Mathematical modelling of the indoor ice arena with two control volumes for calculation of the air exchange

Samvel Sargsyan and Viktor Zhila
Moscow State University of Civil Engineering, Yaroslavskoye shosse, 26, Moscow, 129337, Russia
E-mail: SargsyanSVI@mgsu.ru

Abstract. The existing methods of calculation of ventilation and air conditioning systems in the indoor ice skating arenas specify the audience stand area zone separately of the ice rink space. They do not take into account interaction of the zones, which have different temperature and moisture parameters. Calculation of the required air exchange of the ice field area is represented herein through mathematical modelling, which reasonably divide the space volume in two distinctive control areas. A mathematical model of the physical process, which takes place in the indoor ice arena space, enables determination of the air exchange to get the required normative parameters of the air in separate space KOs. The suggested method proposes a procedure of the microclimate parameter calculation of separate control volumes of the indoor ice arena space, when the air is distributed according to an “up-to-down” scheme. It will permit to determine the parameters and the operation modes of supply and exhaust ventilation equipment. The method takes into account the processes of heat- and mass transfers in two distinctive control volumes of the ventilated area under permanent conditions. Methodical bases are developed for physically reasonable way of calculating the required air exchange, bearing maximal consideration of the factors influencing heat-air processes in the ventilated volume as a whole and according to two separate typical control volumes of the indoor ice arena ventilated space. The dependence of changes of the relative air consumption in an axis-symmetric jet from the sectional area of the hole, the height of location and the dynamic coefficient of the diffuser are given herein. The method allows determination of the location height and the type of the air diffuser, as well as the air parameters at the jet outlet from the diffuser to provide the design air parameters at the jet inlet into the skating-rink area. There are presented the air jet temperature changes at the jet inlet in the serviced area, as well as the air jet temperature changes at the outlet of the diffuser depending on the amount of the inflow air and the location height of the diffusers. The submitted I-d diagram shows the changes of the air inflow jet settings in the indoor skating-rink space with two control volumes, when the air exchange is made according to the “top-to-down” scheme. The graph-analytical method of the air parameter calculations in the skating-rink area on the basis of I-d-chart, allows to consider the process of mixing air of two control volumes and to clarify the air parameters at the diffuser jet outlet, taking into account the type of the jet, the height of the diffuser location and the characteristics of the diffuser. If the air exchange of the ice rank zone is performed according to the “top-to-down” scheme, the availability of heat and humidity emissions in II KO (stands zone) makes reasonable provision of the inflow air supply by the smallest possible number of the air diffusers, as well as determination of the height of the air diffuser location closer to the served area of the ice rink.
1. Theoretical and practical foreword issues

Indoor ice arenas are referred to sports facilities, which shall meet strict hygiene requirements. The task of ensuring the required microclimate parameters in the sports constructions of this kind necessitates designing of such systems of ventilation and air conditioning, which may provide the required parameters of the air environment for the audience and for the contesting athletes [1, 2, 3, 4, 18, 19]. Based on the foregoing, it is possible to allocate two zones with the air characteristic parameters within in the volume space of the ice arena:

- the audience stand area;
- the area, which is located directly above the ice rank surface, 1.5 m high, with the ice coating.

The speed properties and other quality characteristics of the ice coating depend on the uniform distribution of the main air parameters: moisture content, relative humidity and temperature at the area located just above the surface of the ice coating.

The ice coating temperature depends on the type of the sports event (Table 1) [1, 2, 3, 4, 18, 19].

| Activity               | The air temperature in the skating rink space (at the height of 1.5 m from the ice), °C | The air temperature in the skating rink space (with the audience), °C | Temperature of ice, °C | Relative humidity of the skating rink, % |
|------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------|------------------------|-----------------------------------------|
| Hockey Play            | «+» 6 ÷ «+» 10                                                                        | «+» 18                                                              | «-» 6.5 ÷ «-» 5.5      | 30 ÷ 45                                  |
| Figure skating         | «+» 10 ÷ «+» 13                                                                       | «+» 18                                                              | «-» 4.0 ÷ «-» 3.0      | 30 ÷ 45                                  |
| Competition            |                                                                                       |                                                                     |                        |                                         |

2. Actuality of the above stated subject

The growing number of indoor ice arenas under construction and reconstruction is accompanied by increasing demands of the functional efficiency of ventilation and air-conditioning systems, which are subject to a special attention due to architectural planning and sanitary-hygienic provisions.

Reduced natural heat supply resources make them more expensive, that is why the resource saving measures have become a very actual task in designing of the ice area microclimate systems. Ventilation and air-conditioning systems consume big amounts of thermal energy, and often are the main consumers of thermal and electrical power [5].

The effectiveness of ventilation and air conditioning systems mainly depends on the air exchange organization scheme (AEOC). Traditional air exchange calculation procedures do not cover the entire diversity of the factors influencing heat and mass transfer in the space, as well as do not take into account the AEOC. This leads to deviation of the air parameters from the design values in the serviced area zones [6,7,8].

Depending on the type of the held events, the systems providing microclimate of the indoor ice arenas shall enable the required temperature and humidity modes of individual volumes of the space. Absence of the required air parameters in the ice rink zone may result in a poor quality of the ice and fogging over its surface.

Proceeding from the above, design decisions and the engineering analysis are of greater importance nowadays. Rational design decisions shall be made using mathematical modeling of aerodynamic, heat and mass transfer and other processes, which take place in the spaces under designing. The effectiveness of the systems, which provide the indoor ice arena microclimate, depends on the adopted AEOC of ventilation and air-conditioning systems, as well as engineering methods of calculation of these systems.

Based on the foregoing, it may be stated, that the development of the scheme and the methods of engineering calculations of ventilation and air conditioning systems of indoor ice arenas is an actual
task. Improvement of the quality of the designing decisions and calculation of the microclimate performance systems in indoor ice arenas will help to reduce their energy consumption [6,7,8].

3. Methods of the air thermal processes in the ice arena space with two control volumes. Formulation of general task

The ice arena space shall be considered as a building element. The research is focused on the processes associated with the movement of air in the space volume of indoor ice arenas: jet flows in an enclosed space, temperature distribution and the air movement, as well as the diffusion of harmful emissions in the ventilated space.

The ice arena space shall be examined as an object, which includes two control volumes (KO), each of them possibly having supply and removal of air, the absorption or release of harmful substances. The ice arena spaces are divided into two control volumes, where the separated air conditioning systems enable strictly required parameters of air [9, 10, 11, 12, 13, 14, 15].

The first control volume of the ice arena includes the area directly located over the ice surface, 1.5m high, together with the inflow jet, where provision shall be made of a normal function of the skating-rink and the ice surface (KO1).

The second control volume includes the stand area for spectators, where it is necessary to provide a comfortable environment for the audience (KO2). The flows of substances and energy may pass through the borders of the control volumes. Within each control volume the flows may be absorbed or emitted. External effects may occur at the borders of each control volume. The surface of a control volume is called the control surface (CS).

The structural scheme of the microclimate formation in the indoor ice arena volume is given in the figure 1.

Air conditioning and ventilation systems of an indoor ice arena are destined to prevent the mist formation at the skating rink surface, to enable absence of the condensate on enclosing building and technological structures and elements, to meet the required sanitary and hygienic parameters in the audience area with the permanent presence of the spectators.

![Figure 1. Structural scheme of the microclimate formation in the indoor ice arena space with two control volumes](image-url)

The ice arena space is divided conventionally into two control volumes KO. The air parameters in each KO are conventionally taken as homogeneous ones.

Each KO has typical temperature and humidity parameters. It shall be taken into account, that II KO air parameters make an influence on the I KO microclimate parameters, if the microclimate
parameters of KO data are created by different air conditioning and ventilation systems. Each of the two KOs has the surfaces with low temperatures, which consume heat, and those with high temperatures, which educe thermal emissions.

Thermal and air processes in the KOs shall be described by the preservation laws (mass and energy).

Mathematical model of the physical process, which takes place inside the space of the indoor ice arena, enables determination of the air exchange to provide the required normative air parameters in separated KOs of the ventilated space.

In the general case the KOs of the ventilated space shall be represented as a limited area inside a premise with arbitrarily dissipated sources and discharges of harmful emissions M (V), as well as the ventilation air flows G (V). The members, which describe the flow passage through the CS, are marked herein by the following symbols: M (A) - the flows of harmful emissions; G (A) – the flows of air masses.

Figure 2. General scheme of heat and mass exchange in the ice arena space with two KO: I KO – the 1st control volume; II KO – the 2nd control volume

Figure 2 shows a general diagram of heat and mass transfer in a ventilated space of the indoor ice arena with two KOs. On this basis, the general form of the balance equations of the air consumption and harmful emissions for the ice arena space with two KOs is as follows:

- for I KO:

\[
\begin{align*}
\int_{V_{IKO}} G(V_{IKO})dV_{IKO} + \int_{F_{IKO}} G(F_{IKO})dF_{IKO} &= 0 \\
\int_{V_{IKO}} M(V_{IKO})dV_{IKO} + \int_{F_{IKO}} M(F_{IKO})dF_{IKO} + \int_{V_{IKO}} G(V_{IKO})\Pi(V_{IKO})dV_{IKO} + \\
&+ \int_{F_{IKO}} G(F_{IKO})\Pi(F_{IKO})dF_{IKO} &= 0 \\
\end{align*}
\]

(1)

- for II KO:
\[
\begin{aligned}
&\int_{V_{IKO}} G(V_{IKO}) dV_{IKO} + \int_{F_{IKO}} G(F_{IKO}) dF_{IKO} = 0 \\
&\int_{V_{IKO}} M (V_{IKO}) dV_{IKO} + \int_{F_{IKO}} M (F_{IKO}) dF_{IKO} + \int_{V_{IKO}} G(V_{IKO}) \Pi(V_{IKO}) dV_{IKO} + \\
&\quad + \int_{F_{IKO}} G(F_{IKO}) \Pi(F_{IKO}) dF_{IKO} = 0
\end{aligned}
\] (2)

In the systems of equations the first member of the first equations is the consumption of the air, which flows in or flows out of various KO points.

The second member in the same equations is the mass exchange between the KO itself. The task is to determine the consumptions and the parameters of supplied and discharged air by individual control volumes (zones). The balance equations for separate KOs of the space enable a more proved determination of the required air exchange.

4. Determination of the air parameters in the jet flowing from an air diffuser

The air supply jet extends in the efflux direction, mixing along the way with the ambient air of the II KO. The mixing is followed by an increase in the amount of the transported air, deceleration of the jet and formation of a slow flow of the ambient air towards the jet. Due to the ejection effect, some heat and water vapors penetrate from the second KO to the first one. Thus, the jet contributes to the balancing of the air parameters all over the entire space volume, thereby reducing the efficiency of the air exchange.

The air incomes through the inlet nozzles in the amount \( G_0 \) of \( t_0 \) temperature and \( d_0 \) moisture content (Fig. 3). A jet of the supply air, evolving in the efflux direction, assimilates heat and humidity emissions from the II TO. The air in the II KO corresponds to the \( t_{III} \) temperature and \( d_{III} \) moisture content. The air flow in the jet increases from the initial \( G_0 \) to \( G_{emp} \) in the calculated cross section due to the air ejection the II KO. At the end of its progress the jet having the \( t_{emp} \) temperature and \( d_{emp} \) moisture content flows in the serviced zone area. Some part of the jet heat is spent on compensation for convective heat losses from the serviced area air to the ice surface \( Q_{conv, ice} \).

![Figure 3. Calculation diagram of heat and air processes in the I KO](image)

The formula for calculation of the required air parameters at the exit of the jet from the air diffuser in the ventilated area of the ice arena with two control volumes derives from the systems of balance equations, which have been made for the I KO of the skating rink, together with the air supply jet according to the mass and heat (3), as well as according to the mass and the moisture content (5).

From the balance equations for the air supply jet we define the air parameters at the outlet of the diffuser to provide the desired air parameters at the inlet of the jet in the skating rink zone.
The balance equation of the inflow jet according to the consumption and the heat as per a diagram on the figure 3, becomes as follows

\[
\begin{align*}
G_0 + (\beta - 1)G_0 &= \beta G_0; \\
ct_0 G_0 + ct_{\text{n}}(\beta - 1)G_0 &= ct_{\text{cmp}} \beta G_0
\end{align*}
\]  

(3)

The air temperature at the jet outlet from the air diffuser may be derived from the equation (3)

\[
t_0 = t_{\text{cmp}} - t_{\text{n}}(\beta - 1).
\]  

(4)

The air supply jet equation per consumption and the moisture content, according to the diagram of the figure 3, becomes as follows

\[
\begin{align*}
G_0 + (\beta - 1)G_0 &= \beta G_0; \\
\text{cd}_0 G_0 + \text{cd}_{\text{n}}(\beta - 1)G_0 &= \text{cd}_{\text{cmp}} \beta G_0.
\end{align*}
\]  

(5)

The equation (5) enables determination of the jet air temperature at the air diffuser outlet

\[
d_0 = d_{\text{cmp}} - d_{\text{n}}(\beta - 1).
\]  

(6)

When calculating the required air exchange and the supply air parameters at the jet outflow from the air diffuser, the air parameters in the characteristic points can be identified using a 1-d chart the humid air to provide the required air parameters at the jet inflow to the skating rink area using the method of two-zone mathematical modeling of the ventilated indoor ice arena space.

From equations (4) and (6) it is obvious that the preliminary values of the temperature and moisture content of air at the outflow from the diffuser depend on the coefficient \( \beta \) - the relative air consumption in the jet to enable the required normative parameters in the serviced area of the skating rink.

The relative air consumption in the axis-symmetric and flat jets is determined by the known formula [17]:

For an axis-symmetric jet

\[
\beta = \frac{2x}{m A_0^{0.5}}.
\]  

(7)

For a flat jet

\[
\beta = \frac{\sqrt{2}}{m} \frac{x}{\sqrt{b_0}}.
\]  

(8)

According to the equations (7) and (8), the value of the relative air consumption in the jet depends on the area of the living section of the diffuser \( A_0; b_0 \), the length of the jet \( x \) and the dynamic factor of the jet \( m \): \( \beta = f (A_0, b_0, x, m) \). The length of the jet from the diffuser to the entrance of the serviced area of the rink is determined as \( x = H_{b,p} - h_{0,3} \), the height of serviced area makes \( h_{0,3} = 1.5 \text{ m} \).

For changes of the air relative consumption in the axis-symmetric jet, depending on the area of the diffuser living section, with known values of \( m = 6.8 \), \( H_{b,p} = 12 \text{ m} \), see figure 4.
Figure 4. The dependency of relative air flow in an axisymmetric jet (β) on or cross-sectional area of the air distributor opening (A₀) for m=6,8, H₉,₉=12 m

From the above diagrams it follows, that the height of the diffuser location H₉,₉ has the greatest impact on the change of the coefficient of the air relative consumption in the jet (mixing) β. The higher the air diffusers are mounted, the greater amount of the II KO’s ambient air is involved by the jet in the I KO. In spaces with high thermal emissions or in the rooms with other harmful emissions, it is recommended to set the air diffusers at a low height to reduce the mixing.

This method allows determination of the optimal installation height and the features of the air diffusing equipment, as well as the air parameters in the outflow jet from the diffuser, to ensure specified parameters of the air jet inflow into the serviced zone of the ice field.

5. Determination of the analytical dependence, which allows calculation of the required air exchange in the indoor ice arena space using a mathematical model with two KOs (control volume)

To determine the required air exchange KO1 in the place of the ice field location, using a mathematical model of an indoor ice arena space with two KO s, in the most general form, can be deduced from the systems of balance equations written for KO1, where is the ice rink (9), and for the supply air jet (11) for air and heat consumption.

The Fig. 3 shows a design scheme of heat-air processes in the I KO (in the area of the ice field). The balance equation in accordance with the scheme depicted in Fig. 3 takes the form:

for the ice field area KO1:

\[
\begin{align*}
G_{\text{comp}} - G_{yx} &= 0 \\
G_{\text{comp}}t_{\text{comp}}c_a + Q_{m.s} - Q_{r.h.c.} - G_{yx}t_{yx}c_a &= 0
\end{align*}
\] (9)

For the jet in the KO1 volume:

\[
\begin{align*}
G_0 + ( \beta - 1 )G_0 &= G_{\text{comp}} \\
G_0t_0c_a + ( \beta - 1 )G_0t_Bc_B &= G_{\text{comp}}t_{\text{comp}}c_a \\
G_0\beta &= G_{\text{comp}} \\
t_{\text{comp}} &= t_0 + ( \beta - 1 )t_B/\beta
\end{align*}
\] (10) (11) (12) (13)

Where: \( G_{\text{comp}} \) – is the air consumption in the supply air jet at the inlet of the serviced area of the KO1 ice field, kg/h; \( G_{yx} \) – is the amount of the discharging air, kg/h; \( G_0 \) – is the amount of air, which
is flowing out of the air diffuser, kg/h; $t_0$ – is the air temperature during the outflow from the air diffuser, °C; $t_{cmp}$ – is the temperature of the supply air jet at the inlet to the serviced zone of the ice field, °C; $t_{js}$ – is the temperature of the air outflow, °C within the KO II volume; $t_{B1}$ – is the temperature of the serviced zone above the ice surface, °C; $t_{BII}$ – is the air temperature in II KO; $\beta$ – is the air relative consumption in the jet (the jet mixing coefficient); $Q_{m, air}$ – is the convective heat supply from the air to the ice surface, W; $Q_{m, p}$ – thermal flows from people, W; $c_v$ – is the air specific heat, kJ/(kg·°C).

Being solved in common, the equations (9) and (10) enable calculation of the air consumption in the supply jet $G_{cmp}$ at the entrance to the ice rink serviced area of KOI:

$$G_{cmp} = \frac{Q_{m, air} - Q_{m, p}}{c_v(t_{cmp} - t_{B1})}$$  \hspace{1cm} (14)

In equation (16) we substitute the equation of the relations (11), (12) and deduce the formula for calculation of the required air exchange $G_0$ of the ice field zone:

$$G_0 = \frac{3.6(Q_{m, air} - Q_{m, p})}{c_v(t_0 + (\beta - 1)t_{BII} - \beta t_{B1})}, \text{kg/h}$$  \hspace{1cm} (15)

The got analytic dependence (15) allows determination of a relationship between the characteristics of the air diffusing equipment, the height of its installation and the temperature of the inflow air to be supplied to the ice rink area.

When designing ventilation and air-conditioning systems of the serviced ice arena zones, one must strive to exclude an intensive mixing of supply air, which is supplied to the area of the ice field, with the II KO’s air being of a high heat content. Inflow of a higher amount of supply air in the ice zone will lead to an intensive mixing of air masses of the Ist and the II nd KOs. As a result, the air temperature above the surface (at a height of 1.5 m from the ice) may exceed the required value.

To take advantage of the proposed method of calculating the required air exchange it is necessary to impose additional conditions in respect of the provision of sanitary-hygienic characteristics of the jet, when it inflows the serviced zone of the ice field.

A comprehensive calculation of the air exchange and air diffusion has been made by the patterns of the jet streams and the peculiarities of their development taking into account the main characteristics of the air diffusers.

The range of variation of the quantity of the inflow air, which is supplied to the area of the ice field to enable the required parameters, depends on the amount of the thermal excess emitted by the II KO audience (the stand zone), the air diffuser characteristics, the height of its location and the supplied air temperature. The thermal emissions get their maximal values when the stands are completely filled.

An exact account of the factors, which make an influence on the air parameters in the ice field zone, enables determination and estimation of availability of the required air parameters in the area under service.

The Fig. 5 and 6 show the dependence of the amount of supply air $G_0$ from the supply air temperature $t_0$ at different heights of the location of the air diffusers $H_{b,p}$ and the jet temperature changes $t_{cmp}$ at the entrance in the serviced area depending on the amount of the supply air $G_0$ at different heights of the diffuser location.
When calculating the required air exchange to be supplied to the area of the ice field and determining the parameters of the supply air in the outflow from the diffuser for provision of specified parameters of the air entering the supply jet in the serviced ice rink area, the use of the mathematical model for an indoor ice arena space with two KOs, enables calculation of the air parameters in the characteristic points by the graphical-analytical method, using I-d diagram of the moist air.

The Fig. 9 shows the I-d diagram of changes of the supply air parameters in the zone of the ice field (I KO), if heat and humidity emissions are subject to any changes in the II KO (area of stands). The point P describes the parameters of the state of air flowing out of diffusers. When calculating the following air parameters were used in the II KO:

The П-Стр segment refers to the process of assimilation of heat and moisture, due to the mixing with the supply air jet from KO II, the flow of intake air supplied to the ice zone. The Стр-Вл segment refers to the process of cooling of the supply air flowing into the serviced zone, when the air transfers the evident convective heat of the ice surface.
The values of the air parameters in the serviced area of the skating rink and their range depend on the heat-humidity relation in the II KO (stands area) and the air relative consumption in the jet.

The task of achieving the required parameters in the supply air jet at the inlet to the serviced area of the ice field (the point Fig. 8), if any changes of heat and humidity emissions occur in the area of the stands, shall be provided by varying the supply air temperature (points П1, П2, П3, figure 6). Reduction of heat and humidity emissions in the area of the stands is accompanied by an increase in temperature of the supply air from the point П1 to point П3.

6. Conclusions
A method of calculation of the microclimate parameters in individual control volumes of the indoor ice arena space has been proposed for organization of the air diffusion according to a "top-to-down" scheme to determine the parameters and modes of operation of the air supply and exhaust facilities.

The method allows determination of the location height and type of the air diffuser, as well as the air parameters at the jet outflow from the diffuser to provide the required air parameters at the jet inflow to the skating rink area.

Graph-analytical method of the air parameter calculation in the ice rink area, on the basis of the I-d-chart, allows to consider the process of the air mixing of the two control volumes and to clarify the parameters of air at the jet outlet from the diffuser based on the type of the jet, the location height and characteristics of the air diffuser.

The existing methods of calculation of ventilation and air conditioning systems in indoor ice arenas treat separately the audience stand area for spectators and the ice rink area, do not take into account the interaction of the zones, which have different temperature and humidity parameters.

The division of the indoor ice arena space into two KOs permits to describe more accurately the processes under investigation occurring within the space volume and to find a well-founded required air exchange.

A mathematical model of the physical process occurring indoors of the covered ice arena space enables determination of the air exchange for provision of the normalized air parameters in separated KOs of the space.

The availability of heat and humidity emissions in the II KO (stands area) in the organization of the air exchange of the ice field zone according to the "top-to-down" scheme makes it reasonable to supply the inflow air with the smallest possible number of air diffusers, and the installation height of the diffusers closer to the served area of the ice field.

References
[1] Volkov A A Some particular features of the air diffusion in ventilation systems of the audience halls / A A Volkov, I S Margolina, A A Borodkin // AVOK. - 2010. - No 2. - p. 54-59.
[2] Kokorin O Ya Analysis of energy SKV indices for spaces of training skating rinks equipped by different systems of cold and heat / O Ya Kokorin, N V Tovaras, A P Inkov // Refrigeration technique. - 2007. - No 10. – p. 14-19.
[3] Kokorin O Ya, Tovaras N V Engineering systems of spaces with artificial ice or snow. M.: KURS, INFRA-M, 2014. 240 p.
[4] Pankratov V V Climatization particularities of ice arenas / V V Pankratov, N V Shilkin // AVOK. - 2009. - No 8. - p. 24-36.
[5] Bogoslovsksiy V N et al. Air conditioning and cold supply. – M.: Stroyizdat, 1985. – 367 p.
[6] Shepelev I A Aerodynamics of air flows in a premise / A I Shepelev. – M.: Stroyizdat, 1978. – 144 p.
[7] Grimitin M I Air distribution in a premise. St-Petersbourg: “Avok Severo-Zapad” Publishing House, 2004. 320 p.
[8] Ponchek M I, Shilkrot E O Ventilation of premises with air temperature stratification / In
Collected Works: Conf. reports. News of theory and practice of the air diffusion in production and public buildings. – L.: LDNTP, 1988. – P. 42-46.

[9] Titov V P, Sargsyan S V Processes of the air state changes made on the i-d diagram at two-zone model of the ventilated space. – Dep. Vo VNII NTPI No 10910, 18.02.91., 1991, Bibliographical Index of deposed manuscripts, issue.5.

[10] Sargsyan SV, Rymarov A G Materials of International scientific and practical conference “Theoretical bases of heat and gas supply and ventilation”, MGSU, Moscow, 23-25 November 2005, p. 147-149.

[11] Sargsyan S V Methods of determination of the quantity and the characteristics of air diffusers located in the upper zone of the premise when the air is supplied by vertical jets. Scientific and technical revue MGSU Bulletin, Special edition 2/2009, MGSU, Moscow, p. 452-456.

[12] Titov V P, Sargsyan S V Universal two-zone model of a space for calculation of the required air exchange/ in Collected works: Labor protection in industry. Penza, 1991.

[13] Sargsyan S V, Spirin A D Calculation of the air exchange at the laboratory of fire-resistance testing of construction elements and structures by the method of zone balances. Scientific and technical revue MGSU Bulletin, Issue 8/2014, MGSU, Moscow, p.

[14] Sargsyan S V Investigation of the ways to organize the air exchange and air diffusion systems on physical models in the laboratory conditions // Scientific review. – 2015. – No 16. – p. 68-71.

[15] Sargsyan S V Methods of laboratory testing of the procedures of the air exchange organization on physical models // Scientific review. – 2015. – No No 16. – p. 76-79.

[16] Shepelev IA Aerodynamics of air flows in a premise. –M. Stroyizdat. 1978. – 144 p.

[17] Yang, C Ventilation and Air Quality in Indoor Ice Skating Arenas / C Yang, P Demokritou, Q Chen, J Spengler // ASHRAE Transactions. - 2000. - Vol. 106, pt. 2.-Pp. 4405-4414.

[18] Žák A, Sikula O, Trcala M (2013). Analysis of Local Moisture Increase of Timber Constructions on Ice Arena Roof. Advanced Materials Research. 2013. Vol. 649, pp. 291-294.