Indoor air quality in ice skating rinks in Hong Kong

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Abstract

Indoor air quality in ice skating rinks has become a public concern due to the use of propane- or gasoline-powered ice resurfacers and edgers. In this study, the indoor air quality in three ice rinks with different volumes and resurfer power sources (propane and gasoline) was monitored during usual operating hours. The measurements included continuous recording of carbon monoxide (CO), carbon dioxide (CO2), total volatile organic compounds (TVOC), particulate matter with a diameter less than 2.5 μm (PM2.5), particulate matter with diameter less than 10 μm (PM10), nitric oxide (NO), nitrogen dioxide (NO2), nitrogen oxide (NOx), and sulfur dioxide (SO2). The average CO, CO2, and TVOC concentrations ranged from 3190 to 6749 ppm, 851 to 1329 ppm, and 550 to 765 ppm, respectively. The average NO and NO2 concentrations ranged from 69 to 1006 ppm and 58 to 242 ppm, respectively. The highest CO and TVOC levels were observed in the ice rink which a gasoline-fueled resurfacer was used. The highest NO and NO2 levels were recorded in the ice rink with propane-fueled ice resurfacers. The air quality parameters of PM2.5, PM10, and SO2 were fully acceptable in these ice rinks according to HKIAQO standards. Overall, ice resurfacers with combustion engines cause indoor air pollution in ice rinks in Hong Kong. This conclusion is similar to those of previous studies in Europe and North America.

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Keywords: Indoor air quality; Ice skating rink; Resurfacer; HKIAQO

1. Introduction

Indoor air quality in ice skating rinks has become a public concern due to the use of propane- or gasoline-powered ice resurfacers and edgers. The operation of the equipment to clean and resurface the ice leads to elevated concentrations of air pollutants. The main pollutants emitted are carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter (PM). High levels of CO and nitrogen dioxide (NO2) have been reported in many ice skating rinks (Anderson, 1971; Berglund et al., 1994; Brauer and Spengler, 1994; Brauer et al., 1997; Lee et al., 1994; Levesque et al., 1990; Levy et al., 1998; Pennanen et al., 1997a,b; Yoon et al., 1996). In general, propane-powered ice resurfacers emit more NOx and less CO, VOCs, and particles than gasoline-powered resurfacers (Clarck, 1988; Pennanen et al., 1997a).

Studies of indoor air quality in ice skating rinks have been conducted in North America and European countries, where ice skating activities are popular (Brauer and Spengler, 1994; Pennanen et al., 1997a; Rosenlund and Bluhm, 1999; Yoon et al., 1996). Brauer and Spengler (1994) reported that 1-week average NO2 concentrations above 1000 ppm were measured in 10% of 70 northeastern US rinks. The median NO2 level inside rinks was 180 ppm, more than 10 times higher than the median outdoor concentration. Indoor NO2 concentrations in 19 enclosed ice skating rinks were measured by Levy et al. (1998). Rinks in which propane-fueled resurfacers were used had a daily mean indoor NO2 concentration of 206 ppm, compared with 132 ppm for gasoline-fueled and 37 ppm for electric-powered resurfacers. In Scandinavian countries, Pennanen and colleagues (1997a) characterized air quality in five Finnish indoor ice arenas and reported that the highest 1-h average CO and NO2 concentrations ranged from 17 to 29 ppm and 0.14 to 3.96 ppm, respectively. The 3-h total VOC concentrations ranged from 150 to 1200 μg/m3. Scientists from Sweden identified that the
most important source of exposure to VOCs was the indoor ice skating arenas, where levels of up to 4240 ppb were measured during 1-h periods (Berglund et al., 1994). In addition, an international survey of NO2 levels inside indoor ice skating facilities was conducted in 332 ice rinks located in nine countries (Brauer et al., 1997). The mean NO2 level for all rinks in the study was 228 ppb, with a range of 1–2680 ppb.

The adverse effects of CO and NO2 on human health in ice rinks have been reported for many years. The symptoms of CO poisoning include dizziness, headache, cough, and vomiting (Coueffin and Fraser, 1981; Penney, 2000; Spengler et al., 1978; USEPA, 1996; WHO, 1999). Exposure to elevated NO2 concentrations are associated with various respiratory ailments, such as throat irritation, cough, dyspnea, and chest tightness (Bylin et al., 1985; Hedberget al., 1989; Rosenlund and Bluhm, 1999; Samet et al., 1987; Smith et al., 1992; Soparkar et al., 1993).

Although many studies have been conducted in different indoor environments in Hong Kong (Guo et al., 2003; Lee, 1997; Lee and Chang, 2000; Lee et al., 1999, 2001, 2002a, b; Li et al., 2001), indoor air quality in ice skating rinks has not been fully investigated. Moreover, previous studies in North America and European countries have focused mainly on CO and NO2 concentrations; other air pollutants, such as total VOCs, particulate matters (PM2.5 and PM10), and CO2, have not been studied. Therefore, the objectives of this study are to assess the indoor air quality in ice skating rinks in Hong Kong and to provide quantitative information on levels of target air pollutants before and after resurfacing. The study also intends to compare indoor air quality at the ice skating rinks with the recommended Hong Kong Indoor Air Quality Objective (HKIAQO) (HKEPD, 1999). The outdoor and indoor air quality objectives in Hong Kong are presented in Table 1.

### 2. Methods

#### 2.1. Selection of ice skating rinks

There are three large indoor ice skating rinks in Hong Kong, each located in one of three different large shopping malls. General descriptions of these three rinks are presented in Table 2.

The open hours of the rinks are from 10:00 to 20:00. The estimated number of people skating per hour is 100. The majority of ice skaters are youngsters aged from 4 to 18 years. Each ice skater generally spends 1–3 h in the rink. Rink A is gradually crowded after 15:00 in the winter and after 13:00 in the summer. Usually, there are many ice skaters in rinks B and C on weekends and weekdays nights.

#### 2.2. Sampling and analysis

During resurfacing, which took about 15 min, the rinks were closed temporarily. To obtain the true peak exposure of ice skaters to air pollutants, the sampling was conducted immediately after resurfacing. The sampling equipment was put in a specially designed bag that was carried by a trained ice skater while he/she skated in the rink. Simultaneously, air samples were taken just outside the rinks and outside the building to estimate the real effects of ice resurfacing on human health.

### Table 1
Outdoor and indoor air quality objectives in Hong Kong

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>HKAQOa</th>
<th>HKIAQOb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide (CO)</td>
<td>&lt; 30,000 µg/m³ (1-h average)</td>
<td>&lt; 30,000 µg/m³ (1-h average)</td>
</tr>
<tr>
<td></td>
<td>&lt; 10,000 µg/m³ (8-h average)</td>
<td>&lt; 10,000 µg/m³ (8-h average)</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Nitric oxide (NO)</td>
<td>NA</td>
<td>&lt; 1000 ppm (8-h average)</td>
</tr>
<tr>
<td>Nitrogen dioxide (NO₂)</td>
<td>300 µg/m³ (1-h average)</td>
<td>&lt; 200 µg/m³ (1-h average)</td>
</tr>
<tr>
<td></td>
<td>150 µg/m³ (24-h average)</td>
<td>&lt; 50 µg/m³ (8-h average)</td>
</tr>
<tr>
<td></td>
<td>180 µg/m³ (24-h average)</td>
<td>180 µg/m³ (8-h average)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>800 µg/m³ (1-h average)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>350 µg/m³ (24-h average)</td>
<td></td>
</tr>
<tr>
<td>Sulfur dioxide (SO₂)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total volatile organic compounds (TVOC)</td>
<td>NA</td>
<td>&lt; 3000 µg/m³ (8-h average)</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**a** HKAQO, Hong Kong air quality objective for outdoor air.

**b** HKIAQO, Hong Kong indoor air quality objectives for non-industrial environments (recommended).

### Table 2
General description of the three ice skating rinks in Hong Kong

<table>
<thead>
<tr>
<th>Rink</th>
<th>Area (m²)</th>
<th>Resurfacing (times per day)</th>
<th>Fuel used</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>650</td>
<td>4</td>
<td>Propane</td>
</tr>
<tr>
<td>B</td>
<td>1200</td>
<td>5</td>
<td>Gasoline</td>
</tr>
<tr>
<td>C</td>
<td>800</td>
<td>5</td>
<td>Gasoline</td>
</tr>
</tbody>
</table>

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health. Since resurfacing was conducted 4–5 times per day, two to three sets of samples were collected each day to reflect the effects of ice resurfacing.

The air pollutants investigated included CO, carbon dioxide (CO₂), nitric oxide (NO), NO₂, NO₃, total volatile organic compounds (TVOCs), sulfur dioxide (SO₂), particulate matters 2.5 (PM₂.₅, aerodynamic diameter <2.5 μm), and particulate matters 10 (PM₁₀, aerodynamic diameter <10 μm). Relative humidity (RH) and temperature were also recorded in the ice skating rinks. Although the major source of particulate matters was the ice resurfacer and the ice resurfacer is known to generate particles less than 10 μm in aerodynamic diameter, PM₁₀ were still measured in this study. This is due to the fact that in the HKIAQO there is a recommended standard for PM₁₀ in indoor environments. We wanted to determine whether the PM₁₀ concentrations in the rinks abided the HKIAQO standard.

A portable Q-Trak monitor (Model 8551, TSI Inc., St. Paul, MN, USA) was used to monitor the indoor and outdoor CO and CO₂ concentrations, RH, and temperature. Two Dust-Trak air monitors (Model 8520, TSI Inc.) were used to measure PM₂.₅ and PM₁₀ concentrations in indoor and outdoor air. The dust monitors measured PM₂.₅ and PM₁₀ at 30-s intervals at a flow rate of 1.7 L/min. A ppbRAE monitor (Model PGM 7240, RAE Systems, Sunnyvale, CA, USA) was used to measure TVOC concentrations. All samples were taken beginning at 15 min before ice resurfacing and stopping at 60 min after resurfacing. The samples of NO, NO₂, NO₃, CO, and SO₂ were collected during the target sampling periods. The sampled air was drawn into 12-L Tedlar bags by a portable air pump (Model HFS-513A, Gillian Ltd.) for 15 min before, during, and after ice resurfacing. A short exposure time was adopted because it corresponded to the relevant exposure time of an ice skater during training.

After sampling, the air bags were shipped to the laboratory for analysis. CO was measured with a Thermo Electron Gas Filter Correlation CO Ambient Analyzer (Model 48, Thermo Environmental Instruments Inc., Franklin, MA, USA). NO–NO₂–NO₃ was analyzed with a Chemiluminescence NO–NO₂–NO₃ Analyzer (Model 42, Thermo Environmental Instruments Inc.). SO₂ was measured with a Pulsed Fluorescence SO₂ analyzer (Model 43B, Thermo Environmental Instruments Inc.).

2.3. Quality assurance and quality control

Before sampling, the Q-Trak was calibrated with standard CO₂ gas at a known concentration. Pre- and postzero checks of the Dust-Trak monitors were carried out. Before each measurement, the Dust-Trak was rezeroed. The Dust-Trak is an optical instrument that detects particles in the air matrix by optical scattering, using the optical diameter instead of the aerodynamic diameter. Therefore, a separate calibration was carried out to convert the Dust-Trak data into corresponding concentrations obtained by the gravimetric method. Details for calibration can be found in our previous publications (Lee et al., 2001, 2002a,b; Li et al., 2001). The ppbRAE TVOC monitor was calibrated using a calibration gas (isobutylene) with a known concentration of 10 ppm supplied by the manufacturer.

Prior to sampling, the air bags used for sampling were flushed with zero air at least five times. The cleaned air bags were then filled with zero air and analyzed by the gas instruments to ensure that they were clean. After sampling, the air bags were put into a large black plastic bag to avoid exposure to sunlight and transported to the laboratory for analysis within 1 h.

3. Results and discussion

3.1. CO and CO₂ concentrations

Temporal variations of CO and CO₂ inside the three ice skating rinks were measured and are presented in Fig. 1. Continuous measurements showed that the CO levels inside the rinks were closely associated with the use of combustion-powered resurfacers. It was found that the CO concentrations increased due to engine emissions and then declined due to the mixing and exchange of air by the ventilation system. When resurfacing was started, the CO concentration in rink A increased from a background level of 2286 to a maximum concentration of 5714 μg/m³. When resurfacing was completed, the CO level fell to 2286 μg/m³ after 60 min. In rink B, the CO concentration sharply increased from 2286 to 16,000 μg/m³ and then fell to 3429 μg/m³ after resurfacing. The CO concentration in rink C increased from 3429 to 8000 μg/m³ during resurfacing and then decreased to 2286 μg/m³ after resurfacing. The percentages of CO increase in rinks B and C were much higher than that in rink A. This was due to the gasoline-fueled resurfacers used in rink B and C and the propane-fueled resurfacers used in rink A.

The CO₂ concentrations in the three rinks were almost constant, indicating that ice resurfacing did not substantially affect the levels of CO₂ in the rinks.

3.2. NO and NO₂ concentrations

The levels of NO and NO₂ in the three rinks are presented in Fig. 2. The measurements were conducted before, during, and after resurfacing. The sampling duration was 15 min, as this is the time needed for resurfacing. We found that the concentrations of NO and NO₂ significantly increased in rink A while
resurfacing occurred. The levels of NO and NO\textsubscript{2} in rinks B and C, however, rose only slightly during resurfacing. The NO concentration in rink A was 1006 \(\mu\)g/m\textsuperscript{3} during resurfacing, which was more than 13 times the pre-resurfacing level. However, the NO levels in rinks B and C during resurfacing were only 1.65 and 1.32 times, respectively, pre-resurfacing levels. Similarly, the average NO\textsubscript{2} concentration in rink A during resurfacing was 242 \(\mu\)g/m\textsuperscript{3}, 2.4 times that before resurfacing. In rinks B and C, however, the NO\textsubscript{2} levels were relatively stable before and during resurfacing.

The concentrations of NO and NO\textsubscript{2} in rink A were 7.3 and 4.2 times, respectively, those in rink B and 11 and 3.9 times, respectively those in rink C. The higher NO and NO\textsubscript{2} concentrations in rink A compared to those in the other rinks were due to the difference in engine emissions in rink A and gasoline fuel in (propane fuel rinks B and C). This result is consistent with those of previous studies (Clark, 1988; Pennanen et al., 1997a).

The average NO\textsubscript{2} concentration in rink A during resurfacing exceeded the HKIAQO standard of 200 \(\mu\)g/m\textsuperscript{3} (1-h average), and in rinks B and C the levels of NO\textsubscript{2} were below the standard. (In general, the results obtained in this study were compared to the 1-h average Objectives; if this was not applicable, the pollutant concentrations were compared to the 8-h average Objectives.)

There were several factors that affected the actual levels of CO and NO\textsubscript{2} in the rinks, such as the type of fuel used by the resurfacers, resurfacing frequency, volume and air exchange rates of the rinks, and other emission sources. NO\textsubscript{2} levels inside the rinks were also affected by the rate of formation of NO\textsubscript{2} from NO (Brauer et al., 1997; Pennanen et al., 1997a).

3.3. TVOC concentrations

The TVOC concentrations in the three rinks were continuously monitored and the temporal changes are shown in Fig. 3.

In rink A, the TVOC concentration increased from about 484 \(\mu\)g/m\textsuperscript{3} to a maximum value of 827 \(\mu\)g/m\textsuperscript{3} during resurfacing and then decreased to 500 \(\mu\)g/m\textsuperscript{3} 30 min after resurfacing. The increase in the rate of TVOCs due to resurfacing was 71\%. The TVOC concentration in rink B started at around 560 \(\mu\)g/m\textsuperscript{3} and increased to 682 \(\mu\)g/m\textsuperscript{3} during resurfacing, falling to 600 \(\mu\)g/m\textsuperscript{3} afterword, an increase of TVOCs during resurfacing of 22\%. The TVOC concentration in rink C increased from 660 to 887 \(\mu\)g/m\textsuperscript{3} during resurfacing an increase of 34\%, and then fell to 740 \(\mu\)g/m\textsuperscript{3} 30 min after resurfacing. The results indicate that resurfacing significantly affected the TVOC levels inside the rinks.

It is difficult to compare the results obtained by different studies due to the differences in sampling and analytical methods. It is even more difficult to interpret

![Fig. 1. Continuous measurements of CO and CO\textsubscript{2} inside the ice skating rinks; and the duration of each resurfacing was about 15 min.](image1)

![Fig. 2. Indoor levels of NO and NO\textsubscript{2} in the three rinks.](image2)
VOC measurements because the compounds causing complaints or health effects are not well known (Pennanen et al., 1997a, b). In addition, VOCs can be emitted from other sources, such as building materials and maintenance and service activities. The TVOC measurements conducted in Finland with Tenax sampling and gas chromatography showed that TVOC concentrations in five ice arenas ranged from 140 to 1200 \( \mu g/m^3 \) (Pennanen et al., 1997a). In this study, the measured TVOC concentrations were in the range of 484–887 \( \mu g/m^3 \).

3.4. \( PM_{2.5} \) and \( PM_{10} \) concentrations

Fig. 4 shows continuous measurements of \( PM_{2.5} \) and \( PM_{10} \) in the ice skating rinks, including the resurfacing period. We found that resurfacing had an insignificant influence on the concentrations of \( PM_{2.5} \) and \( PM_{10} \) in the three rinks. The average \( PM_{2.5} \) concentration ranged from 28 to 62 \( \mu g/m^3 \) inside the three rinks, and the levels of \( PM_{10} \) were between 50 to 79 \( \mu g/m^3 \) in indoor air. The \( PM_{10} \) levels in the rinks were lower than the HKIAQO standard of 180 \( \mu g/m^3 \) (8-h average).

3.5. \( SO_2 \) concentrations

The \( SO_2 \) concentrations in the rinks are shown in Fig. 5. We found that the \( SO_2 \) levels in the three rinks were approximately 10 ppb. There were no significant differences among the three rinks, suggesting that independent sources contributed to the \( SO_2 \) concentrations in the rinks, most likely the penetration of \( SO_2 \) from ambient air. The main sources of \( SO_2 \) in Hong Kong ambient air are vehicular exhaust and power plants. We also found that the \( SO_2 \) levels did not change much during resurfacing in the rinks, indicating that resurfacers had no effect on \( SO_2 \) concentrations.

3.6. Comparison of indoor and outdoor concentrations of target air pollutants

The average concentrations of target air pollutants inside rinks, outside rinks, and outdoors are presented in Table 3. The ratios of air pollutant concentrations inside rinks to concentrations outside rinks (IR/OR) and inside rinks to outdoors (IR/O) are also listed in the table. The IR/O ratios of CO were over 1.00, ranging from 1.55 to 5.72 in the three rinks. The major indoor source of CO in the rinks was resurfacers. The outdoor levels were measured at a location outside the shopping mall. The CO concentrations outside the rinks were also measured at a location of 100–150 m away from the rink on the same floor of the shopping mall. The CO concentration outside rink A was higher than that outside rinks B and C and that inside rink A, indicating that sources of CO existed outside rink A. A food court beside rink A might be the contributor of the elevated CO concentration. The IR/OR ratios were 2.84 and 1.06 for rinks B and C, respectively, reflecting the effect of ice resurfacing on indoor air quality. The mean CO concentrations in the three rinks and outdoors were all
below the HKIAQO and HKAQO (the standard for outdoor air) standards of 30,000 μg/m³ (1-h average).

The average CO₂ concentration in rink B was higher than the 1000ppm stated in the HKIAQO standard (8-h average). Indoor CO₂ levels were found to be variable. Besides the combustion of fuel by resurfacers, the high CO₂ levels recorded in the rinks were attributed to overcrowding and an insufficient supply of fresh air. The IR/O ratios were between 1.68 and 2.76.

The average PM₂.₅ and PM₁₀ concentrations inside the rinks were lower than those measured outdoors. In outdoor air the mean PM₂.₅ concentrations ranged from 97 to 134 μg/m³ and the average PM₁₀ concentrations were between 138 and 157 μg/m³. The increased concentrations of PM₂.₅ and PM₁₀ were probably related to the locations of the outdoor air samples and nearby heavily trafficked roads. In Hong Kong, many public buildings are ventilated with an MVAC system. PM₂.₅ and PM₁₀ carried in ambient air are drawn into the public buildings and are filtered through these systems. Air conditioner filters are used to reduce the amounts of particulate matter from entering buildings. These PM values and the use of these filtering systems lead to the conclusion that the resurfacers had little effects on the levels of particulate matters in the rinks.

The mean TVOC concentrations were below the HKIAQO standard inside and outside the rinks. The TVOC concentrations inside the rinks were higher than those outside the rinks and in outdoor air, reflecting the influence of resurfaces inside the rinks. The TVOC concentrations inside rinks B and C (gasoline-fueled resurfacer) were higher than that inside rink A (propane-fueled resurfacer). This suggests that gasoline-fueled resurfacers generated more TVOCs than the propane-fueled resurfacer. This result is consistent with previous studies (Clarck, 1988; Pennanen et al., 1997a).

![Fig. 4. Continuous measurements of PM₂.₅ and PM₁₀ in the three ice skating rinks.](image)

![Fig. 5. SO₂ concentrations in the three ice skating rinks.](image)
The TVOC concentrations outside the rinks were also higher than those of in outdoor air, indicating the existence of TVOC sources outside the rinks. The elevated TVOC concentrations outside the rinks were probably due to the food-preparation activities of the vendors outside the three rinks while vehicular emissions might be the source of the TVOC concentrations in the nearby outdoors.

The average NO concentration inside rink A was 4.15 times that outside the rink A and 4.5 times that in the outdoor air. However, in rinks B and C the NO concentrations inside the rinks were lower than those of the outdoor air. We attribute this to the combustion of the fuel in rink A, which is consistent with results reported by Clarck (1988) and Pennanen et al. (1997a). The average NO concentrations of the outdoor air of the three rinks were very similar indicating that the NO level throughout Hong Kong is constant, likely coming from vehicular emissions.

The NO2 concentration in rink A was 242 μg/m³, which was above the HKIAQO standard of 200 μg/m³ and higher than that outside the rink and in the outdoor air. In rinks B and C the NO2 levels inside the rinks were close to those observed outside the rinks and in outdoor air, suggesting that propane-powered resurfacing generated much more NOx than gasoline-powered resurfacing.

The SO2 concentrations inside the rinks, outside the rinks, and in the outdoor air were very similar, indicating that resurfacing did not contribute to SO2 levels.

### 4. Conclusions

Ice resurfacers caused air pollution problems in all three ice rinks. The main pollutants produced by ice
resurfacers were CO, NO, NO₂, and TVOCs. The concentrations of CO, NO, NO₂, and TVOCs increased during ice resurfacing and fell following ice resurfacing. All concentrations fell to background levels 60 min after the cessation of ice resurfacing, except for that of NO in all three rinks and for CO that of rink B.

The inside rink concentrations of CO, CO₂, TVOCs, NO and NO₂ in all three rinks were higher than the concentrations outside the rinks and outdoors. In contrast, the PM₁₀ and PM₂.₅ concentrations in outdoor air were higher than those inside and outside the rinks, likely due to the PM emitted by vehicles.

The average CO₂ concentration in rink B and the NO₂ concentration in rink A exceeded the HKIAQO standard. The mean CO, TVOC, and CO₂ concentrations in the three rinks and outdoors were all below the HKIAQO and HKAQO standards. Although occasional low-level exposure may not produce any immediate symptoms, long-term exposure could have significant health effects on the very young and elderly.

Some countermeasures can be taken to reduce the adverse effects of ice resurfacing such as increasing ventilation at the skating rinks and checking these systems regularly; retuning or repairing resurfacing equipment regularly; installing a catalytic converter on resurfacing equipment; installing an oxygen sensor in resurfacing equipment to regulate fuel leaniness or richness; and decreasing the resurfacing schedule to reduce the frequency of emissions of exhaust. Over the long term, the existing resurfacers should be replaced by electric ice-resurfacing equipment; electric resurfacers are able to reduce and even eliminate exhaust emissions. Other advantages of electric resurfacers include reduced operational expenses and that ventilation is not required during resurfacing. However, the cost of these resurfacers, approximately 60% higher than that of fuelled equipment, is a barrier for many arena operators. A compromise alternative is the use of resurfacing equipment powered by natural gas.

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References


