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Experimental study and numerical prediction of thermal and humidity conditions in the ventilated ice rink arena

Agnieszka Palmowska*, Barbara Lipska

Department of Heating, Ventilation and Dust Removal Technology, Silesian University of Technology, Konarskiego 20, 44-100, Gliwice, Poland

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A B S T R A C T

An ice rink arena is a place where the ventilation system has to deal with the presence of spectators and skaters (who have different requirements), and with the temperature of the ice surface below 0 °C. An important problem that arises is excess moisture, leading to condensation of water vapour onto the ice surface and inner surface of the ceiling. The aim of this presented paper was to experimentally identify physical phenomena occurring in the actual ventilated ice rink arena in Gliwice (Poland) and to check whether the developed numerical model correctly reproduces such phenomena and how it should be improved for this purpose. Long-term and short-term experimental research was carried out to obtain data for boundary conditions, to identify changes in thermal and humidity conditions and for experimental validation of simulation results. Air parameters: speed, velocity, temperature and relative humidity were measured. Thermal imaging measurements were also carried out. The numerical model was prepared by means of the Ansys CFX 14.5. Improvement of the moisture flux numerical modelling was carried out. The scope of validation encompassed the comparison of indoor airflow pattern, air parameters (above the ice surface and on the outskirts of the ice rink) and temperature of the ceiling. The numerical model was able to map real conditions in the object with good agreement between measured and predicted values. The mean deviations for all studied cases did not exceed values of 0.03 m/s for speed, 1.1 °C for temperature and 15% for relative humidity of the indoor air.

1. Introduction

An ice rink arena is a ventilated large-volume building, used for sports and recreational activities. Ice rink design and operation are totally unique and differ in many ways from standard buildings [1]. Therefore, the proper operation of a ventilation system with adequate conditions for users, along with the maintenance of good technical condition of the facility is required. It means that the conditions need to meet the ventilation requirements for people inside the building, and that the building is safe for the people within. However, there are no fixed standards and guidelines exist for the design of ventilation systems in ice rink arenas, especially in terms of air distribution systems, so therefore there is a great need for further research.

An ice rink arena is a facility where ventilation system has to deal with an ice surface temperature of below 0 °C and the presence of people, both spectators and skaters, whose requirements are different (from the point of view of thermal comfort). Ventilation must meet the requirements of both parties. However, thermal comfort conditions were not analyzed in this paper. An important problem that occurs in such objects is the risk of exceeding the permissible moisture level in the indoor air, leading to condensation of water vapour contained in the air onto the wall surfaces and formation of fog above the ice surface.

Therefore, the ventilation system in an ice rink arena should fulfil the following functions:

- Maintaining adequate thermal and humidity conditions for users of the ice rink arena, which is the function of ventilation or air heating,
- Removing excess moisture above the ice surface, which is the function of dehumidification [2],

A detailed description of the air parameter requirements was discussed by Palmowska and Lipska [3].

Due to geometry and complex flow phenomenon, it is difficult to

* Corresponding author. Politechnika Śląska, Katedra Ogrzewnictwa, Wentylacji i Techniki Odpylania, ul. Konarskiego 20, 44-100, Gliwice, Poland.
E-mail address: agnieszka.m.palmowska@gmail.com (A. Palmowska).

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predict the effects of the ventilation system by using traditional engineering methods. Therefore, a CFD technique is used for scientific research in this field. This method, based on the basic equations of fluid flow and heat, can be used for researching the flow of air, heat, moisture and contaminants in such facilities. The CFD allows us to check and test different design solutions [4], which is an advantage over a physical experiment. Furthermore, it can be used to improve thermal and humidity conditions in the ventilated facilities [5].

As a rule, the CFD does not replace the measurements completely, but the amount of experimentation and the overall cost can be significantly reduced. Moreover, it enables an assessment of ventilation work effectiveness, as early as at the design stage. Last but not least, the CFD modelling is a useful tool for the optimization of ventilation systems from the viewpoint of fulfiling the users' requirements. It should be noted that the CFD modelling can be burdened with errors, thus it must be validated experimentally before starting appropriate tests with its use [6]. Nowadays, the design of sports arenas is not complete without one or more simulations of the indoor air flow. Analyses of this type are used to determine the best air conditioning systems and ensure that the occupants are exposed to a predefined thermal comfort range most or all of the time [7].

So far, ventilation issues in ice rinks are relatively unknown and poorly supported by research. In literature only a few numerical studies underpinned by the experiment can be found: the Gjøvik Olympic Cavern Hall (Norway) [8], the ice rink arena in Greater Boston (USA) [9,10], and the ice rink arena in Montreal (Canada) [11,12]. The results of numerical calculations of these objects were validated by comparison with the results of the measurements. The research carried out for the facility in Gjøvik is the first experimental identification of conditions in a ventilated ice rink and its numerical modelling to be documented in literature. The distributions of temperature and air velocity were compared. In simulations, thermal radiation with the use of Discrete Transfer Model (*DTM*) was taken into account. Air temperature and velocity distributions were also compared for the ice rink arena in Greater Boston. Additionally, CFD technique was used to validate the spread of contaminants such as PFT and CO [10]. In the object arena in Montreal calculations results were compared with measured air velocity in the real object and with the use of its physical model. The impact of different emissivity of the ceiling on the air parameters and the ceiling's temperature was additionally studied [12].

It should be noted that the scope of all published studies encompassed just temperature and velocity distribution of air, and spread of contaminants in such objects. None of these studies took into account the modelling of moisture flow in the whole building, except an attempt of humidity modelling by Daoud et al. [13] in the ice rink arena in Montreal. Ventilation air was the only source of moisture considered in such a simulation. A humidity transport model, programmed using MATLAB, returned the heat transfer due to condensation on ice as a heat gain to the ice surface in the energy model. Results of calculations, in terms of humidity, were not validated due to the lack of experimental data in this field.

In the indoor ice rink thermal imaging measurements allow detection of moisture on the surface of building partitions as in the cases of residential buildings or industrial facilities. The use of infrared thermography for building diagnostics was discussed by Balaras and Argiriou [14]. The main advantage of this method is possibility to perform non-destructive tests. Nevertheless, the infrared thermography is not free from errors (surface emissivity, camera calibration, etc.). The use of thermal imaging measurements in experimental studies to validate the results of numerical calculations for ice rinks has not been yet published in literature, as well as in research in the field of ice rink ventilation.

In literature only numerical results of tests (without experimental validation) for objects Hodynka Arena, Tsherepovets Arena (Russia) [7] and the designed ice rink in Wadowice (Poland) [2,15,16], as well as only experimental studies for ice rinks located in Honk Kong [17] and Taipei (China) [18], also can be found. For example, in Ref. [7] the CFD method was used to better understand the interior conditions and flow behavior for a range of usage scenarios. The goal of these simulations was to determine how well the planned ventilation systems work to meet the desired indoor conditions [7].

The aim of the presented research was (1) to experimentally identify characteristics of physical phenomena occurring in the actual ventilated ice rink arena and (2) to check whether CFD prediction by a developed numerical model supported by experiment reproduces correctly such phenomena and (3) how it should be improved for this purpose.

2. Experiment

2.1. Tested object and the phenomena taking place

The facility used for the test was the indoor ice rink “Tafla” in Gliwice (Poland) with external dimensions: length 66 m, width 37 m and a maximum height of 11 m. Inside the building there is an ice rink with the dimensions 30×60 m (Fig. 1). The use of the hall as an ice rink is expected in the period of time from October to May for different kinds of sports and recreational activities, including curling.

Inside the building thermal and humidity conditions are maintained by mechanical mixing ventilation with an integrated air distribution system. A detailed description of the air distribution systems used in ice rink arenas was discussed by Stobiecka et al. [15]. It is carried out by side air supply with the use of long-throw jet nozzles and air exhaust under the ceiling by rectangular exhaust grilles. Because of economical reasons, the designed indoor air temperature amounts to $+5$ °C and air dehumidification is not anticipated. The air handling unit, located on the roof of the technology building, is designed for 2 fan speeds: higher (second, II), when outdoor air temperature, t_e, is over $+5$ °C and lower (first, I), when outdoor air temperature is below $+5$ °C.

In the ice rink arena a series of complex flow phenomena takes place. Firstly, there is movement of supply air jets, which largely shapes conditions in the facility. It has an influence on air speed distribution. The air speed value just above the ice surface is very important from the users' thermal comfort viewpoint. Moreover, low air speed minimizes load on the ice making system, while too high air speed could cause ice melting, adversely affecting its quality. The air speed above the ice surface should not exceed the value of 0.25 m/s [19]. Secondly, there are also phenomena in the ice rink arena connected with the heat transfer, e.g. heat gains or losses through the building structure, heat losses from the ice surface, heat gains from the lighting system and from people. Heat exchange in the ice rink occurs by radiation and convection. It also includes vapour diffusion or condensation on the ice sheet, which is an important contributor to the ice sheet heat load. The cold ice surface, directly opposite the ceiling, absorbs heat by radiation. As a result, the inner surface of the ceiling is colder than air below it [20]. It should be observed that the water vapour contained in the air will condense on the surfaces which are colder than the room's air dew point temperature. Thirdly, in the ice rink arena a flow of moisture also occurs from different sources. Indoor sources of moisture are only people and the temporary work of ice resurfacer. Moisture is supplied into the ice rink arena with the ventilation air and by infiltration. It is very important that moisture gains can also occur from the ice rink surface. However, in most cases, moisture