Numerical Study of the Non-Azeotropic Mixture Outflow in Event Accident in the Building Cooling System

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Abstract. The range of values of the pressure of the refrigerating agent at adiabatic compression of vapors in the compressor, within which the cycle of operation of the cooling machine should be carried out, is graphically represented. The distribution of concentrations of a harmful substance – a refrigerating agent in the volume of a room in the event of depressurization of the building's cooling supply elements is studied and the most dangerous area for human health and the critical time spent in it are determined. The amount of refrigerating agent in the system is determined depending on the cooling capacity of the outdoor unit and on the length of the freon lines, taking into account the parameters of the outdoor air. An analytical dependence is developed for determining the time of leakage of the refrigerating agent into the volume of the room, depending on the configuration of the air conditioning system and its cooling capacity. Based on the study of changes in the amount of refrigerating agent and the time of its expiration before reaching the maximum permissible concentration in the working area of the room, recommendations are presented for optimizing the parameters for monitoring the content of harmful substances in the room air, depending on the characteristics of the system.

1. Introduction

Currently, there is an active construction of public buildings with a large number of rooms with different characteristics. By functional universality, they include objects of single-functional purpose and multi-faceted use, universal, rapidly transforming, as well as blocked, in which various institutions are located. During their construction, it is necessary to provide systems for ensuring the microclimate of premises that have a high degree of energy efficiency and lead to minimal capital and operating costs.

Air conditioning systems are the most dynamically developing in terms of the use of modern technologies, as well as in terms of demand all over the world. For the above-listed buildings, it is most rational to provide multi-zone systems with variable refrigerant consumption. The advantage of
the system lies in the considerable length of inter-block communications, as well as in the elimination of the loss of cooling capacity of the air conditioner.

From the point of view of design, multi-zone systems with variable cooling agent flow rate consist of the following elements: one or more external compressor and condenser units combined in a single freon circuit, two or three cooling agent pipelines, tees or distribution combs (refnets, collectors, splitters), cooling agent distribution units when designing systems with heat recovery, internal air handling units, individual and central control panels, control systems based on a central computer. For multi-zone air conditioning systems with variable refrigerant flow, the process of direct evaporation of freon in the internal units – local air conditioners is characteristic, so in the case of depressurization of the elements of the refrigeration circuit, the refrigerant may enter the breathing zone of people in the serviced area. In this regard, it is necessary to study the issue of controlling the content of harmful substances in the volume of the room and find the optimal solution to eliminate the negative impact of the refrigerating agent on the well-being of a person.

2. Analytical studies of the operation of compressor equipment and the parameters of the room's air environment during depressurization of the elements of the cooling system

Multi-zone systems with variable refrigerant flow rate belong to the class of air conditioning systems with direct evaporation of the working substance in indoor units (local air conditioners). As a result of analytical studies of the system operation, it was found that when connecting indoor units to one outdoor unit, the ratio of

\[
\frac{\text{actual quantity}}{\text{maximum quantity}} \geq 0.7
\]

there may be breaks in the connections of pipelines or shaped parts, as well as the failure of elements of climate equipment [1, 2, 5-7, 10-15].

The most common problems with the building's cooling system associated with leaks of the refrigerating agent are shown in the table 1.

| Air conditioning system element | System malfunctions |
|---------------------------------|---------------------|
| Indoor and / or outdoor unit     | Depressurization in interblock communications |
|                                 | Malfunction of fan units, compressors, motor motors |
| Drainage system                 | Contamination of the drainage system |
|                                 | The appearance of a freon leak |
|                                 | Malfunctions in the condensate drainage system |

To detect the leakage of the refrigerating agent from the system, it is necessary to determine the deviation from values the operating pressure of refrigerating agent during adiabatic vapor compression in the compressor. During the day, the pressure drop is not constant and depends on the change in the operating parameters of external and internal air, as well as the operating modes system [3, 9, 12, 17-19]. To determine the working differential pressure of the suction and discharge of the refrigerating agent (for example, R410A), the graph shown in Figure 1 is proposed.
Figure 1. Diagram of the distribution of the working pressure of the suction and discharge of the refrigerant R410A during adiabatic vapor compression in the compressor.

In the event of an emergency depressurization of the freon circuit, people in the serviced premises may enter the breathing area. Since $\frac{\mu_f}{\mu_{air}} = 1.01...5.00$, where $\mu_f$ – molecular weight of the refrigerating agent, $\mu_{air}$ – is the molecular weight of the air, when the refrigerating agent leaks, it accumulates in the working area of the room, which will entail a negative impact on human health.

Depressurization and leakage of the refrigerating agent can occur in any room where the operation of a multi-zone air conditioning system is provided. However, it was found that rooms of a smaller volume are more susceptible to an emergency situation compared to the rest, served by a single air conditioning system [16, 20, 21]. Schematically, the movement of the refrigerating agent during depressurization, as well as its accumulation in the volume of the critical (calculated) room during the estimated time of leakage, is shown in Figure 2.
Figure 2. Diagram of the movement of the refrigerating agent in case of an emergency leak into the volume of the room.

In the course of analytical studies of the effect on the human body of currently used refrigerants in the air conditioning systems of public buildings in the case of contact with the respiratory zone, it was found that the critical time of evacuation of people from the premises is 0.16 hours [4, 8, 16].

3. Determination of parameters for monitoring the occurrence of leakage of the refrigerating agent

When checking for the emergency concentration of the refrigerating agent in the serviced premises, it is necessary to determine the time $\tau$, h, during which it will accumulate in the working area to a concentration equal to the maximum permissible value, the value of which is determined based on the balance of the harmful substance in the volume of the serviced area of the room:

$$V_{wz} \times dC_f = L \times C_f \times d\tau + G_f \times d\tau - L \times C_{f \text{int}} \times d\tau,$$

(1)

where $V_{wz}$ – volume of the serviced area of the room, m$^3$; $C_f$ – concentration of the refrigerating agent in the serviced area of the room, mg/m$^3$; $L$ – volume flow rate of ventilated air, m$^3$/h; $C_{f \text{int}}$ – outgoing air, mg/m$^3$; $G_f$ – amount of refrigerating agent that entered the room during the time $\tau$, mg/h.

The amount of refrigerating agent in the air conditioning system, kg, is determined depending on the cooling capacity of the outdoor unit and on the length of the freon lines according:

$$M_f = 0.083 \times G \times (J_{in} - J_{fin}) \times (1 + 0.01 \times l_p),$$

(2)

where 0.083 – empirical coefficient [5-7, 21]; $G$ – mass flow rate of ventilated air, kg/h; $J_{in}, J_{fin}$ – initial and final enthalpy of air passing through the indoor unit, kJ/kg; $l_p$ – freon line length, m (in theoretical studies, 100 m is accepted).

Taking into account the critical time of people staying in the serviced room, the time of the refrigerant leakage, h, is determined by the analytical dependence:
\[ \tau_n = \frac{V_{wz}}{L} \ln \left( \frac{C_f \cdot L \cdot \tau_{n-1} \cdot (V_{wz} + L \cdot \tau_{n-1}) + M_f \cdot (V_{wz} + L \cdot \tau_{n-1}) - L \cdot \tau_{n-1} \cdot M_f}{\tau_{n-1} \cdot (V_{wz} + L \cdot \tau_{n-1}) L \cdot \left( \frac{M_f}{V_{wz}} - C_{MPK}^f \right)} \right), \] (3)

where \( C_{MPK}^f \) – maximum permissible concentration, mg/m³.

The results of theoretical studies of determining the time of leakage in the room of refrigerating agents currently used in air conditioning systems are presented in Figure 3.

![Figure 3. Change in the amount of refrigerating agent and its expiration time before reaching the maximum permissible concentration in the working area of the room, depending on the cooling capacity of the air conditioning system.](image)

Taking into account the critical time spent by people in the working area of the room, it is possible to determine the maximum cooling capacity of a multi-zone air conditioning system, depending on the brand of the refrigerating agent and its calculated mass, at which, in the event of its leakage in the room and fixing by gas analyzers, there is a sufficient amount of time to perform measures to prevent harm to human health.

It is an irrational decision to limit the scope of application of multi-zone air conditioning systems with variable refrigerant flow according to the studied feature. It is advisable to fix the leakage of the substance as quickly as possible and implement measures before the critical time.

It is necessary to determine the installation location of the gas analyzer and the value of the fixed concentration of the refrigerating agent in the room. The concentration of a gas-containing harmful substance on the x-axis, mg/m³:
\[ C_f = \frac{M_f}{\rho_f^{0.33}} \sqrt[3]{\frac{r}{3.2 \cdot \tau_d}} \]  

where \( \rho_f \) – vapor density of the refrigerating agent at the design temperature and pressure, kg/m\(^3\); \( r \) – distance from the place of leakage of the refrigerating agent to the gas analyzer, m; \( \tau_d \) – time when the gas analyzer detects an excess of the concentration above the standard value, h.

If \( M_f = M_f^{\text{critical}} \) for the refrigerating agent according to Figure 3 and \( C_f = C_f^{\text{MPK}} \), response time of the gas analyzer sensor at a distance \( r \) from the source can be found:

\[ \tau_d = \left( \frac{r}{3.2 \cdot \left( \frac{M_f^{\text{critical}}}{\rho_f} \right)^{0.33}} \right)^2 \]  

Appropriate installation location in the room of the gas analyzer is determined for fixing an emergency leak of the refrigerating agent with the specification of the concentration to detect which it is configured. It is also possible to predict the time of leakage of the cooling agent and the time after which measures will be taken to eliminate the consequences of depressurization of the elements of the air conditioning system.

A comparative analysis of the time it takes to reach the maximum permissible concentration of the refrigerating agent in the volume of the working area of the room and to detect a leak by triggering a gas analyzer sensor installed at a distance is shown in Figure 4.

**Figure 4.** Comparative analysis of the duration of filling the volume of the working area of the room with a refrigerating agent and the time of determining the leakage of sensors-a gas analyzer.
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Thus, the longer the cooling capacity of the system is, the longer the leak detection time during depressurization

4. Conclusion
Thus, the results of theoretical studies systematize the knowledge on the control of the parameters of the operation of climate equipment and can be used in monitoring deviations from the calculated values in compressor and condenser units.

An analytical relationship is proposed for determining the amount of refrigerating agent in a multi-zone air conditioning system, which complements existing practices that use aggregated calculation methods for a specific refrigerating agent.

A method has been developed for estimating the time during which the volume of the working area of the room will accumulate the refrigerating agent to the maximum permissible concentration, depending on the cooling capacity of the air conditioning system. As a result, it is possible to predict the time required for the evacuation of people and the adoption of measures to reduce it to standard values. Also, at the design stage of construction projects with a large number of small-volume rooms, make decisions on the number of cooling circuits.

It is established that when optimizing the control parameters, it is possible to take into account the concentration of harmful substances in the room air with a sufficiently high accuracy and not to allow their accumulation in the working area for the refrigeration circuit intended for a large number of rooms. A solution is proposed that includes the determination of the concentration of the harmful substance at the installation site of the gas analyzer. As a result, the actual location of the sensor can be changed with the specification of its response time, which is less than the critical value in advance.

The presented solutions will allow us to design multi-zone air conditioning systems with a variable flow rate of the refrigerating agent, characterized by a large amount of cooling capacity, while ensuring safety for human health in the event of depressurization of the cooling supply elements and leakage of the refrigerating agent into the room volume.

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