**UV-TREATMENT AND AIR QUALITY IN A POOL FACILITY**

Therese Bergh Nitter1, Kristin v Hirsch Svendsen2

1Institute for Civil and Environmental Engineering, Norwegian University of Science and Technology

2Institute for Economy, Department for Health, Safety and Environment, NTNU

E-mail address: [therese.nitter@ntnu.no](mailto:therese.nitter@ntnu.no) (corresponding author), [kristin.svendsen@ntnu.no](mailto:kristin.svendsen@ntnu.no)

Postal address:

Høgskoleringen 7A

7491 Trondheim

Norway

We investigated how UV treatment of pool water affects the concentration of trihalomethanes (THM) and chloramines (NCl3) in the air above one therapy pool. One-hundred sixty-two samples of tTHM and 36 samples of NCl3 were collected simultaneously at poolside and in the extract channel in a room with one therapy pool for two days a week over a period of five weeks. When the UV lamp was on, the concentration of combined chlorine in the water decreased 58%, the concentration of tTHM in the air increased 37%, and the concentration of NCl3 in the air decreased 15%. Between 42% and 56% of the gases in the air are recirculated back into the poolroom along with the recycled air. The correlation between NCl3 and THM in the air was stronger when the UV treatment was on (r2 = 0.963) compared to when the UV treatments was off (r2 = 0.472). Using a linear mixed model, 30% of the variability in THM was attributed to UV treatment. For NCl3, thenumber of bathers was the most important predictor variable. UV treatment has a limited effect on airborne NCl3 but increases the air concentration of tTHM.

Keywords: UV treatment, chloramines, trihalomethanes, linear mixed effect model, air quality, pool facility

**List of abbreviations**

ACH - Air changes per hour

AM - Arithmetic mean

AR (1) - First order autoregressive

ATD - automatic thermal desorption

BDCM - Bromodichloromethane

DBCM - Dibromochloromethane

DBP - Disinfection by-products

ML - Maximum likelihood

NCl3 – trichloramines

OR – Odds Ratio (odds of being exposed if you are diseased, divided by the odds of being exposed if you are not diseased)

REML - Restricted maximum likelihood

SD - Standard deviation

TCM - Chloroform

TBM - Bromoform

tTHM - sum of the four most common trihalomethanes in swimming facilities (TCM, BDCM, BDCM and TBM)

UV- Ultraviolet

**INTRODUCTION**

To prevent the growth of hazardous microorganisms, it is mandatory that pool water be disinfected. However, oxidizing biocides, such as chlorine, will react with the contaminants in the water and thereby create a variety of hazardous disinfection by-products (DBPs), some of which are known for their ability to trigger asthma attacks (NCl3) and for being possibly carcinogenetic to humans (trihalomethanes (THM), haloacetic acids (HAA), and nitrosamines). The types of disinfectant and water may introduce different precursors and DBPs, thereby representing different health effects (Nitter et al., 2017).

In accordance with Norwegian regulations, it is mandatory to control the water concentration of free and combined chlorine continuously if hypochlorite is used to disinfect the pool water (Norwegian Ministry of Health, 1996). In most of the approximately 900 Norwegian swimming facilities, the water is treated with UV radiation in addition to hypochlorite. This is mainly due to the UV treatment’s well-documented effect on reducing the concentration of combined chlorine in the water and for inactivating microorganisms by absorption (Cassan et al., 2006; World Health Organization, 2006; Cossec et al., 2016;). Combined chlorine consists of the three DBPs, i.e., mono-, di-, and tri-chloramine (NCl3), and in previous literature it has been found that all three components can be degraded by UV irradiation (Jing & Blatchley, 2009). The most commonly used UV lamp for pool water treatment in Norway is a medium-pressure UV lamp which emits wavelengths between 200 nm and 600 nm.

A significant correlation between NCl3 and tTHMs in the air, and tTHMs in the water and air have been found (Cossec et al., 2016). The concentration of THMs in the air is consequently higher compared to those measured in the water (Cossec et al., 2016; Tardif et al., 2016). Although the results are somewhat inconsistent, several researchers have documented different formation potentials of certain DBPs when UV treatment, followed by chlorination, is used in the water treatment system. Some researchers have found that the use of UV treatment in the water treatment system leads to an increase in the concentrations of TCM and BDCM and other DBPs, in the air and water (Cassan et al., 2006; Cossec et al., 2016). The increase in certain DBPs is explained by the increase in active chlorine and by radicalizing mechanisms initiated by UV irradiation (Cassan et al., 2006). The THMs are not formed directly via exposure to UV treatment, but rather when the water is post- chlorinated after UV treatment. This result is explained by the increased reactivity of organic precursors present in the pool water towards chlorine when the water is treated by UV (Spiliotopoulou et al., 2015). The theoretical effect of UV treatment is found to decrease significantly with increased water turnover time (Soltermann, 2015).

*Health effects related to exposure to airborne NCl3 and THM*

Of the combined chloramines, NCl3 is the component that has received the most attention, as it is suspected of being the main trigger for asthma and other respiratory irritations (Thickett et al., 2002; Jacobs et al., 2007). At 20 ºC, NCl3 is estimated to be 966 and 286 times as volatile than mono- and di-chloramine, respectively (Holzwarth et al., 1984), and when combined chlorine is measured in the air, NCl3 is the dominant component. In several epidemiological cross-sectional studies, researchers have found an increased odds ratio (OR) amongst swimmers and lifeguards (exposed) compared to non-swimmers (unexposed) for sore throat, chest tightness, and more severe airway irritations (Jacobs et al., 2007, Graff et al., 2013). NCl3 is considered the most important cause behind the increased prevalence of symptoms (Hery et al., 1995; Jacobs et al., 2007), although the agreement is somewhat inconsistent (Graff et al., 2013). The World Health Organization has acknowledged these health effects, and, in 2006, a proposed limit value for exposure to chlorine species, expressed as NCl3, of 0.5 mg/m3 was published (World Health Organization, 2006). No limit value for exposure to NCl3 in Norwegian indoor swimming pool facilities exists.

No evidence of cancer or increased toxicity has been found in studies in which animals have been exposed to mono- or di-chloramine. The health concern related to exposure to chloramines in humans and animals is increased inhalation toxicity related to exposure to NCl3 (Hery et al., 1995; Massin et al., 1998). THM, represented by the four components chloroform (TCM), bromodichloromethane (BDCM), dibromchloromethane (DBCM) ,and bromoform (TBM), is characterized by the European Chemical Agency (ECHA) as one of the quantitatively most important groups of DBPs (The European Chemicals Agency, 2017). TCM and BDCM are classified as possible carcinogenetic to humans by the international agency for research on cancer (IARC) (World Health Organization, 2017). Long-term exposure to THMs is associated with increases in the prevalence of bladder cancer and stillbirth (Villanueva et al., 2006; Rivera-Núñez et al., 2018). Both THM and NCl3 are extremely volatile and present in higher concentrations above the water surface compared to in the pool water (Jacobs et al., 2007). From animal studies, the liver is found to be the most likely target organ for DBP exposure (Li et al., 2015).

UV treatment is used in the water treatment system to reduce the concentration of combined chlorine in the water. However, it is shown that use of UV treatment does not affect the concentration of NCl3 considerably in the water when the turn-over time is several hours (Soltermann, 2015). It is therefore hypothesized that this applies also for the air and that use of UV treatment will increase overall exposure of airways.

The aim of this work is to understand the impact on the concentrations of THM and NCl3 in the air when a medium-pressure UV lamp is used in the water circulation system. In addition, a linear mixed effect model will be applied to identify which determinants contribute the most to the observed variability in the two exposure variables and how much of the variability can be attributed to the UV treatment of the water circulation system.

**METHODS**

*Pool dimensions, air handling, and water treatment*

The subject of this study was a poolroom with one therapy pool. To maintain the concentration set points of free and combined chlorine, the pool water is disinfected using sodium hypochlorite (NaOCl) in addition to a medium-pressure UV lamp with an intensity of 75 mJ/cm2. When the UV lamp was switched on, it was always at 100% power. The pH value is adjusted using H2SO4, and the turnover time for the pool water is approximately six hours. The pool water flow rate is approximately 35 m3/h. No water is taken out of the swimming pool, but water lost due to evaporation is replaced by fresh water. All of the water is filtered through sand filters, and about 15-20% is also filtered through charcoal. Backwashing is performed every Thursday morning. The total air and water volumes are approximately 4300 m3 and 210 m3, respectively. The average number of air changes per hour (ACH) is 10, and between 40-60% (4-6 ACH) of the air involved in the ACH is fresh air from outside. The air is supplied from the floor, then flows up along the window façade on one side of the poolroom, and then is extracted via an exhaust grill (4 m2), which is located on one of the walls diagonal to the supply duct and approximately two meters away from the pool border. The study object is used mostly for arranged water activities, such as swimming for babies and water aerobics, and, from Monday to Friday, most hours are booked from 9:00 to 20:00 The swimming pool is also used for public swimming on the weekends.

**Sampling strategy**

In total, 162 and 36 stationary air samples of THM and NCl3, respectively, were collected on Tuesdays and Thursdays for five weeks. The UV treatment was switched off for two weeks, turned on for two weeks, and then switched off again for one week. In the final week, samples were collected on Tuesday and Thursday from 09:00 to 12:00, while, for the first four weeks, samples were collected on Tuesdays and Thursdays from 09:00 to 12:00 and then again from 13:00 to 16:00.

Air samples of THM and NCl3 were collected from the poolside (location 1) and exhaust grill (location 2) simultaneously using two stationary test stands. Three air samples of THM (two from sampling location 1 (0.30 m above the floor and 0.05 m above the water’s surface) and one from sampling location 2 (0.30 m above the floor)) were collected simultaneously each hour. Two samples of NCl3 (one from sample location 1 and one from sample location 2) were collected every third hour. Additional air samples of THM were also collected in the supply duct on two different days to document the amount of THMs being recycled back into the poolroom with the recirculated air.

**Data collection and analysis**

**Air samples of NCl3 in the air**

To collect information about NCl3 in the air, a total of 180 L was sampled onto glass fibre filters impregnated with sodium carbonate and diarsenic trioxide. The filters where attached to an air pump (SKC Air sampler) calibrated to deliver 1 l/min for 180 minutes, in accordance with previously published methods. Using this method, information about mono-and dichloramine, as well as other oxidant forms of chloride, is also measured. However, NCl3 accounts for around 90% (Hery et al., 1995; Massin et al., 1998). The air flow though the filter was verified four times during the sampling period of 180 min. In total, four NCl3 samples were collected each sampling day. All of the NCl3 samples were prepared by and sent to the accredited laboratory in the Department of Occupational and Environmental Medicine at Umeå University Hospital, Sweden for analysis.

**Air samples and analysis of THM**

The sampling, analysis, and quality assurance for collecting samples of THM in the air are based on the published methods US EPA TO-17 (United States Environmental Protection Agency, 1999) and the ISO 16017 (International Organization for Standardization, 2000). The samples were obtained by pulling air onto automatic thermal desorption (ATD) tubes containing 200 mg of Tenax TA 35/60 (Markes Int.) using three low-flow pumps (Markes Int.) with an average flow rate of 40 ml/min for 20 min. The low-flow pumps were calibrated in situ, both before and after each sample. Before and after sampling, the ATD tubes were stored in an airtight container with charcoal. Each ATD tube was sealed using Swagelok caps combined with PTFE ferrules and packed in uncoated aluminium foil to avoid contamination and losses. The analysis setup, as well as calibration methods, are explained by the authors elsewhere (Nitter et al., 2017). The analysis of THM was performed at the Department Industrial Economy and Technology Management at Norwegian University of Science and Technology (NTNU).

Information on sample type, number, height and location, water activity and number of bathers where recorded during the sampling days. The concentration of free and combined chlorine, the pH-value and the water temperature are automatically measured at intervals of 120 s and the values was collected from the supervisory control and data acquisition system. Control samples to verify the concentration of free- and combined choline was collected and analysed by the technical staff, three times a day, using the N,N-diethyl-p-phenylenediamine (DPD) method. The air temperature, relative humidity, and outside temperature where recorded continuously using three EasyLog USB. One EasyLog was placed outside the window of the pool facility and the two others were attached to the two test stands. The ventilation log was also collected from the supervisory control and data acquisition system after each day of sampling.

**Statistical analysis**

Air samples were interpreted and analysed with the data program Statistical Package for the Social Sciences 25.0 (SPSS). Descriptive data, such as the arithmetic mean (AM), standard deviation (SD), lowest and highest values obtained (min-max), for the different variables are presented in Table 1. Both exposure variables were positively skewed and log-transformed before statistical analysis. A t-test was applied to compare the different chemical-physical parameters measured when the UV treatment was switched off and on.

A linear mixed-effects model was applied to identify how much of the variability in the log-transformed tTHM and NCl3 could be attributed to the significant determinants of exposure. The advantages of a linear mixed-effects model include the ability to account for the correlation between the repeated observations and to take effects that unfold during the experiment into account (Baayen et al., 2008). The concentration patterns for the two sampling locations were identical, meaning that the concentrations measured at location 2 were highly dependent on the concentrations measured at location 1. By default, the subjects are assumed to be independent and therefore the dependency between the two sampling locations was accounted for by taking the average of both sampling locations, leaving only one sample location for the analysis. To account for the correlation between the repeated samples, first order autoregressive (AR (1)) was used for the covariance structure. This structure assumes the correlation function decays exponentially as the intervals between the measurements increase.

One model was built stepwise and separately for each of the two exposure variables (ln tTHM and ln NCl3). The determinants of exposure were treated as fixed effects, and only those that improved the fit of the model significantly, as judged by the likelihood ratio test (p >0.05), were kept in the final model. While the model was built, estimates were made using the method of maximum likelihood (ML). In the final model, the method of restricted maximum likelihood (REML) was used to estimate the variance component, considering that REML yields less biased estimates of the variance components compared to ML.

**RESULTS AND DISCUSSION**

The arithmetic means (AM), standard deviations (SD), and the lowest and highest values observed for the different physical-chemical parameters are listed in Table 1. Water temperature, air temperature, pH value, number of bathers, free chlorine, and RH had very low variability. However, with the exception of TBM and the number of bathers, all variables varied significantly between when the UV treatment was switched off and on. No values exceeded the limit values established in the Norwegian regulations for swimming pools and spas (Norwegian Ministry of Health, 1996).

Slightly higher concentrations of tTHM (14%) and NCl3 (10%) were observed by the poolside (location 1) compared to in the extract channel (location 2), and the contamination level observed in the two sampling locations was statistically significant (p=0.02). On average, 2% difference in tTHM was observed between the two heights, 0.05 m (above the water surface) and 0.30 m (above the floor), by the poolside, and this result was statistically insignificant (p=0.66). Based on this result, only samples collected 0.30 m above the floor at location 1 were used in the linear mixed-effects model.

Table 1: Descriptive statistics of the concentrations of tTHM and NCl3 obtained with and without the use of UV treatment in the water treatment system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | | **N** | **AM** | **SD** | **Min** | **Max** |
|
| tTHM (µg/m3) | UV off | 90 | 153 | 36 | 89.9 | 281.5 |
| UV on | 70 | 209 | 56 | 122.0 | 385.3 |
| TCM (µg/m3) | UV off | 90 | 98 | 22 | 59.5 | 179.9 |
| UV on | 70 | 138 | 40 | 77.4 | 268.6 |
| BDCM (µg/m3) | UV off | 90 | 22 | 5.2 | 13.9 | 40.8 |
| UV on | 70 | 37 | 9.8 | 22.7 | 66.4 |
| DBCM (µg/m3) | UV off | 90 | 6.7 | 2.1 | 2.0 | 13.3 |
| UV on | 70 | 10 | 2.8 | 6.3 | 18.4 |
| TBM (µg/m3) | UV off | 90 | 27 | 11 | 11.9 | 62.8 |
| UV on | 70 | 24 | 9.7 | 14.3 | 66.7 |
| NCl3\* (µg/m3) | UV off | 20 | 277 | 63 | 190 | 420 |
| UV on | 16 | 235 | 29 | 190 | 290 |
| ClComb (mg/l) | UV off | 10 | 0.40 | 0.05 | 0.30 | 0.44 |
| UV on | 8 | 0.17 | 0.04 | 0.13 | 0.24 |
| ClFree (mg/l) | UV off | 10 | 0.97 | 0.01 | 0.89 | 1.02 |
| UV on | 8 | 0.95 | 0.05 | 0.95 | 0.98 |
| pH | UV off | 10 | 7.2 | 0.03 | 7.15 | 7.22 |
| UV on | 8 | 7.2 | 0.02 | 7.13 | 7.20 |
| Bathers | UV off | 90 | 11 | 9.7 | 0 | 33 |
| UV on | 71 | 10 | 9.3 | 0 | 26 |
| Tout (ºC) | UV off | 90 | 2.0 | 3.7 | - 3.4 | 9.9 |
| UV on | 71 | 9.4 | 1.7 | 6.7 | 13.5 |
| RH (%) | UV off | 90 | 50 | 2.8 | 42.9 | 56.5 |
| UV on | 71 | 51 | 3.1 | 43.5 | 56.3 |
| Tin (ºC) | UV off | 90 | 33 | 0.3 | 31.6 | 33.0 |
| UV on | 71 | 33 | 0.2 | 32.1 | 32.9 |

\*NCl3 equivalent. Abbreviation: N= Number of samples; AM= arithmetic mean; SD= standard deviation; ClComb= Combined chlorine, ClFree= Free chlorine, Tout = Outdoor temperature, RH = Relative humidity; Tin = Indoor air temperature

The results show that, when the UV treatment was on, the concentrations of tTHM, TCM, DBCM, and BDCM increased by 37%, 41%, 51% and 68%, respectively, compared to when the UV treatment was switched off. The concentrations of NCl3 and TBM decreased by 15% and 12%, respectively.

Air samples of tTHM collected from the outlet of the supply duct on two different days showed that between 42% (afternoon) and 56% (morning) of the contaminants extracted from the poolroom are recirculated back into the poolroom. Although only two samples were collected from the supply duct during the sampling period, the ventilation log showed that the air changes per hour and the fresh air supply were approximately constant throughout the sampling period.

**Prediction of the air concentration of THM and NCl3 with and without UV treatment in the pool water**

The Shapiro Wilk test for normality showed that the log-transformed exposure variables of tTHM, TCM, DBCM, BDCM, and NCl3, show no significant deviation from normality. TBM however did not seem to follow a normal distribution. In Table 2, the Pearson correlation coefficients between the log-transformed tTHMs and NCl3 are shown for when the UV treatment was switched off and on. However, the Pearson correlation coefficient is suspected to be sensitive to non-normality and thus was not used to explain the correlations between TBM and NCl3. As shown in Table 2, the correlation between airborne levels of NCl3 and tTHM, BDCM, and TCM were stronger when the UV treatment was switched on compared to when the UV treatment was switched off.

Table 2: Test for Pearson’s correlation between the normally distributed exposure variables

|  |  |
| --- | --- |
| **UV on** | |
| tTHM (three hours) vs. NCl3 | 0.936\*\* |
| TCM vs. NCl3 | 0.914\*\* |
| BDCM vs. NCl3 | 0.893\*\* |
| DBCM vs. NCl3 | 0.493 |
| **UV off** | |
| tTHM (three hours) vs. NCl3 | 0.472\* |
| TCM vs. NCl3 | 0.761\*\* |
| BDCM vs. NCl3 | 0.543\* |
| DBCM vs. NCl3 | 0.447 |

\*p=0.05, \*\*p=0.01

**Variability and correlation between repeated measures using LMM**

Although the contamination levels observed at the two sampling locations were significantly different from each other, the between sampling location variability was low with respect to both ln tTHM (0.0057) and ln NCl3 (0.0034). This suggest that the room is well mixed and that the concentration obtained at sample location 2 is highly dependent on the contamination level obtained at sampling location 1. As shown in Tables 3 and 4, the only factors contributing significantly to the fit of the model, judging by the likelihood ratio test, were bathers and UV treatment.

Table 3: Linear mixed-effects model of the log-transformed tTHM

|  |  |  |
| --- | --- | --- |
|  | **Ln tTHM model (n=54)** | |
| **Determinant** | **Random effects model B (SE)** | **Mixed effect model B (SE)** |
| Intercept | 5.13\*\* (0.026) | 5.19\*\* (0.07) |
| UV treatment  Off  On |  | -0.30\* (0.08)  0 |
| Bathers |  | 0.011\*\* (0.002) |
|  | **Variance** | **Variance** |
| Within sampling location variance  Correlation between repeated measures  Variability attributed to UV  Variability attributed to bathers | 0.071 (0.02)  0.56 (0.12) | 0.04 (0.011)  0.52 (0.12)  -29.5 %  -14.1% |

Abbreviations; N=Number of samples (average of sampling location 1 and 2 collected simultaneously), SE= Standard error, \*p=0.05, \*\*p=0.01

When UV treatment was added to the ln tTHM model, the variability was reduced by 29.5%, and the fit of the model was improved significantly (p=0.000) compared to the model in which no factors were included. As shown in Table 3, approximately 14% of the variability observed in ln tTHM could attributed to the bathers in the pool.

Table 4: Linear mixed-effects model for the log-transformed NCl3

|  |  |  |
| --- | --- | --- |
|  | **Ln NCl3 model (n=18)** | |
| **Determinant** | **Random effects model B (SE)** | **Mixed effect model B (SE)** |
| Intercept | 5.57\* (0.088) | 5.31\*\* (0.12) |
| UV treatment  Off  On |  | 0.23\* (0.10)  0 |
| Bathers |  | 0.011\* (0.004) |
|  | **Variance** | **Variance** |
| Within sampling location variance  Correlation between repeated measures  Variability attributed to bathers  Variability attributed to UV | 0.046 (0.012)  0.55 (0.33) | 0.035 (0.011)  0.64 (0.12)  -29%  +9% |

Abbreviations; N=Number of samples (average of sampling location 1 and 2 collected simultaneously), SE= Standard error, \*p=0.05, \*\*p=0.01

When UV treatment was added as determinant in the ln NCl3 model, this factor did not significantly improve the fit of the model (p=0.06), and UV treatment as fixed factor was insignificant with a p-value of 0.09. However, when the variable bathers was added to the model first, UV treatment became significant, and both variables together significantly improved the fit of the model, judging by the likelihood ratio test.

Approximately 29% of the variability observed in ln NCl3 could be attributed to the bathers in the pool. When UV treatment was added to the model, the variability increased by 9%. In general, the observed concentration of NCl3 varied more when the UV treatment was switched off compared to when the UV treatment was switched on. This pattern was not observed for tTHM.

**Occurrence of NCl3 and THM in the air with and without UV treatment of the water circulation system**

As expected, higher concentrations of tTHM (37%) were measured in the air when the UV treatment was switched on. This result is in accordance with previous studies (Cossec et al., 2016). However, in some studies, the results show that, even though lower concentrations of combined chlorine were measured in the water of pools disinfected using UV treatment and chlorine, no significant effect was observed in the level of NCl3 in the air between pools with and without UV treatment (Gérardin et al., 2005; Cossec et al., 2016;).

In our study, when the UV lamp was switched on, the concentration of combined chlorine in the water decreased by 58% (the ratio of off vs. on is 2.35), but the concentration of combined chlorine in the air only decreased by 15.2% (the ratio of off vs. on is 1.18). The formation of NCl3 in the pool water is considered to be a rather fast process (Soltermann, 2015), and, due to the high volatility of NCl3 and a turnover time of six hours, this component is likely to transport from the water to the air before the water is treated through the water treatment system.

The correlation between tTHM and NCl3 was stronger when the UV treatment was switched on (r = 0.936, p=0.01) compared to when the UV treatment was switched off (r = 0.472, p=0.05). This finding suggests that NCl3 and tTHM can be used to predict the contamination level of one another when the UV treatment is switched on. The within and between variability of sampling locations also suggest that the contamination level in this specific poolroom, with an ACH of 10 and a fresh air supply of between 40 - 60%, is well mixed. Even though the chosen ventilation strategy does provide mixing of the contaminants in the poolroom, the samples collected form the supply channel shows that the potential for reducing the contamination level is between 42% and 56 % if filters able to adsorb gasses in the air are installed in the return air channel of the air-handling unit.

Approximately 30% and 14 % of the variability observed in ln tTHM could be attributed to UV treatment and bathers, respectively, and the difference in observed concentration of tTHM when the UV treatment was switched off and on was highly significant (p=0.003). For the NCl3 model, most of the variability observed could be attributed to the number of bathers in the pool (approximately 29%). When UV treatment was added to this model, the variability increased by 9%, and UV treatment became a significant determinant only when the variable bathers was added to the model first. Considering that NCl3 is more volatile and less water soluble in comparison to the four THMs, this fact might explain why NCl3 is affected more by the bather load than tTHM.

The main advantage of a linear mixed effect model is to take effects that unfold during the experimental period into account (Baayen et al., 2008). This advantage is especially important for exploratory studies in which the effects of different implements are to be determined and effects are most likely to unfold during the experimental period, such as bather load, chlorine concentration in the water, and outdoor temperature. The importance of a linear mixed effect model is also highlighted by the dependency and large correlation estimated between the repeated samples.

A significant dose-dependent increase in the prevalence of red eyes, itchy eyes, runny nose, loss of voice, and significant decrease in forced expiratory volume (FEV1) have been found in pool workers exposed to pool air (Thickett et al., 2002; Fantuzzi et al., 2012). However, in these studies, the only observed contaminant in the air was NCl3. These studies are also based on a very limited number of samples, which makes the estimated dose-response relationship highly questionable. In some studies conducted in Sweden, the researchers have also found a relationship between exposure in pool facilities and increased prevalence of respiratory illnesses; however, this was not described by the measured level of NCl3 in the air (Fornander et al., 2012). It is therefore questioned whether one should focus on a single component knowing that several of the components in pool facilities might interact with each other. The increased prevalence of certain diseases is acknowledged to be caused by long-term exposure in the poolroom. Based on the study design in previous studies, the specific dose-response relationship between exposure to NCl3 and health effects is somewhat questionable. However, the effort should be expended on reducing the overall exposure level. To reduce the level of combined chlorine in the water other methods, such as increased turnover time and fresh water supply, reduced concentration of free chlorine or other filtration methods could be tested and considered, if microbiological and hygienic water quality is maintained.

**CONCLUSIONS**

UV treatment in the water system reduces the concentration of combined chlorine in the water but has only a limited effect on the level of NCl3 in the air. However, UV treatment also increases the concentration of other DBPs, such as THM, of which we have little knowledge. Combined chlorine is controlled continuously in the water of Norwegian swimming pools, and hazard control are implemented immediately if the level becomes unacceptably high. To prevent increased formation of other DBPs combined chlorine in the water should be controlled using methods besides UV treatment, such as reduce/remove DBP precursors, increased fresh water supply, increased turnover time, adsorbents in the ventilation return-air channel, or improved bather hygiene. The limit value for combined and free chlorine in the water could also be reduced as long as doing so does not affect the hygienic parameters.

**FUNDING**

This project is founded and supported by the Departments of Civil and Environmental Engineering at NTNU

**REFERENCES**

Cassan, D., Mercier B., Castex F. & Rambaud A. 2006. Effects of medium-pressure UV lamps radiation on water quality in a chlorinated indoor swimming pool. *Chemosphere,* **62**(9), 1507-1513. doi:http://dx.doi.org/10.1016/j.chemosphere.2005.06.006

Cossec C., Laurent A-M., Person A., Laurie I.R. & Claude Beaubestre. 2016. Trichloramine and trihalomethanes concentrations in air or water of Paris indoor swimming pools and impact of different water treatment methods. *Pollution Atmospherique*,228, 1-14. doi: <https://doi.org/10.4267/pollution-atmospherique.5492>

Gérardin F., Hecht G., Huber-Pelle G. & Subra I. 2005. Traitement UV: Suivi de l'évolution des concentrations en chlorforme et en trichlorure d'azote dans les eaux de baignade d'un centre aquatique. *Hygiene et sécurité du travail,* pp. 19-30.

Fornander L., Ghafouri B., Lindahl M. & Graff P. 2013. Airway irritation among indoor swimming pool personnel: trichloramine exposure, exhaled NO and protein profiling of nasal lavage fluids. *International Archives of Occupational and Environmental Health,* **86**(5), 571-580. doi:https://doi.org/10.1007/s00420-012-0790-4

Fantuzzi G., Righi E., Predieri G., Giacobazzi P., Petra B. & Aggazzotti G. 2012. Airborne trichloramine (NCl3) levels and self-reported health symptoms in indoor swimming pool workers: Dose-response relationships. *Journal of Exposure Science and Environmental Epidemiology*, **23**(1), 88-96. doi:10.1038/jes.2012.56

Hery M., Hecht G., Gerber J.M., Gendre J. C., Hubert G. & Rebuffaud, J. 1995. Exposure to chloramines in the atmosphere of indoor swimming pools. *The Annals of Occupational Hygiene,* **39**(4), 427-439. doi:http://dx.doi.org/10.1016/0003-4878(95)00013-5

Holzwarth G., Balmer R. G. & Soni L. 1984. The fate of chlorine and chloramines in cooling towers Henry's law constants for flashoff. *Water Research,* **18**(11), 1421-1427. doi:http://dx.doi.org/10.1016/0043-1354(84)90012-5

International Organization for Standardization. 2000. ISO 16017-1:2000(E). *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography* (Vol. ISO 16017-1:2000(E)).

Jacobs J. H., Spaan S., van Rooy G.B.G.J., Meliefste C., Zaat V.A.C., Rooyackers J. M. & Heederik D. 2007. Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers. *European Respiratory Journal,* **29**(4), 690-698.

Jing L. & Blatchley E.R. 2009. UV photodegradation of inorganic chloramines. *Environmental*

*Science and Technology*, **43**(1), 60–65. doi:<https://doi.org/10.1021/es8016304>

Li J.-H., Wang Z.-H., Zhu X.-J., Deng Z.-H., Cai C.-X., Qiu L.-Q., Chen W. & Lin, Y.-J. 2015. Health effects from swimming training in chlorinated pools and the corresponding metabolic stress pathways. *PloS one,* **10**(3), <https://doi.org/10.1371/journal.pone.0119241>

Massin N., Bohadana A.B., Wild P., Hery M., Toamain JP. & Hubert G. 1998. Respiratory symptoms and bronchial responsiveness in lifeguards exposed to nitrogen trichloride in indoor swimming pools, **55**(4), 258-263.

Nitter T. B., Kampel W., Svendsen K. v. H. & Aas B. 2017. Comparison of trihalomethanes in the air of two indoor swimming pool facilities using different type of chlorination and different types of water. *Water Science and Technology: Water Supply,* **18**(4), 1350-1356. doi:10.2166/ws.2017.201

Norwegian Ministry of Health. 1996. *Regulations for swimming facilities, swimming pools and sauna* (Original title: Forskrift for badeanlegg, bassengbad og badstu m.v), Rule [LOV-2011-06-24-29-§8](https://lovdata.no/lov/2011-06-24-29/%C2%A78), Norway.

Baayen R.H., Davidson D. J. & Bates D. M. 2008. Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language,* **59**(4), 390-412. doi:10.1016/j..jml.2007.12.005

Rivera-Núñez Z., Wright J. M. & Meyer A. 2018. Exposure to disinfectant by-products and the risk of stillbirth in Massachusetts. *Occupational and Environmental Medicine,* **75**(10), 742-751. doi:10.1136/oemed-2017-104861

Soltermann F. 2015 *Trichloramine in swimming pool water: analysis methods, factors influencing its fate and effects of UV treatment.* PhD thesis, ETH-Zürich. doi:https://doi.org/10.3929/ethz-a-010414646

Spiliotopoulou A., Hansen K. M. S. & Andersen H. R. 2015. Secondary formation of disinfection by-products by UV treatment of swimming pool water. *Science of The Total Environment,* 520, 96-105. doi:http://dx.doi.org/10.1016/j.scitotenv.2015.03.044

Tardif R., Catto Cyril., Haddad S., Simard S. & Rodriguez M. 2016. Assessment of air and water contamination by disinfection by-products at 41 indoor swimming pools. *Environmental Research,* 148, 411-420. doi:<https://doi.org/10.1016/j.envres.2016.04.011>

The European Chemicals Agency. 2017. *Guidance on the Biocidal Products RegulationVolume V, Guidance on Disinfection By-Products*. Report ECHA-17-G-01-EN, ECHA, Helsinki, Finland. doi: 10.2823/72847

Thickett K. M., McCoach J. S., Gerber J. M., Sadhra S. & Burge P. S. 2002. Occupational asthma caused by chloramines in indoor swimming-pool air. *European Respiratory Journal,* **19**(5), 827-827.

United States Environmental Protection Agency*. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air- Second edition* 1999. Report EPA/625/R-96/010b, US EPA, Ohio, USA.

Villanueva C.M., Cantor K. P., Grimalt J. O., Malats N., Silverman D., Tardon A., Garcia-Closas R., Serra C., Carrato A., Castaño-Vinyals G., Marcos R., Rothman N., Real F. X., Dosemeci M. & Kogevinas M. 2006. Bladder cancer and exposure to water disinfection by-products through ingestion, bathing, showering, and swimming in pools. *American Journal of Epidemiology,* **165**(2), 148-156.

World Health Organization. 2006. *Guidelines for safe recreational water environments volume 2 swimming pools and similar environments*, Report ISBN 92 4 154680 8, WHO, Geneva, Switzerland.

World Health Organization. 2017. *Guidelines for Drinking-Water Quality* *fourth edition,* Report **ISBN**: 978 92 4 154995-0, WHO, Geneva, Switzerland.