THE EFFECT OF ICE RESURFACING ON CARBON MONOXIDE LEVELS IN INDOOR ICE ARENAS

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Abstract

Once in awhile the news reports incidences of carbon monoxide poisoning in ice arenas. Nobody really thinks about whether or not the level of carbon monoxide will exceed to such a level that poisoning could occur in an ice arena. The purpose of this research study was first, to determine the carbon monoxide level before and after ice resurfacing and second, to check if the level, after ice resurfacing, was within the acceptable range. Thirty indoor ice rinks were chosen randomly from Greater Vancouver and the Fraser Valley. Two sets of samples were taken in each ice rink. The first set of samples was taken before ice resurfacing took place and the second set of samples was taken after ice resurfacing. Four readings were taken near the ice rink surface before and after ice resurfacing. A Q-Trak was used to measure carbon monoxide, temperature, and humidity. The statistical analysis was conducted by using the Number Crunching Statistical Software (NCSS). For the first part of the study, in which two sample sets were taken in each ice rink and the difference in levels were noted, a two-tailed t test was performed. The results obtained indicated that this study was statistically significant. For the second part of the study, a chi-square test was used to determine if the samples taken after ice resurfacing were within the acceptable range of carbon monoxide set by Health Canada and Ontario Recreation Facilities Association Inc. Two out of thirty ice arenas did exceed the acceptable range of 11ppm set by Health Canada; however, all thirty ice arenas were within the acceptable range of 25ppm set by Ontario Recreational Facilities Association Inc. Attaching carbon monoxide sensors on walls and tuning the Zamboni regularly are recommended for ice arenas in order to reduce the occurrence of carbon monoxide poisoning.

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Introduction

People have been skating as early as 1564. Rivers would freeze in the winter and people would skate on the frozen bodies of water. These rivers were known as the natural ice rinks. It was not until 1879 that the first mechanical refrigerated ice rink was built in the United States (21). In these early days, no rinks had a permanent, multipurpose floor (21). Most places put pipes on wooden stringers on leveled ground and covered them with sand. The construction on ice rinks has seen great evolution. The fundamental logic of how indoor ice rinks work is the same as how refrigerators or air conditioners work.

There are a few basic parts to the system: a compressor, heat-exchanging pipes, an expansion valve, and a refrigerant. The system absorbs heat from the evaporation of the refrigerant. As this liquid evaporates, it creates a cool feeling and since refrigerant evaporates at a very low temperature, it can produce freezing temperatures inside the refrigerator (4). Ice rinks work the same way. First, the compressor raises the refrigerant's pressure and temperature allowing the refrigerant to dissolve by the heat of pressurization (4). The refrigerant will change into liquid form and then flows through the expansion valve. In the expansion valve, the liquid refrigerant experiences a low-pressure zone from a pervious high-pressure zone. This process evaporates the refrigerant and at the same time it absorbs heat, making it cold. The main difference between an ice rink and a refrigerator is in the refrigerant. A calcium-chloride solution called brine water is used in ice rinks. This solution is pumped through the pipes that are underneath the ice (28).

Forming the ice is important in ice rinks. To reach ideal thickness, accuracy on applying the water is important. Between 45,000L to 57,000L of water is needed to form a hockey rink surface (28). Besides the ice, the construction of the building is also vital. To build an ice rink, the site has to be excavated and leveled because ice requires a surface that is leveled to a 1/8 inch tolerance (30). In terms of ventilation, the building should be well ventilated to maintain good air quality and circulation. High humidity in indoor ice arenas will create fog on the ice (28). Heat and humidity will vary depending on the temperature and the number of spectators in the ice arena; therefore, the ventilation and the temperature of ice rinks must alter to compensate for these aspects.

Lately, the news articles have reported incidences of carbon monoxide poisoning in ice arenas. This is an interesting topic to the public because no one thinks about whether or not the level of carbon monoxide will exceed to such a level that poisoning will occur in an ice arena. For example, when people are watching a hockey game in an ice arena, the only thing they have in their mind is to watch the game and enjoy their time there. No one will think about the level of gases in the arena. Ice hockey players are the same. Their focus is to play a good hockey game and win the competition. So what could carbon monoxide do to people?

What is Carbon Monoxide?

Carbon monoxide is a product of incomplete combustion from carbon substances. These substances or materials include propane, oil, gasoline, natural gas, coal or wood (8). Carbon monoxide is a gas that has no smell, color, or taste and those characteristics make carbon monoxide a hazardous and dangerous indoor air quality issue. Carbon monoxide can come from unvented kerosene and gas space heaters, furnaces, woodstoves, gas stoves, fireplaces, and water heaters (34). Leakage or poorly maintained appliances may release carbon monoxide indoors as well. Automobiles, trucks, or bus exhaust from attached garages, nearby roads, or parking areas can also be a source of this elusive gas (33). Tobacco smoke is another major source contributing carbon monoxide to indoor air. For outdoor air, the major polluter for carbon monoxide is the automobile; although small amounts do come from processes involving the combustion of organic matter such as power stations and waste incineration (10).

Health Effects of Carbon Monoxide

Carbon monoxide exposure can sometimes be misled as influenza or food poisoning (34). At low concentrations, symptoms can include fatigue in healthy people and chest pain in people with heart disease (33). Tiredness and shortness of breath, tightness across the forehead, flushed skin and slightly impaired motor skills can also occur at low concentrations (8). At higher concentrations, symptoms such as headache, weakness, confusion, disorientation, nausea, and dizziness can occur (34). Carbon monoxide exposure is lethal at very high concentrations. There are some people who are more vulnerable to carbon monoxide poisoning, hence fetuses, infants, elderly, and people with heart disease, respiratory illness, and anaemia (34). According to the National Safety Council, approximately 300 people die each year from carbon monoxide poisoning and thousands of others visit hospital emergency rooms (34).

Exposure to high levels of carbon monoxide results in adverse human health effects and the explanation behind this is the formation of carboxyhemoglobin. Blood contains hemoglobin and it carries oxygen which circulates around the body. If high levels of carbon monoxide are inhaled into the body, the carbon monoxide will attach to the hemoglobin which takes away the space for oxygen binding to the hemoglobin. The affinity of hemoglobin to carbon monoxide is 240 times greater than that of oxygen, influencing oxygen delivery and utilization at the cellular level (20). Humans normally have carboxyhemoglobin in the body to start with. The normal carboxyhemoglobin level in the body is one to three percent; the average level is about five percent for smokers; the level for carbon monoxide poisoning to occur is fifteen to twenty percent; and severe poisoning has levels up to twenty-five percent (25).

The treatment to cure carbon monoxide poisoning is to generate high flow of oxygen into the body. If the carboxyhemoglobin level in the body is above forty percent, hyperbaric oxygen therapy should be used (24). Hyperbaric oxygen therapy boosts oxygen in the body at a certain pressure to reduce the half-life of carboxyhemoglobin and dissolve the oxygen in the blood to save life even if hemoglobin is not present (25).

Exposure Levels

There are different levels set for indoor and outdoor air pollutants. According to the United States National Ambient Air Quality Standards, there is no indoor air standard for carbon monoxide; but the outdoor air standards are 9,500 $\mu g/m^3$ (9.5ppm) for an eight-hour period and 35,500 $\mu g/m^3$ (35.5ppm) for a one-hour period (35).

The standards for carbon monoxide outdoors in the United States and Canada are different, though the values are close. The Canadian guidelines provide three levels for a reference. For an eight-hour period in Canada, the maximum desirable level is 6,000 $\mu g/m^3$ (6ppm); the maximum acceptable level is 15,000 $\mu g/m^3$ (15ppm), and the maximum tolerable level is 20,000 $\mu g/m^3$ (20ppm) (5). For a one-hour period, the maximum desirable level is 15,000 $\mu g/m^3$ (15ppm) and the maximum acceptable level is 35,000 $\mu g/m^3$ (35ppm) (5). British Columbia has more strict guidelines than the Canadian standards. For an eight-hour period, the maximum desirable level (level A) is 5,500 $\mu g/m^3$ (5.5ppm); the maximum acceptable level (level B) is 11,000 $\mu g/m^3$ (11ppm), and the maximum tolerable level (level C) is 14,300 $\mu g/m^3$ (14.3ppm) (5). For a one-hour period, level A is 14,300 $\mu g/m^3$ (14.3ppm), level B is 28,000 $\mu g/m^3$ (28ppm), and level C is 35,000 $\mu g/m^3$ (35ppm) (5).

The World Health Organization (WHO) also has recommended guidelines for carbon monoxide in ambient air. The recommended level for fifteen minutes, thirty minutes, one hour, and eight hours are 100 mg/m^3 (87ppm), 60 mg/m^3 (52ppm), 30 mg/m^3 (26ppm), and 10 $mg/^{m3}$ (9ppm), respectively (17). The values set for carbon monoxide by all organizations and governments are similar, the only difference is the different unit used when presenting the value. Generally, the Canadian guidelines are more stringent than the standards in the United States and those established by WHO.

There are more guidelines set for carbon monoxide outdoors than indoors. The British Columbia Workers' Compensation Board sets up an occupational exposure limit for carbon monoxide for workers. The eight-hour exposure limit for carbon monoxide is 25ppm and 100ppm for short-term exposure (6). Health Canada sets up an exposure guideline for carbon monoxide in residential areas (9). In this case, the acceptable short-term exposure ranges for carbon monoxide for indoor air are ≤11ppm as an eight-hour average concentration and ≤25ppm as a one-hour average concentration (9). There is no indoor carbon monoxide level set for an indoor sporting facility in British Columbia; however, Ontario Recreation Facilities Association Inc. (ORFA) sets up suggested guidelines for air quality in ice arenas in Ontario (23). According to their suggested guideline, the average carbon monoxide level during every hour that the ice is used by public shall not exceed 25ppm (23).

Incidence of Carbon Monoxide Poisoning

As an indoor air pollutant, carbon monoxide does not only occur in the household. Carbon monoxide can be a problem for indoor sporting events. There are significant incidences where people obtain carbon monoxide poisoning in sports arenas.

In 1996 there were complaints of exposure to exhaust fumes in an ice skating arena in Seattle. Paramedics and fire fighters evacuated the patrons out of the arena. That particular arena has two ice rinks on the lower level and a bingo hall on the upper level. People started to get symptoms like fatigue, headache, and dizziness after the first rink was resurfaced. The rink was resurfaced by a twenty-year old propane-powered ice resurfacing machine. The concentration of carbon monoxide was obtained and it was found out to be 354ppm. An investigation was conducted later to find the source of the carbon monoxide and the ice resurfacing machine was to blame. The ice resurfacing machine was the only carbon monoxide source in the arena and it seemed that there was a malfunction with the machine. The ventilation system in the arena was not on when the ice resurfacing machine was in operation and a high concentration of carbon monoxide was trapped in the arena (12).

In 2003 there were complaints of dizziness and nausea during a college hockey game in an ice arena in Burrillville, Rhode Island. People were evacuated from the arena due to a carbon monoxide leak. At least twenty people were reported to be treated in a hospital. It was later revealed that the carbon monoxide leak was caused by the ice resurfacing machine and the associated fumes coming from the machine (31).

It seems that most incidences of carbon monoxide poisoning outside homes seem to be caused by ice resurfacing machines. These machines, Zambonis, are usually powered by gasoline, diesel, or propane. If Zambonis are not functioning properly, carbon monoxide can be produced and released at high concentrations into the atmosphere. Ice resurfacing machines should be maintained regularly according to the manufacturer's specifications. Besides maintaining the ice resurfacing machine in a good condition, good and adequate ventilation will prevent the buildup of carbon monoxide in the local atmosphere. Ice resurfacing machines should warm up in an area that is well ventilated. It is also suitable to equip ice resurfacing machines with a portable exhaust hose that fits on the exhaust pipe of the machines and vents carbon monoxide to the outdoors (31).

Purpose of the Study

Due to the increased awareness in people regarding the dangers of carbon monoxide, carbon monoxide detectors are getting popular. Carbon monoxide detectors detect the concentration of carbon monoxide that is in the air. An alarm will sound if carbon monoxide is building up to a harmful level. This will make people aware of the presence of carbon monoxide level indoors and appropriate actions can and should be taken. Carbon monoxide levels in indoor sporting arenas should be assessed critically because of the number of people that can be affected. The range of people that may be affected is wide. Those susceptible will include skaters, ice hockey players, bystanders, and maintenance workers. There should be a designated person to monitor the level of carbon monoxide in the ice arena regularly to ensure the level is within the acceptable range. The purpose of the current research study was to monitor the carbon monoxide concentration in ice arenas and examine if the levels of carbon monoxide were within the acceptable range.

Methods and Methodology

Carbon Monoxide Meters

To ensure the levels of carbon monoxide are within the acceptable range, carbon monoxide levels should be monitored. There are many carbon monoxide detectors available on the market, but choosing the right one can be confusing. Carbon monoxide detectors are mostly used at home or in the office to sense the presence of carbon monoxide. The detector will sound or alarm if there is carbon monoxide in the ambient air. Common carbon monoxide detectors used at home or in the office are not suitable to use in ice rinks because these detectors need to be plugged into an electrical outlet. It is best to use battery-powered gas instruments to monitor the carbon monoxide levels in ice rinks. Gas instruments have several functions: detection, monitoring, and analysis. The detection function in gas instruments works in the same way as in the carbon monoxide detectors used at home or in the office. The purpose of monitoring is to determine which gas is being measured and the amount that is present in the atmosphere (1). Analyzers detect all the gases present in the atmosphere and the data can be used for further analysis (1). The price for a carbon monoxide meter varies from $60 to $800 (16). Six carbon monoxide meters will be discussed including in the following: personal gas monitors, passive diffusion tubes, pump and tube systems, digital carbon monoxide meters, carbon monoxide stick meters, and portable combustion analyzers.

Personal gas monitors are able to monitor toxic gases or oxygen in the atmosphere continuously (16). It is supplied with an electrochemical sensor to monitor carbon monoxide. The measuring range for carbon monoxide is 0-500ppm and the device is CSA approved (16).

No pump is required to measure carbon monoxide using passive diffusion tubes. They are simple to use and are the least expensive of all choices available. Diffusion tubes for carbon monoxide contain an absorbent substance and an indicator that bind to the carbon monoxide molecules present in the sample being tested. When the absorbent takes up the carbon monoxide, the indicator present will change color suggesting that carbon monoxide is present. The amount of carbon monoxide detected is proportional to the length of the color change displayed in the diffusion tube. Therefore, the color change in the tube indicates the presence of carbon monoxide and the length of the color change corresponds to the concentration of carbon monoxide (16). For example, if the length of color change is short, that means the concentration of carbon monoxide is low. The measuring range is from 1.04 to 2,000ppm. One disadvantage of this technique is that it is not very accurate because there is no displayed reading provided and the experimenter must extrapolate the reading from the tube directly.

The pump and tube system works in similar fashion to the passive diffusion tube except that a pump is required to push an air sample through the analyzer (16). The concentration of carbon monoxide is obtained through the color change in the tubes. The range of carbon monoxide detection is 5-1,000ppm.

Digital carbon monoxide meters give accurate measurements and are easy to use. These meters can detect carbon monoxide from 0-1,000ppm with 1ppm resolution (16). The accuracy of the meter is ± 10ppm.

The stick meter is similar to the digital meter since it has similar resolution and accuracy as the digital meter. One advantage of the stick meter is that it can measure carbon monoxide from 0-10,000ppm (16). Response time is quick as it only takes less than five seconds to perform a reading.

The combustion analyzer is the most expensive among the discussed because it can detect up to five gases. It can detect carbon monoxide up to 10,000ppm (16).

The instrument used in this study was the TSI Q-Trak. It can monitor four parameters: carbon monoxide, carbon dioxide, temperature, and humidity. The Q-Trak can measure carbon monoxide from 0-500ppm with ± 3ppm accuracy (27). The response time is quick as it only takes less than one minute to take a reading. An advantage of the Q-Trak is that it has datalog memory built into the unit (27). Calibration of the instrument is described in Appendix B. After calibrating the Q-Trak, the gas sampling function will be set to carbon monoxide and when it is time to take the reading, the instrument will be set to read. Once the instrument displays a value, the measurement for carbon monoxide gas will be recorded in the memory of the unit. The Q-Trak is portable, easy to handle and use. This instrument was used in this study because it was available for loan at the BCIT Environmental Health Department. The meters discussed in the above section were all quite expensive to purchase for this study.

Methods

The purpose of this research study was first, to determine the carbon monoxide level before and after ice resurfacing and second, to check if the level, after ice resurfacing, was within the acceptable range. There were two sets of guidelines for exposure limit on carbon monoxide in British Columbia. One set was for occupational exposure and the other set was for residential exposure. Since there were no guidelines for carbon monoxide in an indoor sporting facility in British Columbia, one of the two sets was chosen for the comparison of the results. In this research study, the results obtained were compared with two sets of guidelines: the residential exposure set by Health Canada and the ORFA guidelines. The purpose for using the residential exposure guideline was because the exposure limit was more stringent than the guidelines for occupational exposure set by Health Canada. Therefore, the results obtained were compared with levels $\leq$ 11ppm. The results obtained were also compared with the carbon monoxide guideline suggested by ORFA, which was $\leq$ 25ppm.

To obtain significant statistical data, thirty ice rinks were measured for carbon monoxide levels. The locations of all ice rinks available were listed in Appendix A of which thirty were selected randomly for this study. All thirty ice rinks chosen were in Greater Vancouver and the Fraser Valley as the cost of performing this study was limited going to other BC locations. Two sets of samples were taken in each ice rink. The first set of samples was taken before ice resurfacing and the second set of samples were taken after ice resurfacing. The difference was evaluated to determine if there was a significant change in carbon monoxide levels after ice resurfacing. The second part of the study was to use the carbon monoxide levels obtained after ice surfacing and compare them with BC and ORFA standards.

Before proceeding with sampling, the ice rinks chosen were approximately the same size so the ice resurfacing time was about the same. The size of the rink was determined by asking ice rink management or personnel. Therefore, the measurements for carbon monoxide obtained were standardized for the apparent differences in the rink sizes. Also, this would ensure that the size of the ice rink would not affect carbon monoxide measurements. Hence, the results achieved were consistent and valid. For this research, almost all chosen ice rinks were standard sizes used for playing hockey. After deciding on the ice rinks, permission was asked for the sampling to take place in the ice rinks. The list of contacted people is listed in Appendix C. The time of day that samples were collected was considered to obtain a consistent and non-biased result, the reason being that this study was concerned with comparing carbon monoxide levels at an ice rink before and after ice resurfacing. Moreover, a Zamboni cleaned the ice only after the rink was used by its patrons. Therefore, carbon monoxide levels were measured when an ice rink was used and needed resurfacing. This was why the time of the day for measuring carbon monoxide was important. Inclusion criteria were indoor ice rinks in Greater Vancouver and the Fraser Valley, and ice rinks that were used and resurfaced by Zambonis. Exclusion criteria were outdoor ice rinks, ice rinks that were not used and not resurfaced by a Zambonis, and any rinks that were cleaned by electric Zambonis.

Furthermore, the locations of where the samples were taken were similar in all thirty ice rinks. Samples were taken near the ice rink surface, where four readings were taken before and after ice resurfacing, for a total of eight measurements per rink. All readings in all rinks were recorded close to the ice over the rink fencing wall that runs the ice's perimeter. The reason for sampling carbon monoxide near the ice surface was because this was where most exposure to carbon monoxide would occur relative to the rest of the ice arena. Since almost all ice rinks were for hockey purposes, therefore, the most susceptible people having carbon monoxide poisoning will be the players on ice. For this reason, samples were taken near the ice surface in order to determine if the levels were safe. It was best to take several readings and get an average, thus, to eliminate any bias on a reading taken only in one location. Figure 1 depicts where the four readings were taken at an ice rink (30).

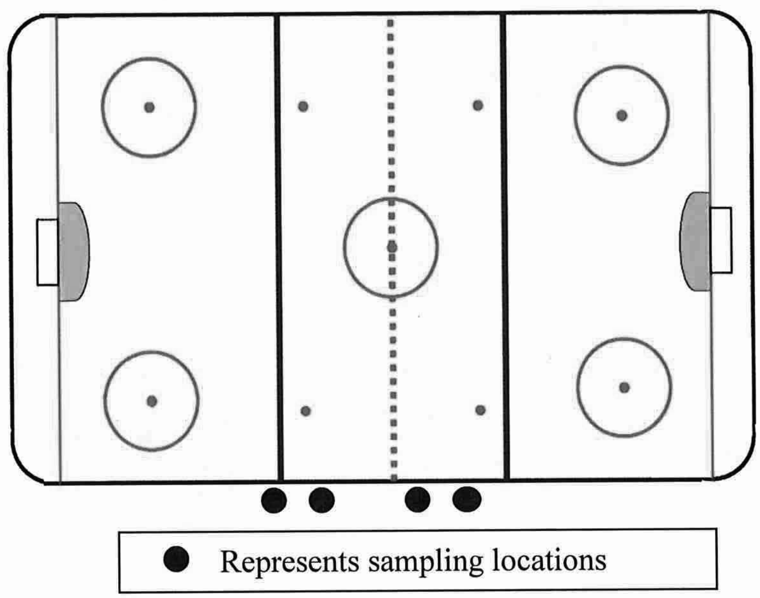

Figure 1

Temperature and humidity were recorded by the Q-Trak to note the effect of temperature or humidity on carbon monoxide ventilation. The reason for recording temperature and humidity was to determine whether adequate ventilation was taking place in the ice arena. Carbon monoxide poisoning occurs because the ventilation system of the facility does not ventilate out carbon monoxide, so high levels of the gas stay in the arena.

The number of people in the ice rink was noted as well because this would affect the carbon monoxide levels as well as the humidity and temperature in the ice rink. This was another reason as to why taking readings consistently at the same time of the day was important. For example, at 7pm nearly all ice rinks were at near capacity watching a hockey game, since hockey is in season right now. Also, at 1pm nearly all ice rinks were used by children for skating as a part of their physical education curriculum. Thus, taking measurements at these times were optimal because ice was resurfaced more often.

The reliability and validity of measurements were ensured by calibrating the Q-Trak, taking multiple (four) samples at one time, taking samples near the ice surface, standardizing for various rink sizes, collecting samples before and after ice resurfacing, and performing thirty trials for this experiment. A set of pilot trial runs for this experiment was conducted prior to commencing this study to ensure any flaws were eliminated and appropriate amendments to the protocol were made. Originally, the samples were to be taken on all four sides of the rink. Almost all of the rinks sampled were ice hockey arenas and, therefore had protective glasses all around the rink. It was then impossible to conduct sampling in this manner without getting onto the rink. Due to the research budget, it was not feasible to go onto the rink and get samples. Therefore, these locations were changed to on the players' benches because of the easier access to the new sampling locations.

Statistical Analysis

After collecting the data, the data was used for statistical analysis. This analysis was conducted by using the Number Crunching Statistical Software (NCSS). Appendix D contains all the readings for carbon monoxide levels, humidity, and temperature. Numeric data was collected for statistical analysis.

First Part of the Study

For this part, in which two sample sets were taken in each ice rink and the difference in levels were noted, a two-tailed t test was performed. The average of the four readings per rink were calculated to get a mean reading of the carbon monoxide level for both before and after ice resurfacing for each ice rink. Also, standard deviations for the means were calculated in order to describe the variance amongst the raw data collected. Next, a two-tailed test was conducted to obtain a p-value for statistical significance. Appendix E contains a copy of these results. The null hypothesis stated that there was no difference between levels of carbon monoxide before and after ice cleaning from a Zamboni. The alternative hypothesis stated that there was a difference between the two. If the p-value (probability level) was less than 0.05, that suggested that the results rejected the null hypothesis. The p-value obtained from the trial test was 0.401491 according to the Equal-Variance T-Test Section. The results did not reject the null hypothesis because the p-value obtained was greater than 0.05, so that means the results were statistically significant. It did not accept the alternative hypothesis because there was no difference between the two levels. Also, the p-value for the difference>0 was 0.799, meaning the results were statistically significant for the null hypothesis because the p-value was greater than 0.05. The means and standard deviations for each rink are reported in Appendix D. The standard deviations range from 0-0.8, indicating a small difference between readings for each rink.

Second Part of the Study

A chi-square test was used to check if the samples taken after ice resurfacing were within the acceptable range of carbon monoxide of 11 ppm set by Health Canada and 25ppm set by ORFA. Details of the two results are listed in Appendix F and G, respectively. The null hypothesis was that the carbon monoxide levels, after ice resurfacing, in all ice rinks complied with the Health Canada standards or ORFA standards. The alternative hypothesis stated the carbon monoxide levels in all ice rinks varied and did not comply with those standards. For the Health Canada standards, the p-value for the results was 0.000048. Since the p-value obtained was less than 0.05, the results rejected the null hypothesis. For the ORFA standards, the p-value obtained was 0.00240 and was less than 0.05, further rejecting the null hypothesis. With both results rejecting the null hypothesis, this indicates not all rinks complied with the Health Canada and ORFA standards.

Discussion

Eight out of thirty rinks had carbon monoxide levels of 0ppm. However, carbon monoxide was noted in most rinks and levels ranged from 0.25-25ppm. Of the twenty-two rinks that noted carbon monoxide levels, most rinks had levels at or below 5ppm. Only two rinks had high levels of carbon monoxide at 15ppm and 25ppm. These two rinks started with relatively high levels of carbon monoxide before ice resurfacing and they were both in the same ice arena in Burnaby.

The first objective of the study was to determine if there were any differences in levels of carbon monoxide before and after ice resurfacing. When looking at the data, there were differences in carbon monoxide levels before and after ice resurfacing; however, the differences were not significant enough to make note in the statistical analysis, since the majority of the thirty ice rinks did not show significantly high levels of carbon monoxide. The second objective of the study was to determine if the carbon monoxide levels after ice resurfacing exceeded the guidelines. This study compared the results with two sets of guidelines; the first was the residential exposure set by Health Canada, and the second, the exposure limit set by Ontario Recreation Facilities Association (ORFA). The residential exposure limit for carbon monoxide is ≤11ppm. Two of the thirty rinks did not comply with this guideline. On the other hand, if the results were compared with the level set by ORFA of 25ppm, all thirty rinks were complying. The difference level between the two guidelines is due to the area of interest. In the Health Canada standard, it is for residential exposure so the level will be lower due to the issue of enclosed spaces. Whereas, the ORFA standard determines the standard solely for recreational facilities; therefore, the level is more suitable to compare the results with in this study.

One interesting point to note was that temperature of the ice rinks tended to decrease after ice resurfacing while relative humidity would increase. This was mostly due to the water added to the ice when the Zambonis were resurfacing the ice. The water added onto the ice became cold like ice water, which made the temperature in the ice arenas colder. With cold water added to the ice, more water vapor was in the ambient atmosphere. The increased water vapor added to the humidity in the atmosphere; therefore, the relative humidity increased when the ice was being resurfaced. There is no evidence showing that increased humidity or temperature will contribute to the occurrence of carbon monoxide. However, high relative humidity will contribute to mold growth in an ice arena potentially contributing to mold contamination. Mold can produce mycotoxins which could cause allergic reactions in individuals and therefore, it is a health concern.

In some of the ice arenas, carbon monoxide sensors were attached on the wall for monitoring. The staff in the ice arenas usually checked the levels every 8 hours. Not all rinks had carbon monoxide sensors on wall for monitoring. Attaching carbon monoxide sensor on walls is encouraged to monitor carbon monoxide levels, especially for ice arenas that detected higher levels of carbon monoxide.

Limitations

There is always room to improve in a research study. The study could have been better if the study budget was greater to provide access to taking samples on the ice itself. Even though taking four samples on players' benches would give a general idea of the carbon monoxide level in an ice arena, only one area in the ice arena was being tested. If there is more money available, all four sides of the ice rink can be sampled on the ice to get a more accurate result. Taking samples on all sides will also reduce the bias of the results. Again, the results of the study could be biased because only one area was being sampled.

Conclusions

The purpose of this research study was first, to determine the carbon monoxide level before and after ice resurfacing and second, to check if the level, after ice resurfacing, was within the acceptable range. Thirty indoor ice rinks were chosen randomly from Greater Vancouver and the Fraser Valley. Statistics had proven that there was no difference on the carbon monoxide level before and after ice resurfacing. Two out of thirty ice rinks did not comply with the residential exposure level set by Health Canada of 11ppm, while all thirty rinks complied with the 25ppm set by the Ontario Recreation Facilities Association. Attaching carbon monoxide sensors on walls would be recommended to all ice arenas to monitor the levels of carbon monoxide. This would enable ice arena maintenance staff and PHI/EHOs to effectively monitor carbon monoxide levels in these premises. Monitoring of carbon monoxide would reduce the risk of carbon monoxide poisoning and protect all individuals in ice arenas. Servicing the Zamboni regularly is also recommended to repair any deficiencies before a problem occurs.

Recommendations

As discussed earlier, attaching carbon monoxide sensors on walls and servicing the Zamboni are recommendations which would reduce the occurrence of carbon monoxide poisoning. Further research can be done on all four sides of the ice rink and taking carbon monoxide samples on the ice in order to obtain more accurate results. Another potential research study can entail looking at the relationship between the number of times the Zamboni is serviced and the apparent carbon monoxide levels recorded.

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Appendix

Appendix A – Locations of Ice Rinks (4)

Abbotsford Recreation Centre – 34690 Old Yale Road, Abbotsford, BC
Aldergrove Community Arena – 2882 – 272nd Avenue, Aldergrove, BC
Burnaby 8 Rinks Arena – 6501 Sprott Street, Burnaby, BC
Burnaby Winter Club – 4990 Canada Way, Burnaby, BC
Canlan Ice Sports (North Vancouver)—2411 Mount Seymour Parkway, N. Van., BC
Centre Ice – 3600 Townline Road, Abbotsford, BC
Cloverdale Arena – 6090 – 176th Street, Surrey, BC
Copeland Sports Centre – 3676 Kensington Street, Burnaby, BC
Coquitlam Sports Centre – 633 Poirier Street, Coquitlam, BC
Great Pacific Forum – Planet Ice – 10388 Nordell Ct., Delta, BC
Harry Jerome RecCentre – 123 East 23rd Street, North Vancouver, BC
Kensington Park Arena – 6159 Curtis Street, Burnaby, BC
Langley Civic Centre – 20699 42nd Avenue, Langley, BC
Langley Twin Ice Rinks – 5700 Langley By-pass, Langley, BC
Langley Sportsplex – 20165 – 91A Avenue, Langley, BC
Magnussen RecCentre – 2300 Kirkstone Road, North Vancouver, BC
Matsqui Recreation Centre – 3106 Clearbrook Road, Abbotsford, BC
Minoru Arenas – 7551 Minoru Gate, Richmond, BC
Moody Park Arena – 701 – 8th Avenue, New Westminster, BC
MSA Arena – 2323 Emerson Road, Abbotsford, BC
North Delta Recreation Centre – 11415 – 84th Avenue, Delta, BC
North Shore Winter Club – 1325 E. Keith Road, North Vancouver, BC
North Surrey Recreation Centre – 10275 – 135th Street, Surrey, BC
Port Coquitlam Recreation Complex – 2150 Wilson Avenue, Port Coquitlam, BC
Queen's Park Arena – 1st Street & 3rd Avenue, New Westminster, BC
Richmond Ice Centre – 14140 Triangle Road, Richmond, BC
Seafair Sports Centre – 3100 Francis Road, Richmond, BC
Sungod Arena – 7825 – 112th Street, Delta, BC
South Delta Recreation Centre – 1720 – 56th Street, Delta, BC
Stardust Skating Centre – 10240 – 135th Street, Surrey, BC
Total Sport Entertainment – 2300 Rocket Way, Coquitlam, BC

* The highlighted ones were the ones being sampled. Some of these arenas had more than one rink in the facility. Those were considered as one rink because the ventilation system was separated from the other rinks. Also, every rink, even in the same arena, had its own Zamboni, so it was treated as one sample location.

Appendix B. Calibration of Q-Trak

CO_2
http://www.bnl.gov/esh/shsd/SOP/PDF/IH97260.pdf
Both zero CO_2 air and a span gas concentration are needed for calibration.

Procedure:

1. Select *Calibration* from main menu
2. Select *CO* and press *Enter* key
3. Cover the probe with the calibration collar and ensure a tight fit
4. Install the regulator on the zero calibration gas and connect tubing to the fitting marked Gas In.
5. Press the *Enter* key and turn on the gas (0.3LPM)
6. Press the *Enter* key again to begin zero gas calibration. After averaging the zero gas the display shows "Zero Cal Complete".
7. Turn off the gas. Press the *Enter* key again.
8. Attach the regulator to the span gas and press the *Enter* key
9. Adjust the span gas concentration using the *up/down arrow* keys
10. Press the *Enter* key to accept
11. Turn on the span gas and press the *Enter* key to begin calibrating. When complete the display reads "Span Cal Complete".
12. Turn off the gas, press the *Enter* key and remove the calibration collar.

CO

Repeat all steps listed above with a cylinder containing carbon monoxide.

Temperature/Humidity

Procedure:

1. Locate the temperature sensor and the reference device so that they sense the same air conditions
2. Select *Temp2* from the *Calibration* menu by using the up/down arrow keys
3. A reminder appears the ensure the environmental conditions are stable before continuing with the calibration
4. Compare reading on monitor and with the reading from the reference device. Adjust the value by using the up/down arrow keys so the displayed measurement is the same as the measurement indicated by the reference device. Press the *Enter* key to accept
5. The screen will highlight "Cal Complete" after completion of calibration. Press the *Enter* key to continue

Appendix C. List of Contacted Personnel

Mr. Al Walls (604) 291-0626 (Burnaby 8 Rinks)

Mr. Dale Isley (604) 448-5356 (Richmond)

Mr. Den McInnis (Port Coquitlam)

Mr. Duncan Jessman (604)841-9817

Mr. Gary (604) 856-1517 (Aldergrove/Langley)

Mr. Gaye Stewart (604) 952-3053 (Delta)

Mr. Jamie Rennie (604) 591-4792 (Surrey)

Ms. Jo Anne Powell (604) 448-5351 (Richmond)

Mr. John McMurchy (Delta)

Ms. Joyce Fordyce (604) 933-6060 (Coquitlam)

Mr. Kerry Bysouth (604) 952-3028 (Delta)

Ms. Lisa Hartley (604)859-4264 (Abbotsford)

Mr. Steve Naper (604) 952-3028 (Delta)

Mr. Wendell Cornwall (604)320-2202 (Burnaby)

Appendix D

Carbon Monoxide Levels

Arenas	Before (ppm)				Mean	SD	After (ppm)				Mean	SD
	1	2	3	4	(ppm)		1	2	3	4	(ppm)	
Kensington Arena	0	0	0	0	0	0	0	0	0	0	0	0
North Delta Recreation Centre	0	0	0	0	0	0	0	0	0	0	0	0
Sungod Arena	0	0	0	0	0	0	0	0	0	0	0	0
Bill Copeland -South	0	0	0	0	0	0	1	1	1	1	1	0
Bill Copeland -North	0	0	0	0	0	0	1	1	1	1	1	0
Minoru Arena - Stadium	0	0	0	0	0	0	0	1	0	0	0.25	0.5
Minoru Arena - South Rink	0	0	0	0	0	0	1	1	0	0	0.5	0.5773503
Moody Arena	0	0	0	0	0	0	0	0	0	0	0	0
Queen's Arena	2	2	1	2	1.75	0.5	3	4	3	3	3.25	0.5
Port Coquitlam Recreation Centre- Green	4	3	3	2	3	0.8164966	4	4	4	4	4	0
Port Coquitlam Recreation Centre- Blue	0	0	0	0	0	0	0	0	0	0	0	0
Matsqui Recreation Centre	4	4	4	4	4	0	3	4	3	3	3.25	0.5
MSA Arena	1	1	1	1	1	0	1	1	1	1	1	0
Abbotsford Recreation Centre	2	2	2	2	2	0	4	3	3	3	3.25	0.5
8 Rinks - Blue B	4	4	4	4	4	0	5	5	5	4	4.75	0.5
8 Rinks - Red A	3	3	3	3	3	0	2	2	2	2	2	0
8 Rinks - Blue A	4	3	3	4	3.5	0.5773503	3	3	3	3	3	0
8 Rinks - Gold A	2	2	2	2	2	0	5	5	5	5	5	0
8 Rinks - Green B	17	17	17	17	17	0	25	25	25	25	25	0
8 Rinks - Green A	2	2	2	2	2	0	5	4	5	5	4.75	0.5
8 Rinks - Gold B	8	7	8	8	7.75	0.5	15	15	15	15	15	0
Aldergrove Community Arena	0	0	0	0	0	0	1	1	1	1	1	0
Langley Civic Centre	1	0	0	1	0.5	0.5773503	0	0	0	0	0	0
Coquitlam Sports Complex - Main Arena	0	0	0	0	0	0	0	0	0	0	0	0
Coquitlam Sports Complex - Annex Arena	0	0	0	0	0	0	1	1	1	1	1	0
Richmond Ice Centre - Coliseum	3	3	3	3	3	0	3	2	3	2	2.5	0.5773503
Richmond Ice Centre - Gardens	1	1	1	1	1	0	3	3	2	2	2.5	0.5773503
Richmond Ice Centre - Garage	1	1	1	1	1	0	1	0	0	1	0.5	0.5773503
Richmond Ice Centre - Forum	2	2	1	1	1.5	0.5773503	2	2	2	2	2	0
Richmond Ice Centre - Pond	3	2	3	2	2.5	0.5773503	3	2	2	3	2.5	0.5773503
Richmond Ice Centre - Igloo	1	0	0	0	0.25	0.5	0	0	0	0	0	0

Appendix D
Humidity and Temperature Levels

Arenas	Humidity (%RH)		Temperature (oC)		Number of People
	Before	After	Before	After	
Kensington Arena	55.3	58.4	13.8	11.7	Parent & Tot Skate - 15 people
North Delta Recreation Centre	58.8	63.4	7.1	5.7	0 at time of sampling
Sungod Arena	55.3	56.4	7.9	6.2	Family Skate - 8 people
Bill Copeland -South	50.8	49.0	11.8	10.2	School PE cirriculum - 20 people
Bill Copeland -North	51.8	52.3	12.3	11.9	Hockey practice - 12 people
Minoru Arena - Stadium	56.3	58.2	12.8	11.6	Children Skate - 25 people
Minoru Arena - South Rink	56.4	57.2	13.0	11.4	Hockey Game - 20 people
Moody Arena	59.8	57.4	13.9	16.5	Skating - 20 peopple
Queen's Arena	62.0	72.7	12.8	9.8	Hockey practice - 15 people
Port Coquitlam Recreation Centre- Green	75.1	75.4	8.9	7.6	Children Skate - 25 people
Port Coquitlam Recreation Centre- Blue	62.8	78.7	13.5	7.5	Senior Skate - 5 people
Matsqui Recreation Centre	66.1	76.2	15.6	8.5	0 at time of sampling
MSA Arena	68.4	81.4	14.9	9.3	Family Skate - 8 people
Abbotsford Recreation Centre	79.1	71.8	11.0	11.6	Skating - 16 people
8 Rinks - Blue B	65.2	65.4	13.1	14.0	Figure Skating - 13 people
8 Rinks - Red A	61.9	68.4	12.9	8.8	Hockey Game - 12 people
8 Rinks - Blue A	67.4	62.4	10.1	12.6	Figure Skating - 5 people
8 Rinks - Gold A	68.2	71.3	9.2	7.3	Hockey Game - 12 people on ice; 5-6 on bench
8 Rinks - Green B	69.8	55.1	6.4	14.1	Hockey Practice - 13 people
8 Rinks - Green A	75.6	65.8	5.7	10.2	Hockey Game - 12 people on ice; 2 on bench
8 Rinks - Gold B	65.5	62.0	7.8	10.2	Figure Skating - 32 people
Aldergrove Community Arena	68.0	82.7	11.1	5.9	0 at time of sampling
Langley Civic Centre	59.8	67.4	11.9	9.3	Stick & Puck Practice - 20 people on ice; 6 spectators
Coquitlam Sports Complex - Main Arena	71.7	74.7	11.9	10.2	0 at time of sampling
Coquitlam Sports Complex - Annex Arena	65.2	60.5	10.8	14.6	Figure Skating - 15 on ice; 17 spectators
Richmond Ice Centre - Coliseum	52.8	65.3	17.3	9.2	0 at time of sampling
Richmond Ice Centre - Gardens	66.8	59.0	9.1	11.9	0 at time of sampling
Richmond Ice Centre - Garage	68.9	70.6	11.8	7.9	Hockey Game - 12 on ice; 8 spectators
Richmond Ice Centre - Forum	70.8	72.4	9	10.9	Hockey Practice - 19 on ice; 9 spectators
Richmond Ice Centre - Pond	74.3	71.2	8.8	7.3	Hockey Practice - 14 on ice; 4 spectators
Richmond Ice Centre - Igloo	73.9	66.2	8.2	8.4	Hockey Practice - 10 on ice; 2 spectators

Appendix E – Two Tailed t-test

Two-Sample Test Report

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Database

Descriptive Statistics Section

Variable	Count	Mean	Standard Deviation	Standard Error	95% LCL of Mean	95% UCL of Mean
C1	31	1.959677	3.30725	0.5939996	0.7465683	3.172786
C2	31	2.870968	5.012015	0.9001845	1.032546	4.70939

Note: T-alpha (C1) = 2.0423, T-alpha (C2) = 2.0423

Confidence-Limits of Difference Section

Variance Assumption	DF	Mean Difference	Standard Deviation	Standard Error	95% LCL of Mean	95% UCL of Mean
Equal	60	-0.9112903	4.246068	1.078503	-3.068617	1.246036
Unequal	51.96	-0.9112903	6.004848	1.078503	-3.075502	1.252921

Note: T-alpha (Equal) = 2.0003, T-alpha (Unequal) = 2.0067

Equal-Variance T-Test Section

Alternative Hypothesis	T-Value	Prob Level	Decision (5%)	Power (Alpha=.05)	Power (Alpha=.01)
Difference <> 0	-0.8450	0.401491	Accept Ho	0.132184	0.040061
Difference < 0	-0.8450	0.200745	Accept Ho	0.209141	0.066773
Difference > 0	-0.8450	0.799255	Accept Ho	0.006562	0.000809

Difference: (C1)-(C2)

Aspin-Welch Unequal-Variance Test Section

Alternative Hypothesis	T-Value	Prob Level	Decision (5%)	Power (Alpha=.05)	Power (Alpha=.01)
Difference <> 0	-0.8450	0.402008	Accept Ho	0.131764	0.039765
Difference < 0	-0.8450	0.201004	Accept Ho	0.208719	0.066400
Difference > 0	-0.8450	0.798996	Accept Ho	0.006589	0.000817

Difference: (C1)-(C2)

Tests of Assumptions Section

Assumption	Value	Probability	Decision(5%)
Skewness Normality (C1)	5.3227	0.000000	Reject normality
Kurtosis Normality (C1)	4.5452	0.000005	Reject normality
Omnibus Normality (C1)	48.9896	0.000000	Reject normality
Skewness Normality (C2)	5.3516	0.000000	Reject normality
Kurtosis Normality (C2)	4.4565	0.000008	Reject normality
Omnibus Normality (C2)	48.5001	0.000000	Reject normality
Variance-Ratio Equal-Variance Test	2.2966	0.025944	Reject equal variances
Modified-Levene Equal-Variance Test	0.4735	0.494054	Cannot reject equal variances

Appendix F – Chi-Square Test (11ppm)

Cross Tabulation Report

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Database

Counts Section

	C2				
C1	**Compliance at 11 ppm**		**No**	**Yes**	**Total**
0	0	0	8	8	
0.25	0	0	1	1	
0.5	0	0	2	2	
1	0	0	5	5	
2	0	0	2	2	
2.5	0	0	3	3	
3	0	0	1	1	
3.25	0	0	3	3	
4	0	0	1	1	
4.75	0	0	2	2	
5	0	0	1	1	
15	0	1	0	1	
25	0	1	0	1	
Actual CO (ppm)		1	0	0	1
Total	1	2	29	32	

The number of rows with at least one missing value is 0

Chi-Square Statistics Section

Chi-Square	64.000000	
Degrees of Freedom	26	
Probability Level	0.000048	Reject Ho

WARNING: At least one cell had an expected value less than 5.

Appendix G – Chi-Square Test (25ppm)

Cross Tabulation Report

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Database

Counts Section

	C2			
C1	**Compliance at 25 ppm**		**Yes**	**Total**
0	0	8	8	
0.25	0	1	1	
0.5	0	2	2	
1	0	5	5	
2	0	2	2	
2.5	0	3	3	
3	0	1	1	
3.25	0	3	3	
4	0	1	1	
4.75	0	2	2	
5	0	1	1	
15	0	1	1	
25	0	1	1	
Actual CO (ppm)		1	0	1
Total	1	31	32	

The number of rows with at least one missing value is 0

Chi-Square Statistics Section

Chi-Square	32.000000	
Degrees of Freedom	13	
Probability Level	0.002402	Reject Ho

WARNING: At least one cell had an expected value less than 5.

Two-Sample Test Report

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Database

Median Statistics

Variable	Count	Median	95% LCL of Median	95% UCL of Median
C1	31	1	0	2
C2	31	1	0.5	3

Mann-Whitney U or Wilcoxon Rank-Sum Test for Difference in Medians

Variable	Mann Whitney U	W Sum Ranks	Mean of W	Std Dev of W
C1	409	905	976.5	69.70467
C2	552	1048	976.5	69.70467

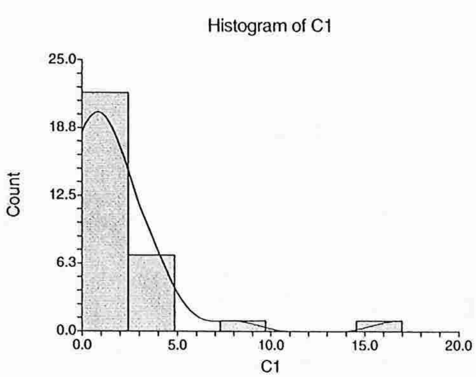
Number Sets of Ties = 10, Multiplicity Factor = 8808

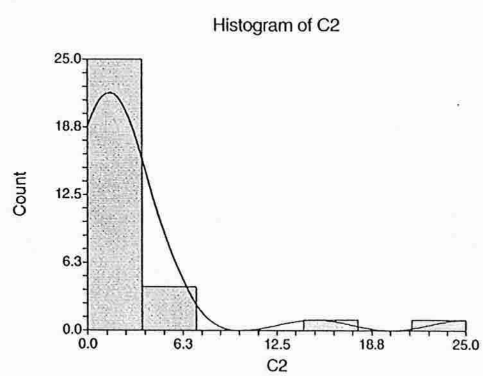
	Exact Probability		Approximation Without Correction			Approximation With Correction		
Alternative Hypothesis	Prob Level	Decision (5%)	Z-Value	Prob Level	Decision (5%)	Z-Value	Prob Level	Decision (5%)
Diff<>0			-1.0258	0.305007	Accept Ho	-1.0186	0.308401	Accept Ho
Diff<0			-1.0258	0.152503	Accept Ho	-1.0186	0.154200	Accept Ho
Diff>0			-1.0258	0.847497	Accept Ho	-1.0329	0.849182	Accept Ho

Kolmogorov-Smirnov Test For Different Distributions

Alternative Hypothesis	Dmn Criterion Value	Reject Ho if Greater Than	Test Alpha Level	Decision (Test Alpha)	Prob Level
D(1)<>D(2)	0.129032	0.3454	.050	Accept Ho	0.9634
D(1)<D(2)	0.129032	0.3454	.025	Accept Ho	
D(1)>D(2)	0.000000	0.3454	.025	Accept Ho	

Plots Section





Two-Sample Test Report

Page/Date/Time 3 06/03/2006 3:06:00 PM
Database