THE IMPACT OF VENTILATION ON AIR QUALITY IN INDOOR ICE SKATING ARENAS.

Philip Demokritou[1], Qingyan Chen[2], Chunxin Yang[2], John Spengler[1].

[1] School of Public Health, Harvard University, Boston, USA
[2] Department of Architecture, Massachusetts Institute of Technology, Cambridge, USA

ABSTRACT

The combustion byproducts from the fuel-powered ice resurfacing equipment impose a potential health risk to both athletes and spectators. A field survey in ten ice rink arenas in the Greater Boston and Nova Scotia areas indicates that the fuel of the re-surfacer as well as the mechanical ventilation system primarily affect indoor air quality (IAQ) in such a unique building environment. The computational fluid dynamics (CFD) technique and other experimental methods such as tracer gas methods have been used to systematically investigate the impact of air exchange rate, air distribution method, and ventilation control strategies on IAQ. It was found that a mechanical ventilation system is a necessity and its aforementioned parameters play an important role on its ability to reduce effectively the contamination levels. With the CFD technique, design and operating guidelines for the ventilation systems can be developed to maximize ventilation effectiveness.

KEYWORDS: Air distribution, ice skating rinks, IAQ assessments, ventilation effectiveness, CFD, carbon monoxide, air change rate

INTRODUCTION

There are thousands of indoor ice rink arenas in the United States, Canada and Europe. Combustion byproducts from the use of fossil fuel-powered ice re-surfacing equipment especially from not properly maintained engines and poor mechanical ventilation have a compromising effect on IAQ. Previous studies reported CO and NO_2 concentration levels up to 100 times as high as the usual urban air concentrations with both acute and chronic health effects to be documented [1,2,3]. Dilution ventilation along with other pollution source control technologies is the most widely used strategy, applied to lower the contamination level below the threshold limit. Many arenas may not have a mechanical ventilation system or the system does not effectively reduce the contamination levels below the threshold limits.

The concentration level of various pollutants within an ice rink facility depends highly on the fuel type of the ice resurfacer, the frequency of resurfacing and the degree of ventilation [4]. Most of the studies for ice rinks report only the presence or absence of the ventilation system. Little information is available on how the ventilation system in an ice rink interacts with the contaminants. Information about the impact of significant ventilation parameters such as the effectiveness of the ventilation system, air distribution method, air exchange rate and ventilation control strategy rarely were reported and investigated in these studies. On this paper a parametric analysis of the aforementioned parameters will be presented.

METHODS

Field Survey

The present study conducted a field survey on ten ice rink arenas in the greater Boston area and Nova Scotia focusing on the effect of ventilation to IAQ. In this field survey, detailed information about the arena, type of re-surfacing equipment and ventilation system are collected. The temperature of air, air distribution method, ice surface and walls temperature, relative humidity, and major gaseous pollutant concentrations were also measured.

Only four of the ice rink arenas have a complete mechanical ventilation system including supply and exhaust fans. The rest of them have only an exhaust fan. Eight of the ice rink arenas under investigation are considered small community type arenas. Small ice rinks may have a similar mechanical ventilation system with limited air distribution throughout the arena. The system consists of one or two air supply inlets located up high on one wall and one or two exhaust air outlets on the opposite wall. On the contrary, in two large ice rink arenas, air is uniformly distributed and exhausted from multi-locations. The critical question is, how important the air distribution method is for IAQ. A smoke test revealed a highly non-uniform indoor air diffusion in terms of air velocity and air mixing pattern because of limited air distribution and the glass shielding around the ice sheet.

Another important ventilation parameter documented in our survey is the air exchange rate, which is defined as supply airflow rate divided by the volume of the ice rink. The air exchange rates for the 10 arenas are very scatter from 0.1 (1/hr) to 3.5 (1/hr). In many cases, air exchange rate is too low to achieve an acceptable level of IAQ.

The survey also investigated the control strategy of the ventilation system. None of the ice rinks has exact guidelines for the operation of the ventilation system. The managers operated the system according to their experience. In most cases, the ventilation system runs only during the resurfacing period and it is often shut off when the resurfacing equipment leaves the ice sheet.

CO and NO_2 concentrations are monitored in all surveyed ice rinks regularly because of the Massachusetts regulations, usually 3 or 4 times a week. In some cases the World Health Organization (WHO) threshold limit of 110 ppb NO_2 for one hour was exceeded and CO levels were also elevated up to 18 ppm. Three of the surveyed arenas use electric re-surfacers, four use re-surfacers fueled by propane or gasoline without a catalytic converter and three arenas use propane or gasoline powered resurfacers with some type of catalytic converters. The study found that the fuel type of the re-surfacing equipment is the most important parameter affecting IAQ in an ice rink Those arenas with electric re-surfacing equipment did not have elevated CO and NO_2 concentration levels.

Numerical Analysis using a CFD model

Besides the experimental tracer gas methods used to determine contamination dispersal within ice rinks arenas,[5], advanced numerical methods were also used in this study to investigate ventilation performance. A previously developed and validated CFD model ,[6], was used to study the impact of ventilation parameters such as air distribution method, ventilation effectiveness, air exchange rate and ventilation control strategy.

The numerical simulations predicted the airflow, temperature and contaminant concentration profiles for the ten ice rink arenas. From these distributions the effect of fundamental ventilation parameters such as air exchange rate, air distribution method and ventilation effectiveness on IAQ can be investigated. The simulations used CO as a normalized contaminant source. The normalized CO source can also represent other contaminants, such as NO_x and HC. The simulations have been performed for both transient and steady state conditions. Transient conditions were applied to investigate the dynamic contamination dispersal during and after an ice resurfacing cycle. In this case, the re-surfacer resurfaces the ice surface for only a period time for about eight to ten times per day.

In addition to the distributions of contaminant concentrations, the present investigation used also the mean age of air and ventilation effectiveness to evaluate the ventilation system performance. Many definitions have been used to describe how effectively a ventilation system removes the contaminant from the space. Nielsen's definition , [7], was used to calculate ventilation effectiveness, η_v:

$$\eta_v = \frac{C_{ex}}{C_{ave}} \qquad (1)$$

where:
C_{ex} = the concentration in the return opening, kg/m^3
C_{ave} = the average concentration, kg/m^3

RESULTS AND DISCUSSION

For the ten surveyed ice rinks, Figure 1 summarizes the computed results by the average CO concentration, the mean age of air, and the ventilation effectiveness, respectively under steady state conditions for their existing conditions. It was found that even ice rinks with similar type of ventilation systems can have different IAQ levels. Ice rinks with no mechanical ventilation systems or with only an exhaust air system are less effective to keep contamination levels low. A parametric analysis for all fundamental ventilation parameters was then performed to quantify the impact of these parameters on IAQ.

Air exchange rate

The study on the ten ice rinks shows that air exchange rate is the most fundamental ventilation parameter. The average CO concentration, ventilation effectiveness and mean age of air have been calculated for various air exchange rates for the ice rink arena No 6. For the simulations, a constant and uniform emission rate of CO (mg/m^2) from the resurfacer was assumed on ice surface. Ventilation system was also on all the time (steady state conditions). Figure 2 shows the variation of the average CO concentration and the vertical CO concentration profile at the center of the rink under various air exchange rates for this particular air distribution method and resurfacer emission rate. Obviously, the average CO concentration and mean age of air in the ice rink decreases with the increase of air exchange rate, while the ventilation effectiveness remains almost the same at approximately 0.6. The constant ventilation effectiveness is anticipated since the air distribution method is the same for all the simulations. Figure 2 can be used to estimate the air exchange rate required to reduce average CO concentration below a certain limit. This provides a valuable design guideline for the ventilation system of this arena. The results also indicate that the CO concentration is very high near the ice sheet because of the negative buoyancy created by the cold ice surface. This characteristic is unique for such as building environment.

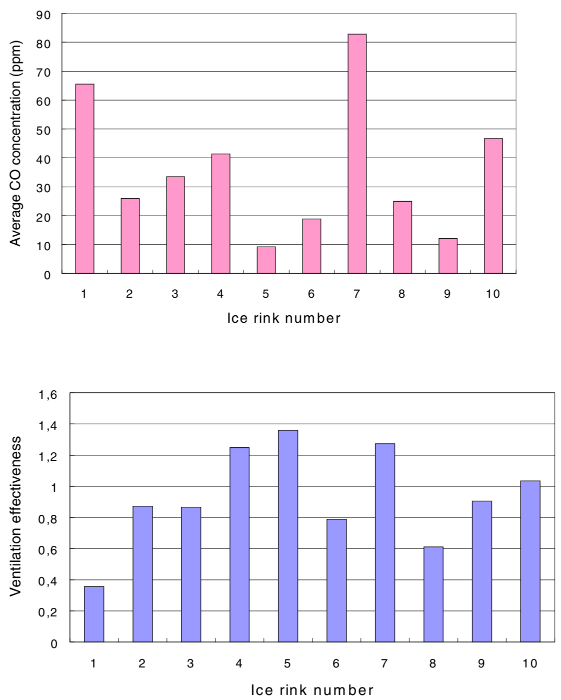

Figure 1. Ventilation system performance for the ten ice rink arenas.

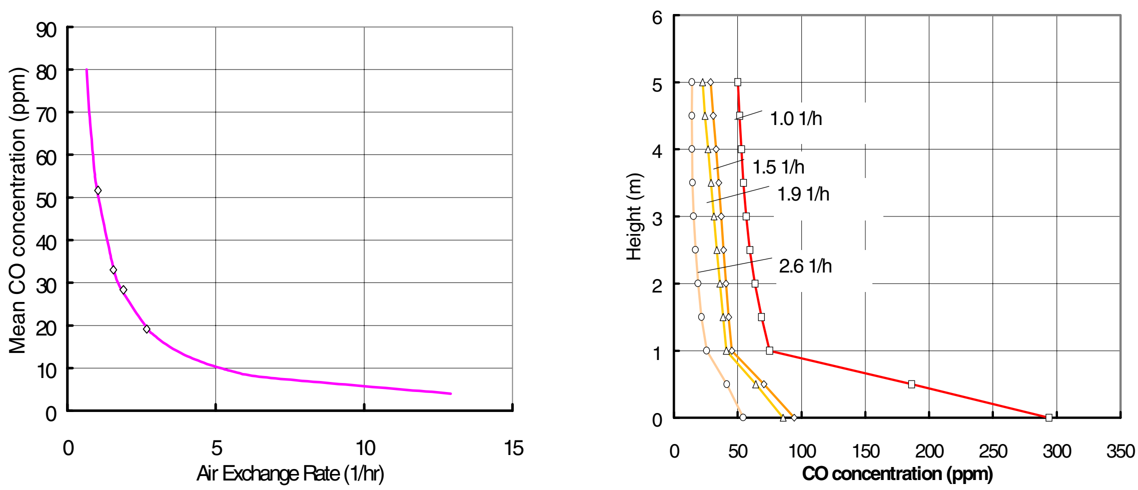

Figure 2. Indoor air quality of ice rink No. 6 as a function of air exchange rate.

Air distribution method

In order to investigate the impact of the air distribution method on IAQ, three different air distribution systems have been numerically investigated, again for the ice rink No. 6 under steady state conditions. Figures 3(a) to 3(c) show the three alternative design scenarios. In the first design scenario, the only one air inlet in the original design is substituted by four smaller inlets with unchanged total inlet area and total air flow. The second hypothetical design scenario has four exhaust air outlets located at the bottom of the rink's side shielding, close to the ice surface as detailed in Figure 3(d). The third design scenario distributes air supply inlets at both side walls and exhaust air outlets at both sides of the ice rink shielding. Figure 4 shows the vertical CO concentration profiles at the center of the rink for the different air distribution methods. It is clearly shown that the CO concentrations in the skaters' zone can be reduced by a factor of three with a proper air distribution system.

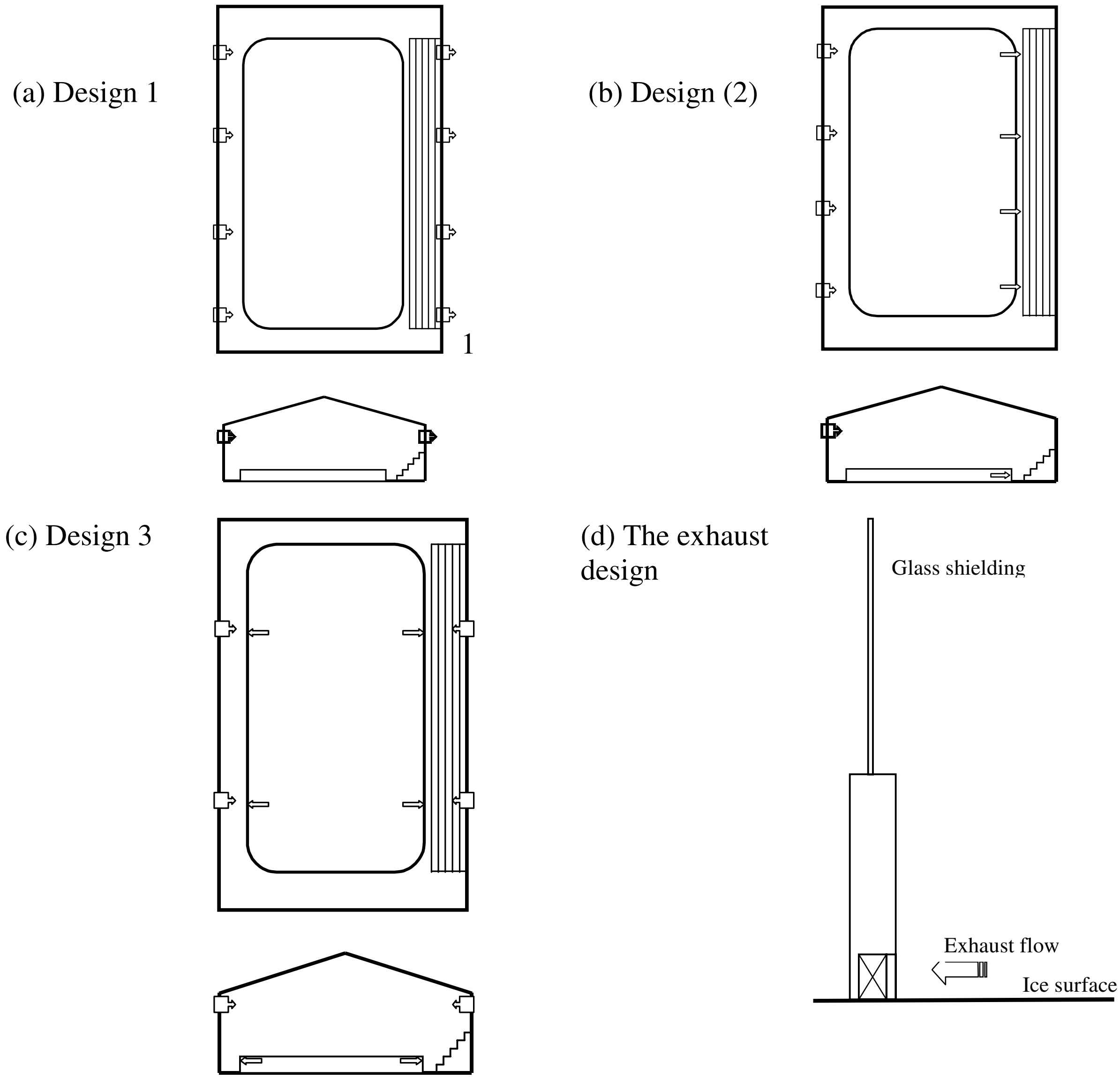

Figure 3. Air distribution methods.

It is apparent that design scenario 1 does not affect significantly the IAQ in the ice rink since the average CO concentration, mean age of air and ventilation effectiveness remain the same as those for the existing system. This is expected since the buoyancy effect which dominates the air flow pattern in the arena is still the primary driving force for the airflow. On contrary, for the design scenarios 2 and 3, on which the exhaust is located close to the ice surface, the CO concentration, mean age of air, and ventilation effectiveness are considerably improved.

Ventilation operational strategies

In order to investigate the dynamic contamination dispersal during and after an ice resurfacing cycle a numerical simulation has been performed on ice rink No. 3. The resurfacer was assumed moves in circles around the ice area for a certain period of time while the ventilation system is on all the time (transient condition). Figure 5 shows the computed CO concentration and the comparison with the experimental data for ice rink No. 3. The computed results are in good agreement with the experimental data.

Two new parameters were introduced for the evaluation of IAQ under transient conditions: purge time and peak contaminant concentration. Purge time is the time from the beginning of

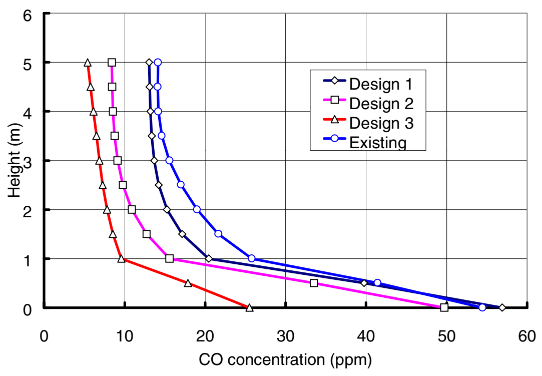

Figure 4. The CO concentration at the center of ice rink No. 6 under different air distribution methods.

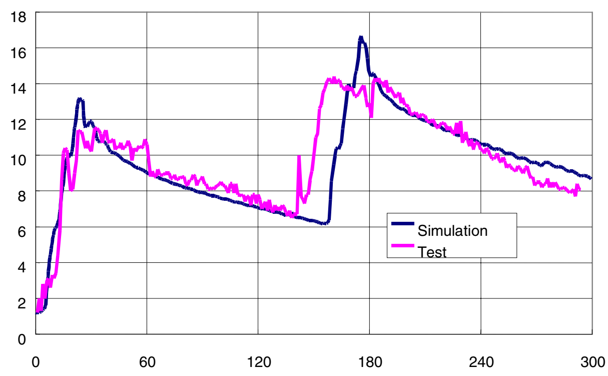

Figure 5. CO concentration profiles during and after resurfacing cycles in ice rink No.3.

the resurfacing cycle and until the average concentration level returns to its levels before the resurfacing. The peak contaminant concentration during the resurfacing process is the maximum contaminant concentration. Both the purge time and peak contaminant concentration during resurfacing process are related to the ventilation system and its fundamental parameters, such as air exchange rate, air distribution method, etc, as well as the other building characteristics such as volume and rink shielding. The purge time and peak contaminant concentration can be predicted by the CFD technique, as shown in Figure 5. A possible ventilation control strategy to lower contamination exposure both in terms of time and peak level is to increase for certain period of time the air exchange rate or to activate a supplementary exhaust system located close to the ice surface for certain period of time (>purge time) during and after the ice resurfacing cycle. Another strategy might be to evacuate both athletes and spectators from the rink for the purge time period. More thorough investigation is needed in order to quantify the effect of the various ventilation control strategies.

CONCLUSIONS

This paper presents a systematic evaluation of IAQ in ice rinks as a function of the air exchange rate, air distribution method and ventilation control strategies. The contaminant concentration and the mean age of air in the ice rink decrease with the increase of air exchange rate, while the ventilation effectiveness remains almost the same. Locating the exhaust air outlets low at the rink shielding area can reduce considerably the contamination level in the athletes zone. CFD methods are a valuable tool for the IAQ assessment of such a unique building environment.

REFERENCES

1. Spengler, J.D., Stone, K.R., Lilley, F.W. 1978. "High carbon monoxide levels measured in enclosed skating rinks," J. Air Pollut. Control Assoc., 28: 776-779.
2. Brauer, M. and Spengler, J.D. 1994. "Nitrogen dioxide exposures inside ice skating rinks," Am. J. Publ. Health, 84: 429-433.
3. Anderson D., 1971. "Problems created for ice arenas by engine exhaust." Am Ind Hyg Assoc J., 32: 790-801.
4. Pennanen, A.S., Vahteristo, M, and Salonen, R.O. 1998. "Contribution of Technical and Operational Factors to Nitrogen Dioxide Concentration in Indoor Ice Arenas," Environment International, 24(4): 381-388.
5. Demokritou, P., Yang C., Chen Q., Spengler J., 1999. "An experimental method for contaminant dispersal characterization in large industrial buildings for IAQ applications." Submitted to Building Environment.
6. Yang Chunxin, Demokritou Philip, Chen Qingyan and Spengler John, 1999. "Validation of a CFD model for IAQ applications in ice skating arenas", Submitted to Journal Indoor Air..
7. Nielsen, P.V. 1994. "Prospects for computational fluid dynamics in room air contaminant control," Proc. 4th Int. Symp. on Ventilation for Contaminant Control, Stockholm.