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Investigation of Air Quality Problems in an Indoor Swimming Pool: A Case Study

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ABSTRACT

Introduction: Trichloramine (NCl_3) is the contaminant suspected the most to cause irritative respiratory symptoms among swimmers and swimming pool workers. Following complaints by employees working in an indoor swimming pool, this study set out to identify the determinants of NCl_3 air concentrations in that particular swimming pool.
Methods: To document NCl_3 air levels, air samples ($n = 26$) were collected once or twice a day for 3 h, at least 3 days per week, between October and December 2011. Water samples were taken three times during air sampling to verify free chlorine, chloramines, alkalinity, conductivity, pH, water temperature, and turbidity. Water changes were also recorded, along with the number of bathers. Ventilation (outdoor air flow) was modified to verify the influence of this important variable. Data were evaluated by analysis of variance.
Results: Mean NCl_3 air concentration was 0.38 mg m^{-3}. The best model explaining variations of NCl_3 air levels ($r^2 = 0.83$) included sampling period ($P = 0.002$, NCl_3 was higher in the evening versus the morning), water changes ($P = 0.02$, NCl_3 was lower with water changes between 60 and 90 min day^{-1} versus <60 min day^{-1}), and ventilation ($P = 0.0002$, NCl_3 was lower with ≥2 air changes per hour (ACH) versus <1 ACH).
Discussion and conclusion: Although based on only 26 air samples, our results indicate that ventilation is an important determinant of NCl_3 air concentration in swimming pool air. There is limited information available on the air quality of indoor swimming pools and the relationship with ventilation. Efforts are needed to document the situation and to develop state-of-the-art facilities for ventilation of indoor swimming pools.

KEYWORDS: air quality; chloramines; chlorine; disinfection by-products; NCl3; swimmer; swimming pool; swimming pool worker; trichloramine; ventilation

INTRODUCTION

Disinfection of the water in public pools is mandatory due to the risk of infection. However, disinfection processes generate different by-products that may result in risks to bathers and swimming pool workers. Some of these by-products can be irritating to the eyes and respiratory system.

When chlorine makes contact with nitrogen-containing organic matter introduced by swimmers, monochloramine, dichloramine, and trichloramine (NCl_3)

are formed. The latter is particularly volatile and irritating (Gagnaire *et al.*, 1994; Massin *et al.*, 1998; Parrat *et al.*, 2012). For that reason, and because of its frequent occurrence in the air of indoor swimming pools, NCl_3 is the most likely contaminant suspected to cause irritative respiratory symptoms among swimmers and workers (Jacobs *et al.*, 2007; Baxter, 2012).

There are some guidelines on NCl_3 concentrations in indoor swimming pool air. In 2006, the World Health Organization (WHO, 2006) suggested a limit of 0.5 mg m^{-3}. More recently, in France, the 'Agence française de sécurité sanitaire de l'environnement et du travail' (AFSSET) issued a reference limit of 0.3 mg m^{-3} (AFSSET, 2010) mainly for young children and workers. After a study of 30 swimming pools in Switzerland via a health questionnaire, Parrat *et al.* (2012) argued for similar concentrations as occupational exposure limits. Finally, in a report dedicated to ensuring safe environments for workers and others who may be exposed to chloramines, the organization Worksafe BC in British Columbia (Canada) recommended a value of 0.35 mg m^{-3} (WorkSafe BC, 2014).

Following complaints by workers experiencing irritative ocular and respiratory symptoms in an indoor swimming pool, the objective of this study was to investigate the impact of water quality and ventilation on NCl_3 levels.

METHODS

Sampling was done for 7 weeks in 2011, from October 24 to December 8. Pool length, width, and depth were 25, 14, and 1.04–3.7 m, respectively. Pool capacity was 794 936 L. At least 3 days per week, excluding weekends, one or two samples per day were taken for 3 h by pump (SKC, Model 224-PCXR8) adjusted to 1 l min^{-1} connected to filters (Pallflex Tissuquartz, Pall Life Sciences) impregnated with sodium carbonate and arsenic trioxide to trap chlorine compounds at one station on the side of the pool near the center of its length, at a height of 30 cm as close to the pool as possible (60 cm) to maximize the chances of seeing variations in NCl_3 levels while avoiding splashing. Twenty-six samples were taken during the entire study. To evaluate the influence of sampling period, each week, at least one sample was collected in the morning, one in the afternoon, and another in the evening. During air sampling, water samples were taken three times at a point close to the air sampling station, at 15–30 cm below the water surface.

Ventilation system capacity was 382.3 cubic meters per minute (c.m.m.) with a heat recovery system and dehumidifier. Air supply was located near the floor at the pool's perimeter. The water filtration system comprised two natural stone filters with a capacity of 3.3 square meters of filtration surface per filter. Pool water was treated with sodium hypochlorite.

We verified free and total chlorine concentrations in water with a colorimeter (Hach, DR870), and chloramine concentrations were deduced by the difference between total and free chlorine. pH and conductivity were determined by pH meter/conductimeter (Oakton, WD-35630–50). Alkalinity was verified by titration with sulfuric acid solution. Turbidity was measured by nephelometry (Hach, 2100N). Finally, air samples were analyzed to ascertain NCl_3 concentration by chloride determination with ion chromatography (Héry *et al.*, 1995). Other variables documented were number of bathers during the sampling period and water changes (water input from the drinking water network) during the day.

The ventilation system was controlled by percentage of damper openings. It was generally adjusted to 12% of total capacity. Ventilation was modified every week to verify its impact (Table 1). Outdoor air admission was closed for different periods during the night (from 0 to 6 h) to investigate the effect of closing outdoor air dampers at night. After data collection, the number of air changes per hour (ACH) was estimated according to the following formula:

ACH = (ventilation system capacity in c.m.m.) × (% fresh air/100) × 60/(room volume), where % fresh air was approximated with recorded temperatures of outdoor air, return air, and mixed air with the formula: % fresh air = $(T_{return} - T_{mixed})/(T_{return} - T_{outdoor})$.

We used univariate analysis of variance to verify the relationship between NCl_3 air concentrations and different potentially associated variables (sampling period, water changes, ACH, ventilation closed at night, average number of bathers, average chloramine, and free chlorine concentrations in water during air sampling). Variables related to NCl_3 air levels ($P < 0.3$) in univariate analysis were examined using multivariate models.

RESULTS

When calculating ACH after data collection, it was found that a mechanical problem affected damper control when the system was run at low capacity

Table 1. Design verifying the impact of ventilation.

Week	Number of samples	Ventilation closed during the night (number of hours)	Opening dampers (%)	ACH (mean for the week)
1	3	0	70	4.0
2	3	6	70	3.3
3	3	0	45	2.5
4	4	3	45	1.4
5	6	6	45	1.5
6	3	0	10	0.1
7	4	5	20	0.0

(between 10 and 20%), which explained the low ACH documented for Weeks 6 and 7 (Table 1).

During the 7-week project, mean NCl_3 air concentration was 0.38 mg m^{-3} (SD = 0.15; range: 0.11–0.70). In water, mean free chlorine and chloramine concentrations were respectively 1.4 mg l^{-1} (SD = 0.2; range: 0.9–1.9) and 0.6 mg l^{-1} (SD = 0.1; range: 0.4–0.8), while temperature was 28.3°C (SD = 0.5; range: 27.3–29.0). On average, 17.3 people (SD = 6.9; range: 5–30) were present during sampling, and the average period of water changes calculated per day was 62.7 min day^{-1} (SD = 20.1; range: 30–135) (60 min = 13 249 l).

Table 2 presents the final multivariate model describing the relationship between NCl_3 air concentrations and the variables identified in univariate analysis. The ventilation (P = 0.0002), the period of sampling (P = 0.002), and the water changes (P = 0.02) were related to the NCl_3 air concentrations. The coefficient of determination (r^2) was 0.83. We verified the interaction between sampling period and ventilation closed at night, but it was not significant (P = 0.46).

DISCUSSION

NCl_3 is a potent respiratory irritant (Baxter, 2012). It has been related to respiratory symptoms in swimmers (Lévesque *et al.*, 2006) and swimming pool workers (Jacobs *et al.*, 2007; Parrat *et al.*, 2012). A recent study suggested that exposure to NCl_3 may contribute to asthma development (Nordberg *et al.*, 2012).

The sampling period, water change quantity, and ventilation were the variables statistically associated with NCl_3 air concentration. Surprisingly, ventilation closed at night was not related to air contamination, and there was no interaction with sampling period. The integrated value of NCl_3 air concentrations documented for periods of 3 h could elucidate these results. With ventilation rates between 1.4 and 4 ACH (Table 1), closing the ventilation at night probably had more impact at the beginning of the sampling period in the morning, but was less significant after 3 h.

The number of bathers during the sampling period was not related to NCl_3 air concentrations. Nevertheless, as a whole, morning and afternoon (mean = 0.35 and 0.36 mg m^{-3}) concentrations were lower than in the evening (mean = 0.51 mg m^{-3}), probably reflecting swimming pool activity during the day.

Free chlorine and chloramine concentrations in water were not statistically related to NCl_3 air levels, probably due to the stability of these parameters during the study, which could be probably explained by the significance of water changes. The latter were clearly related to air contamination by NCl_3 (P = 0.02), concentrations being higher with water changes of <60 min day^{-1} (Table 2).

As expected, ventilation rates were also strongly associated with NCl_3 air concentrations (Table 2). Between 1 and 2 ACH, and at <1 ACH, the average NCl_3 levels were 0.42 and 0.50 mg m^{-3}, respectively. However, when the pool was ventilated at 2 ACH or more, the average NCl_3 concentrations were lower (≥2 ACH: 0.30 mg m^{-3}), reflecting the strong influence of this variable on air contamination.

The value of 0.30 mg m^{-3}, as documented for ventilation rates >2 ACH, was of a similar order of

Table 2. Final multivariate model[a] describing the relationship between NCl_3 air concentrations and different variables.

Variables	Number of samples	NCl_3 Mean ($mg\ m^{-3}$)	NCl_3 95% confidence interval	*P* values
Period of sampling				***0.002***[b]
Morning	10	0.35	0.29–0.41	
Afternoon	9	0.36	0.30–0.42	1
Evening	7	0.51	0.44–0.57	0.01
Water changes (min day^{-1})				***0.02***[b]
<60	6	0.49	0.42–0.56	
60 to <90	13	0.36	0.32–0.41	0.02
≥90	7	0.36	0.29–0.44	0.08
Air changes per hour				***0.0002***[b]
<1	7	0.50	0.44–0.57	
1 to <2	10	0.42	0.35–0.49	0.19
≥2	9	0.30	0.24–0.35	0.0003
Ventilation closed at night				***0.55***[b]
Yes	9	0.42	0.37–0.46	
No	17	0.39	0.33–0.46	0.55

[a]Coefficient of determination of the model: $r^2 = 0.83$.
[b]Global P-value for the variable.

magnitude as recent guidelines proposed in France (AFSSET, 2010), in British Columbia (WorkSafe BC, 2014), and by Parrat *et al.* (2012). We cannot extrapolate the results of this case study to all indoor swimming pools, but for the swimming pool investigated in our study, a ventilation rate of 2.5 ACH corresponded to approximately 0.157 c.m.m. m^{-2} (0.5 c.f.m. ft^{-2}), the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard for indoor pools (Cavestri and Seeger-Clevenger, 2008). Therefore, for this swimming pool, the ASHRAE standard would be sufficient to meet NCl_3 guidelines emitted in France and British Columbia.

CONCLUSION

In the province of Québec, as in many countries worldwide, there is no standard for NCl_3 in the atmosphere of indoor swimming pools. From a public health perspective, considering the large number of people in swimming pools every day, such a standard should be highly recommended. At the moment, values around 0.30 mg m^{-3} (AFSSET, 2010; Parrat *et al.*, 2012) or 0.35 mg m^{-3} (WorkSafe BC, 2014) are being suggested. Moreover, although there are papers in the literature on water and air quality in swimming pools, to our knowledge, few studies on ventilation systems in relation to air contamination in indoor swimming pools have been reported. Ventilating indoor swimming pools is not easy (Baxter, 2012), particularly in cold climates. As reflected by the results of this study, more research is needed on the design of ventilation systems able to exhaust NCl_3 and replace it with fresh air at ground (deck) level (Cavestri and Seeger-Clevenger, 2008) and appropriate standards about the performance of the ventilation systems in indoor swimming pools should be issued.

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DECLARATION FOR PUBLICATION

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