The Design Challenges of Multipurpose Arenas

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SUMMARY

The design of the HVAC and ice rink refrigeration system in an arena is a challenging optimisation task. To ensure that the requirements for the indoor conditions and the ice temperature will be fulfilled, the HVAC and the ice rink systems have to be optimised with the interactivity of each other in mind. This challenging optimisation task is solved with advanced and effective multiphysics and CFD simulation tools. The heat and moisture balance of the arena is solved dynamically with multiphysics tool with 3D simulation of ice rink heat balance. CFD (Computational Fluid Dynamics) is used to support the design of air distribution and indoor thermal conditions. These calculations form the bases for the MEP design solutions where integration of heating, cooling, dehumidification, energy conservation and the use of outside energy resources are optimised to achieve the most economical investment.

INTRODUCTION

Most multipurpose arenas that exist today are usually used for skating in some form, for sport activities or for recreational and leisure purposes. The design of the HVAC and ice rink refrigeration system in an arena is a challenging optimisation task. Ice rink facilities share all the same concerns: energy usage, operation costs and indoor climate. Multipurpose arena design and operation are totally unique and differ in many ways from standard buildings. Each arena should be taken as an individual project. The design solution which functions greatly in the last built arena may not be the ideal solution for another new arena under construction. The project specific requirements for the indoor conditions and ice temperature during events as well as usage of the arena form the boundary conditions for the design project.

The most important to know about multipurpose arenas are to understand their features compared to other kind of buildings. These special features are due to /1/:

- Indoor conditions vary a lot depending on the usage of the arena. In an ice rink high inside temperature differences occur in the same indoor climate, from -4°C to +24°C. At the same time these internal climate zones must be controlled and stay stable. In concert situation there exists also large heat loads from equipment which should also be handled.
- Differences in indoor climate also cause humidity problems that must be under control.
- Air tightness is more important feature of the building envelope than thermal insulation.

The aim of this paper is to present HVAC and ice rink design solutions of the multipurpose arenas. The requirements for indoor conditions, in heat and moisture balance of the arena and ice rinks, CFD simulations and some guidance of HVAC design are presented.

REQUIREMENTS FOR INDOOR CONDITIONS AND ICE TEMPERATURE

The requirements for the indoor conditions and the ice temperature set a basis for design calculations of the HVAC and ice rink piping system in Multipurpose Arenas.
Indoor air design values for multipurpose arenas are presented in Table 1.

Table 1. Indoor air design values for multipurpose arenas /1,2/.

Action	Air temperature		Ice temperature	Max. relative humidity	Heat loads		Min. fresh air intake
	Rink at 1.5 m	Tribune (operative)			Lighting	People	
Hockey	[°C]	[°C]	[°C]	[%]	[W/m]		[dm³/s/ occupant]
- game	+6	+10…+15	-5	70	40	80/spectactor	4…8/spectator
-training	+6	+6…+15	-3	70	20	125/player	12/player
Figure							
-competition	+12	+10…+15	-4	70	40	80/spectactor	4…8/spectator
- training	+6	+6…+15	-3	70	20	125/player	12/skater
Other	+18	+18	-	-	20	80 W/person	8/person

The most of the Arenas are scheduled for an all-year round use with a short break during peak summer conditions. This all-year round use imposes challenges in the design work because of increasing outdoor heat and humidity loads.

In practise, the indoor temperature varies between 10-12 °C above the ice during practice session, to 12-14 °C during competition races. The relative humidity ranges between 40-65% all year around. The temperature in the spectator areas is expected to be slightly higher than above the ice, 14-15°C. The ice surface temperature is in the range of -3..-10 °C. In some cases the ice temperature is wanted to keep much lower than presented in Table 1. It is quite normal that the ice rink is dimensioned at -6°C. The air flow velocity above the ice should not exceed 0.25 m/s.

HEAT AND MOISTURE BALANCE OF THE ARENA AND ICE RINK

Quite often the ice rink piping is built “as the previous ice rink” without thoughtful analyses of the different factors that affects the ice temperature in the arena in question. To ensure that the requirements for the indoor conditions and the ice temperature will be fulfilled the HVAC and the ice rink systems have to be optimised with the interactivity of each other in mind. This challenging optimisation task can be solved with advanced and effective energy simulation, multiphysics and CFD simulation tools.

To establish the expected indoor conditions it is essential that the cold load to the space from the ice surface is taken into account. Vice versa, the ice rink cooling capacity is not possible to be calculated without taking into the account the different heat loads and the indoor conditions, its temperature and humidity. To figure out the complexity of the design work, Figure 1 shows the interactions between different factors.

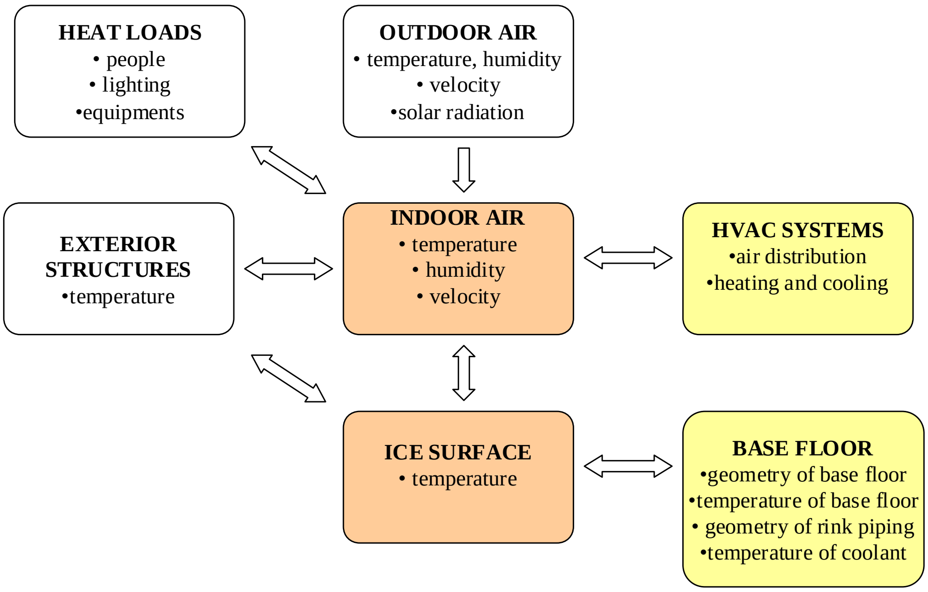

Figure 1. Interactions between different factors in Arena.

As we can see from the figure 1 there are plenty of factors that affect the indoor conditions. These are heat loads from the spectators and competitors, lighting and equipment, infiltrated and conducted outdoor heat loads, the supply air, additional heating load and the cooling load from the ice surface trough conduction and condensation. The people supply air and condensation rate to the ice surface and outdoor infiltration affects in addition the humidity of the indoor air. The moisture from the air condenses on the ice surface and has therefore a drying effect on the indoor air humidity.

Heat balance of the arena is presented in Eq.1.

$$\rho c_p V \frac{\partial T}{\partial t} = Q_{people}(t) + Q_{ligh}(t) + Q_{eq}(t) + Q_{AC}(t) + Q_{\inf}(t) + Q_{str}(t) + Q_{ice}(t)\,, \qquad (1)$$

where ρ is the density of the air, c_p heat capacity of the air, V is the volume of the Arena, T is the temperature of the air, t is calculation time and Q is the heat load. The subscript *ligh* denotes lighting, *eq* denotes equipment, *AC* denotes air conditioning, *inf* denotes infiltration and *str* denotes structures.

Equation 2 presents moisture balance of the arena.

$$\rho V \frac{\partial x}{\partial t} = \dot{X}_{AC}(t) + \dot{X}_{aircirc}(t) + \dot{X}_{\inf}(t) + \dot{X}_{people}(t) + \dot{X}_{ice}(t) + \dot{X}_{other}(t)\,, \qquad (2)$$

where x is the absolute humidity of the air and $\dot{X}$ moisture content. The subscript *aircirc* denotes circulated air.

The indoor conditions and the heat loads from people, lighting, equipment and building structures as well as the ground floor structure with ice rink piping have a strong effect on the ice surface temperature. In general, the final heat load to the ice surface varies between 155 to

320 W/m² depending on the activity and outdoor conditions. In practise the heat load to the ice is reasonable to keep under 220 W/m². Otherwise, the coolant inlet temperature to the ice rink piping has to be diminished radically down to -18°C to maintain the ice temperature at -6°C. In that case the energy economy of the refrigeration production will deteriorate substantially.

Figure 2 a) presents typical ice rink slab. The heat equation for the ground ice rink slab with boundary conditions for the ice surface, piping and ground are shown in Equations (3)-(6).

$$\rho_m c_{p,m} \frac{\partial T_m}{\partial t} = k_m \nabla^2 T_m \tag{3}$$

$$k_m \frac{\partial T_m}{\partial y}(y = h) = Q_{conv,a} + Q_{rad} + Q_{cond} \tag{4}$$

$$k_m \left(\frac{\partial T_m}{\partial y} + \frac{\partial T_m}{\partial y}\right) = Q_{conv,ht} \tag{5}$$

$$k_m \frac{\partial T}{\partial y}(y = 0) = Q_{ground} \tag{6}$$

where k is the heat conductivity and h is the height of the slab. Subscript m denotes material in the ground slab, a denotes air, *conv* denotes convection, *rad* radiation, *cond* condensation and *ht* heat transfer medium.

In Equation (4) the heat loads are the following:

- Convective load from the ambient air. The convective load depends on the temperature difference between the air and the ice and the heat transfer coefficient of the ice surface.
- Radiant load from the lighting and structures. The ice surface absorbs heat from the surrounding floors, walls, ceiling and lighting.
- Moisture load, condensation from the ambient air. The moisture load is proportional to the convective load and the ratio increases with increasing humidity in the air.

Additional loads, which influence on the ice rink cooling needs are the coolant circulation pumps, slab cooling during ice making, resurfacing and ice building during maintenance intervals and ice building.

To achieve indoor conditions and ice rink slab temperature distribution, the equations (1)-(6) are solved with multiphysics simulation software. In Figure 2 b) show an example of the temperature distribution of the ice rink slab. The geometry of the rink piping and the coolant inlet and outlet temperatures are essential in maintaining the ice surface at a required temperature level.

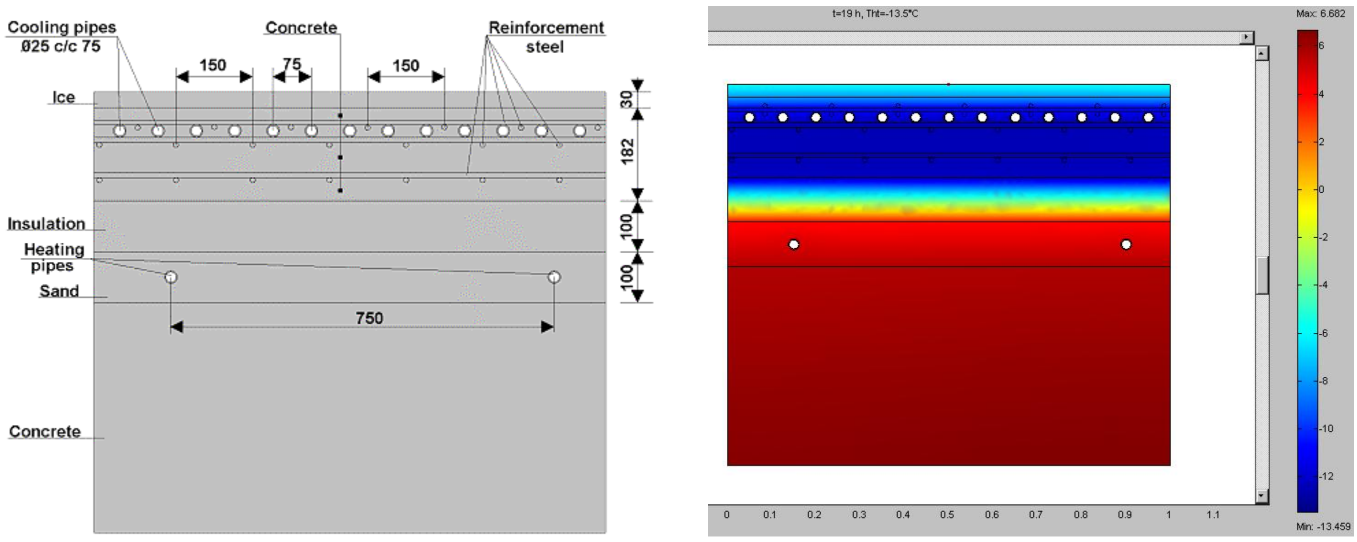

Figure 2. a) The ground floor with ice rink piping system, b) Example of the temperature distribution of the ice rink slab.

INDOOR AIR SIMULATIONS IN MULTIPURPOSE ARENAS

CFD is typically used to study indoor air conditions in spaces where design requirements are high and detailed information on flow field is important. CFD is a numerical calculation method and the realistic modelling of a indoor air environment is not an easy task. Supply air jets, forced and natural convection, and heat sources and sinks cause very complicated 3D flow field. At first, the important properties affecting flow phenomena have to be identified. Then the mathematical model is created and the space is divided into small control volumes. The conservation equations of mass, momentum, and energy are discretized and solved approximately using a numerical method. The accuracy of this calculation depends on the mathematical model, the numerical method, the calculation mesh, assumptions, initial values and iteration convergence. The typical focus is to compare different supply air distribution systems and wall constructions, and heat sources, which affect the indoor air environment. In addition, the results can be used to illustrate HVAC solutions to customers.

The first round of simulations involves individual air supply devices to test and compare operating conditions. The results allow the design team to choose the appropriate devices for each specific location. The device simulation results are compared to air jet theory and to the manufacturer's profile data and measurements if possible. The simulated supply air jet profiles are then used as boundary conditions in whole arena simulations. The device models and simulation results are then saved to an object library for future projects.

The challenge is to design the supply air distribution so that fresh air flows to fully occupied zones and improves the thermal conditions. Draft, humidity, and temperature levels during different types of events in winter and summer conditions are considered. The benefits of the simulations are that they provide the possibility to try out different air flow device types or supply air systems, such as mixing, displacement, or a combination of both. Usually, first assumptions have to be corrected several times before the target is reached. It seems like a correctly performed CFD simulation is the only calculation method that can capture the indoor air flow field with the accuracy necessary for design purposes. In figure 3 is shown the simulated temperature distribution in arena during the ice hockey and concert events on summer time design day conditions.

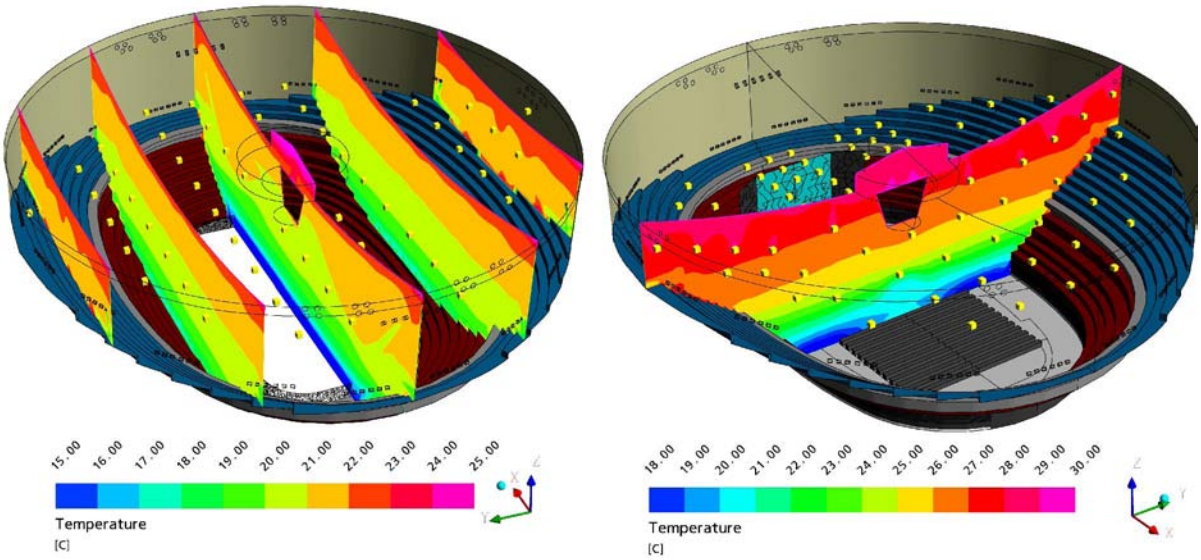

Figure 3. Temperature stratification of the Hodynka Arena in Moscow. On the left-hand side the ice hockey event and on the right-hand side the concert event.

The most challenging aspect in CFD simulations is how to have a realistic simulation results for design purposes. The conclusions should be made with care and compare different models and assumptions with experiments before the realistic results can be reached.

THE HVAC DESIGN

To maintain optimum indoor conditions all year around is a challenging task for the HVAC designer. The usage based on event varies greatly from maximum spectators to home team practice sessions. Then we have a very big open space where the occupied zone is in focus with special consideration to the ice area where a low temperature is a bonus but no condensation or fog build up is appreciated. It is obvious that for the base events such as ice-hockey, concert, small scale PR, ice-hockey practice, maintenance (empty) have to be calculated at winter and summer conditions in order to find out the design air flows and capacities for the these different functions of the air-conditioning units. It is sometimes useful to check with autumn conditions to see if the moisture balance can be obtained. The indoor condition calculations and CFD simulations set basis for HVAC design.

The moisture balance within the design set-points is as important as the temperature balance. The impact of the ice surface is essential to take into account. In cold to moderate climates the maximum air flows obtained for temperature balance are usually sufficient for moisture control. Quite often the spring conditions with ice-hockey game with maximum ventilation air demand and maximum indoor loads gives the design load for cooling. The same is for winter conditions with an empty hall, where optimum indoor conditions are maintained, gives the peak load for heating and autumn for dehumidification. If the skating activity is an yearly activity dehumidification during the summer period has to be calculated as well.

In the arena a heating demand exists as long as we have an ice surface, even during summer period.

Since the arena space itself has usually no outside walls, the only outside surface is the roof. The heat load from sun radiation to the arena is partly connective and partly radiation. The connective heat transmission has a small impact on loads, where as the radiation to the surfaces below are contributing to the total load which has to added to the total load. For some time low emissivity surface materials have been developed to diminish this factor.

The air distribution is one of the most interesting challenges in the design process. There are several parameters to consider in finding the most optimal solution. We want to achieve as low ice surface velocity as possible to keep the connective heat flow to the ice surface at a minimum level. In the spectator area with full seating we have a natural connective vertical thermal flow which will be very decisive for the arena flow pattern. This will create a high degree of stratification which with a displacement supply air distribution is an aim we want to achieve. At the same time a small vertical stratification is also desired to minimise the heating capacity demand and to avoid condensation on envelope structures during small load events such as practice sessions or maintenance periods.

There are very few options to show with design calculations how a solution will work, except with CFD modelling tools. It also gives a chance to test several air flow patterns. The air distribution solution has to selected in detail with the selection of each supply and exhaust air device. Only then is it possibly to find the optimum air distribution in the arena with a CFD simulations method.

It seems reasonable to apply several supply air methods in order to optimise the indoor climate and energy usage. During maintenance or practice periods the solution with vertical induction jets outside the ice surface in a circular pattern seems to have the best possible mixing with the space itself giving a small temperature gradient. At the same time it is possible to avoid the thermal influence of heating or dehumidification during spring and summer conditions. During events with spectators displacement ventilation around the ice rink in combination of active displacement diffuser in the perimeter of the upper spectator area seems to give the best end result.

To maintain a good indoor climate and achieve a low energy usage an advanced control strategy has to be adopted. To keep even indoor conditions at a variety of internal load situations the temperature, relative humidity and CO2 is monitored at several locations in the arena space. Usually CO2 is chosen since it is easily measured and has a rather good correlation with indoor air quality and many standards gives also level limits.
From the event calculations pre-programmed event control strategies can easily be determined.

Even if fire protections is outside the focus of this paper it is on important parameter to consider. The air-conditioning solution at best supports the fire protection solution giving small or no additional HVAC installations.

DISCUSSION

HVAC and ice rink design of the multipurpose arena is challenging optimisation task. The indoor conditions vary a lot according to usage of the hall. Different factors influences indoor conditions. To meet the requirements of energy efficiency and good indoor conditions the influences of the heat loads, ice surface, HVAC system and structures have to take into consideration. The utilisation of the advanced simulation and modelling methods together with multiphysic and CFD calculation tools ensure good background for HVAC and ice rink design.

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