Promising methods of ice control of air heat pump evaporators

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Abstract. Heat pumps are used as alternative equipment in the arrangement of hot water treatment and heating of buildings and premises. The principle of the device and functioning of heat pumps, the processes that take place during the removal of low-potential heat are described. The features of the operation of air heat pumps at subzero temperatures are disclosed. The reasons for the low transformation coefficient of air heat pumps at negative outdoor temperature are considered. This paper describes the main existing methods for ice control of heat exchangers of air heat pumps: the method of the reverse of the refrigerant, bypass method, method of ice control with non-freezing solutions, accumulative method, method of thawing using the electrical warming up evaporator, defrosting with the help of the air flow, their advantages and disadvantages in the process at low temperatures. A promising method for removing ice from heat exchangers using mechanical vibrations is presented. The operating parameters of air heat pumps with different thawing methods are given. It examines their effectiveness when the air temperature is -25°C, a comparison of energy consumption for ice control of the outdoor unit of heat exchanger of air heat pump, presents photos of the process of removing ice from the air evaporator of heat exchanger.

1. Introduction
Air heat pumps belong to the equipment from the field of alternative energy.

The perspective and energy efficiency of heat pumps consists in the use of thermal energy of technological emissions from various technological productions, with its subsequent application in hot water supply and heating [1-3]. Air heat pumps (AHP) are successfully used in countries with moderate winters. Their share is 82% of the total number of heat pumps sold. In countries with cold winter periods, the number of heat pumps sold is only 23%, as geothermal heat pumps have the main advantage over air ones – the ability to operate at low temperatures (Fig. 1) [4].

The reason for the low efficiency of AHP, using the heat of the surrounding air, is the frostbite of the external unit of the heat exchanger, the fight against which requires significant additional energy costs and is an urgent task.
The main element of heat pumps are: the external heat exchanger unit (evaporator), the internal unit (condenser), the compressor, the flow controller.

2. Materials and methods
There are seven main methods to solve the problem of frostbite in the working parts of the external unit of heat exchanger of heat pump.

2.1. Reverse
In the heating mode, the vaporous, hot refrigerant compressed by the compressor enters the condenser, which transfers high-potential heat to the building heating system. After giving the heat to the room, the refrigerant changes its aggregate state and passes into the liquid phase.

The liquid refrigerant passing through the temperature control valve (TCV) enters the external evaporator, in the low-pressure zone, again changes its aggregate state and turns into steam, consuming low potential heat from the outside air. In view of the fact that there is moisture in the atmospheric air, it condenses on the evaporator, then, almost instantly, it turns first into frost, and then into a layer of ice.

The performance of the heat exchanger drops by about 20 times. Various methods of monitoring the state of the heat exchanger determine the critical moment of icing of the working surface of the evaporator and give a signal to switch the four-way valve.

The refrigerant begins to move in the opposite direction and the heat from the condensation of the refrigerant goes to thaw the outdoor unit of the heat pump. After the ice is removed, the heat pump switches from thawing mode to heating mode. Thawing by the reverse method is technically a simple, well-proven method.

Most heat pumps produce thawing by using the reverse movement of the refrigerant. The main disadvantage of the method is that with a decrease in the outdoor air temperature, the number of thawing cycles increases, leading to a decrease in the performance of the AHP. This method of combating frostbite is particularly effective up to 0 °C outside air [4, 5]. The scheme of the reverse method is shown in Fig. 2.
2.2. Bypass
This method works in a similar way to the reverse scheme. During the thawing period of the evaporator of the outdoor heat pump unit, a hot refrigerant is also used. In this scheme, part of the hot refrigerant from the discharge line is directly fed to the evaporator via a bypass.

The heat exchanger, which has received heat in this way, thaws, and the bypass is switched off and the heat pump goes into normal operation for heating. In this method, thawing occurs without stopping the heating mode and the ice is removed as it occurs without bringing the heat exchanger to a critical state. The main disadvantage of this method is the reduction of the conversion coefficient at negative temperatures [6].

2.3. The method of thawing with non-freezing solutions
In this method, before the formation of a snow coat, the controller gives the command to stop the fan of the outdoor unit evaporator, as a rule, a solution of 50% glycerin is used, which is fed to the sprayer by means of a pump through the supply pipes. The reagent under pressure passing through the nozzles turns into an aerosol, which falls on the surface of the evaporator, preventing the formation of ice crystals (Fig. 3).

The advantage of using reagents to combat icing is that almost no energy consumption is required, but there are disadvantages – a large consumption of the reagent, the need to clean it, the need to stop the blowing process during the aerosol spraying process [7].

2.4. Defrosting with the help of the air flow
This method works as follows, at the time of formation of the “snow coats” automation of heat pump gives the command to stop the compressor, heat exchanger stops to cool, as the boiling refrigerant stops, blower evaporator comes to more intense mode of operation, the air flow passing through the fins of the heat exchanger warm it after defrosting of the heat exchanger of the heat pump continues to operate as usual. This method requires a more complex design, works effectively at positive temperatures, and does not require large energy consumption.
2.5. Ice control using electrical heating method
One of the most common methods of thawing in cold storage rooms has found wide application in the ice control in air heat pumps. The evaporator of the air heat pump is equipped with a thawing heater. When it is heated, the ice thaws and is removed through the steam trap, after which the heat pump begins to operate in heating mode. Some manufacturers arrange the heating of the condensate pan, as well as the drainage system and the blades of the blowing fan. Disadvantages – it requires stopping the operation of the heat pump for the time of thawing, a large consumption of electricity for the operation of heating elements. As the outdoor air temperature decreases, the operating time of the de-icing equipment increases [9].

2.6. Accumulative method
When the heat pumps operate in the heating mode, part of the heat is sent to the heat exchanger – accumulator with a substance that changes its aggregate state in the process of heat accumulation. Basically, it is a salt CaCl₂·H₂O, which changes from a solid state to a liquid state with an increase in temperature [10]. During the thawing mode, the heat accumulated in the heat exchanger – evaporator is used for heating during the transition from the liquid phase to the solid phase.

This method of defrosting (Fig.4) equalizes the operating mode of the heat pump and is very effective at short-term lowering of the outdoor temperature. The disadvantage of this method is the inefficiency in prolonged frosts, energy consumption in the process of heat accumulation.

The above are the most common methods of combating frostbite of the outdoor unit of the heat exchanger, which are often used in combination, but all of them eventually (except for the method of spraying reagents) remove the ice by temperature action, heating the entire evaporator to a positive temperature, the electricity consumption in all methods depends directly on the temperature of the outdoor air and its humidity.
Figure 4. Scheme of operation of a heat pump with heat storage: 1 - compressor; 2 - four-way valve; 3 - heat exchanger-accumulator; 4 - internal heat exchanger; 5 - capillary tube; 6 - external heat exchanger; 7 - gas-liquid separator; F1 ... F5 - solenoid valves; Sensors: T - temperature, Q - humidity, p - pressure, v - air velocity; Indices: d - discharge, s - suction.

3. Results
One of the most promising ways to ice control today is the use of mechanical vibrations [11], which are fed to the heat exchanger. Ice and frost lose their ability to stay on the surface of the heat-removing heat elements of the evaporator, while it is not necessary to stop the operation of the heat pump, as the process of breaking the ice lasts for several seconds. The cost of electricity for the creation of electromechanical vibrations is minimal; there is no need for a heated drainage system.

The removal of the destroyed ice crystals is carried out by the airflow passing through the evaporator. Figure 5 shows a photo of a heat exchanger with ice obtained at a temperature of -90°C. The studies were carried out at an ambient temperature of -25°C. As a result of mechanical action due to the oscillation of the heat exchanger, the formed ice is removed. The duration of the exposure is 2 seconds, the frequency is 22 kHz, the polarization current is 12-20 A, and the power factor (cosΦ) is 0.7. The use of column-type heat exchangers makes it possible to operate the evaporator unit without a fan, this is an additional energy saving and simplification of the design of the heat pump.

The comparison of energy costs for the removal of ice by different methods is carried out. The efficiency was evaluated by a coefficient that takes into account the energy consumption and thawing time.

Figure 5. Process of removing ice from the heat exchanger.
The results of the research are presented in the table. All the described methods are implemented at an ambient temperature of -25°C.

Table 1. Comparison of the efficiency of ice removal by different methods.

| Method                          | Working time, min | Thawing time, min | Energy consumption, W | Efficiency factor |
|---------------------------------|-------------------|-------------------|-----------------------|------------------|
| Warming up using electric heaters | 22                | 11                | 700                   | 1                |
| Exposure to mechanical vibrations | 10                | 0.04              | 0.56                  | 568              |

Formula for calculating the efficiency coefficient of electricity consumption:

\[ \lambda = \frac{P_1 \times t_2}{P_2 \times t_1} = \frac{700 \times 10}{0.56 \times 22} = 568, \]

where \( \lambda \) - efficiency coefficient, which indicates how many times less or more electricity is consumed, \( P_1 \) – electricity consumption for heating the electric heater, \( P_2 \) – energy consumption for creating mechanical vibrations, \( t_1 \) – operating time of the heat pump with electric heating, \( t_2 \) – operating time of the heat pump with the use of mechanical vibrations.

It follows from the calculation that when using the method of removing ice using mechanical vibrations of the heat exchanger, 568 times less electricity is consumed than when using the most common existing methods.

As it can be seen from the table, the exposure time and energy consumption in the mechanical method are significantly less compared to heating, which indicates its high efficiency.

It should be noted that the use of heat-generating sources based on heat pump installations in heat supply systems in areas where it is rational and competitive will allow comprehensively solving energy, economic, environmental and social problems that are relevant for Russia [12].

4. Summary
A significant disadvantage of air heat pumps is the ice control of the external heat exchanger unit. Solving this problem will lead to a wider geographical distribution of AHP. Currently existing methods of combating freezing require significant energy consumption or an additional heat source integrated into the heating scheme. Development and improvement of methods of mechanical vibrations of the heat exchanger is the most promising method of ice control of evaporator of air heat pumps, increase uptime, save costs of parasitic power.

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