5.

RESULTS AND DISCUSSION

Table 3 shows that, according to contour I (see Fig. 1), the volume of ambient air flow (V^1_{air}, m^3) drawn in by the fan and supplied to the evaporator lines varies depending on the brand of freon in the range from 268 m^3/h for freon R32 to 317 m^3/h for freon R290, which corresponds to a thermal energy of 4.6 kW, as shown in Fig. 3.

According to contour II (see Fig. 1), the volume of ambient air flow (V^2_{air}, m^3), taking into account the density of saturated freon vapor, ranges from 124.75 m^3/h for R32 freon to 153.48 m^3/h for R290 freon, which corresponds to thermal energy of 2.2 kW, and gives a thermal output of 6.4 kW, as shown in Fig. 3.

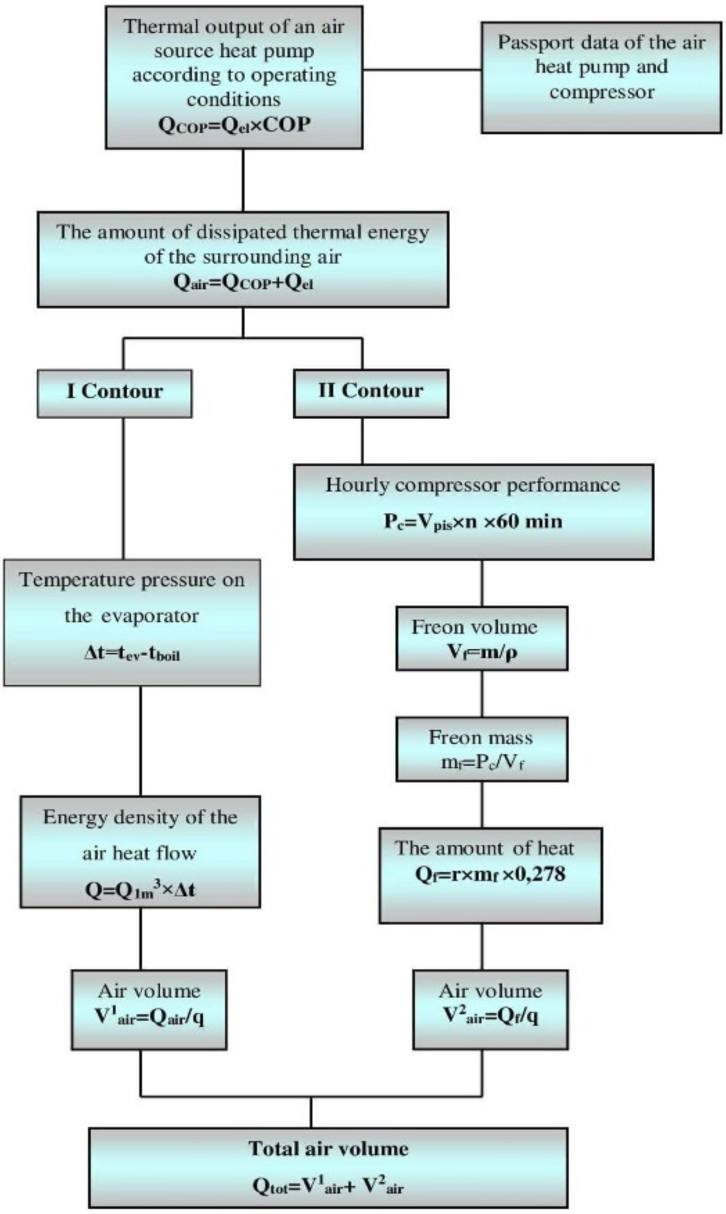

Fig. 4. Air volume calculation scheme of the I and II contours

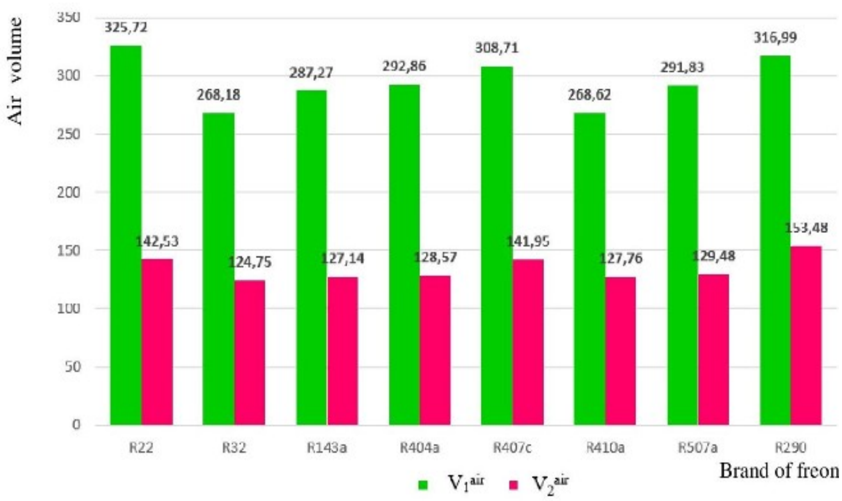

Fig. 5. Diagram of air volume indicators for various refrigerants

The value of the volume index is significantly affected by the thermophysical properties of the working fluid, for example, in the first circuit, the value of the latent heat of vaporization has an advantage, and in the second circuit, the density of the refrigerant. A comparative analysis of the calculation results for selected brands of freons shows the R32 and R410 are preferred; their thermophysical indicators have higher boiling points and latent heat of vaporization; this affects the mass of pumped freon, the price of which is relatively low in compare with other brands. Also, the advantage of these freons is the low values of their environmental safety indicators: ozone depletion potential and global warming potential [17-19].

Thus, the value of the ambient air potential (see Table 3) is largely determined by the performance of the intake fan, which supplies the required air volume to the evaporator, which provides the required heat output of the air source heat pump.

DISCUSSION QUESTIONS

In general, the amount of dissipated thermal energy received from the surrounding space (air) depends on many related parameters, such as: the power of the compressor and exhaust fan, the characteristics of the freon contour of the heat pump connecting pipelines [20-26]. Therefore, when calculating, it is desirable to take into account the influence of external forces, which allowed the authors to make a number of assumptions.

Firstly, a hypothesis was put forward about the existence of the phenomenon of induced induction of mutually withdrawn energy from the air and some electromagnetic radiation of the freon contour. Their joint vortex magnetic field contributes to the formation of mechanical (ponderomotive) forces, the magnitude of which is not large, but always depending on the pressure force and the operating mode of the devices of the evaporation-condensation unit (evaporator, condenser, thermostatic valve). These flows, acting (enveloping) on the lines and the compressor, add their share of energy when pumping the working fluid (freon) along the circuit, helping to overcome the hydraulic resistance of the refrigerant vapor in the lines. The value of this share of thermal energy in such conditions depends on the very nature of the working fluid (freon) and the physical state of its "radiation".

The energy-mechanical effect of the pressure force on the way from the evaporator to the compressor corresponds to:

$$P_{FX} = (P_{F2} - P_{F1})/\sum(S_{ev} + S_{c.l}),$$

where $(P_{F2} - P_{F1})$– pressure difference after evaporator and compressor.

Preliminary calculations of this force are from 0.20 to 0.25 W of energy. With further research and description of changes in pressure drop (P_{F2} and P_{F1}), it becomes possible to determine the geometric characteristics of the freon circuit line (diameter).

Secondly, there are irreversible losses in the operation of an air source heat pump, which include:

– losses of thermal energy in the connecting pipeline,

– losses to overcome friction in the compressor,

– losses associated with non-ideality of thermal processes occurring in the evaporator and condenser, as well as with non-ideality of thermophysical characteristics of refrigerants obtained experimentally,

– mechanical and electrical losses in the compressor motor, etc,

– air humidity, resistance in lines, heat losses in lines, losses in the electrical network during on/off, roughness in pipelines inside and outside, natural bypass [27, 28].

The authors believe that it is approximately 10% of the volume of air flow. The total volume of air consumption (V_{tot}), m^3/h, is:

$$V_{tot} = (V^1_{air} + V^2_{air})\cdot 1.1.$$

CONCLUSIONS

The generation and conversion of the energy of the air surrounding the exhaust fan of the air heat pump of the "compressor-freon circuit" system extracts low-potential energy, which generates thermal energy in the freon circuit, heats the working fluid and then transfers thermal power to the coolant through the condenser.

Thus, on the basis of preliminary calculations, the process of extracting thermal energy from the ambient air and with the appropriate modeling of air exchange is shown. In addition, at the inlet to the air heat pump, an analysis of the operation of joint contours I and II and a reflection of thermal and energy-physical phenomena occurring in the compression-freon circuit and the surrounding air space are shown, which makes it possible to calculate and refine the characteristics of heat transfer by modeling this process in order to predict the allowable design parameters of thermal air heat pump performance [29, 30].

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