HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

UDC 697.9

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ORGANIZATION OF AIR DISTRIBUTION OF COVERED MULTIPURPOSE ICE RINKS

Statement of the problem. It is essential to perform the analysis of the methods and algorithms of designing the systems of a climatization of covered multi-purpose ice rinks as well as to perform comparative assessment of domestic and overseas ways of air exchange in air conditioning systems of such structures and to reveal the principal methods of increasing the accuracy of their calculation.

Results and conclusions. On the basis of the analysis the basic disadvantages of the methods and algorithms of calculation and designing air conditioning of covered ice rinks have been revealed. Principal objectives of the study aimed at increasing the accuracy of calculations of climatization systems of ice arenas are formulated taking into account the influence of gravitational forces on development of ventilating streams and an arrangement of income and exhaust devices in relation to the ice field.

Keywords: microclimate of a premise, ice rinks, microclimate of skating rinks, climatization, schemes of air distribution.

Introduction

According to the Federal target program “Development of Physical Culture and Sports in the Russian Federation from 2006 to 2015». There are plans to construct about three thousand sporting structures by the year 2015. Therefore the problems of designing engineering systems of large sporting structures need to be addressed.

One of the most difficult structures in terms of design, construction and service are covered multi-purpose ice rinks for performance of public and sporting events where there is the disassembly of the ice rink and installation of prefabricated arenas [1—2].

The crucial part of designing these complexes is a combination of simultaneous cooling and heating of maintained areas of the overall facility.

Climatization of ice arenas is provided by addressing three major problems [3]:

– maintaining the quality of ice over specified periods and preventing fogs over an ice rink;

– providing health and safety of the air in public spaces;

– preventing a condensate in building structures of ice rinks.

1. Domestic methods of calculating and designing systems of air conditioning of covered rinks

There are currently a number of methods for calculating and designing microclimate systems of rinks. In Russia the most commonly used method is the one suggested by O.Ya. Kokorin [3] where three systems of air conditioning are used in staff rooms of ice rinks, seats and frame structures in order to provide a microclimate of an ice rink.

The air conditioning system of ice rinks is designed with a recommended temperature in the public area in mind. It depends on events being held. E.g., for hockey matches rigid ice is needed which is provided by the ice temperature of -6.5 to -5.5 °C with the air temperature in the ice arena of about 6…10 °C, for figure skating the ice temperature is expected to range from -4 to -3 °C and the air temperature is 10…13 °C.

According to [3], the heat mode in the area of ice rink depends on heat fluxes that mostly result from a negative temperature of the surface of ice. The total number of heat fluxes is given by

$$Q_{т.л.пов} = Q_{т.кон} + Q_{т.рад} + Q_{т.св} + Q_{т.люд}, \quad (1)$$

where $Q_{т.кон}$ is a convective flux from the air to the ice surface, Wt; $Q_{т.рад}$ is a flux of radiation heat from the ceiling to the ice surface, Wt; $Q_{т.св}$ are heat fluxes to the ice surface from lighting equipment, Wt; $Q_{т.люд}$ are heat fluxes from people, Wt.

After a number of heat fluxes was determined, cooling equipment is checked for its capacity to maintain the required temperature on the surface of an ice rink.

Another step in the design is the calculation of incoming air which is determined by even filling of an ice rink with incoming air and making it possible for incoming air to drop along a puff of incoming air to the value necessary in the rink [3].

A number of fresh incoming air, m^3/h is given by

$$L_{пн} = q \cdot n, \tag{2}$$

where q is a healthy standard for fresh incoming air per a skater, q = = 80 m^3/(h·person); n is a number of skaters and referees.

Since a convective heat comes to the air of the ice rink, heat surplus should be used to cool the air down to the required temperature [3]. In order to tackle this problem in a hot season, the air supplied after drying and cooling needs to be heated up to the temperature, °C which is given by

$$t_п = t_{вл} + \frac{3,6 \cdot \left(Q_{т.кон} - Q_{т.люд}\right)}{L_п \cdot \rho_п \cdot c_p}, \tag{3}$$

where $t_{вл}$ is a required air temperature near the ice rink, °C; $L_п$ is a consumption of incoming air, m^3/h; $\rho_п$, $c_п$ is the density and heat capacity of incoming air.

It is advisable that incoming air is supplied from above, through nozzles along the long sides of the ice rink (Fig. 1). Incoming, axisymmetric streams 6 from nozzles 3 that are supplied at 20° have to cause the area 4 of the ice rink to have complete slabs with the speed of the air near the ice no more than 0.25 m/sec. Nozzles are selected according to nomograms based on the above requirements.

Since the amount of fresh air given by formula (2) is not enough for the selected air distributor [3], recirculation makes the flux complete. The air reaches the upper area after interacting with the ice surface and then leaves it through the holes in the exhaust duct 1. In order to maintain the air balance of an area over the ice surface, the consumption of exhaust air is accepted to be equal to that of the supply. A mixture of fresh and recirculation air is delivered in the ventilator for treatment.

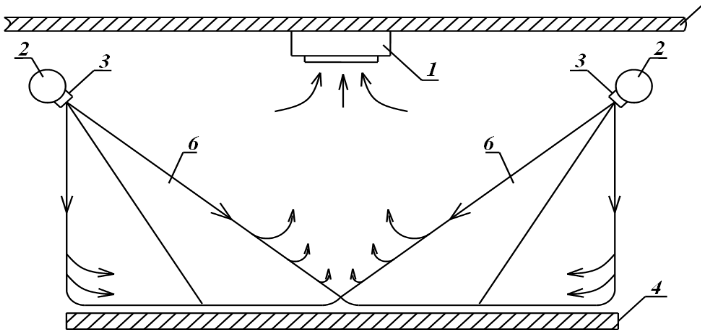

Fig. 1. Principal schematic of air distribution in the air conditioning system of the ice rink:

1 — exhaust duct; 2 — supply duct; 3 — supply nozzles; 4 — area of the ice rink; 5 — slabs of the ice rink; 6 — supply streams

The parameters of supply air are determined using a graphoanalytical method by means of Id-diagram according to the method in [3]. The way air conditioning systems operate during the cold season is determined in a similar fashion.

Climate systems for standing seats should be designed using displacement ventilation (Fig. 2) if the air is exchanged downwards.

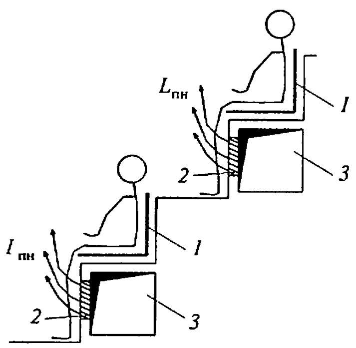

Fig. 2. Air supply under the audience seats: 1 — plastic seats; 2 — supply air distributors; 3 — supply duct; $L_{пн}$ — consumption of supply air of 20 m^3/h per person

Supply air of 20 m^3/h per person is delivered under the seats with the speed of 0.25 m^2/sec and temperature difference of 3 °C between the supply air and the operating area. The air with the temperature as given by (4) is removed from the upper area over the seats:

$$t_у = K_L\left(t_в - t_п\right) + t_п, \qquad (4)$$

where $t_в$ is the temperature of the supply air, °C; $t_п$ is the temperature of the air of the operating area,°C; K_L is efficiency of air exchange determined using the graph [3]. If covered multi-purpose ice arenas are used for sporting, cultural and public events, the rink is cleared of ice and made into a stage with extra audience seats (Fig. 3).

The climate system of the seats continues to operate in the way it did before and the way the system operates over the ice rink depends on an event being held and is made clear by calculations.

Fig. 3. Possible options for the main hall of the ice rink during sporting, cultural and public events

One of the major disadvantages of the method suggested by Kokorin is that areas of the ice rink and seats are regarded separately. As a result, the influence of temperature differences between the supply air over the ice surface and the air removed over the seats is neglected despite the fact it is known to possibly lead to non-even air distribution and faulty operation of the climate system of the ice rink.

Another important flaw of the method under discussion is that due to specific ways in which a necessary amount of supply air is determined, the ratio of fresh and recirculation air is 1:7.5. Therefore there is a need for extra calculations to be carried out of the amount of the air supplied which depends on how many contaminants are emitted in the operation area.

2. Overseas experience of designing climate systems of covered ice rinks

The problem of this nature was discussed in [4] using the example of some artificial rinks in the USA. The distribution of the temperatures and concentration of harmful substances in a building were modeled using the application software CFD (The Computational Fluid Dynamics).

Fig. 4 identifies actual schemes of air distribution in small covered ice rinks with the seating capacity of 1200 people. The study focused on the distribution of harmful substances in the entire facility when different air exchange methods are employed.

In [4] it runs that there is a risk of poisoning caused by combustion products as an ice rink is maintained with special fuel-burning machines.

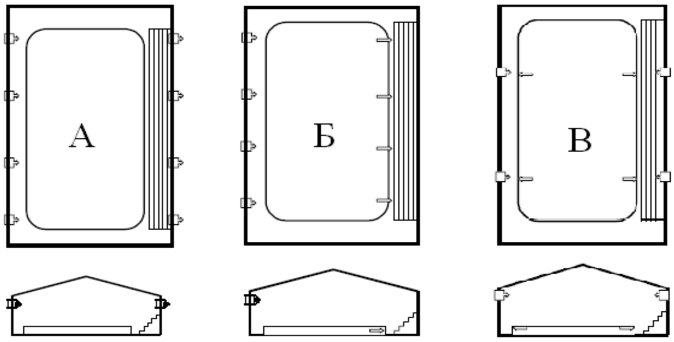

Fig. 4. Schematic of air exchange in covered ice rinks

The research suggests that the most critical factor to affect the efficiency of the removal of harmful substances, the temperature mode and the average “age” of the air over the ice rink is the air [4].

Fig. 5 suggests that the concentration of CO is the highest near the ice surface. This is due to poor circulation of the air in the facility caused by changing temperatures over the ice surface and the upper area of the rink.

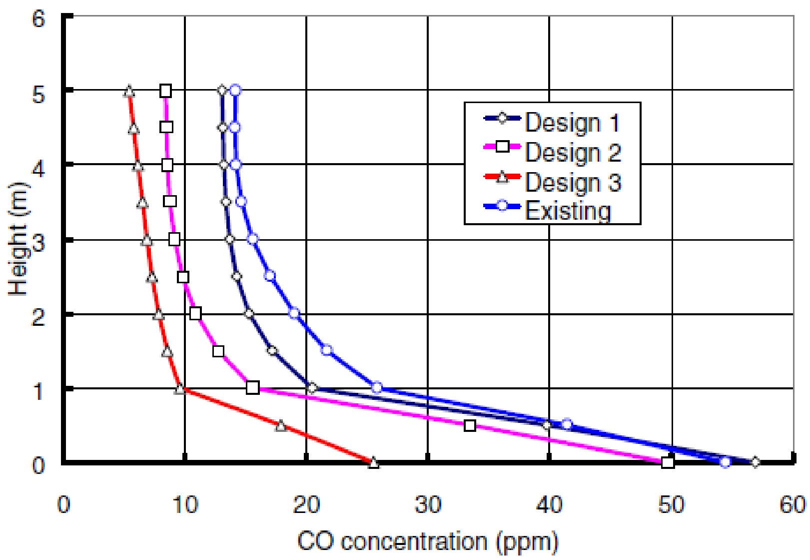

Fig. 5. Distribution of CO over the ice surface in different air distribution schemes

According to [6-8], the efficiency of removal of contaminants shows the speed of removal of contaminants present in the air. It is given by the formula

$$\varepsilon^c = \frac{c_e(\infty)}{c(\infty)} 100\ \%, \tag{5}$$

where $c_e(\infty)$ is the concentration of contaminants in a current mode in the exhaust air; $c(\infty)$ is the average concentration of contaminants in the facility in a current mode (concentration of contaminants are pure in relation to the absolute concentration values, the values are presented as excess of the concentration of contaminants in the outdoor or supply air).

The analysis of Fig. 4 and 5 showed that the schemes where air inlet holes were located in the vicinity to the ice rink allow a reduction in the average "age" of the air, decrease the concentration of CO and improve the efficiency of air exchange [4].

The efficiency of air exchange in the paper under discussion is the speed of air exchange in the facility. It is defined to be the ratio of minimum possible time of air exchange in the facility or nominal constant time τ_n to the actual time of air exchange $\overline{\tau_r}$:

$$\varepsilon_a = \frac{\tau_n}{\overline{\overline{\tau_r}}} \cdot 100 = \frac{\tau_n}{2\langle\overline{\tau}\rangle} 100\ \%. \tag{6}$$

In this country [9—11] the efficiency of air exchange is traditionally reflected by the coefficient of air exchange efficiency $k_{эф}$ which describes the connection between the parameters of the air being removed and the air of the operating area. The coefficient of efficiency depends on the positioning of supply and exhaust equipment, location and power of emission sources of harmful substances as well as some other factors.

As harmful substances and heat excesses are absorbed [10, 12] $k_{эф}$ is determined using the following formulas:

$$k_{эф} = \frac{q_{уд} - q_0}{q_{р.з} - q_0},\ k_{эф} = \frac{t_{уд} - t_0}{t_{р.з} - t_0}, \tag{7}$$

where $q_{уд}$ and $t_{уд}$ is the concentration, mg/m^3 and the temperature, °C, in the air being removed; $q_{р.\,з}$ and $t_{р.\,з}$ is the same in the operating area; q_0 and t_0 is the same in the supply air.

According to the research results [4, 5], it was suggested that a coefficient is introduced to indicate how long harmful substances remain in the facility and increase the ratio of air exchange when concentrations are at their peak.

The major disadvantage of the schemes of air distribution investigated in [4] is that they do not make allowances for individual air conditioning for the ice rink and the seats and therefore the temperature and humidity modes in one of the areas do not comply with the required values.

3. Effect of the height of the maintained ice arena facility on the air parameters in the supply air flows of the air conditioning system of the ice rink

Yet another important factor in providing the required air parameters over the ice rink is the total area of the ice rink facility and more particularly, the distance between the ice surface and supply and exhaust equipment.

Since the temperature of the air supplied is different from that of the air in the maintained area (in covered ice rinks it can go over 10 °C [3]), there are gravitational forces influencing the supply air flows which have a significant effect on its parameters. As inlet holes go further, the ratio of gravitational and inertial forces of a non-isothermal flow increases. The influence of gravitational forces on the flow can be described using Archimedes's current criterion which is calculated for this or that longitudinal section of the flow the distance x away from the air distributor [11—14]. For axial-symmetric and fan flows, Archimedes' current criterion is determined using

$$Ar_x = \frac{n}{m^2} Ar_0 \left(\frac{x}{\sqrt{F_0}} \right)^2, \tag{8}$$

where m and n are coefficients that describe changes in the speed and excess temperature in the flow depending on the type of the nozzle; F_0 is the area of the exhaust hole, m^2; Ar_0 is Archimedes' criterion; x is the distance from the exhaust hole, m.

If the ratio of gravitational and inertial forces is small, flows can be calculated using the formulas for isothermal flows.

Due to a particular way of air exchange, supply air in covered ice rinks is delivered downwards using vertical and slanting axial-symmetrical flows towards the maintained area.

In vertical flows gravitational forces do not actually bend the axis of the flow changing the motion intensity along the axis a lot [11, 15, 16]. Under the effect of gravitational forces the speed and temperatures fields are redistributed and stop being similar in the main area. This is particularly the case when gravitational and inertial forces have the same direction.

Archimedes' current criterion for axial-symmetrical flows is connected with a geometric characteristic if the flow *H* suggested by I.A. Shepelev with a dependence

$$Ar_x = 1,2\left(\frac{x}{H}\right)^2 . \tag{9}$$

During a horizontal air supply, axes of the flow bend under the effect of gravitational forces.

The path of a flow given by Archimedes' current criterion is determined using the formula

$$y = kAr_x x , \tag{10}$$

where y is the deflection of the flow from the horizontal direction the distance x away from the nozzle.

The calculation formula to define the path of horizontal axial-symmetrical flows is

$$\frac{y}{\sqrt{F_0}} = 0,6\frac{n}{m^2}Ar_0\left(\frac{x}{\sqrt{F_0}}\right)^3 . \tag{11}$$

The flow is detached at Ar_x which is equal for axial-symmetrical flows of 0.3 for flat and fan flows it is 0.23 and 0.18 respectively.

The distance to where the flow is detached from axial-symmetrical flows is given by

$$\frac{x}{\sqrt{F_0}} = \frac{0,5m}{\sqrt{nAr_0}} . \tag{12}$$

The calculation dependences to define relative axial speeds, temperatures and consumption are in [9, 10].

If inertial and gravitational forces are similarly directed, the flow is detached and it happens at the values of Archimedes' current criterion of 0.4 for axial-symmetrical flows and 0.5 for flat flows. The distance to the release of the axial-symmetrical flow to its detachment plane can be determined using the formula (12).

The above suggests that since supply flows of air conditioning systems of covered ice rinks are non-isothermal and are affected by gravitational forces which can cause the flow to be detached and its relative speed, temperature and consumption to change. Therefore in order to increase the accuracy of designing microclimate systems of the discussed structures to comply with the requirements [17—19], it is necessary that the influence of gravitational forces on supply air flows is taken into account.

Conclusions

1. The methods and algorithms for designing climate systems of covered multi-purpose ice arenas. Domestic and overseas experiences of air exchange in air conditioning systems of similar structures were compared and assessed.

2. The analysis suggests that the most viable and efficient method of designing air conditioning systems of covered ice rinks is the one set forth by O.Ya. Kokorin.

3. It was also noted that due to a particular way of determining the amount of supply air and local consideration of climate systems of the ice rink and spectators' seats, the accuracy of this way of calculation and design is rivalled by its foreign counterparts.

4. However, both overseas and domestic methods and algorithms of the investigated systems have the averaged indicators at their heart which does not contribute to the accuracy of the calculation. Therefore in order to improve the efficiency of climate systems of covered multi-purpose ice arenas, new design methods should be developed based on temperature, speed and concentration fields considering the effect of gravitational forces on supply and exhaust air flows.

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