



Exposure of cleaning workers to chemical agents and physical conditions in swimming pools and spas

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Abstract

Swimming pools and spas require a high hygiene level, and therefore constant cleaning. In this study, cleaning workers' exposure to volatile organic compounds (VOCs), trichloramine (TCA), and particulate matter (PM) in the swimming pools and spas were evaluated. Also, statistical methods were employed to determine what activities affect the exposure to disinfection byproducts (DBPs). The study was conducted in 32 swimming pools and spas. The measurement locations were pool areas, bathrooms, and locker rooms, both during cleaning and opening hours. During the cleaning, the total volatile organic compound (TVOC) concentrations were low, on average 96, 251, and 91 $\mu\text{g}/\text{m}^3$ for locker rooms, bathrooms, and pool areas, respectively. Similarly, during the opening hours, the TVOC concentrations were on average 78, 125, and 83 $\mu\text{g}/\text{m}^3$, for locker rooms, bathrooms, and pool areas, respectively. This is in line with previous studies investigating cleaning work in other environments. The most prevalent compounds during the cleaning were 2-(2-butoxyethoxy)ethanol (DEGEBE), 2-(2-ethoxyethoxy)ethanol (DEGEE), 2-butyl-1-octanol, trichloromethane (chloroform), decamethylcyclopentasiloxane (D_5), and carbon tetrachloride. The most prevalent compounds during the opening hours were D_5 , D-limonene, carbon tetrachloride (bathrooms and pool areas), and trichloromethane (bathrooms and pool areas). The TCA concentrations during the cleaning in the bathrooms and pool areas were on average 60 and 67 $\mu\text{g}/\text{m}^3$, respectively, and during the opening hours, 28 and 122 $\mu\text{g}/\text{m}^3$, respectively. The use of disinfectants was found to increase the TCA concentration in the bathrooms, while the other cleaning products did not. Even though the TCA concentrations were below the WHO's guideline and the Finnish occupational exposure limit value of 500 $\mu\text{g}/\text{m}^3$, the measured TCA levels were occasionally high enough to pose a risk of irritative symptoms. The PM concentrations were low, both in the real-time monitoring (aerodynamic diameter, $D_{\text{ae}} \leq 15 \mu\text{m}$) and inhalable dust samples ($D_{\text{ae}} \leq 100 \mu\text{m}$). Highest measured inhalable dust concentration was 350 $\mu\text{g}/\text{m}^3$, well below the Finnish occupational limit value of 5,000 $\mu\text{g}/\text{m}^3$ for organic inhalable dust.

Keywords Cleaning work · Trichloramine · Trihalomethane · Particulate matter · Exposure

Introduction

The cleaning sector is globally a significant employer. For example, over 61,000, 4 million, and 2.3 million cleaning workers and janitors are employed in Finland, Europe, and the USA, respectively (Bureau of Labor Statistics; European Cleaning and Facilities Services Industry (EFCI);

Official Statistics of Finland (OSF) 2019). Cleaning work is a necessity for a functioning society: public buildings such as malls, hospitals, schools, and universities are dependent on the cleaning work to keep them clean and tidy. Despite its importance, cleaning work is underpaid, underrated, and physically demanding; furthermore, cleaning workers are exposed to both chemicals and thermal conditions.

A study focusing on the health care sector found that the cleaning workers have a higher risk for a work-related injury than other workers in the sector (Alamgir and Yu 2008). In recent years, research regarding cleaning workers has focused on the prevalence of occupational asthma which is more prevalent among cleaning workers than in many other occupations (Folletti et al. 2017). Due to the nature of the tasks performed, cleaning workers are also susceptible to

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dermal (Mirabelli et al. 2012; Bauer 2013) and ergonomic symptoms (Woods and Buckle 2006; Kumar and Kumar 2008; Luz et al. 2017), such as contact dermatitis and musculoskeletal disorders. Also, increased susceptibility to lung cancer has recently been associated with cleaning work in French and Belgian epidemiological studies (Atramont et al. 2016; Van den Borre and Deboosere 2018). However, no explanation on what the cause could be has been given.

According to previous studies by Suleiman and Svendsen (2014, 2015), some cleaning workers do not possess sufficient knowledge about the possible health hazards of the cleaning products they use, even though safety data sheets (SDSs) may be available. The cleaning products can be roughly classified based on their pH into alkaline (mildly alkaline–highly alkaline), neutral, and acid (mildly acid–highly acid) (Suontamo 2004). Disinfecting cleaning products are usually alkaline; however, some acids are also used as disinfectants (Wolkoff et al. 1998). The compounds included in the cleaning products can be divided into active agents and additives (Wolkoff et al. 1998). The active agents include surfactants (tensides) that are used to lower the surface tension of the water; complexing agents (or water softeners) that bind metal ions, such as calcium; acids or bases to dissolve calcium and fatty substances, respectively, also used to control the pH of the cleaning product; disinfecting agents (especially in disinfecting products) that are used to destroy micro-organisms; and solvents to enhance dissolving of fatty substances (Wolkoff et al. 1998). The additives are usually preservatives, corrosion inhibitors, or fragrances (Wolkoff et al. 1998). Typical compounds found in the cleaning products include benzyl alcohol (solvent), glycol ethers (solvent), ethanolamines (complexing agents), and sodium hypochlorite (disinfectant) (Wolkoff et al. 1998; Nazaroff and Weschler 2004; Singer et al. 2006; Bello et al. 2009, 2013; Wieslander and Norbäck 2010; Gerster et al. 2014b, a). It is important to note that many of these compounds can have adverse health effects and exposure can occur via different pathways. However, the common routes cleaning workers are exposed to cleaning products are via the skin or the respiratory tract. For example, ethanolamines are known skin sensitizers and are suspected to play a role in the development of occupational asthma (Savonius et al. 1994; Lessmann et al. 2009), while all glycol ethers are considered irritants with some having hematological effects (Multigner et al. 2005; IARC Working Group 2006). Also, cleaning products can include compounds not specified in the SDSs, either because these compounds are not considered harmful or the proportion of these compounds is low (Bernstein 2002; Suleiman and Svendsen 2014). For these reasons, exposure assessment of cleaning workers to volatile organic compounds (VOCs) is needed (Suleiman and Svendsen 2014).

Swimming pool and spa cleaners work in a substantially different environment compared to those working in, for example, offices, schools, or daycare centers. Relative humidity and temperature are higher, especially in the pool area, bathrooms, and saunas than in the office environment. Also, swimming pools and spas require high hygiene in certain areas, especially in the bathrooms, toilets, and pool areas, where disinfection of the floor surfaces and the pool water is needed (WHO 2006). Therefore, the cleaning workers in the swimming pools and spas are exposed to numerous disinfection byproducts (DBPs) that are present in the indoor air of the pool areas. These include irritative compounds such as chloramines and trihalomethanes (THMs) and have been the subject of several previous studies (Caro and Gallego 2007; Zwiener et al. 2007; Lee et al. 2009, 2010; Weaver et al. 2009; Richardson et al. 2010; Bessonneau et al. 2011; Schmalz et al. 2011a; Hansen et al. 2012; Westerlund et al. 2015). DBPs are formed in the reactions of the disinfecting chemicals (often NaClO) and organic or inorganic impurities, originating for example from toiletries, sweat, and urine (Hery et al. 1995; Judd and Black 2000; Hsu et al. 2009; Hansen et al. 2012). Trichloramine (TCA, nitrogen trichloride) is the most irritative of the chloramines and it can cause eye and upper respiratory tract symptoms and is suspected to affect the development of asthma (Thickett et al. 2002; Jacobs et al. 2007; Weisel et al. 2009). Also, TCA's formation in water is most prominent at lower pH levels less than 8 (Hery et al. 1995), which the pool water typically is (WHO 2006). In addition, it is the most volatile of the chloramines (Barbot and Moulin 2008). In Finland, an 8-h occupational exposure limit (OEL) value for TCA is $500 \mu\text{g}/\text{m}^3$, which is the same as WHO's guideline value (WHO 2006; Finnish Ministry of Social Affairs and Health 2018). Due to the irritative qualities of the TCA, it has been recommended to set the OEL to $300 \mu\text{g}/\text{m}^3$ (Parrat et al. 2012). Trichloromethane (chloroform) is the most abundant of THMs in the indoor air of swimming pools where chlorine-based (usually NaClO) water sanitation is used (Cammann and Hübner 1995). Besides the environmental factors, the use of different cleaning products in the swimming pool and spa environment is required, due to high hygiene demands in these facilities. These products include disinfectants, alkaline, acidic, and degreasing agents that are often rotated based on the usage of the facility and to preserve the effectiveness of the disinfection. However, to our knowledge, no previous studies investigating the exposure of the cleaning workers occupied in the swimming pools and spas exist. Even though cleaning workers do not spend as much time in the pool area compared to lifeguards, sports instructors, or some swimmers, they are nevertheless exposed to the DBPs and even higher thermal loads. Besides the DBPs released due

to the pool water sanitation, cleaning workers are exposed to the DBPs released due to the use of disinfectants in their tasks. Also, cleaning work is physically demanding, often including repetitive movements such as floor or wall brushing.

The present study aimed to investigate the exposure of cleaning workers to different chemical compounds (VOCs, trichloramine, and particulate matter) evaporating from the cleaning products and the DBPs from the swimming pool water, to evaluate how factors such as the age and size of the building, facility type (swimming pool, spa, or swimming pool with spa section), use of disinfectants and other cleaning products, and the number of visitors affect the cleaning workers' exposure to DBPs. In addition to the chemical exposure, thermal comfort parameters were evaluated.

Materials and methods

Descriptions of the swimming pools, spas, and cleaning tasks

A total of 32 swimming pools and spas were included and one to six cleaning workers (total n : 93) per swimming pool or spa participated in the study. The average age and work experience of the workers were 45 and 6 years, respectively. Ninety-four percent of the workers were female. The swimming pools and spas were in Central, Eastern, Southern, and Western Finland. The list of the swimming pools and their details are shown in Table 1.

Cleaning of the swimming pools and spas took place outside the opening hours of the facilities, usually in the morning between 5:00 and 12:00, or between 20:00 and 3:00 in some facilities. Typically, the tasks performed by the cleaning workers included cleaning the floors and other surfaces (staircases, diving apparatuses, sauna benches, lockers) in the pool area, as well as bathrooms, saunas, and locker rooms. Usually, in the bathrooms, saunas, and pool areas, the cleaning product (disinfectant, alkaline, neutral, or acidic) was first spread on the surface by spraying with a foam sprayer connected to a hose. When cleaning floor surfaces, a single disc machine or hand-held brush was used to brush the cleaning product and rinsed off using either a hose or low- or high-pressure washer. Residual water was then swept from the surface with a floor squeegee. In some cases, the floor cleaning was done using a scrubber-drier machine. Considering the other surfaces (benches, seats, walls), the cleaning product was brushed with a hand-held brush and rinsed off either with a hose or low- or high-pressure washer. The locker room floors were typically cleaned using scrubber-driers and vacuum cleaners. Wiping of lockers was done with damp wipes. All measurements were carried out during the cleaning work (normal work shifts) and the normal

use of the swimming pools and spas (opening hours). The opening hours samples were considered as background samples. The opening hours samples were collected 2 to 4 h after cleaning took place in the facilities where cleaning was performed in the morning. This depended on the usage and schedule of the facility. In the facilities where cleaning was done in the evening after the closing of the facility, the opening hours samples were collected 1 to 3 h before the closing of the facility, or the following morning, which depended on the usage and schedule of the facility.

Cleaning products

In total, 31 different cleaning products were used by the cleaning workers; these consisted of 12 disinfecting, 13 alkaline, 1 neutral, and 6 acidic cleaning products. Safety data sheets (SDS) were evaluated and the identified compounds and hazards are listed in Table 2.

Volatile organic compounds

The VOC samples were collected according to the ISO 16000–6 standard, except for using a combination of Tenax TA (Markes International Ltd., Llantrisant, Wales, UK) and Chromosorb 106 (Sigma-Aldrich Corporation, St. Louis, MO, USA) adsorbent tubes (Tenax TA tube concatenated with Chromosorb 106 tube). This was done to ensure the collection of the chloroform, which has a low breakthrough volume, and is one of the main compounds in the indoor air of the pool area and can additionally be formed in the reactions of the disinfectants and organic impurities (Kroupa et al. 2004; Li and Blatchley 2007; Zwiener et al. 2007; Odabasi 2008). The VOC samples were collected from the breathing zone of the cleaning workers if they agreed to it. In cases where the cleaning worker did not agree to personal sampling, a site in the vicinity of the worker (maximum distance of 3 m) at approximately 1.2–1.5 m height was chosen, and the samplers were moved along as the work progressed. Flow rate for the sampling varied from 0.07 to 0.12 L/min depending on the pumps (SKC AirChek 3000 and 222, SKC Inc., Eighty Four, PA, USA) and the tubes, while sampling times varied from 15 to 60 min. Sampling time depended on the length of the cleaning tasks performed, usually sampling time for cleaning tasks was 30 min. Sampling time for opening hours samples was 60 min.

VOC samples were analyzed using a TD-GC-MS-system: thermal desorption device (Markes TD-100) connected to a gas chromatograph (Agilent 7890A, Agilent Technologies Inc., Santa Clara, CA, USA) equipped with a mass spectrometer (Agilent 5975C). Analyses were done in a SCAN mode. Agilent HP-5MS column (50 m × 200 μm × 0.33 μm) was used. Thermal desorption (TD) temperatures and desorption times were 280 °C for 10 min and 180 °C for 10 min for Tenax TA

Table 1 Information about facilities. The information was collected from interviews of maintenance personnel and from Finnish swimming pool portal (University of Jyväskylä)

Facility type	Year of construction	Year of renovation	Average height	Swimming pool area (m ²)	Pool area (room) (m ²)	Hours open per day	Days open per year	Visitors per year	Filtration type	Ozone treatment	Active carbon	UV	Num-ber of saunas	Num-ber of showers (men's)	Number of showers (women's)
1 Swimming pool/spa	1993		5.6	1281	2360	15	313	343,609	Pressurized sand filtration	Yes	Yes	No	7	47	50
2 Swimming pool/spa	1999	2017	8.9	2064	3520	15	315	794,520	Open sand filtration	Yes	Yes	No	6	32	33
3 Swimming pool/spa	1976	2017	4.9	973	2000	12	290	246,762	Open and pressurized sand filtration	Yes	Yes	No	4	22	19
4 Spa	1986	2007						190,000–200,000					4		
5 Swimming pool/spa	1970	1996	4.7	801	1667	14	327	233,217	Open and pressurized sand filtration	No	No	No	4	13	14
6 Swimming pool/spa	2013		3.9	1042	2058	14	300	280,000	Pressurized sand filtration	No	Yes	Yes	4	17	17
7 Spa	1991		7.3	532	1000	12	358	230,000	Pressurized sand filtration	Yes	Yes	Yes	10	13	14
8 Swimming pool/spa	1985	2006	7.2	1286	2000	13	342	237,337	Pressurized sand filtration	Yes	Yes	Yes	10	34	46
9 Spa	2013							6000–10,000					3	3	3
10 Swimming pool/spa	1982	2001	7.7	435	900	10	250	111,891	Pressurized sand filtration	No	Yes	No	5	11	11
11 Spa	1991	2017											3		

Table 1 (continued)

Facility type	Year of construction	Year of renovation	Average height	Swimming pool area (m ²)	Pool area (room) (m ²)	Hours open per day	Days open per year	Visitors per year	Filtration type	Ozone treatment	Active carbon	UV	Number of saunas	Number of showers (men's)	Number of showers (women's)
12 Spa	1974	2011	6.9	591	1285	15	365	170,000	Pressurized sand filtration	No	Yes	Yes	5	17	17
13 Swimming pool/spa	1992		5.4	588	1600	9	315	106,366	Pressurized sand filtration	Yes	Yes	No	5	14	14
14 Spa	1974	1999	3.2	431	1277	13	365	95,000	Pressurized sand filtration	No	Yes	No	7	12	12
15 Spa	1992		9.2	677	2000	13	330	168,000	Multiple layer filtration	No	Yes	No	5	10	11
16 Swimming pool/spa	1993		5	515	960	12	365	83,500	Pressurized sand filtration	Yes	Yes	No	5	8	7
17 Swimming pool/spa	1966	2008	3.5	412	810	8	340	65,000	Pressurized sand filtration	No	Yes	Yes	3	11	8
18 Swimming pool/spa	1955	2012	7.1	1944		12	340	286,312	Open sand filtration	Yes	Yes	Yes	7	40	40
19 Swimming pool	1974	1997	4.2	462	900	12	320	125,000	Open sand filtration/multiple layer filtration	Yes	Yes	No	3	12	13
20 Swimming pool	1985		4.5	379	2000	14	315	90,855	Pressurized sand filtration	No	No	No	6	16	13

Table 1 (continued)

Facility type	Year of construction	Year of renovation	Average height	Swimming pool area (m ²)	Pool area (room) (m ²)	Hours open per day	Days open per year	Visitors per year	Filtration type	Ozone treatment	Active carbon	UV	Number of saunas	Number of showers (men's)	Number of showers (women's)
Swimming pool	1977	2006	4.1	378	683	15	330	104,734	Pressurized sand filtration	No	Yes	Yes	4	8	10
Swimming pool	1997		5.6	351	522	8	300	70,306	Pressurized sand filtration	Yes	Yes	No	4	10	9
Swimming pool	1996		5.9	448	750	12	302	124,000	Pressurized sand filtration	No	Yes	Yes	4	16	18
Swimming pool	1969		6.3	855	1502	10	310	256,155	Open and pressurized sand filtration	Yes	Yes	Yes	6	29	20
Swimming pool	1976	2004	4.1	345	577	12	288	51,432	Pressurized sand filtration	No	No	Yes	6	6	6
Swimming pool	1971	2017	3.7	281	460	8	250	59,990	Pressurized sand filtration	No	No	No	2	11	12
Swimming pool	1970	1998	4.8	383	708	10	335	89,711	Pressurized sand filtration	No	Yes	No	4	16	13
Swimming pool	1988	2013	5	296	680	13	350	56,500	Pressurized sand filtration	No	Yes	Yes	4	9	9
Swimming pool	1957	2012	4.5	429	2000	15	357	164,908	Pressurized sand filtration	No	Yes	No	4	18	19

Table 1 (continued)

Facility type	Year of construction	Year of renovation	Average height	Swimming pool area (m ²)	Pool area (room) (m ²)	Hours open per day	Days open per year	Visitors per year	Filtration type	Ozone treatment	Active carbon	UV	Number of saunas	Number of showers (men's)	Number of showers (women's)
Swimming pool	1982	2013	4.8	730	1413			222,560	Pressurized sand filtration	No	Yes	Yes	6	19	19
Swimming pool	1974	2002	4.8	751	1100	15	320	339,345	Pressurized sand filtration	No	Yes	No	8	20	20
Swimming pool	1968	2009	6.1	800	1770	14	330	265,331	Pressurized sand filtration	No	Yes	Yes	7	20	18

and Chromosorb 106, respectively. Gas chromatograph (GC) temperature program was 38 °C 4 min hold, 5 °C/min to 210 °C no hold, and 20 °C/min to 280 °C 6.5 min hold. Identification of the compounds was done with a mass spectral library (NIST02, National Institute of Standards and Technology, Gaithersburg, MD, USA), reference compounds (HC 48 Component Indoor Air Standard, Supelco Inc., Bellefonte, PA, USA), and retention times. The concentrations of the compounds were calculated as toluene equivalents using Eqs. 1 and 2. Toluene is used in the quantitation of single VOCs when standard compounds are not available, and TVOC (total volatile organic compounds) concentration is calculated using toluene equivalent (ISO 2004).

$$m_A = \frac{A_A}{b_{St}} \quad (1)$$

$$\rho_A = \frac{m_A}{V_S} \quad (2)$$

In Eqs. 1 and 2, m_A is the mass of the compound, A_A is the chromatogram peak area of the compound, b_{St} is the slope of the standard curve, ρ_A is the concentration of the compound, and V_S is the volume of the sample. Chloroform concentration was calculated as a chloroform equivalent. The HC 48 Component Indoor Air standard used in the quantitation consisted of 48 compounds (including toluene and chloroform) each in a concentration of 1 ng/ μ L in a methanol solution. Correction factors for 2-(2-butoxyethoxy)ethanol (diethylene glycol butyl ether, DEGBE), (2-methoxymethylethoxy) propanol (dipropylene glycol methyl ether, DPGME), and 2-butoxyethanol (ethylene glycol butyl ether, EGBE) were evaluated in a previous study (Ruokolainen and Hyttinen 2019), and they were 2.0, 1.6, and 2.0, respectively. Limit of detection (LOD) was evaluated for chloroform and toluene. With a sampling time of 60 min and sampling volume of 0.12 L/min, the LOD for chloroform and toluene were 0.7 and 0.4 μ g/m³, respectively.

In total, 91 samples were collected during the cleaning work. One sample from each studied room was chosen per swimming pool or spa if only one cleaning product was used, and in some situations, two samples from the same room were chosen when different cleaning products were used (e.g., day 1: disinfectant and day 2: acidic). The most common VOCs are shown in the “Results” section (Table 3). Criteria for these compounds were an average concentration equal to or above 2 μ g/m³, detection in at least 3 samples, and an MS-library identification quality of at least 80%. This was done due to a large number of compounds detected (1,000+).

Trichloramine

Trichloramine was measured in 29 facilities. Samples were taken in the bathroom and the pool area. Samples were

Table 2 List of hazard statements included in the safety data sheets (SDS) of cleaning agents used by the cleaning workers included in the study

Code	Hazard statement	Number of cleaning agents	Percentage of all observed cleaning agents
H290	May be corrosive to metals	14	45%
H314	Causes severe skin burns and eye damage	18	58%
H315	Causes skin irritation	4	13%
H318	Causes serious eye damage	7	23%
H319	Causes serious eye irritation	5	16%
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled	1	3%
H335	May cause respiratory irritation	1	3%
H400	Very toxic to aquatic life	6	19%
H410	Very toxic to aquatic life with long lasting effects	4	13%
H411	Toxic to aquatic life with long lasting effects	1	3%
H412	Harmful to aquatic life with long lasting effects	2	6%
EUH031	Contact with acids liberates toxic gas	2	6%
-	No applicable hazard statements	3	10%

collected in the vicinity of the cleaning worker, at a height of approximately 1.2 m. In addition, sampling was conducted in the same locations during the opening hours of the pools. Trichloramine samples were collected using Millipore™ collectors (Merck KGaA, Darmstadt, Germany) with Na₂CO₃ + As₂O₃ impregnated filters and SKC 224 pumps with a flow rate of 2 L/min (+/- 0.01 L/min), calibrated with mini-Buck calibrator M-5 (A.P. Buck Inc, Orlando, FL, USA). Sampling volumes were 86–596 L and 164–732 L during the cleaning and opening hours, respectively. Sampling times were 43–298 min and 82–366 min, during the cleaning and opening hours, respectively. Samplers were prepared and analyzed at the Finnish Institute of Occupational Health by the method described previously by Hery et al. (1995). The limit of quantitation (LoQ) varied in the analyses between 3 and 10 µg/m³.

Statistical analysis

Statistical analysis was performed using the chloroform and TCA data. The association between cleaning product type and chloroform as well as TCA was analyzed using unequal variances *t*-tests. Association of the TCA and chloroform on the facility type was analyzed using a general linear model (GLM) and Tukey's test was used for pairwise post hoc comparisons. Equality of variances was confirmed using Levene's test. The association of the TCA and chloroform on ozone treatment was analyzed with a *t*-test. The normality of distributions of the TCA and chloroform was confirmed visually and with the Shapiro–Wilk test in critical cases when the main test *P*-value was between 0.02 and 0.08. The correlation of TCA and chloroform with the year of building construction or latest renovation, pool area, and the yearly number of visitors

was analyzed using Pearson's correlation. The yearly number of visitors was used as a rough estimate for swimmer load as the actual number of the swimmers during the measurements was not available. The analyses were done using SAS 9.4 statistical software.

Particulate matter

Particulate matter (PM) was collected gravimetrically using IOM samplers and cassettes (SKC), Millipore fluoropore or mixed cellulose filters (Merck), and SKC 224 pumps calibrated to 2 L/min (+/- 0.01 L/min) with mini-Buck calibrator M-5. Sampling times during the cleaning and opening hours varied between 30–180 and 110–1130 min, respectively. Mixed cellulose (AAWP, nitrocellulose, pore size 0.8 µm) filters (Merck) were used in the first seven sampling campaigns but were replaced by fluoropore (FALP02500, pore size 1 µm) filters in the later sampling campaigns as the water splashes from cleaning work caused some mixed cellulose filters to get wet and damaged. Samples were collected from the breathing zone of the cleaning worker if the worker agreed to it. In cases where the cleaning worker did not agree to personal sampling, a site in the vicinity of the cleaning worker was chosen, and the samplers were moved as the work progressed. Samples were weighed (+/- 2 µg accuracy) with a Mettler Toledo MX5 scale (Mettler-Toledo International Inc., Columbus, OH, USA). Before the weighing, filters were equilibrated in the weighing room for a minimum of 24 h. The conditions in the weighing room varied between 20–21 °C, 32–60%, and 98.3–103.2 kPa for temperature, relative humidity, and barometric pressure, respectively. Inhalable dust concentration was calculated using Eq. 3.

Table 3 The most common VOCs, determined as toluene equivalent concentrations, during the cleaning and opening hours. Average concentration (mean) in $\mu\text{g}/\text{m}^3$, standard deviation (SD), and number of samples they were detected in (*n*). *N.D.*, not detected

Compound	CAS	Locker room, cleaning		Locker room, opening hours		Bathroom, cleaning		Bathroom, opening hours		Pool area, cleaning		Pool area, opening hours							
		Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n						
TVOC	-	96	93	25	78	76	28	251	384	36	125	121	29	91	50	30	83	55	33
(2-methoxymethyllethoxy)propanol (dipropylene glycol methyl ether, DPGME) ⁺	34,590-94-8	37	59	3	N.D.	-	N.D	23	29	6	7	-	1	5	6	5	N.D	-	N.D
(E)-6,10-Dimethyl-5,9-undecadien-2-one	3796-70-1	1	1	4	N.D	-	N.D	2	1	14	1	0	2	1	0	5	1	-	1
1,1'-Oxybisdecane (decyl ether)	2456-28-2	N.D	-	N.D	N.D	-	N.D	40	78	5	N.D	-	N.D	2	-	1	N.D	-	N.D
10-Methylnonadecane	56,862-62-5	N.D	-	N.D	N.D	-	N.D	3	4	6	N.D	-	N.D	0	-	1	1	-	1
1-Butanol	71-36-3	5	1	3	4	1	4	10	6	3	5	4	5	6	3	5	5	2	3
1-Decene	872-05-9	3	3	5	0	-	1	6	12	16	1	1	4	3	2	5	1	1	3
1-Dodecanol	112-53-8	1	1	2	N.D	-	N.D	3	4	3	1	-	1	0	-	1	N.D	-	N.D
1-Octanol	111-87-5	15	-	1	N.D	-	N.D	3	6	9	N.D	-	N.D	30	-	1	N.D	-	N.D
1-Undecene	821-95-4	N.D	-	N.D	N.D	-	N.D	2	2	3	N.D	-	N.D	N.D	-	N.D	N.D	-	N.D
2-(2-Butoxyethoxy)ethanol (diethylene glycol butyl ether, DEGBE)	112-34-5	27	73	11	1	1	7	76	111	18	8	20	11	10	11	16	5	8	6
2-(2-Ethoxyethoxy)ethanol (diethylene glycol ethyl ether, DEGEE)	111-90-0	1	-	1	N.D	-	N.D	18	30	5	2	-	1	2	2	3	N.D	-	N.D
2,6-Dimethyl-7-octen-2-ol (Dihydromyrcenol)	18,479-58-8	2	-	1	1	1	3	9	9	4	5	6	11	4	0	2	N.D	-	N.D
2-Butoxyethanol (ethylene glycol butyl ether, EGBE)	111-76-2	2	1	2	1	-	1	4	6	10	1	-	1	7	-	1	N.D	-	N.D
2-Butyl-1-octanol	3913-02-8	N.D	-	N.D	N.D	-	N.D	20	31	7	0	-	1	3	0	2	N.D	-	N.D
2-Ethyl-1-dodecanol	19,780-33-7	2	-	1	N.D	-	N.D	5	5	10	N.D	-	N.D	3	3	2	N.D	-	N.D
2-Ethyl-1-hexanol	104-76-7	2	2	20	2	3	22	3	3	31	2	2	23	3	2	26	2	1	24
2-Methyl-2-undecanethiol	10,059-13-9	N.D	-	N.D	N.D	-	N.D	3	2	3	N.D	-	N.D	2	2	3	N.D	-	N.D
2-Phenoxyethanol	122-99-6	1	0	4	1	0	2	1	1	14	1	0	2	2	2	3	2	-	1
3,7,11-Trimethyl-1-dodecanol (hexahydrofarnesol)	6750-34-1	2	1	2	N.D	-	N.D	4	3	9	N.D	-	N.D	2	1	2	N.D	-	N.D
3,7-Dimethyl-1,6-octadien-3-ol (linalool)	78-70-6	3	-	1	1	-	1	2	2	4	1	1	6	N.D	-	N.D	1	-	1
5-Undecene	4941-53-1	6	-	1	N.D	-	N.D	3	2	4	N.D	-	N.D	N.D	-	N.D	N.D	-	N.D
Acetic acid	64-19-7	3	2	18	1	1	18	4	4	27	3	4	25	3	2	22	4	14	27
α -Pinene	80-56-8	5	9	17	1	1	20	3	6	28	3	3	23	3	6	23	1	1	18
Benzaldehyde	100-52-7	2	1	24	2	1	28	2	2	36	2	1	28	3	1	30	3	1	33
Benzoic acid	65-85-0	6	4	21	5	4	26	6	6	27	5	4	27	8	8	28	9	7	33
Benzonitrile	100-47-0	N.D	-	N.D	N.D	-	N.D	2	2	5	1	0	2	1	0	8	1	1	19
Benzyl nitrile	140-29-4	N.D	-	N.D	N.D	-	N.D	3	3	3	N.D	-	N.D	1	0	2	N.D	-	N.D
Butanoic acid, butyl ester	109-21-7	2	2	3	5	-	1	1	-	1	1	-	1	2	1	3	1	-	1
Carbon tetrachloride	56-23-5	1	0	2	1	1	2	10	9	12	9	6	7	8	11	7	6	6	7
Chloroform (trichloromethane)*	67-66-3	12	12	16	7	7	16	26	29	29	18	21	27	36	22	30	57	51	30
Cyclodecane	293-96-9	1	0	2	0	0	2	5	4	10	1	0	2	1	1	5	1	-	1

Table 3 (continued)

Compound	CAS	Locker room, cleaning		Locker room, opening hours		Bathroom, cleaning		Bathroom, opening hours		Pool area, cleaning		Pool area, opening hours							
		Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n						
Cyclododecane	294-62-2	9	11	2	1	0	3	2	0	4	1	0	6	3	2	8	3	-	1
Cyclooctane	292-64-8	3	4	4	N.D	-	N.D	7	8	2	2	-	1	1	0	2	N.D	-	N.D
(o-, p-, m-) Cymene	cym	5	3	3	4	3	5	2	-	1	6	6	10	2	1	3	3	3	5
Decamethylcyclopentasiloxane (D ₅)	541-02-6	15	38	25	16	24	28	11	24	36	8	12	29	6	14	29	6	14	33
<i>Decanal</i>	112-31-2	4	2	25	4	2	28	5	3	35	4	2	29	4	2	30	3	2	33
D-limonene	5989-27-5	3	3	6	4	3	11	4	8	12	5	5	19	18	37	5	2	3	7
Eucalyptol	470-82-6	5	5	5	24	47	10	3	2	13	64	104	13	5	10	10	14	21	10
Haloesters	-	5	9	5	1	0	2	8	8	19	1	0	2	2	3	13	1	-	1
Hexadecane	544-76-3	3	8	10	4	5	15	5	8	16	5	4	17	1	1	13	4	4	15
Hexane	110-54-3	2	2	8	1	1	13	6	14	16	2	3	11	2	2	13	3	6	13
Nonanal	124-19-6	3	1	25	3	2	28	4	2	36	3	1	29	2	1	30	2	1	32
Nonylcyclopropane	74,663-85-7	N.D	-	N.D	N.D	-	N.D	5	3	4	1	-	1	N.D	-	N.D	N.D	-	N.D
Octadecane	593-45-3	N.D	-	N.D	0	0	3	4	4	4	1	0	2	2	2	2	0	-	1
Octylcyclopropane	1472-09-9	N.D	-	N.D	N.D	-	N.D	4	2	5	N.D	-	N.D	N.D	-	N.D	N.D	-	N.D
Pentadecane	629-62-9	11	-	1	4	3	7	4	5	8	2	2	12	1	-	1	2	3	9
Propylene glycol	57-55-6	N.D	-	N.D	N.D	-	N.D	3	3	3	N.D	-	N.D	5	-	1	N.D	-	N.D
Undecane	1120-21-4	1	1	5	1	0	3	3	4	18	1	0	5	1	1	12	1	0	6

*Sum of Tenax TA + Chromosorb 106, concentration calculated with own response

†Sum of isomers (34,590-94-8, 13,429-07-7, 20,324-32-7, 13,588-28-8, and 55,956-21-3)

$$c_{\text{IOM}} = \frac{(\Delta m_{\text{IOMfs}} - \Delta m_{\text{IOMf0}})}{V_{\text{IOM}}} \quad (3)$$

In Eq. 3, c_{IOM} is the concentration of inhalable dust, Δm_{IOMfs} is the mass of the IOM filter sample (weight difference of pre- and after measurement weighing), Δm_{IOMf0} is the mass difference of the IOM blank filters before and after measurement (if more than one blank was weighed, the average difference was used), and V_{IOM} is the volume of the IOM sample.

Real-time monitoring of the PM was done with an optical analyzer TSI DustTrak DRX (TSI Inc., Shoreview, MN, USA) in 18 facilities. The data logging interval for the analyzer was 30 s. Monitoring time varied between 22 and 363 min, depending on the duration of the cleaning tasks. The optical analyzer was kept in the close surroundings of the cleaning worker (within 5 m). A gravimetric correction was done to the optical measurements (Eq. 4), by weighing the filter of the analyzer. The filter diameter was 37 mm, and similarly to IOM measurements mixed cellulose (AAWP, pore size 0.8 μm) in the first sampling campaigns and fluoropore (FALP03700, pore size 1 μm) in the later sampling campaigns were used. Weighing of the filters was done using the same procedure as IOM filters.

$$c_{\text{G}} = \frac{(\Delta m_{\text{fs}} - \Delta m_{\text{f0}})}{V_{\text{D}}} \quad (4)$$

$$c_{\text{Corr}} = c_{\text{D}} \times \frac{c_{\text{DAVG}}}{c_{\text{G}}} \quad (5)$$

In Eqs. 4 and 5, c_{G} is gravimetric concentration, m_{fs} is the mass of the DRX filter sample (weight difference of the pre- and after measurement weighing), Δm_{f0} is the mass difference of the blank filter's pre- and after measurement weighing (if more than one blank filter, average of the weighing difference was used), V_{D} is the volume of the DRX sample, c_{Corr} is the corrected concentration, c_{D} is the concentration single DRX time point, and c_{DAVG} is the total average concentration of DRX sample.

Comfort conditions

Temperature and relative humidity measurements were done with a Vaisala HMI41/HMP42 device (Vaisala Oyj, Vantaa, Finland), Testo 435 (Testo SE & Co. KGaA, Lenzkirch, Germany), and TSI IAQ-Calc. A thermographic camera Fluke Ti400 (Fluke Corporation, Everett, WA, USA) was used in some cases to evaluate the surface temperatures. This was mainly done in saunas during the cleaning, where warm surfaces were present.

Results

Cleaning products

Altogether 31 different cleaning products were used in the studied swimming pools and spas. In these cleaning products, 70 different compounds were reported in the SDS. The hazard statements reported in the SDSs of the cleaning products are presented in Table 2. Only three cleaning products had no hazard statements. However, multiple cleaning products could cause irritating or sensitizing symptoms (H315, H318, H319, H334, H335) and the majority (58%) could cause severe skin burn and eye damage (H314), while two cleaning products had the possibility of releasing toxic gas if misused with other agents (EUH031).

Volatile organic compounds

Average TVOC concentrations were relatively low in most situations (Table 3). Concentrations during cleaning in the pool areas, bathrooms, and locker rooms were 90, 258, and 96 $\mu\text{g}/\text{m}^3$. In 43% of the cases, the TVOC concentration was below 100 $\mu\text{g}/\text{m}^3$ and only in 15% of the cases the concentration was above 200 $\mu\text{g}/\text{m}^3$. Table 3 presents the most common VOCs during the cleaning work, and their concentrations during the opening hours of these facilities. In the table, compounds marked in italics are known Tenax TA degradation products (Clausen and Wolkoff 1997; Klenø et al. 2002). Therefore, the indoor air concentrations of these compounds are likely lower.

The most common compound group related to cleaning was glycol ethers: 2-(2-butoxyethoxy)ethanol (diethylene glycol butyl ether, DEGBE), 2-(2-ethoxyethoxy)ethanol (diethylene glycol ethyl ether, DEGEE), (2-methoxymethylethoxy)propanol (dipropylene glycol methyl ether, DPGME). The most abundant glycol ether was DEGBE, which had average concentrations of 10, 76, and 27 $\mu\text{g}/\text{m}^3$ in the pool area, bathroom, and locker room, respectively. During the use of alkaline and disinfecting cleaning products, several hydrocarbons with a poor identification were often present, including long branched aliphatic hydrocarbons and haloesters. Some of the compounds in that range might be acetates of the observed glycol ethers.

Chloroform levels during the cleaning in the locker rooms, bathrooms, and pool area were on average 12, 26, and 36 $\mu\text{g}/\text{m}^3$, respectively. Other halogenated VOCs were also measured during the cleaning, and these included carbon tetrachloride, trichloroacetonitrile, trichloronitromethane, and 1,1,1-trichloro-2-propanone. Outside of

the chloroform and carbon tetrachloride, other halogenated VOCs (e.g., brominated organic compounds) were detected only at trace levels. Both chloroform and carbon tetrachloride have been detected from products containing chlorine-based bleach (Odabasi 2008).

During the opening hours of the swimming pools and spas, the average TVOC concentrations in the locker rooms, bathrooms, and pool areas were 78, 125, and 81 $\mu\text{g}/\text{m}^3$, respectively. The most typical compounds were eucalyptol, decamethylcyclopentasiloxane (D_5), and chloroform. The average concentrations of the chloroform in the locker rooms, bathrooms, and pool areas were on average 7, 18, and 57 $\mu\text{g}/\text{m}^3$, respectively.

Trichloramine

TCA concentrations during the cleaning in the pool areas and the bathrooms were on average 67 and 60 $\mu\text{g}/\text{m}^3$, respectively (see Fig. 1). Whereas during the opening hours of the swimming pools and spas, the TCA concentrations in the pool area and the bathroom were on average 122 and 28 $\mu\text{g}/\text{m}^3$, respectively. The highest TCA concentrations (130, 200, 280 $\mu\text{g}/\text{m}^3$) during the cleaning were measured in the bathrooms while cleaning with disinfectants. Whereas during the opening hours, the highest measured TCA concentration in the bathroom was 100 $\mu\text{g}/\text{m}^3$. Refer to supplementary material Table S1 for more detailed results. Thirteen samples (10.9% of total samples) were below the limit of quantitation (BLoQ), eight of those were in the bathrooms during the cleaning, five in the bathrooms during the opening hours of the buildings, and one in the pool area during the maintenance cleaning of the pool area (pools were drained of water).

Statistical analysis

The use of disinfectants during the cleaning work in the bathrooms increased the chloroform concentration slightly compared to the opening hours ($3.92 \pm \text{SE } 9.72$), whereas the use of the other cleaning products did not increase the chloroform concentration ($-6.41 \pm \text{SE } 5.13$). However, the difference between the effect of the

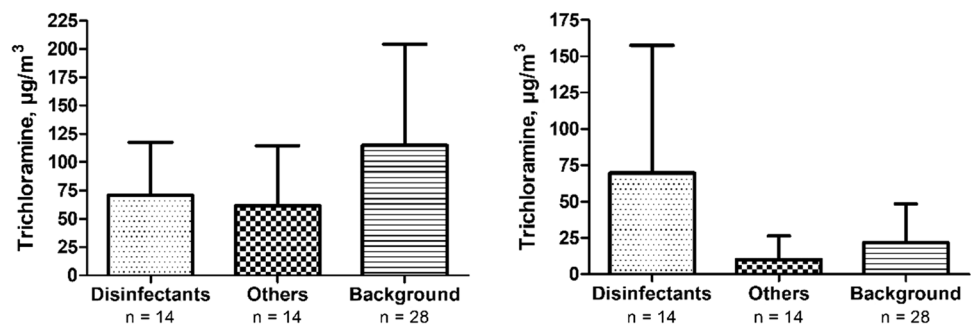
method was not statistically significant (unequal variances t -test: $\text{df} = 25.23$, $t = -0.94$, $P = 0.36$). In the pool area, the concentration of the chloroform was higher during the opening hours than during the use of either disinfectants ($-18.56 \pm \text{SE } 8.84$) or other cleaning products ($-32.50 \pm \text{SE } 17.37$) while cleaning (unequal variances t -test: $\text{df} = 18.1$, $t = -0.72$, $P = 0.48$). The variance of the other cleaning products was significantly higher than that of the disinfectants (Levene's test for equality of variances, $F_{12, 16} = 2.96$, $P = 0.045$).

However, use of the disinfectants during the cleaning work increased the concentration of the TCA statistically significantly in the bathrooms compared to the opening hours ($48.68 \pm \text{SE } 22.14$), whereas during the use of the other cleaning products the TCA concentration was lower than during the opening hours ($-12.39 \pm \text{SE } 5.07$) (unequal variances t -test: $\text{df} = 14.36$, $t = -2.69$, $P = 0.017$). The variance of the disinfectants was significantly greater than that of the other cleaning products (Levene's test for equality of variances, $F_{13, 13} = 19.10$, $P < 0.0001$). Like the chloroform, the TCA concentration in the pool area was higher during the opening hours than during the cleaning work for both the disinfectants ($-45.43 \pm \text{SE } 22.50$) and the other cleaning products ($-53.41 \pm \text{SE } 17.92$) (equal variances t -test: $\text{df} = 28$, $t = -0.28$, $P = 0.78$). The variances between the disinfectants and the other cleaning products were equal (Levene's test for equality of variances, $F_{13, 15} = 1.38$, $P = 0.55$).

The chloroform and the TCA concentrations during the opening hours were compared to see if either could predict the concentration of the other. No correlation between the chloroform and the TCA concentrations was found ($N = 29$, Spearman's $\rho = 0.191$, $P = 0.322$).

Concentrations of the TCA differed between facility types; however, the difference was marginally non-significant (mean \pm 95% CI, swimming pools (type 1): $88.8 \pm 46.0 \mu\text{g}/\text{m}^3$; swimming pools with spa sections (type 2): $173.3 \pm 55.2 \mu\text{g}/\text{m}^3$; spas (type 3): $97.9 \pm 62.6 \mu\text{g}/\text{m}^3$; $F_{2, 26} = 3.19$, $P = 0.0575$). In pairwise comparisons, "facility type 1" differed from "facility type 2," but the difference was marginally non-significant (Tukey's $P = 0.057$). The concentrations of the chloroform did not differ

Fig. 1 Trichloramine concentrations and their standard deviations in the pool area (left) and bathrooms (right) during the cleaning with disinfectants and other cleaning agents (others), and the concentration of the TCA during the opening hours of the swimming pool (background)



among facility types (type 1: $49.6 \pm 26.9 \mu\text{g}/\text{m}^3$; type 2: $67.0 \pm 30.4 \mu\text{g}/\text{m}^3$; type 3: $76.4 \pm 38.1 \mu\text{g}/\text{m}^3$; $F_{2,29} = 0.79$, $P = 0.46$).

The concentrations of the chloroform did not differ between facilities with water ozonation and with no ozonation (ozonation: $79.3 \pm \text{SE } 20.7 \mu\text{g}/\text{m}^3$; no ozonation: $44.9 \pm \text{SE } 6.4 \mu\text{g}/\text{m}^3$; unequal-variances *t*-test: $\text{df} = 11.91$, $t = 1.58$, $P = 0.14$). However, concentrations of the TCA differed between facilities with pool water ozonation and without ozonation, being higher in facilities with ozonation (ozonation: $168.3 \pm \text{SE } 33.0 \mu\text{g}/\text{m}^3$; no ozonation: $99.4 \pm \text{SE } 16.2 \mu\text{g}/\text{m}^3$; equal variances *t*-test: $\text{df} = 24$, $t = 2.08$, $P = 0.048$).

The concentrations of the chloroform and TCA did not correlate with the year of construction or the most recent major renovation (chloroform: $N = 32$, $r = 0.184$, $P = 0.31$; TCA: $N = 29$, $r = 0.192$, $P = 0.32$), or yearly number of visitors (chloroform: $N = 32$, $r = 0.036$, $P = 0.85$; TCA: $N = 28$, $r = 0.248$, $P = 0.20$). The concentration of the chloroform did not correlate with the pool water surface area, but the concentration of the TCA did so (chloroform: $N = 29$, $r = 0.222$, $P = 0.25$; TCA: $N = 26$, $r = 0.427$, $P = 0.030$; Fig. 2).

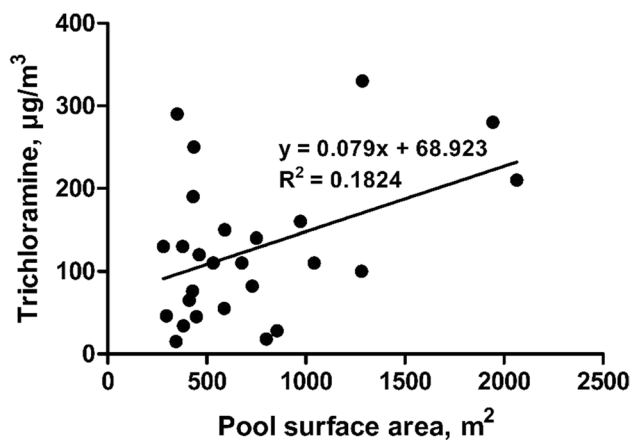
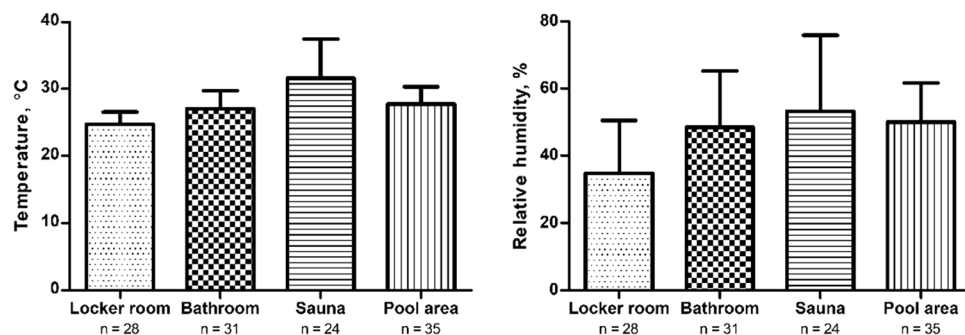


Fig. 2 Linear regression of trichloramine concentration and pool surface area

Fig. 3 Average temperature (left) and relative humidity (right) with standard deviations in locker rooms, bathrooms, and saunas during the cleaning



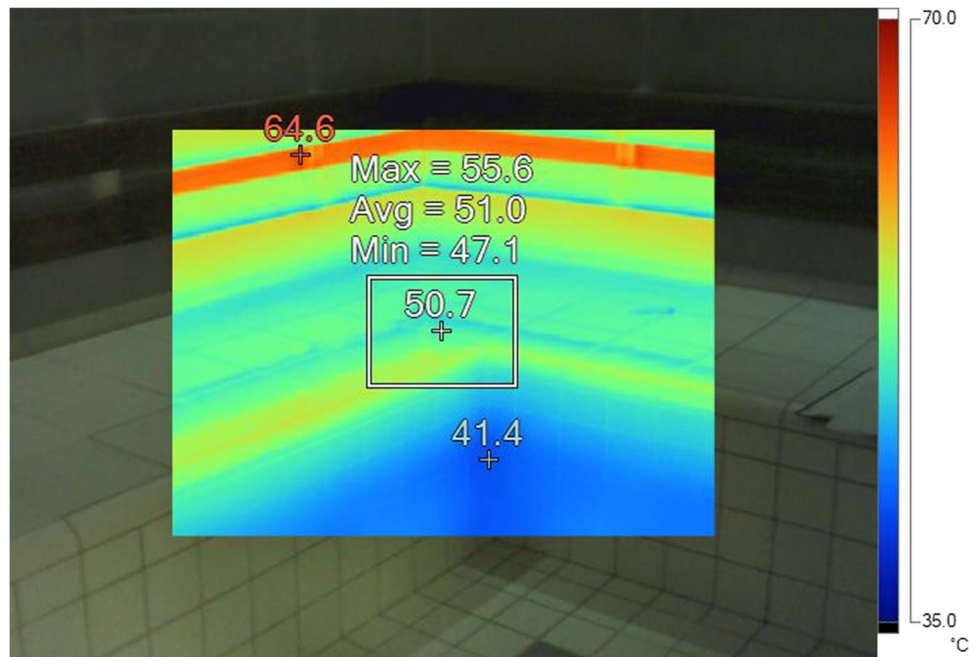
Particulate matter

The inhalable PM concentrations were low. The highest concentration measured from the breathing zone of the cleaning worker was $0.35 \text{ mg}/\text{m}^3$. It was measured during a morning shift that included the cleaning of locker rooms, bathrooms, and pool area. The real-time monitoring yielded similar results to the IOM measurements, although it is worth noting that the location of the monitors was up to 5 m from the cleaning workers so that they could perform their work and protect the devices from splashing water. This may underestimate the exposure of the worker. The average PM_{15} (aerodynamic diameter, $D_{ae} < 15 \mu\text{m}$) concentration during cleaning in the swimming pools and the spas was $0.021 \text{ mg}/\text{m}^3$ (range $0.001\text{--}0.088 \text{ mg}/\text{m}^3$, SD $0.021 \text{ mg}/\text{m}^3$). During the wiping of dust from the top and inside of the lockers, the PM concentration increases momentarily. In total, 6 peaks of greater than $0.500 \text{ mg}/\text{m}^3$ were observed; the highest measured single peak concentration was $4.690 \text{ mg}/\text{m}^3$. Wiping of the lockers takes usually 5 to 10 min; therefore, these exposures are relatively short in their duration.

Comfort conditions

Average temperatures during the cleaning in the locker rooms, bathrooms, saunas, and pool areas are presented in Fig. 3. Refer to supplementary material Table S2 for more detailed results. The average temperature in the saunas during the cleaning was $31 \text{ }^\circ\text{C}$ (ranged from 23 to $45 \text{ }^\circ\text{C}$). In the saunas, the surface temperature was often higher than the air temperature. Figure 4 presents a thermographic camera photograph of a sauna bench surface temperature just before the cleaning. In the pool area, the temperature needs to be $2 \text{ }^\circ\text{C}$ above the water temperature to reduce the evaporation of the water. Besides this requirement, high temperature is needed for customers' thermal comfort. This can be seen from the higher temperatures in the spas than in the swimming pools. The average temperatures in the pool area, bathrooms, and locker rooms were $28 \text{ }^\circ\text{C}$, $27 \text{ }^\circ\text{C}$, and $25 \text{ }^\circ\text{C}$, respectively. The relative humidity is affected by the temperature, weather conditions and the season outside, usage,

Fig. 4 Thermographic camera image of sauna benches just before cleaning. Air temperature in the sauna was 45 °C



and the pool type (whirlpool baths, and the cleaning methods applied). Average relative humidity in the pool areas, bathrooms, saunas, and locker rooms was 53%, 51%, 48%, and 35%, respectively.

Discussion

The cleaning products used in the cleaning of the swimming pool and spa environments were often sensitizing and the majority (58%) had the possibility of causing skin burns or eye damage. Only 10% of the products had no applicable hazard statements. Therefore, the use of proper personal protective equipment (PPE), including shoes and gloves, is essential to prevent dermal exposure to the cleaning products and to decrease the detrimental effects of wet work (Jungbauer et al. 2004). Furthermore, the nature of the cleaning work performed in the swimming pools and spas is often wet, even more so than in other public buildings. Wet work has been established as the major cause of contact dermatitis in the cleaning industry (Jungbauer et al. 2004), further warranting the use of PPE. Also, cleaning workers should familiarize themselves with the SDSs of the used cleaning products and safe work practices to avoid possible harm caused by the misuse of the product or improper work practices. However, this may not always be the case. Dingle et al. (2002) investigated the use of cleaning products in homes and noted that over 30% of the respondents never read the cleaning product labels. The usage of PPE varied significantly between the cleaning workers. In a few cases, the cleaning workers used motorized respirators while working

with disinfecting products. The use of respirators should be considered more often, especially when working with disinfecting products. However, it can increase the exhaustiveness of the thermal load due to the high temperature and humidity in the working areas. During the measurements, the cleaning workers were often observed wearing sandals and not wearing gloves, even when handling products containing hazardous chemicals.

In the swimming pool and spa environments, the exposure of cleaning workers to the VOCs was relatively low. DEGBE was the most common compound related to cleaning, typically in the situations where alkaline cleaning products were used. DEGBE can penetrate through skin and can cause skin irritation and contact dermatitis (Berlin et al. 1995; Nielsen et al. 1998; Gijbers et al. 2004). This makes the use of protective gloves and shoes essential. Berlin et al. (1995) reported a case of a woman having hypersensitivity towards DEGBE, causing burning and erythema of facial skin, and irritation of upper airways and eyes. Nielsen et al. (1998) recommended 9 mg/m³ indoor air quality guideline for DEGBE which is vastly higher than the highest measured DEGBE concentration during the cleaning (correction factor applied concentration 0.8 mg/m³). The Finnish OEL for DEGBE is 64 mg/m³. Of the other glycol ethers, EGBE and DPGME have Finnish OELs of 98 and 310 mg/m³ which are likewise vastly higher than the highest measured EGBE and DPGME concentrations during the cleaning (correction factor applied concentrations 0.0 and 0.2 mg/m³ for EGBE and DPGME, respectively). D₅ was one of the main compounds both during the normal use and the cleaning of the facilities. D₅ is widely used in personal care and hygiene products as

well as in [cleaning products](#), building materials (especially sealants), and even as a food additive (Horii and Kannan 2008; Wang et al. 2009; Rucker and Kummerer 2015; Tang et al. 2015). However, in cases where the cleaning worker did not allow personal sampling, the VOC sampling was conducted in the vicinity of the cleaning worker which may underestimate the actual exposure of the worker. Also, the use of toluene equivalent in the calculation of the single compound concentrations underestimates the actual concentration of especially polar compounds, such as aldehydes (Hyttinen 2007). However, the use of toluene equivalent is a common practice, when reference compounds are not available, also TVOC concentration is always calculated as a toluene equivalent (ISO 2004). Furthermore, as the results are compared to the samples collected during the opening hours, instead of a situation where there is no activity present in the facilities, it is possible that some emissions from the cleaning products are not noticed (e.g., the concentration is higher or close to the same during the opening hours).

The measured TCA concentrations were similar to those of recent studies investigating the indoor air quality in indoor swimming pools (Fornander et al. 2013; Westerlund et al. 2015). Measured TCA concentrations were below the Finnish OEL and WHO's guideline value ($500 \mu\text{g}/\text{m}^3$) (WHO 2006; Finnish Ministry of Social Affairs and Health 2018). However, previous studies have shown that TCA can irritate airways and eyes, even in concentrations below $300 \mu\text{g}/\text{m}^3$ (Parrat et al. 2012; Fornander et al. 2013). Also, in a study investigating occupational TCA and THM exposure in rehabilitation swimming pools (Westerlund et al. 2019), a significant increase in ocular symptoms was observed in TCA concentrations above $20 \mu\text{g}/\text{m}^3$. The use of disinfectants was found to increase the TCA concentrations during the cleaning of bathrooms, likely due to similar reactions as in the pool water (Hery et al. 1995; Judd and Black 2000). Thus, in some cases, the use of disinfecting chemicals may result in irritative symptoms. It is worth noting that the combination of the TCA and THMs (and the other VOCs) can enhance the irritative effects in the lower TCA concentrations (Schmalz et al. 2011b). Furthermore, the background samples were collected during the opening hours of the pools, which can mask the increase of the TCA released during the cleaning of the pool area; however, higher ventilation rates in the pool areas help to dilute the TCA released during the use of disinfecting cleaning products. Also, the sampling of the TCA was performed in the vicinity of the cleaning worker, which may underestimate the actual TCA exposure. Chloroform concentrations did not correlate with those of the TCA, and this can be due to the different impurities causing the formation of these compounds. Also, the sampling time of the TCA was considerably longer than that of the VOCs (including chloroform), so there is a chance that the possible change in the number of swimmers during the

sampling might have affected the concentration of either of the DBPs measured. Similarly, a previous study by Westerlund et al. (2019) showed no correlation between TCA and THM concentrations. Showering before entering the pool is a common practice in Finnish swimming pools and spas, which affects the formation of some DBPs, mainly those that are formed in the reaction of organic impurities from cosmetics, etc. However, this only affects compounds formed with sweat and disinfectants only at the beginning of the swimming activity.

Similar to previous studies done by Bello et al. (2009) and Gerster et al. (2014a), cleaning workers were exposed to multiple irritative compounds at low concentrations. Furthermore, previous studies have associated repeated exposure to low concentrations of irritants with respiratory symptoms, including occupational asthma (Burge 2010; Labrecque 2012; Tarlo and Lemiere 2014). Although ethanalamines were not measured in the present study, they are widely used in [cleaning products](#) (Bello et al. 2009; Gerster et al. 2014b). They are irritants and are connected to the development of asthma (Savonius et al. 1994; Bello et al. 2009; Mäkelä et al. 2011).

Continuous working time spent in the pool area varies depending on the task and the size of the pool area, usually ranging from 15 min to 2 h. During the opening hours of the swimming pools, the cleaning workers performed routine checks in the pool area, bathrooms, and locker rooms, usually once every 2 h. Each of these checks lasted around 20 min. The duration of cleaning workers' exposure to the TCA and THMs is usually shorter than that of lifeguards and sports instructors, who regularly spend the whole workday in the pool area. However, the cleaning workers in the swimming pools and spas are exposed to the TCA daily, which is attributed to their use of disinfectants containing hypochlorite and the evaporation of the TCA from pool water. By contrast, in other environments, the cleaning workers are exposed to the TCA mainly during the use of the hypochlorite-containing disinfectants.

The statistical analysis of the TCA and chloroform concentrations during the opening hours yielded interesting results. The pool water ozone treatment and the pool water surface area both seem to affect the concentration of the TCA and not that of the chloroform. The pool water ozonation seems to increase the TCA concentration as does the increased pool water surface area.

The PM exposure of the cleaning workers was low, and it occurred mostly during the cleaning of the locker rooms while wiping the surfaces and vacuuming the floor. These tasks were usually short. Only a few peaks of high dust concentration were observed in the real-time monitoring, and these were related to the cleaning of the locker rooms. It should be noted, however, that the monitor was not positioned in the breathing zone of the worker and it is possible

that this underestimates the exposure. The concentrations of the inhalable dust were well below Finnish OEL values, which are 5 and 10 mg/m³, for inhalable organic and inorganic dust respectively (Finnish Ministry of Social Affairs and Health 2018). However, PM sampling was done in the vicinity of the cleaning workers when the worker did not allow for personal sampling; it is possible that these results slightly underestimate the exposure to the PM. Also, real-time monitoring was always performed in the vicinity of the cleaning worker.

Comfort conditions in the swimming pools and spas are challenging for the cleaning workers. The high temperature and humidity in the pool area, bathrooms, and saunas, combined with the physical demands and often hectic pace of the cleaning work as well as dermal and inhalation exposure to chemicals, all contribute to the work-related straining. In Finland, cleaning workers in the swimming pools and spas regularly clean saunas that have air temperatures above 30 °C and surfaces that are even warmer. Stoves of the saunas are heated the whole day, usually from 6:00 to 22:00, and the temperature in the sauna is typically 60–80 °C. A good practice is to open the doors of the saunas after the heating has been switched off to enhance the cooling of the sauna and its surfaces, as it takes several hours. The cleaning of the saunas took place usually in the morning before the stove had been turned back on. Nevertheless, the temperature of the sauna was above 30 °C. In some places, the saunas were cleaned soon after the stove had been switched off when the sauna and its surfaces were still hot. The time required for the cleaning of one sauna was typically 10–30 min, depending on the cleaning tasks performed and the design and size of the sauna.

Ramsey et al. (1983) found that working outside the comfort temperature range (17–23 °C) decreased the safety of the work, due to changes in the working manners. This was observed both below and above the optimum temperature range. Cleaning workers in the spas and swimming pools regularly spend multiple hours a day above the comfort temperature zone doing physical work. Depending on the cleaning task, cleaning workers work for prolonged periods at elevated temperatures without a break. This may increase the chance to take unnecessary risks, for example, while cleaning diving apparatuses or other areas presenting the risk of falling or slipping.

Conclusion

The majority of the cleaning products used by the cleaning workers in the swimming pools and spas can irritate skin and eyes or cause severe skin burns, eye damage, asthma symptoms, or breathing difficulties, which warrants using proper protective equipment. However, the

VOC exposure of cleaning workers was relatively low. Although, while using chlorine-containing disinfectants in the bathrooms, exposure to elevated levels of chloroform and TCA occurred, which was evident in the statistical analysis. TCA concentrations during the cleaning can be high enough to cause irritative symptoms. Furthermore, cleaning workers perform their work regularly at elevated temperatures, especially while cleaning the saunas, bathrooms, and pool area, where most of the VOC and TCA exposure occurs. The statistical analysis indicated that the pool water ozonation increases the TCA concentrations in the indoor air of the studied facilities, and the pool water surface area positively correlates with the TCA concentration.

Supplementary information

Table S1. Trichloramine (TCA) concentration during the opening hours and cleaning of the swimming pools. Where smaller than symbol is present the concentration was below the current quantitation limit. (SP = Swimming pool, NM = Not measured, < = below limit of quantitation).

Facility	Facility type	Pool area (µg/m ³)	Pool area (cleaning) (µg/m ³)	Bath- room (µg/m ³)	Bathroom (cleaning) (µg/m ³)
1	SP/Spa	100	21 ^D	26	280 ^D
2	SP/Spa	210	200 ^{AL}	10	< 6 ^{AL}
3	SP/Spa	160	74 ^D	4	14 ^D
4	Spa	41	49 ^D /61 ^{AC}	39	25 ^D /8 ^{AC}
6	SP/Spa	110	67 ^D	< 3	12 ^{AC}
7	Spa	110	89 ^D	22	130 ^D
8	SP/Spa	330 [±]	73 ^{AL}	100	65 ^{AL} /130 ^D
9	Spa	63	7 ^D	14	< 10 ^{AL}
10	SP/Spa	250	88 ^D	7	32 ^D
11	Spa	21	50 ^{AL}	10	9 ^{AL}
12	Spa	150	160 ^D	32	56 ^D
13	SP/Spa	55	37 ^{AL}	18	45 ^D
14	Spa	190	36 ^{AL}	69	6 ^{AL}
15	Spa	110	76 ^{PC/AL}	5	< 4 ^{PC/AL}
17	SP/Spa	65	25 ^{AL}	10	< 9 ^{AL}
18	SP/Spa	280	100 ^{AL}	6	9 ^{AL}
19	SP	120	< 3 ^{AL*}	79	NM
21	SP	130	110 ^{AL}	51	NM
22	SP	290	100	22	< 7
23	SP	45	17 ^D	2	< 5 ^D
24	SP	28	50 ^D	25	14 ^{AL}
25	SP	15	9 ^{AC}	< 4	< 8 ^{AC}

Facility	Facility type	Pool area	Pool area (cleaning)	Bath-room	Bathroom (cleaning)
		($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)
26	SP	130	96 ^D	9	<3 ^D
27	SP	34	40 ^D	14	20 ^D
28	SP	46	44 ^{AL}	<4	6 ^{AL}
29	SP	76	160 ^D	13	220 ^D
30	SP	82	65 ⁺	<3	<6
31	SP	140	34 ⁺	7	NM
32	SP	18	10 ^{PC}	<6	<8 ^D

^Ddesinfectant, ^{AL}alkaline solution, ^{AC}acidic solution, ^{PC}cleaning with pressure washer, ^ssampler capacity exceeded *pools drained of water, ⁺maintenance, no cleaning

Table S2. Temperature and relative humidity of all facilities during the cleaning in different areas.

Facility	Sauna		Pool area		Bathroom		Locker room	
	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
1	-	-	28	54	27	71	25	44
2	34	42	28	67	25	60	24	27
3	36	20	29	41	29	33	25	35
4	34	30	32	51	29	59	25	39
5	26	59	26	70	28	67	24	57
6	23	55	28/25	64/42	22	34	23	20
7	33	74	31	43	31	52	29	47
8	28	92	29	62	28	73	28	65
9	26	53	24	29	-	-	26	26
10	26	55	32/27	36/53	26	39	-	-
11	-	-	34	46	28	38	26	19
12	29	47	29	61	29	70	27	30
13	-	-	30	52	29	42	24	41
14	40	34	27	60	28	72	26	41
15	45	92	26	55	32	33	25	23
16	32	15	29	44	23	40	22	23
17	28	60	31/28	51/35	27	48	24	20
18	39	28	30	51	29	44	26	62
19	28	79	28	58	26	42	-	-
20	-	-	27	57	25	67	-	-
21	45	25	25	56	34	40	23	47
22	28	17	30	31	27	21	24	32
23	-	-	27	34	26	46	-	-
24	29	54	25	41	25	55	23	61
25	-	-	28	27	25	26	24	18
26	33	70	23	63	24	68	23	40
27	28	75	27	58	28	67	27	52
28	30	58	27	50	27	47	27	41
29	30	73	28	61	29	68	25	20
30	29	67	26	36	24	41	21	9
31	-	-	23	65	26	18	24	15

Facility	Sauna		Pool area		Bathroom		Locker room	
	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
32	-	-	24	48	23	21	22	17

If two values are given, then the first one is from the spa area and the second is from the swimming pool area

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Data availability.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

Conflict of interest The authors declare no competing interests.

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