Air distribution in indoor ice skating rinks

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Designing of indoor ice arenas ventilation and air conditioning systems is considered to be a rather complicated issue due to the necessity to maintain considerably varying air parameters in the zone of ice rink and in spectators' zone. Conventional and simplified engineering techniques normally fail to yield adequate values.

Keywords: Indoor ice rinks, CFD, numerical simulation, air distribution, convective-radiative heat exchange.

Designing ice rinks

Heating, ventilating, and air conditioning (HVAC) are among the most energy consumption systems in civil engineering.

Due to the increased need to control the consumption of energy resources reduce negative impacts on the environment, at present, particular attention has been paid to designing "green buildings". HVAC systems are extremely necessary, not only to reduce electricity consumption, but also to make sure that the designed systems, in practice, are able to provide a comfortable environment for human and/or technological requirements for the project, otherwise, we cannot speak about the efficient use of energy resources. Thus, if we develop energy efficient buildings, it is necessary first to analyse the adequacy and quality of engineering solutions which are incorporated in the design.

Modern sports facilities using artificial ice rinks are the structures with very sophisticated technical and high-power consuming engineering solutions. Designation of refrigeration, ventilation and air conditioning systems consist of maintaining the required temperature level of ice rink as well as air temperature and humidity within the space of ice arena bowl. One of the basic designing problems of the ice arena air distribution and conditioning system is the need to maintain different parameters of air in the zone of ice rink (defined by ice surface requirements) and parameters of air in spectators' area.

Tribunes full of spectators generate free-convective warm air flows which could be strong enough to determine air circulation pattern throughout the entire arena bowl space. This creates a hazard of warm and moist air transition towards ice rink space which is inadmissible (ice melting may cause ice surface warping and fog generation above the rink surface).

The design of ice arena air distribution system should take into account interaction of air flows generated by supply air devices and convective air flows generated by spectators. Taking into consideration a very complex character of air flow generated in arena space, to select zones of influence and behaviour of the above-mentioned flows is becoming rather difficult. Besides, the presence of artificial ice lead to necessity take into account the radial component on a considerable part of surfaces participating in heat exchange process (ice, roofing, walls surfaces).

In such case, the designer may encounter deficit of information and techniques enabling him to find proper technical solutions while simplified engineering techniques are no longer yielding adequate values. As a result, it appears that requirements to ice arena air parameters are generally considered in design calculations but not in actual conditions of facilities operation.

The foregoing features generate a need to make use of computational fluid dynamics (CFD) methods based on numerical solution of differential conservation equations, namely, three-dimensional Navier-Stokes equations.

At the same time, numerical simulation of air distribution in indoor ice rinks is an uncommon task demanding in-depth analysis of mathematic model used.

Setting the mathematic model demands consideration of a number of specific features, like assignment of boundary conditions characterizing heat gains by arena bowl and necessity to consider radiative heat exchange.

Below there is a simulation of air flow behaviour formed in the volume of Sochi "Iceberg Arena" (erected for 2014 Olympic Games) by the designed air distribution systems.

The CFD software STAR-CCM+ based on numerical solution of tri-dimensional differential conservation equations has been selected as a research tool.

Radiative heat exchange in indoor ice rink

Radiative component of heat exchange in roofed buildings with artificial ice is a considerable factor. This is due to intermitting radiation in "ice-roof-walls" system. It is necessary to bear in mind that, not only interior surfaces of arena structures may be the source of radiation, but spectators as well. The latter factor should be taken into account in mathematic model.

Assignment of heat generated from spectators.

Correlation between spectators' sensible heat input radiant and convective components within ambient temperature range from 10°C to 26°C is approximately 50% by 50%. Assuming that sensible heat is transferred from spectators to the premise only with convective constituent is leading to overestimation of velocities in free-convective flow above spectators and, as a result, to improper air circulation in the entire volume of arena.

Separate accounting of short-wave and long-wave components outgoing from lighting fixtures.

To illuminate the ice rinks the ice arenas normally employ illumination devices providing angular concentration of light by means of lamps light redistribution inside small solid angles achieved by the use of illumination fixtures reflectors and lenses. Different types of illumination devices are used: based on incandescent lamps (halogen), gas-discharge lamps (metal-halogen lamps, sodium vapour lamp), light diode lamps.

Figure 1. "Iceberg Arena". Sochi. Russia.

Radiation of illumination fixtures, unlike human's radiation, is taking place within visible (λ=380 – 780 nm) and short-wave constituent of infrared (λ = 0.74 – 2.5 µm) radiation range and not within long-wave infrared range (λ = 50 – 2000 µm).

In the mathematical model, it is required to make separate account for narrow-directional high-frequency radiation of lighting fixture (directed to ice surface) and omnidirectional low-frequency radiation emitted by lighting fixtures heated surfaces (including fixtures casings).

Light output value, specified in product documentation, does not contain data regarding amount of power falling on illuminated surface outside the visible range. However, considerable part of illumination fixture radiation power pertains to high-frequency infrared radiation.

While numerical simulation of flow in ice arena bowls it is required to exactly know total amount of energy falling onto illuminated surface.

Illumination fixture surface will emit (by convection and radiation of infrared range low-frequency part) heat. The higher the air velocity is in the zone of illumination fixture installed in the ice rink, the more heat will be withdrawn by convection towards the upper area of premise volume.

Task definition. Object characteristic

"Iceberg" ice arena capacity is 12.000 spectators.

- In order to maintain design requirements regarding thermal and humidity air parameters in "Iceberg Arena" air supply is foreseen:
- via circumferentially located jet nozzle diffusers located 22 meters above the ice rink;
- via swirl diffusers circumferentially located by arena perimeter at 27.8 meters height (first circle);
- via supply grills located by arena perimeter at 12.2 meters height (second circle);
- via grills made in building structures and located under spectators' seats located by arena perimeter (air supply towards under-tribune space) at heights 0.65 – 3.80 m (third circle);

Air is extracted via grilles circumferentially located 32 m above the ice rink with flow rate L_{total} = 48 000 m^3/h and via grilles located by arena perimeter above spectator seat rows at height 25.4 m with L_{total} = 450 000 m^3/h.

Location of air distribution devices is shown in **Figure 2**.

Parameters of ice arena supply air are listed in **Table 1**.

Table 1. Supply air parameters.

Description	q_{total} [m^3/s]	T [°C]	x [g/kg]
Nozzles directed toward ice rink	42 700	18	4
Diffusers (first circle)	82 200	16	4
Grilles (second circle)	283 300	16	4
Grilles (third circle)	19 200	16	4
Grilles in tribunes (third circle)	65 300	18	4

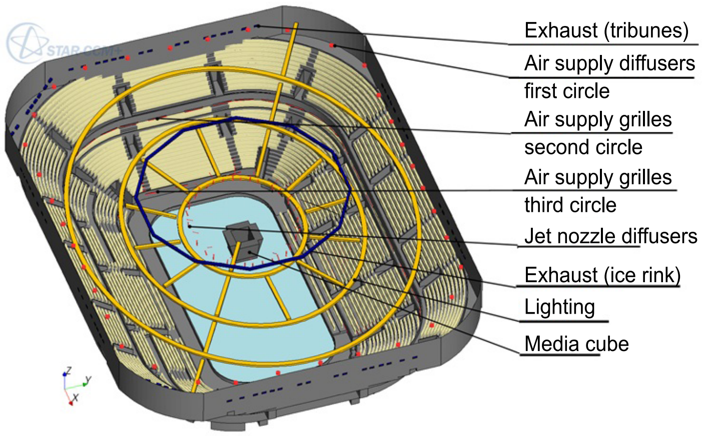

Figure 2. Equipment location.

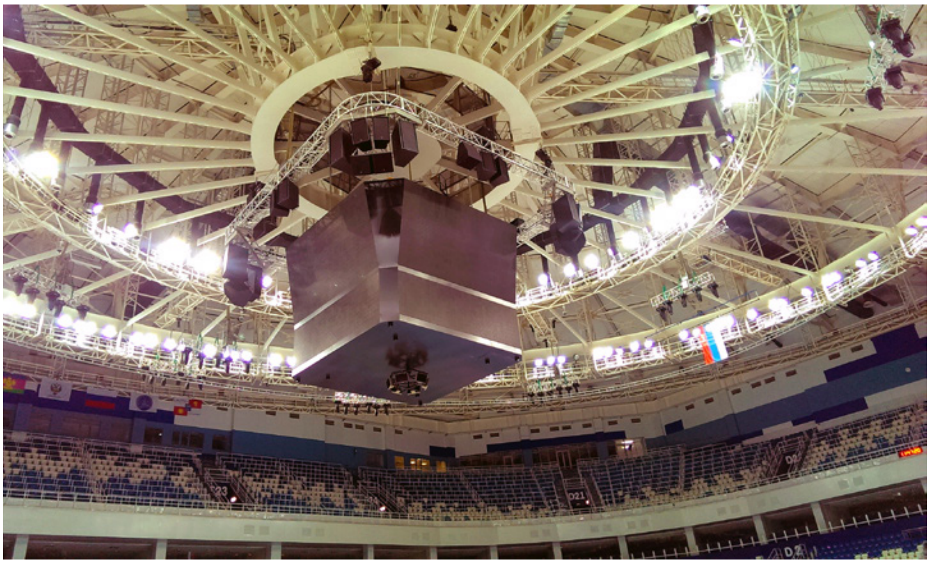

Figure 3. "Iceberg Arena". Sochi. Russia.

For the simulation purpose, we built-up a finite volume computation mesh consists of 14 million cells. Specific attention was paid to mesh resolution in zone of flows delivered via nozzles and diffusers and to computation mesh quality near ice and roofing surfaces.

Simulation results

Simulation results show that originally designed delivery of 18°C air towards ice rink creates excessive air motion in the zone of ice surface disturbing the "cold bedding" which should be provided above ice surface (Figure 4a) and, thus, preventing formation of

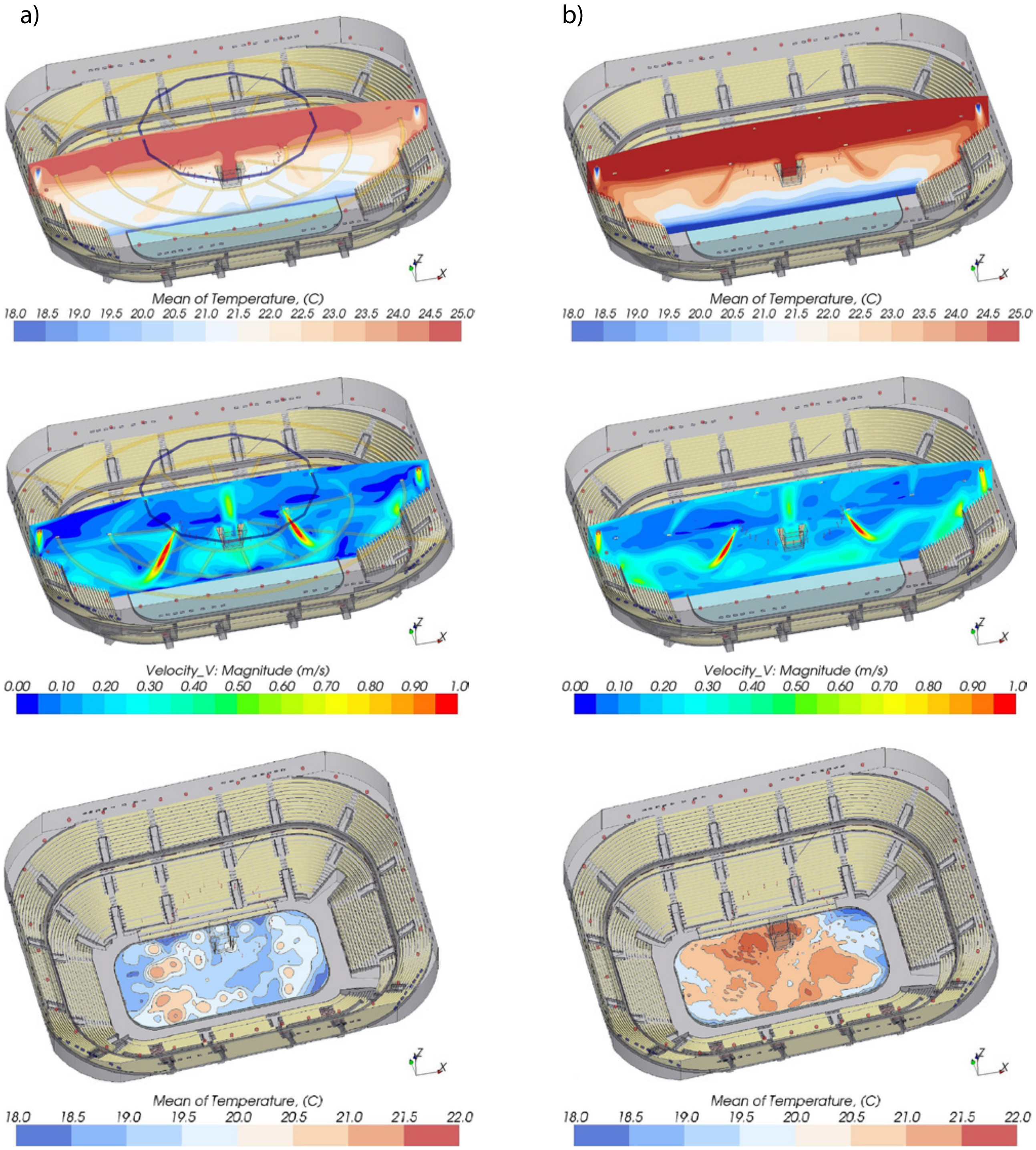

Figure 4. Temperature and velocity field: a) Original design, b) Improved design.

design-required air parameters above the ice surface. In flow distribution areas at 1 meter above the ice surface it is possible to view areas with excessive (up to 21°C) temperatures (**Figure 4a**).

Error in the design solution under consideration took place due to omission of the fact that ice arenas have considerable non-isothermally of air throughout the premise height. Thus, air temperature near ice surface is normally within 12°C – 15°C (depending on the sport event) and it may reach 24°C – 26°C as measured in the top part of the premise. In view of the above, we can conclude that 18°C air delivered via air jet nozzles can be treated as "cold" (being accelerated relatively to isothermal flow), while approaching the ice surface it may be treated as "warm" (it begins to come up). That complicated behaviour of inflow is not correctly described by equipment selection program which takes into account nozzles output temperature and air temperature in the proximity to ice surface. In such case long-range capability of supply air is considered to be much lower than it is in reality. The latter reason caused, as verified by numerical simulation results, ingress of warm air (drawn-up by supply air) to ice rink zone and, as a result, considerable increase of air temperature in the said area.

To improve the design solution, it was proposed to increase supply air nozzles temperature from 18°C to 23°C.

Calculations results show that in the latter case flows delivered by the nozzles are not reaching the ice rink surface and the "cold bedding" is no longer disturbed (**Figure 4b**). Temperature 1 meter above the ice surface is falling from 20°C to 15°C (**Figure 4b**).

Improvement of design decision enabled the operators to avoid (during further exploitation of arena) ice melting, ice surface warping and fog generation above the ice surface.

Physical experiment

Physical experiment was performed in "Iceberg Arena" bowl without spectators and players, with ventilation and air conditioning systems operating and illumination system operating. Measurements were performed for a series of points located in different levels throughout arena height. Correlation of results of physical and numerical experiment performed for identical boundary conditions is shown in **Figure 6.**

As seen from above figures, data variation in physical and numerical experiments in temperature fields amounts to less than 5% and less than 10% in moisture content fields. Accuracy of ventilation and air conditioning system flow rates adjustment is normally around 10%, therefore, there is no need to obtain more accurate calculations since accuracy of boundary conditions assignment is approximately 10%. Therefore, accuracy of mathematic model is sufficient for analysis of ice arenas air distribution designs.

Conclusion

Radiative component of heat exchange in indoor ice rink is considerable and it should be taken into account in the mathematic model.

Figure 5. "Iceberg Arena". Sochi. Russia. Physical experiment.

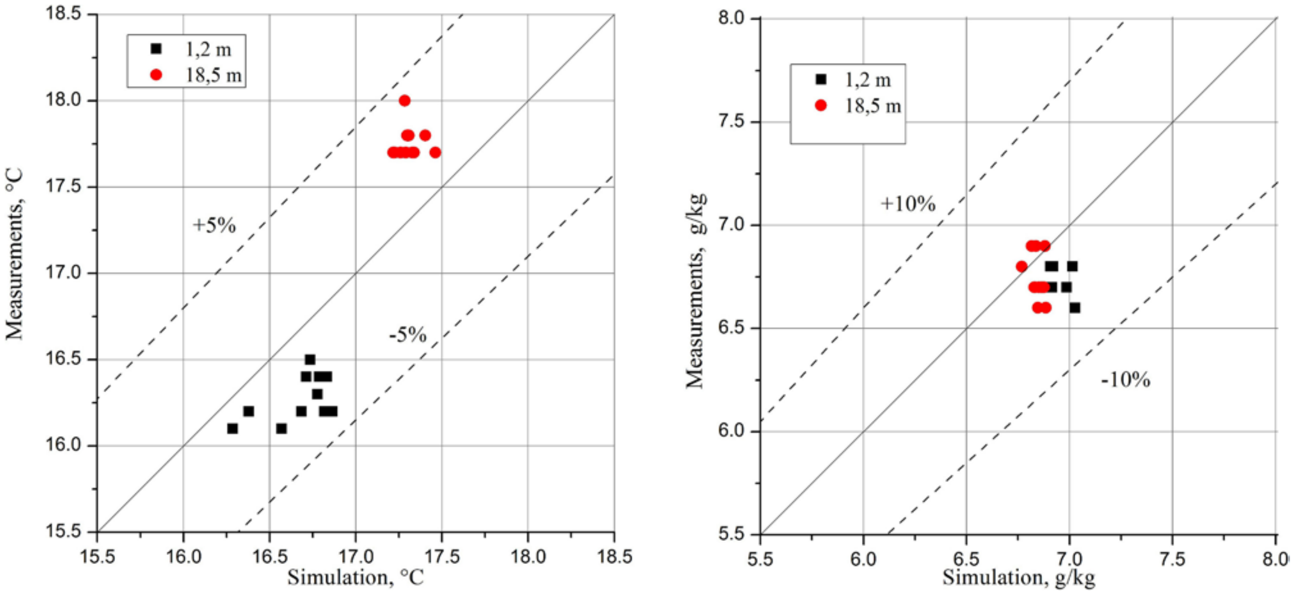

Figure 6. Correlation of numerical simulation and physical experiment results.

Assignment of sensible heat inputs outgoing from spectators only via convective component may lead (due to considerable increased values of free-convective flow velocities) to improper air circulation in the entire volume of ice arena bowl.

Heat flows from heated surfaces of illumination fixtures should be modelled with account to separation into radiative and convective components.

Applying of numerical simulation methods to analyse air distribution in Sochi "Iceberg Arena" enabled the researchers to reveal defects of original design and, therefore, prevented the implementation in the design of an ineffective solution.

Correlation of results of numerical simulation (performed with no spectators inside arena) with physical experiments results gave 4% – 7% calculation mismatch. ■

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