Optimization of ventilation of an indoor ice rink by numerical simulation of air flows

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Abstract. An important task in the design of objects with artificial ice cover is to provide them with a modern ventilation and air conditioning system, which allows maintaining the parameters of the air environment in the volume of the arena's premises. A properly organized air exchange with an accurately calculated flow rate should ensure stable and comfortable air parameters on the roller for various zones. However, due to the complexity of the picture of thermal, mass transfer and air processes occurring during the operation of the ice arena, standard design techniques often do not allow to obtain the desired result. Therefore, at the present stage, it is extremely urgent to raise the quality of design of these objects, which can be done using the capabilities of the computer 3D-modeling method. At the moment, in the Russian Federation, modeling of air flows in the design of indoor ice platforms is used only in the construction of large facilities of national scale. This work presents a practical study on the possibility of using the method of numerical computer modeling to develop solutions to improve the ventilation systems of an existing facility of regional significance.

1. Introduction

Currently, the Russian Federation, is actively building social and recreational facilities, including indoor ice structures with artificial turf, both according to unique and standard designs.

During the construction of such structures, along with high requirements for architectural and construction solutions and the level of comfort, specific microclimate requirements are imposed, which must be provided by ventilation and air conditioning systems [1-3]. Without compliance with these requirements, the normal functioning of the structure is impossible.

One of the main problems in the design of ventilation and air conditioning systems for ice arenas is the need to maintain different values of the parameters of internal air near the ice surface and in the stands[1-4]. Failure to comply with the requirements for air parameters at the ice surface will lead to uneven thawing of ice, curvature of its surface. In addition, the parameters of the air environment directly affect the emotional and physical condition of spectators and athletes [5-8]. However, often in practice, at facilities constructed in accordance with regulatory requirements, it is still not possible to fully ensure the required air condition. This fact indicates a very difficult task, and the need to find new, more effective methods for designing microclimate support systems for ice facilities.

This conclusion is confirmed by the studies of engineers who, using mathematical modeling methods, performed an analysis of design solutions for air distribution in Olympic venues [9]. The
studies showed that the initial design solutions do not provide the necessary parameters of the air environment near the ice field and require appropriate adjustments. It is extremely difficult to predict the distribution of air temperature in the arena volume in order to take it into account when drawing up the design solution without involving mathematical modeling methods, and for some cases it is impossible [4,10]. The considered problem arises when calculating not only ice arenas, but also any objects that are characterized by a substantially uneven temperature distribution. In such cases, mathematical modeling methods are a necessary tool for analyzing and adjusting inherent design solutions for air distribution.

2. Study description
The problems described above arose during the operation of the Source Ural artificial-fitness complex with artificial ice in Yuzhno-Uralsk, Chelyabinsk Region. The building was designed according to an individual project in 2012, and put into exploitation in 2018 (figure 1).

![Figure 1. The photo of the object of study.](image)

2.1. The main characteristics of the facility:
The area of ice cover: 1800 sq.m. The purpose and mode of operation: year-round training and competitions in the game of hockey, and mass skating of people.

The indoor ice rink accommodates: during the competition, 476 spectators and 50 athletes; during the training period - 50 athletes; in the period of mass skating - 100 people.

2.2. The main problems at the facility:
Immediately after entering the facility in full-scale operation, the following main problems emerged:

1. In space above the ice there is an increased humidity, sometimes turning into a state of fog;
2. There is an accelerated melting of ice;
3. Air distribution devices do not provide uniform distribution of air over the ice.

In order to find ways to solve these problems, a scientific and practical study of the object was carried out.

2.3. Goals and objectives of the study
The purpose of the work is: development of measures providing the best condition of the ice cover and optimal microclimate parameters in various areas of the indoor ice rink, using the capabilities of the method of numerical simulation of processes.

Based on the goal, the following tasks were formulated:

- Study and analysis of domestic and foreign experience in creating indoor ice structures;
- Study of the object of study and analysis of existing design solutions for ventilation;
- Building a numerical 3D computer model of the existing air distribution systems of the ice rink based on project documentation and analysis of the causes of the problems;
2.4. Description of existing ventilation solutions and their analysis

According to the project, 2 systems of mechanical supply and exhaust ventilation with partial air recirculation SEV1 and SEV2 were made to serve the ice arena hall. The SEV1 system is single-zone, it serves only the ice arena zone in the amount of 22,500 m³/h. The SEV2 system is dual-zone, partially serving the ice arena area in the amount of 12,500 m³/h and the stand area in the amount of 9,520 m³/h. The air for supplying to the arena area is heated in central unit to \( t_s = +14^\circ\text{C} \), for heating the supply air provided to the stands to \( t_s = +18^\circ\text{C} \), a zone air heater is installed on the duct branch to this zone. To combat excess moisture, a fully recirculated system with an adsorption dryer DT 7500 Special is provided. The location of the air ducts in these systems in the volume of the ice arena is shown in figure 2. To maintain the required temperature of the ice field, a compression refrigeration unit with a cooling capacity of 448 kW is provided. Estimated air temperatures accepted: in the area near the ice surface \( t_{asf} = +10^\circ\text{C} \); in the working area above the field (at the level of 1.5 m from the ice surface) \( t_{aw} = +14^\circ\text{C} \); in the area of the stands \( t_{ast} = +18^\circ\text{C} \).

In order to analyze the design decisions for compliance with regulatory requirements, a test calculation of the main project indicators was carried out: the required capacity of the chiller, the calculation of the required air exchanges for the ice arena zones in the competition, training and mass skating modes and for the stands in the competition period and the calculation of excess moisture. As a result of the analysis, the following conclusions were obtained:

- The verification calculations showed that the project correctly determined all the thermal and energy indicators for servicing the ice arena zone. Thus, for the maintenance of the facility, a radical reconstruction of the ventilation system with the change of thermal and ventilation equipment is not required.
- The necessary air exchange is provided in the ice arena area, and an insufficient amount of air is supplied to the stands area, therefore it is advisable to provide a separate supply and exhaust unit for servicing the stands area.
- The results of the design decisions verification confirmed the conclusions made during the study of the Sochi ice facilities [9] and were evidence that a more accurate adjustment of the distribution of air and heat flows using the capabilities of the computer simulation method is necessary.

2.5. Peculiarities of the formulation of the problem of mathematical modeling

The use of simplified balance methods, laws of formation of jet flows, etc., for a reliable description of the behavior of air flows in the “bowl” of ice arenas is very difficult, and in most cases practically impossible [11]. This is due to such features as: significant non-isothermal flow in space (both in height and in horizontal sections); interaction of forced air flows (supply jets from nozzles, diffusers) and intense freely convective flows (warm air flows rising from an array of spectators); the need to take into account the radiation component on a significant part of the surfaces involved in heat transfer (ice and roof surfaces). These features lead to the need to use methods of computational fluid dynamics for analysis and subsequent adjustment of design decisions for the air distribution of ice arenas. In other words, methods based on the numerical solution of the system of three-dimensional Navier - Stokes differential equations are required. SolidWorks software package was chosen as a tool for solving these equations.

To build a model of the real distribution of picture flows, the following actions were performed:

1. According to the architectural and construction drawings, a geometric 3D model of the ice rink was created with the image of the existing structures of the ice field, stands and air ducts (figure 2);
2. The boundary conditions were set on the surfaces of the geometric model: temperature, speed, pressure, air direction, as well as the heat flux from heating elements and people; 3. The construction of 2-D diagrams of air velocities and temperatures in various characteristic sections of the room was completed. Visualization of the simulation results of heat and air flows with the existing operation of the building ventilation systems is presented in figures 3-5.

![Figure 2](image2.png)

In this figure, the supply air ducts of the SEV1 and SEV2 systems are shown along the outer walls of the building, the exhaust ducts are shown in the center of the ceiling, the air supply to the stands is shown by the descents.

![Figure 3](image3.png)

From Figure 3 it is seen that a uniform temperature distribution is not provided on the ice surface; a zone of elevated temperature (+12 °C) is formed in the center of the arena and in the zone near the sides there is a risk of condensation, since the temperature there is less than 5 °C.
The diagrams in figure 4 shows that there is an *uneven* distribution of speed in the served area, the presence of stagnant zones over the field, as well as excess speed limits in the stands area (> 0.5 m/s).

This figure shows the presence of *significant stagnant zones* in the center of the rink and at the sides.

### 2.6. Conclusions about the existing ventilation

Based on the results of building a model of the existing ventilation, the following *conclusions* were made:

- The constructed computer model of air flows clearly shows that the cause of violations of the requirements of the air-thermal regime is the incorrect air distribution of flows in the indoor ice rink.
- The reason for the uneven distribution of air flows is the incorrect tracing of the air ducts and the location of the air distributors, which is why the speed of air movement changes stepwise.
- The constructed model of thermal fields shows that the air temperature in the working area and near the ice does not meet the standards and there is a risk of condensation near the sides, amplified by the formation of stagnant zones.
2.7. Description of new design solutions
The analysis of the constructed numerical model of flows showed that it is necessary to provide a more uniform distribution of temperature and air velocity over the room, for which purpose the design of air ducts and air distributors should be changed.

The decisions were to make the following changes in ventilation systems:
1. To supply fresh air to the ice arena area and to the stands area by separate installations, i.e. to use the SEV2 system only for supplying air to the tribune zone, and supply to the field zone only with the SEV1 system and the drainage system;
2. For servicing the ice field zone, in the SEV1 system, to change the air duct routing, interchanging the location of the supply and exhaust branches, and to add additional supply air ducts. Thus, the supply branches should be located in the center (instead of the exhaust), and in the middle between the outer walls and the center of the ceiling (additional branches), and the exhaust ducts should be placed along the outer walls (instead of the supply). Thus, it is possible to concentrate the air supply to the center of the room, squeezing it to the outer walls, according to the scheme recommended by O.Y. Kokorin [4,10].
3. To carefully study the issue of the location and replacement of the supply air distributors with new models - nozzle ALAa 1-20-V from Swegon [12] and changing their number to 45. Convective cold from the ice surface enters the air above the ice field, which must be compensated by warm air so that fog does not form. The air velocity at the ice surface should not be more than 0.25 m/s, the air temperature is 10°C. The temperature difference between the supply air and the air near the ice surface is recommended to be taken no more than \( \Delta t = 8 \div 12 \ ^\circ C \) [3]. Since the height of the ducts is 7 meters, a temperature difference \( \Delta t = 4 \ ^\circ C \) was adopted. When selecting nozzles, special attention was paid to the uniformity of the distribution of the supply air by the nozzles, for which purpose the distribution graphs of the supply jets were shown, in Figure 6.

![Figure 6. Distribution of the supply stream over the surface of artificial ice. View from](image)

![Figure 7. Distribution of the supply stream over the surface of artificial ice. Side view.](image)

2.8. Verification of the effectiveness of the proposed solutions
The effectiveness of the proposed measures was verified by building a new numerical model of air and heat flows. The visualization of the results of constructing this model is presented in figures 7-9.
Figure 8. 2-D diagram of temperature distribution at ice surface level

The diagram in figure 8 shows that a high degree of uniform temperature distribution in the range $+10 \, ^{\circ}\text{C}$ is ensured.

Figure 9. 2-D diagram of velocity distribution at the ice level.

The diagram in figure 9 shows that the requirement of not exceeding the normalized air velocities above the ice field (0.25 m/s) and in the area of the stands (0.3 m/s) is ensured.

3. Findings from the study

The study showed that, the method of computer numerical simulation of heat and air flows, made it possible to prove that after making the proposed changes to the design of existing systems of supply and exhaust ventilation, it is possible to achieve significant improvements in the parameters of the air environment necessary for the comfortable operation of the ice structure. As a result of the proposed changes on the surface of the ice field, a uniform distribution of temperature and velocity fields is ensured, without sharp fluctuations in temperature and stagnant zones. The required microclimate parameters are provided in various technological zones: in the working area of the ice field, the temperature is maintained at $t_{\text{w}} = +10 \pm 14^{\circ}\text{C}$, and the temperature near the ice surface $- t_{\text{s}} = +10^{\circ}\text{C}$. The temperature in the area of the stands is maintained at $t_{\text{st}} = +18 \pm 21^{\circ}\text{C}$. Also, the required air mobility of 0.25 m/s is provided in the working area.
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