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Air quality in an indoor swimming pool facility

Master's thesis in Energy Use and Energy Planning
Supervisor: Guangyu Cao
June 2019

Master's thesis

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Kunnskap for en bedre verden

Preface

This master thesis is a part of a Master of Technology / Civil Engineer degree in the programme Energy planning and Energy Use at the Norwegian University of Science and Technology in Trondheim. It is worth 30 ECTS and are written at the department of Energy and Process Engineering.

The master thesis assignment was given by SIAT. SIAT is working with research in sports facilities and sports technology and contributes with several project and master assignments each year.

Earlier, a master thesis on air quality in swimming pools in Trondheim was written. This thesis aims to continue this research, measuring several parameters and looking at solutions to improve the air quality in a swimming pool facility.

Several persons have contributed to this project. Firstly, I want to thank Therese Bergh Nitter for taking initiative for this thesis assignment. She has contributed on the analyzation in the laboratory, helped me with the measurements and has helped me to improve the quality of my text. This thesis would have been impossible to carry out without her and her knowledge about this theme.
Secondly, I want to thank my supervisor at the department, Guangyu Cao, for guidance during the semester and for giving advises for the writing of the thesis.

I want to thank Camfil AS Trondheim for letting me borrow two air purifiers for testing in the swimming pool. I also want to thank Kjetil Øvretveit and Hallgeir Revhaug for providing information and for letting me do measurements at Pirbadet.

Finally, I want to thank my dad, Jo Morten Grande, for helping me with proofreading, and my classmates for making this semester social and fun.

I hope my thesis will be useful and that it can help to increase the competence regarding exposure of disinfectant bi-products in the swimming pools.

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Summary

Swimming pool is today used for both sports, recreation, therapy and swimming training for users of all ages. In Norway, the climate allows only a few months of outdoor swimming and indoor swimming pools are therefore built. To keep the water in the swimming pool free of microorganisms such as viruses, mould, bacteria and protozoa, it is essential that the water is disinfected. In Norway, chlorine is used as a disinfectant alone, or together with UV radiation. When chlorine reacts with organic and inorganic material from the bathers, undesirable disinfection by-products (DBPs) are formed. Some of these DBPs are volatile and are therefore present in the air that the bathers inhale. Today, more than 700 DBPs have been identified, and they have been suspected of causing health effects such as irritated eyes, respiratory problems, skin disorders and in the worst case, cancer. One of the most important groups of volatile DPBs is trihalomethane (THM). THM has also been found to correlate with several other types of DBPs.

The purpose of this thesis is to understand how DBPs forms and look for opportunities to lower the exposure. This was done by taking air samples of THM and at the same time test a type of carbon filter. In addition to THM, measurements of parameters such as CO_2, free chlorine, combined chlorine, temperature, pH, air change per hour and number of bathers were conducted and obtained to look at correlations to THM. To look at the effect of the carbon filter, two air purifiers with carbon filter was used. The air samples and measurements were made in a swimming pool in Pirbadet in Trondheim. The pool is disinfected using chlorine in the form of NaOCl and UV radiation. All the samples and measurements were taken at the same place in the four weeks. Sampling of THM was performed by pumping air for approx. 40 ml / min through a tube filled with Tenax TA for 20 minutes. Sampling and analysis were performed according to US EPA Method TO-17 and ISO 16017 and the analyses were performed with automatic thermal desorption (Markes int) connected to Agilent Technologies 5975T LMT-GC / MSD.

During one day of measurements, the THM concentration varied from around 90 $\mu g/m^3$ to over 200 $\mu g/m^3$ and the CO_2 concentration varied from around 500 ppm to over 700 ppm. The other parameters that were measured/obtained; RH, water temperature, temperature, free chlorine, combined chlorine and air change per hour were stable throughout the day. The CO_2 concentration was found have a significant correlation with the THM concentration.

If the results are seen in a longer time-perspective, it turned out that the concentration of combined chlorine, which was measured two times a day, varied from day to day and there were found a significant correlation between combined chlorine and the average value of THM concentration.

The results of the carbon filter testing in the swimming pool showed no sign of reduction in the THM concentration. It was a hypothesis that the carbon would absorb some of the THM gases, but the results showed that the THM concentration was on average higher when the air purifiers were turned on. This is believed to be due to increased visitor load which led to increased THM concentration.

The conclusion of this thesis is that THM correlates with CO_2- and combined chlorine concentration, and the carbon filter tested did not reduce the THM concentration. It can be an

option to install CO_2 sensors, and let the fresh air supply be controlled by the CO_2 concentration in addition to the air temperature and relative humidity to reduce the THM concentration. To test whether carbon filters can function as a suitable absorbent to reduce the exposure of DBPs, an improved test method is required. This can be, for example, to recreate a swimming pool climate in a laboratory and test different types of carbons, or to carry out parallel measurements with and without carbon filters in a swimming pool.

Sammendrag

Svømmebasseng benyttes i dag til både sport, rekreasjon, terapi og svømmeopplæring for brukere i alle aldre. I Norge er klimaet slik at utendørs svømmebasseng kun kan brukes noen få måneder i året. Derfor er det bygd flere innendørs svømmebasseng for å sikre tilgang året rundt. For å holde vannet i bassenget fri for mikroorganismer som virus, sopp, bakterier og protozoer, er det essensielt at vannet desinfiseres. I Norge brukes primært klor som desinfiseringsmiddel alene, eller sammen med UV bestråling. Når klor reagerer med organisk og uorganisk materiale fra de badende dannes uønskede desinfiserings bi-produkter (DBPer). Noen av disse DBPene er flyktige og er derfor til stede i luften som de badende puster inn. I dag er over 700 DBPer identifisert, og mistenkes å forårsake helseeffekter som irriterte øyne, respirasjonsproblemer, hudlidelser og i verste fall kreft. En av de viktigste gruppene av flyktige DPBer er trihalometan (THM). THM domineres i hovedsak av kloroform ($CHCl_3$), bromodiklormetan (BDCM), dibromoklormetan (DBCM) og bromoform ($CHBr_3$). THM er dessuten funnet å korrelere med flere andre typer DBPer.

Hensikten med denne masteroppgaven er å forstå hvordan THM dannes og hva som forårsaker eksponeringen i tillegg til å se på muligheter for å senke den. Dette ble gjort ved å ta luftprøver av THM og samtidig teste en type kullfilter. I tillegg til THM, ble det også gjort målinger og innhentet verdier av CO_2, friklor, bundet klor, temperatur, pH, luftskifte per time og antall badende for å se på korrelasjoner med THM. For å se på effekten av kullfilter ble det brukt to luftrensere med tilhørende kullfilter. Luftprøvene og målingene ble gjort i et opplæringsbasseng i Pirbadet i Trondheim som desinfiseres ved bruk av klor i form av NaOCl og UV bestråling. Alle prøvene og målingene ble tatt på eksakt samme sted. Prøvetaking av THM ble utført ved å pumpe luft i ca. 40 ml/min gjennom et rør fylt med Tenax TA i 20 minutter. Prøvetaking og analysen ble gjort i henhold til US EPA Metode TO-17 og ISO 16017 og analysene ble gjennomført med automatisk termisk desorpsjon (Markes int) koblet til Agilent Technologies 5975T LMT-GC/MSD.

I løpet av én dag med målinger, varierte THM konsentrasjonen fra rundt 90 $\mu g/m^3$ til over 200 $\mu g/m^3$ og CO_2 konsentrasjonen fra rundt 500 ppm til over 700 ppm. De andre parameterne som ble målt/innhentet; RF, vanntemperatur, temperatur, fri klor, bundet klor og luftskifte per time varierte ikke mye. CO_2 konsentrasjonen ble funnet å ha en signifikant korrelasjon med THM konsentrasjonen.

Sett i et lengre tidsperspektiv med alle målingene sett i sammenheng viste det seg at konsentrasjonen av bundet klor, som ble målt to ganger hver dag, varierte fra dag til dag og det ble bevist en signifikant korrelasjon mellom bundet klor og gjennomsnittlig verdi av THM.

Resultatene fra utprøvingen av kullfilter i svømmebassenget viste ikke forventede resultater. Det var en hypotese at kullet skulle adsorbere noe av THM gassene, men det viste seg at THM konsentrasjonen var gjennomsnittlig høyere når luftrenserne ble slått på. Dette antas å være på grunn av økt besøksbelastning som førte til økt konsentrasjon av THM.

Konklusjonen fra dette studiet er at THM konsentrasjonen er funnet å korrelere med CO_2- og bundet klor konsentrasjonen, og at kullfiltrene som ble testet reduserte ikke konsentrasjonen av THM. Det kan være en mulighet å installere CO_2 sensorer, og la frisklufts mengden styres av CO_2 konsentrasjonen i tillegg til temperatur og relativ fuktighet, for å senke THM konsentrasjonen. For å teste om kullfilter kan redusere eksponeringen av THMer er det nødvendig med en utbedret testmetode. Dette kan for eksempel gjøres ved å gjenskape et svømmebasseng-klima i et laboratorium og teste ulike kulltyper, eller å gjennomføre parallelle målinger med og uten kullfilter i et svømmebasseng.

Abbreviations

ACH	Air change per hour
BDCM ($CHBrCl_2$)	Bromodichloromethane
Blind tube	Sorbent tubes that is not used for samples but are analysed
CAM	Chloramine
$CHBr_3$	Bromoform
$CHCl_3$	Chloroform
CO_2	Carbon dioxide
DCAM	Dichloramine
DBCM ($CHBr_2Cl$)	Dibromochloromethane
DBP	Disinfectant bi-product
GC	Gas Chromatography
HAA	Halogenated acetic acids
HAN	Haloacetonitriles
HK	Haloketones
HVAC	Heating, Ventilation and Air Conditioning
IARC	The International Agency for Research on Cancer
ISO	The International Organization for Standardization
Kp	Permeability constant
MCAM	Monochloramine
MSD	Mass selective detector
PTFE casings	Holster made of polytetrafluoroethylene
RH	Relative humidity
Spiking	To inject substances and standards on the sorbent tubes
SPSS	Statistical Package for the Social Sciences
TCAM	Trichloramine
THM	Trihalomethane
tTHM	Total trihalomethanes (sum of all four THMs)
US EPA	United States Environmental Protection Agency
UV radiation	Ultra violet radiation
VOC	Volatile organic compounds
WHO	World Health Organization

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1 Introduction

Swimming pools have over the years become a very popular arena. Both swimming exercise, injury recovery and various sports such as water polo, swimming and diving are activities that occurs in a swimming pool. Some say there where swimming competitions in Japan over 2000 years ago. In Europe it is assumed that the competitions started around 1790 and in Norway the competitions in swimming started around 1885. [1]

Swimming pools needs disinfection to prevent growth of bacteria and biological contaminants to ensure that the user of the swimming pools is not infected by microorganisms. The water source swimming pools uses contains a small amount of organic and nitrogen matter, and when bathers are in the pool, additional reactants such as urine, cosmetics, sweat and skin particles are mixed with the other materials. When these materials and reactants react with the chlorine in the water, unwanted disinfectants bi-products (DBPs) are formed. Several DBPs has been discovered lately, which has led to increased concern about exposure of these DBSs. The health damage these DBPs represents, depends on toxicity, concentration, exposure time and type of exposure. [2]

In spring of 2017, a master thesis was written concerning DBPs in chlorine-disinfected swimming pools with the aim of investigating the exposure of a group of DBPs in two swimming pools in Trondheim, as well as looking at the distribution of these DBPs. This thesis is aiming to continue studying the DBPs in swimming pools, looking at ways to lower the concentration of these substances, and find a way to make it easier to understand the formation of the DBPs in the future. This thesis is written on behalf of Senter for Idrettsanlegg og Teknologi (SIAT), and it is close cooperation with them though the thesis period. [3]

The DBPs measured in this thesis is called trihalomethanes (THM). THM is one of the largest groups of DBPs present in swimming pools. Of all the trihalomethanes, four are measured in this thesis because these are the most common ones in swimming pools. They are called $CHCl_3$ (chloroform), bromodichloromethane (BDCM), dibromochloromethane (DBCM) and $CHBr_3$ (bromoform). [4]

As mentioned, chlorination of swimming pools forms many DBPs. Chloroform usually being the most dominant substance. Chloroform is a toxic and possibly carcinogenic substance, so it is not desirable for the bathers to be exposed to this substance in high concentrations. Studies have shown that DBPs exposes through inhalation, ingestion and dermal routes [5, 6]. It is also higher concentration near the poolside, compared to other places in the swimming pool area. Studies have also shown that there are some differences in different heights over the poolside. In this thesis all the measurements where conducted in the same place to give an indication of which external factors affect the concentration, and whether air purification solutions lower the concentration of THM. All the samples were conducted about three meters away from the water surface.

Earlier studies have measured THM using activated carbons inside the sampling tubes as an absorbent. But a carbon filter for the indoor air has not been tested in any studies. Thus, it were decided to look at the effect of air purifiers with carbon filter. [7]

In addition to THM, the CO_2 concentration were measured. CO_2 is formed by the breathing of humans and animals and is therefore considered to have a connection with how much THM it is in the air. Thus, there may be a correlation between THM and CO_2. In the case of correlation, it can be used to facilitate future measurements of THM in the air, and possibly change the way of regulating the ventilation in the pool.

1.1 Issue

In cooperation with SIAT and based on previous studies and literature, the following problem is derived;

Are there any correlations between trihalomethane- and CO_2 concentration and how does an air purifier with carbon filter affect the concentration of trihalomethanes?

The reason for choosing this issue is due to some hypothesis;

- CO_2 correlates with the number of bathers
- THM concentration correlates with the CO_2 concentration
- Carbon filter absorbs THM and reduces the concentration significantly
- THM concentration is reduced with high ventilation rate

To answer the problem in the best possible way, the following has been done;

- Literature study of THM and other DBP in swimming pools
- Prepared a test strategy plan for testing carbon filter and measure THM concentration variations
- Conducted measurements of THM, CO_2, relative humidity (RH) and temperature in Pirbadet through four weeks
- Analysis and discussion of results and discuss possible measures to improve the air quality
- Conclusion and recommendation for further work

1.2 Literature review

This master thesis has been cumulative in that is has attempted to build on research already done and trusted. Literature search has therefore been a significant part of the thesis. The reason for the literature study was to make an overview and understanding of the challenges associated with air quality and indoor environment in swimming pools. The theory chapter is also based on literature from books, previously completed subjects and articles to find background information about all the elements in this project, such as ventilation, indoor air quality and indoor environment. In addition, studies were conducted on how THM and CO_2

concentration are in swimming pools in general. This was to map what can be done to improve the air quality, and especially the THM concentration.

At the beginning of the master thesis, it was necessary to refresh the knowledge in the subject relevant to the assignment. The focus was on subjects like Indoor air quality and HVAC in swimming pools. The second step was to search in different databases, finding studies and articles by using keywords relevant to the assignment. Keywords such as; THM, DBP, Swimming pool, air quality, carbon filter and CO_2 were used the most when searching in the databases. Good and relevant studies and articles was sorted out for further investigation. Looking through these article's reference list gave even more references to search for. The most relevant and interesting studies and articles were studied. Only references published in reputable journals and by reliable research institutions have been used.

The databases used was mostly PubMed, NTNU Oria, ScienceDirect and Google scholar.

1.3 Structure

This project is structured in four main sections and nine chapters. The first section is introduction and includes the first chapter. The second section is the theory and includes chapter two, three and four. The fourth is the method and includes chapter five and six, while the last section presents the results, and includes chapter seven, eight and nine.

The first chapter presents the background and objective for this study. Further, the theory is presented. The theory chapter contains information about demands and air quality in swimming pools, different DBPs present in swimming pools, disinfection of the bathing water, and measures to reduce DBPs. The next chapters include a presentation of the study object and what method is used for the measurements. The last chapters include a presentation of the results from the field measurements including discussions and possible improvements. In addition, the conclusion and suggestions for further work is presented.

1.4 Limitations

The DBPs in the pool area does not only include THM, but also many other DBP groups. This thesis is limited to measuring the concentration of THM only. To get a more accurate result of the DBP exposure, more groups of DBPs cloud have been measured. All the measurement where done in one pool in Pirbadet. This pool is not necessarily representative for the general conditions in pools. The results are based on stationary samples and the measurement results are not necessarily representative of the air quality at other points than those measured.

The measurement equipment can never be 100% accurate. The results will be affected by the equipment and outside conditions. The number of repeated measurements could have been higher to ensure more accurate and transient results. Also, some of the measurement equipment could be placed closer to the occupied zone or the breathing zone, but it could not be done because of the chance of disturbing the bathers and expose the equipment to water.

1.5 Citation

The citation and source reference are made in the way that when a source comes at the end of a sentence, it applies only to that sentence. When a source is referred in the end of a section, it applies to the entire section. This citation style is called Vancouver. Vancouver uses numbers to refer to the literature list. Due to many sources, this method was chosen to create a flow in the text, without interruptions with authors etc.

2 Demands for swimming pools in Norway

This thesis has a focus on the formation and concentration of DBPs caused by disinfecting products and bathers. It is important to understand why the water is disinfected, so that measures to reduce the DBPs do not go at the expense of disinfectants ability to inactivate harmful microorganisms [8]. Disinfecting products keeps the water free of harmful microorganisms that can cause infections and even death. This chapter describes the demands for disinfection and ventilation in swimming pools in Norway. In addition, some biological factors for disinfecting the pool is described.

2.1 Biological factors

Microorganisms can as mentioned cause fatal infections in the users of the pool. Therefore, disinfection of the pool is always a priority [9]. Bacteria, rot, virus, protozoa and algae can appear in the water from the bathers [10]. These microorganisms thrive best in surrounding like 30-40 degree Celsius and this makes swimming pools a suitable environment [11]. A bacteria like Escherichia coli O157 is the most known dangerous bacteria to thrive in bathing water and affect bathing humans. The bacteria are transferred when swimming in a sewage polluted pool. Bloody diarrhea, fever and kidney failure are some consequences from E-Coli [12].

To prevent growth of such microorganisms, it is important that the users uses the shower and wash themselves before entering the pool [10]. There is also a requirement that the bacteria Pseudomonas aeruginosa is not present in the water. This bacterium can be antibiotic-resistant and causes pneumonia, urinary tract infection, and inflammation in the ear canals, also called swimmers ear. It is easy to identify and can handle chlorination better than most bacteria and the formation of this bacterium is best between 20 ºC and 42 ºC, so it is important to use chlorine to avoid this type of bacterium. [13]

Legionella is another bacterium that needs to be prevented. This bacterium grows in biofilm with other microorganisms such as algae and amoebas. Optimal growth conditions are achieved at temperatures between 20 ºC and 50 ºC and at pH values between six and seven. Sources that emit aerosols, such as showers and whirlpools are referred to by the Norwegian Institute of Public Health as the most important sources of infection. Previously, legionella bacteria have occurred in a whirlpool bath in Pirbadet due to lack of disinfection [14, 15]. In general, there are good routines to prevent legionella in public pools and whirlpools in Norway. Legionella bacteria are more likely to occur in private showers and whirlpools.

2.2 Water quality and circulation system demands

Any pool bath should have a circulation system that ensures hygienically satisfying conditions and operating routines that ensure proper operation of the circulation system [9]. Figure 1 shows how a normal circulation system can be. This include overflow gutters, bottom drain, levelling tank, purification plant with pump and filter and a station for disinfection. Regular measurements of other parameters should also be taken to ensure a satisfying water quality.

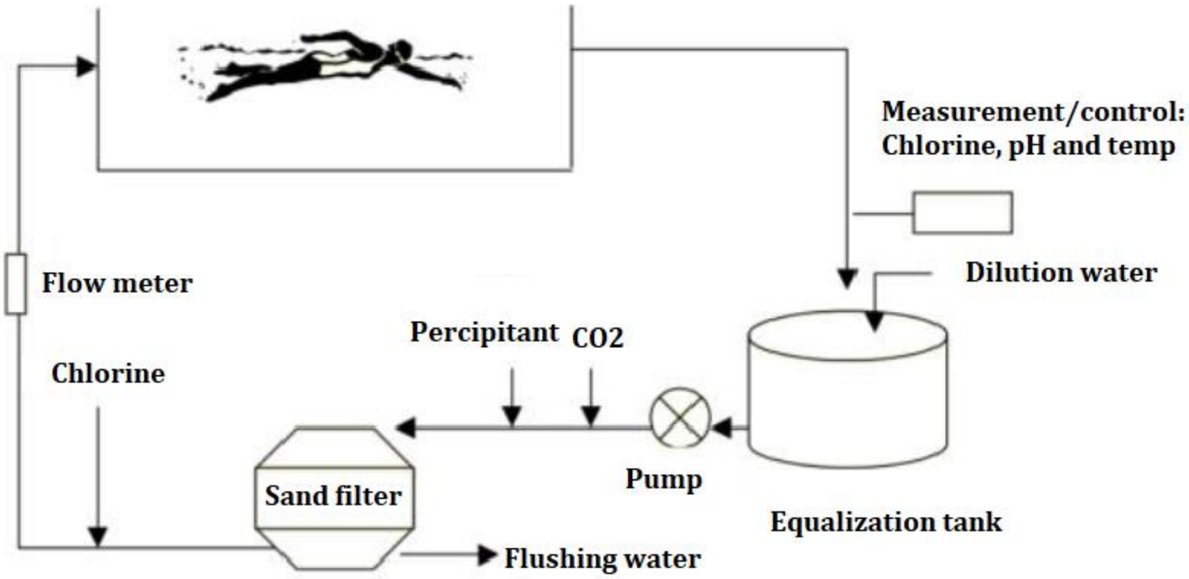

Figure 1. Normal circulation system for a swimming pool [10].

When the bather is in the pool, organic particulate matter such as dead skin cells, cosmetics, soaps, creams, sweat, urine and hair is added to the water. Organic matter such as algae, coagulated protein and bacteria occurs naturally from fresh water. Light particles float to the surface and are then removed by the overflow gutters. These overflow gutters ensure cleaning of the water by preventing contaminated water from flowing back into the pool. Heavier particles will sink to the bottom and will be transported away by the bottom drains, especially when the pool is not in use. The water from the overflow and bottom drains go to the equalization tank to ensure a uniform water level in the pools. [16]

The circulation system has a cleaning/purification system to reduce the concentration of pollutants. The purification system has a filter where particulate matter in the pool is separated from the water at a passage through a bed of granular material, also called filter grains. In pools there are several types of such filters: Sand filter, pressure diatomite filters and vacuum diatomite filters. These filters differ from the normal filters because they can remove particles that are smaller than the pore openings. The pores in the filter are typically 35-50 µm, but can, because of electrostatic properties, filtrate particles down to 1 µm. [10]

After the filtration, the water is disinfected. The main purpose of disinfecting the pool water is to eliminate pathogenic microorganisms, and to reduce the total number of bacteria. Upper limit of the total number is set to 10 per ml. Pathogenic microorganisms should not be present in a 100-ml water sample when the number of bathers is approximately at the highest. In Norway, chlorine is used alone or in combination with UV-radiation. The disinfection products should be added continuously, and the circulation system should add at least 2m^3 of water every hour. When the pool is in use, there should be added another 30 litres of new water per bather to remove enough pollutants, and to replace evaporated water. With water temperature over 34 ºC, 60 litres of water per bather is required. [10]

Since the DBPs are formed in a reaction between organic material and chlorine disinfection, the concentration of the by-products is very dependent on how much bound and free chlorine it is in the water. The ministry of health and care services in Norway have listed minimum and maximum values for chlorine use in the water. Free chlorine reacts with nitrogen-containing and organic compounds in the water and form DBPs. Combined chlorine is also called chloramines which is a type of DBP. Chloramine is the source for the "pool smell" in swimming halls. High amount of chloramine can cause irritation to eyes and mucous. The concentration of these compounds is kept as low as possible, but not compromise with the disinfecting properties. Table 1 shows the limit values for free and combined chlorine. [16, 17]

Table 1. Limit values for free- and combined chlorine [9].

Temperature	**The waters lowest content of free chlorine [1]**	**The waters highest content of combined chlorine [2]**
=<27°C	0,4 mg/l	3 mg/l
27-29°C	0,5 mg/l	3 mg/l
29-33°C	0,7 mg/l	4 mg/l
33-37°C	0,9 mg/l	4 mg/l
>37°C	1,0 mg/l	4 mg/l

[1] Measured at the outlet of the pool before filtration and before adding new disinfectant, cf § 17
[2] The content of combined chlorine compounds must never exceed 50% of the measured value of free chlorine. The value of combined chlorine should be as low as possible and should not exceed 0.5 mg cl/l

The measurements should be taken at least every third hour when in use, and four times a day if not in use. Other parameters that shall be measured every day is turbidity, colour number and pH value. Turbidity is the water containment of organic and inorganic particles and is measured in Formazine Turbidity Unit (FTU). Colour number describes the amount of humus is raw water. pH value describes the acidity of the water and is important regarding corrosion and effective disinfection. The limit values of these parameters are listed in Table 2. [9]

Table 2. Limit values for good water quality [9].

Parameter	**Limit values**
Turbidity [mg/l Pt]	0,5
Colour number [FTU]	5
pH-value	7,2 - 7,6

2.3 Air quality demands

The treatment methods to DBPs is mainly high water-exchange rate, effective water treatment systems and that users shower before use. DBPs like THM will also be present in the ambient air if it is present in the water [18]. The Norwegian working environment act has regulations for air temperature and air volumes. Also, there are limit values for exposure of chloroform and bromoform. A maximum of eight-hour average exposure is allowed. No exposure limits have been set for other DBPs in the air. To maintain a good air quality in the swimming pools, there are some guiding values and norms for air velocity, RH, ventilation and temperature and general demands for the air quality in all buildings regarding the CO_2 concentration. [19, 20]

2.3.1 Air temperature

Many different activities in swimming pools set different demands for air temperature and humidity. A wet body gives warmth to the environment by moisture on the skin evaporating towards the air's wet bulb temperature. This affects the thermal comfort for the bathers. It is recommended to keep the temperature between 1-3 ºC higher than the water temperature to avoid evaporation from wet skin [21-23], and to keep the RH inside the range of 50-60% to ensure a comfortable air [24]. Naturally, therapy pools may have some higher temperatures than 30 ºC. In England there are some recommended water temperatures for different usage of the pool. These are listed in Table 3 [25].

Table 3. Pool temperatures [25].

Pool use	Temperature range
Competitive swimming and diving, fitness swimming, training	26-28
Recreational swimming and adult teaching	27-29
Leisure waters	28-30
Children's teaching	29-31
Babies, young children, disabled and infirm	30-32
Hydrotherapy and aquatic rehabilitation pools	32-36

2.3.2 Ventilation

The ventilation is today controlled by the temperature and the RH, and a large amount of the supply air is recirculated air because it helps to keep the humidity and temperature at desired levels. The ratio between fresh air and recirculated air is controlled using set points for air temperature and RH. Traditionally, this ventilation strategy was chosen to prevent condensation on windows due to the cold climate in Norway, but today stricter energy requirements now mandate the use of new better windows with lower heat losses, so the condensation on the window is no longer considered to be importance [26].

To ensure a desired indoor climate in the swimming pool arena, SINTEF byggforsk have suggested an air change of four to seven changes per hour. In therapy swimming pools, an air change of eight to ten is suggested. The air velocity in the swimming pool arena is crucial in how much water that evaporates from the pool, and thus how much DBPs that flows in the air. SINTEF recommends using the strictest proposals of these:

- 1.4 l/s per m^2 footprint
- 2.8 l/s per m^2 water surface

These two proposals are suggested to ensure a high enough air velocity to control the evaporation of the water, but the air velocity should not be above 0.15 m/s by the water surface. This can cause draft and unpleasantly cold air [24].

Experience shows that there is increased evaporation from a pool with a lot of activity. This is because increased area is in contact with the air as a result of waves, water turbulence and wet bathers. This makes it complicated to estimate just how much that evaporates from the water and into the air. SINTEF Byggforsk refers to experience when calculating the emitted moisture from water to air, these are shown in Table 4.

Table 4. Experience from evaporation in different water temperatures [24].

Pool category	Water temperature (ºC)	Evaporation (kg/(m^{2}h))
Private pools	27-28 ºC	0,10
Public pools -Daytime -Medium operation -Nighttime	28 ºC	 0,25 0,20 0,10
Hot water pools	32-36 ºC	0.35-0.50
Waterslide	31 ºC	0.5 kg/h per meter
Whirlpool	36-38 ºC	0.90-1.0

SINTEF byggforsk is not a law and must therefore not be observed, but it represents suggestions for best practice and is basically voluntary to follow.

2.3.3 CO_2

The most traditional way to indicate the air quality is to measure CO_2 in the air. CO_2 is measured in part per million (ppm). The CO_2 concentration in outdoor air varies during the year, with an average of 400 ppm in Norway. According to NS-15251 it is important to look at the difference between the indoor and outdoor CO_2 concentrations to determine how well the indoor air quality is. Four categories are made to describe the air quality requirements. These categories are listed in Table 5. For example, a surgery room should aim to have category 1, with less than 350 ppm difference between the outdoor and the indoor air. Public places like swimming pools should aim to achieve category 2. [27]

Table 5. Recommended CO_2 concentration. NS-EN 15251 [27].

Category	ppm difference between indoor and outdoor air
1	350
2	500
3	800
4	>800

CO_2 is also an indicator of the number of people in the room because it comes from humans and animals' breath. More humans in a room provide more pollution, and thus a higher requirement for fresh air supply to keep air quality at an acceptable level.

3 Disinfection chemistry

Chlorine is as mentioned used as a disinfection method alone, or in combination with UV radiation. The chemistry in the pool is dependent on several factors such as pH value, temperature and type of disinfection. It is crucial to understand how the DBPs are formed and the factors for these formations, to achieve balance between adequate inactivation of microorganisms while minimizing the formation of DBPs. The chemistry of free chlorine and the disinfectant NaOCl are explained. In addition, UV radiation and pH value are explained in this chapter.

3.1 Free chlorine

How chlorine kills bacterias, cysts and other organisms is an academic puzzle. Regardless of the disinfectant agent, however, it is agreed that the effectiveness of the various components is a function of the active components ability to penetrate the cell wall of the microorganisms. Chlorine penetrate the cell wall, and then the disinfection component attack the enzyme groups inside the cell so the organism dies [28].

It is the level of free chlorine that decides the waters ability to disinfect. Free chlorine is the sum of HClO (subchloric acid) and OCl^- (hypochlorite ion) [29]. The most important one for disinfection is HClO. HClO is separated in water to H^+ and OCl^-. In the pH range of 6.5 to 8.5, the reaction is referred to as incomplete as both HOCl and OCl^- will be present, see Formula 1. HClO's low molecular weight and absence of electrical charge makes it suitable to penetrate the cell wall of microorganisms. Chlorine is most effective in low pH values. If the pH value is increased, more chlorine needs to be used to achieve the same disinfection, see Figure 2 for the change of amount of HOCl at 30 ºC water temperature with increasing pH value. [28]

$$OCl^- + H_2O \leftrightarrow HOCl + OH^- \tag{1}$$

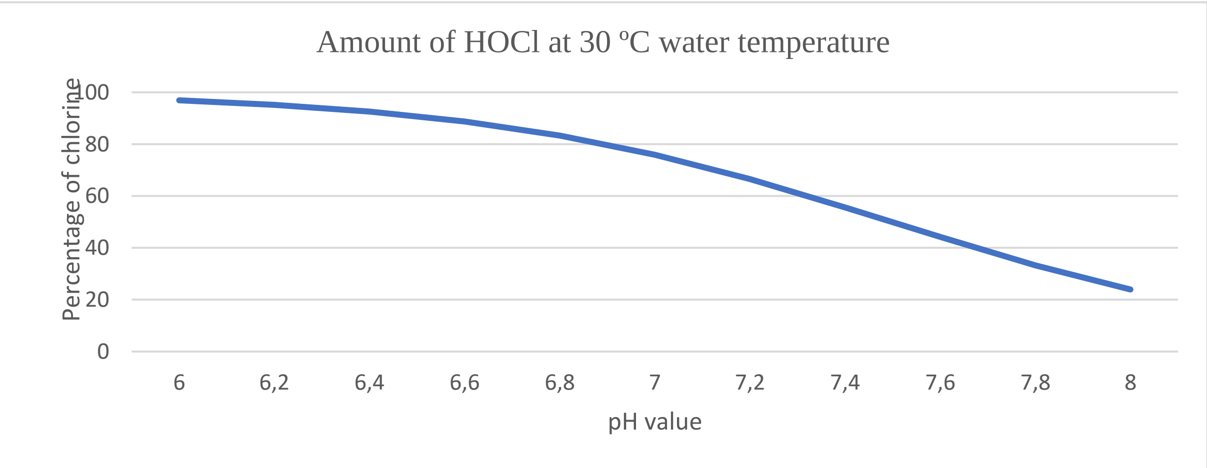

Figure 2. Amount of HOCl at 30 ºC water temperature [28].

3.2 Sodium hypochlorite

In contact with water, sodium hypochlorite (NaOCl) reacts as in Formula 2. The speed of the reactions is catalysed by increasing temperature, the concentration of chlorine, the concentration ratio of HOCl and OCl^- and the time of contact. WHO describes this compound as safe, easy to handle and cheap [30]. NaOCl's reaction with organic and unorganic compounds creates DBPs like THM, Haloacetics acids (HAA), haloacetonitriles (HAN), chlorine hydrates and chloramines. [28, 31, 32]

$$NaOCl + H_2O \leftrightarrow HOCl + Na^+OH^- \tag{2}$$

Calsium hypochlorite ($Ca(OCl)_2$) is also used as disinfectant in some pools. NaOCl and $Ca(OCl)_2$ have the same active components (HOCl), but the substances represent different properties in use. NaOCl can lose a significant part of disinfection (chlorine) after a short storage time due to light, temperature, presence of heavy metal such as copper, nickel, cobalt and iron. The more concentrated, the faster it deteriorates. When hypochlorite deteriorates, chlorite and chlorate are formed, but this process occurs more rapidly for NaOCl, compared to $Ca(OCl)_2$. As hypochlorite loses its disinfectant properties, more disinfectant must also be added to maintain the level of free chlorine. NaOCl will also form bromates in pre-treated water if the substance is produced by electrolysis of sodium chlorite or if there are impurities of bromides in the salt used to prepare the substance. Studies of NaOCl shows that it forms more brominated DBPs, higher pH value and higher concentrations of tTHM, compared to $Ca(OCl)_2$ [33, 34]. The advantages of NaOCl is that it tears less on pumps and pipes in the circulation system, and therefore the maintenance costs will be lower [35].

3.3 UV radiation

UV radiation is intended to provide a bacteriological improvement in the pool. Wavelengths of 265 nm gives the maximum performance of disinfection. UV radiation act as a catalyst of the chlorines' oxidizing effect. The radiations are absorbed in water and works momentaneous, so UV radiation is not suitable as the primary disinfectant, but it is often used as secondary disinfectant in Norway. A widely used argument for applying UV radiation is the well-documented effect of the method on reducing the concentration of combined chlorine in the water [36]. UV radiation has also been shown to be effective against the formation of cryptosporidium, a protozoan resistant to oxidizable disinfectants such as chlorine [30]. [37, 38]

It is well documented that UV radiation reduces the concentration of combined chlorine in the water, but several studies shows that the radiation contributes to higher concentration of tTHM [38-40]. The reason for this may be that UV radiation of chlorinated water leads to the formation of free radicals such as OH*, H* and Cl*. After the reaction between the organic matter and the free chlorine, the chlorine radicals breaks the bond between carbon and hydrogen and lead to increased formation of chloroform [39]. However, studies of THM and UV radiation are somewhat ambiguous. Some say that UV accelerate the concentration of tTHM, while others say the opposite [41]. Research is also inconsequent regarding the formation of other DBPs than THM by use of UV radiation [42].

3.4 pH value

The efficiency of chlorine depends on pH value in the water, as seen in Figure 2. Studies conducted about DBPs and pH shows that the lower the pH value, the lower concentration of DBPs. Especially THM is dependent on pH value. High pH value gives higher concentrations of THM, and opposite. It is also essential to keep the pH value above the lowest allowed value of 7.2 to avoid that bacteria and microorganisms grows. [8]

4 DBP pollutions

As mentioned, organic and nitrogenic matter reacts with chlorine and forms unwanted DBPs. The source of these materials are the bathers. Urine, hair, sweat, skin, lotions, makeup and stool are organic matter which are transferred into the water from humans [10]. Today, more than 700 DBPs are identified, and several of them have been linked to causing cancer and other sicknesses [43]. Using chlorine as disinfectant in the water will result in the main part of DBPs to be; HAA, THM, HAN, haloketones (HK) and small amounts of other DBPs. Many parameters can describe how hazardous the different substances can be. Kp-value, for example, described the substances ability to penetrate the skin. High Kp-value means high ability to penetrate, and vice versa.

In this chapter a more detailed description of THM is presented since this DBP is measured in the field study. In addition, a short description of HAA, HAN, HK and other DBPs are presented.

International Agency for Research on cancer (IARC) have made a classification list on carcinogenic hazards different compounds can have. This classification list is shown in Table 6.

Table 6. Classification groups. IARC [44].

Group 1	Carcinogenic to humans
Group 2A	Probably carcinogenic to humans
Group 2B	Possibly carcinogenic to humans
Group 3	Not classified as carcinogenic to humans

4.1 Trihalomethanes

Trihalomethanes (THM) are chemical compounds in which three of the four hydrogen atoms of methane are replaced by halogen atoms. THM are environmental pollutants and are considered carcinogenic [45]. THM is three halogen atoms connected to one carbon compound, and this compound is formed when free chlorine and organic matter is present in water [46]. THM is very reactive since there are only one electron missing to form stabile compounds (group 17 in the periodic system) [47]. THM is formed fastest during the first four hours after the chlorination. Bromine-containing THMs forms faster than chloroform [8]. THM formation is also dependent on temperature and contact time. Higher temperature accelerates the formation, in addition to the amount of humic acids, high pH and the amount of bromide ions in the water accelerates the formation of THM. Considering health hazards, there are four THMs that are of interest and will be measured in the field study. In addition to chloroform, three bromine-containing THMs are considered: BDCM, DBCM and bromoform. These four substances are mapped in swimming pools and drinking water in many studies. In the following subchapters, these four substances are described and the health hazards are mapped. [28]

4.1.1 Chloroform

Chloroform itself is colourless, volatile and has limited solubility in water. It has a sweet smell that starts if the concentration is above 420 mg/m^3 [48]. Toxicity is observed in dogs. Dogs was exposed to a chloroform-containing toothpaste six times a week for 7,5 years and got damage on the liver [49]. WHO has therefore set limit values for chloroform to 15 µg/kg body weight [36]. EU has set a limit value of exposure of chloroform to 10 mg/m^3 [50]. WHO has set a guiding value for chloroform in drinking water to 300 µg/l. This was set due to the volatility of chloroform and the ability to penetrate the skin [30]. Chloroform is classified in group 2B by IARC, which means that they can be carcinogenic to humans. Humans absorb chloroform either orally, dermally or by inhalation.

The health effects of chloroform are substantial. The substance has high ability to penetrate the skin (high Kp value) and has also some fat dissolving ability. Therefore, studies of exposure to chloroform has shown to damage the outer skin layer called stratum corneum [51]. Hydrated and wet skin accelerates the uptake of chloroform and is distributed in all parts of the body, but blood, kidney, lungs and the nervous system have the highest concentrations. Inhalation of chloroform in a concentration from 100 to 400 mg/m^3 have caused health hazards like depression, headache and digestive problems. It has also been found to aggravate allergic inflammatory reactions. [52]

The concentration of chloroform in exhaled air has been found to increase with increasing water temperature. Higher temperatures also increases dermal uptake. [53]

4.1.2 Bromoform

Bromoform is a brominated organic solvent with a yellow colour and a sweet odour like chloroform. It is soluble in water and evaporates into the air. Bromoform is especially produced in saltwater swimming pools. It is less volatile than chloroform, but it has the highest Kp value which means it penetrates the skin very fast [54]. Tests on rats shows that by exposure of bromoform, it has been formed a tumour on the colon. Therefore, WHO have set a limitation of bromoform to 17,9 µg/kg bodyweight and 100 µg/l in drinking water [30]. In Norway the limit values for bromoform are 5 mg/m^3 in the air [20]. No evidence have concluded that it is carcinogenic to humans, and it is therefore categorized in group 3 (not carcinogenic to humans) [44].

Although it is categorized in group 3, there have been some studies that shows health hazards after exposure to bromoform. 100 rats received 0-200 mg/kg bromoform in corn oil by gavage, 5 days per week for 103 weeks. Under these two years, they found a significant evidence of carcinogenic activity, especially on female rats [55]. There is also a relationship between exposure to bromoform and impaired brain activity, which practically will mean tiredness [56], in addition to irritating eyes and problem with the respiratory functions [54].

4.1.3 Bromodichloromethane and dibromochloromethane

WHO has set a maximum guiding value of 100 µg/l and 60 µg/l of BDCM and DBCM respectively in drinking water [30]. Tolerable daily intake (TDI) of BDCM is set to 21,4 µg/kg bodyweight, while DBCM has not specified TDI. BDCM is classified by IARC in group 2B while DBCM are classified in group 3.

Exposure to BDCM and DBCM have both been shown to cause liver and kidney damage as well as irritation on the skin, mucous membranes and respiratory tract [57, 58]. Experiments on rats studying the effect of BDCM and chloroform showed that BDCM was significantly more hepatic compared to chloroform. At the same time, exposure to BDCM appeared to be more toxic to kidneys [59]. DBCM is similar to bromoform considering health hazards [56].

4.1.4 Total trihalomethane, tTHM

In addition to bathing water and drinking water, trihalomethane is also exposed trough food and beverages, indoor air and also some medicines [60]. THMs are absorbed through the skin, lungs and intestine and is then metabolised via enzymes that can break down fat-soluble substances into more water-soluble metabolites that are transported out by the kidneys. By inhalation, THM are considered to enter the digestive system by passive diffusion [61]. Total THM are likely to cause more damage together by all four substances, than alone. Studies on rats show that simultaneous exposure of the four THMs gave higher concentrations in the blood than separate exposure, and are therefore likely to be more toxic together [62]. Studies also show that bromine-containing THMs are more genotoxic and mutagenic compared to chloroform [63, 64]. Bromide-containing THMs has been found to increase the risk of developing bladder cancer [65]. The four THM should therefore not be treated as one, since they have different effects on the body.

There are some guiding values for maximum concentration of these THMs, both in drinking and bathing water. Usually, the four THMs occur together, so the requirements set by different countries is for tTHM. Norway have no limit value for tTHM in bathing water, but have set a requirement of 100 µg/l in drinking water [66]. WHO recommends concentrations of tTHM below the requirements for drinking water in bathing water for countries who have not set a limit value. Guiding values for some countries are listed in Table 7.

Table 7. Guiding values for THM in water and air.

Country	Guiding value bathing water	Guiding value air [c]	Source
Sweden	100 µg/l [a]	$CHCl_3$:10 mg/m^3	[29]
Germany	20 µg/l [a]	$CHCl_3$:2,5 mg/m^3	[67]
Denmark	25 & 50 µg/l [b]	$CHCl_3$:10 mg/m^3 $CHBr_3$:5 mg/m^3	[68]
France	100 µg/l	$CHCl_3$:2,5 mg/m^3	[69]
Australia	25 µg/l	Not specified	[11]
Netherlands	50 µg/l [a]	$CHCl_3$:2,5 mg/m^3	[70]
Norway	Not specified	$CHCl_3$:10 mg/m^3 $CHBr_3$:5 mg/m^3	[20]

[a] Calculated from chloroform, [b] water temperature over 34 ºC: maximum 25 µg/l, under 34 ºC: 50 µg/l,
[c] Eight-hour occupational exposure

4.2 Haloamides

When halogens and ammonium is present in the water, they create haloamides (CAM, bromamides and chloramines). Ammonium comes from urea that is added to the water through sweat, skin and urine [3].

In the reaction between ammonium and HOCl, inorganic chloramines (CAM) is formed, also called combined chlorine [71]. The relative proportion of the different chloramines is dependent on the pH value in the water. Monochloramines is highly presented in pH value around 6-8, dichloramines (DCAM) is presented in pH between 5-6, and trichloramine (TCAM) is presented in pH under 5. In Norway, guidelines say that exposure of chloramines should not exceed 0,5 mg/l in the water [9]. WHO recommends a concentration of chloramines under 0,5 mg/m^3 in the air. Studies have shown that exposure of chloramines can cause eye and respiratory irritations, and lungs can be more prone to allergy formation [72, 73]. Trichloramine is suspected to cause increased prevalence of occupational asthma among pool workers [74].

4.3 Halogenated acetic acids - HAA

HAA is formed when the water is chlorinated. The hydrogen atom in the acetic acid is replaced by either Cl^- or Br^+ atoms [75]. Nitrogenic matter have more contribution to the formation of HAA than natural organic matter from humans. Increased temperatures accelerate the formation of HAA which is often seen as the second most important DBP after THM. Generally low pH values have some connections to higher concentration of HAA. There are six main types of halogenated acetic acids formed in bathing water: mono-, di- and tri-chloroacetic (MCAA, DCAA, TCAA), mono- and dibromoacetic acids and bromochloroacetic acids (MBAA, DBAA, BCAA) [76, 77]

Studies conducted with rats and mice have shown that HAA may cause kidney, bladder and rectal cancer at exposure [30]. Studies conclude that accidental oral ingestion is the only source to be exposed to HAA. HAA have 0,04 % contribution while THM have 99,6 % contribution to the risk of cancer by exposure to swimming pools. [78, 79]

4.4 Other DBPs

Haloketones (HK) is another DBP that is present both in drinking and bathing water. The two main haloketones in drinking water is 1.2-dichloropropanone and 1.1.1-trichloropropanone (DCP and TCP). HA is only formed if the pH value is under eight. HA penetrates the skin within minutes but are not as permeable as chloroform. HA is found to induce DNA destruction in the E-coli bacteria and have found to be mutagenic in a type of salmonella bacterium. HA is therefore suspected to be harmful to humans, although it is not classified in IARCs carcinogenic scale. [80, 81]

There are also DBPs that are formed from the nitrogenic organic compounds and disinfection in the water. Nitrogenous by-products (N-DBPs) may be more carcinogenic, genotoxic and cytotoxic compared to carbonaceous DBPs [82]. A nitrosamine (N-DBP) is considered, compared to THM, to be up to 600 times more carcinogenic by oral ingestion. The nitrosamine is called N-nitrosodimethylamine (NDMA) and is classified by the IARC in group 2A, which means it is likely to be carcinogenic to humans. It is 100 times less permeable through the skin compared to chloroform. [83]

Other N-DBPs that is likely to be more toxic than THM is haloacetonitriles (HAN). It is formed by a reaction between chlorine and organic matter in the water. HAN is not classified by IARC, but are assumed to be toxic. [84]

Inorganic DBPs such as chlorate, chlorite and bromate can also be present in bathing water. Chlorates are formed by the decomposition of hypochlorite. Chlorate and chlorite are not classified by IARC. Based on the physicochemical properties of chlorate and chlorite, neither skin uptake nor inhalation is considered as relevant exposure, but exposure to chlorite and chlorate could have a connection to various congenital anomalies [85]. Bromate, on the other hand, have been classified in group 2B by IARC which means it is likely to be carcinogenic. In Netherlands they have set a limited value of bromate to 100 µg/l in bathing water, while WHO have set a provisional guideline level of 25 µg/l [86]. Other DPBs suspected of being harmful to health are substances that formed after reaction with parabens, UV filters, ingredients in skin care products and free chlorine [87].

Table 8 shows a summary of the DBPs mentioned in this chapter.

Table 8. Summary of DBPs.

	Guiding value		**Kp (cm/h)**	**IARC classification [44]**
	Air (mg/m3)	**Bathing water (mg/l)**		
Chloroform	See Table 5	See Table 5	0,16 [a]	2B
BDCM	See Table 5	See Table 5	0,18 [a]	2B
DBCM	See Table 5	See Table 5	0,2 [a]	3
Bromoform	See Table 5	See Table 5	0,21 [a]	3
MCAM	-	0,5 [c]	-	3
DCAM	-	0,5 [c]	-	3
TCAM	0,5 [b]	0,5 [c]	-	3
MCAA	-	0,8 [d]	$1,1 \times 10^{-3}$ [a]	-
DCAA	-	1,5 [d]	$1,9 \times 10^{-3}$ [a]	2B
TCAA	-	8,0 [d]	$1,9 \times 10^{-3}$ [a]	3
MBAA	-	0,8 [d]	$1,4 \times 10^{-3}$ [a]	-
BCAA	-	-	$1,6 \times 10^{-2}$ [a]	-
DBAA	-	1,0 [d]	$2,6 \times 10^{-2}$ [a]	-
DCP	-	-	$7,5 \times 10^{-4}$ [a]	-
TCP	-	-	$4,5 \times 10^{-4}$ [a]	-

[a] [80], [b] [36], [c] [9], [d] [88]

4.5 THM in air samples

In freshwater pools, it is usually chloroform that dominates the four THMs. In one study in a freshwater swimming pool, chloroform had a concentration of 46,1±18,6 µg/m^3 of totally 58 ± 22,1 µg/m^3 of tTHM [89]. Another study of a freshwater swimming pool disinfected with

NaOCl showed that only 8% of sample DBPs were THM, but there were higher concentrations of HAN, HAA and HK. In this study, chloroform was the dominant substance with 87% of tTHM. [90]

A study investigated the effects of the management factors such as ventilation and water treatment in indoor swimming pools on the concentration of DBPs such as THM. The results showed that the number of bathers have direct effect on THM concentrations. It also showed that the concentration correlated with the fresh air supply and exhaust conditions. When exhaust fan was turned off, the THM concentration was higher than when the exhaust fan was turned on. Other factors like fan speed, pool age and basin area were also found to be correlated with the concentration of individual THMs in both water and air. [91]

There are several factors that influence the concentration of THM in the air. Both the number of bathers, air change, pH value, chlorine quantity, and circulation system are of importance for the formation of THMs.

4.6 Correlations

Since THM are measured in this thesis it is important to understand how THM is related to other DBPs and external factors. Earlier studies have found some correlations which is interesting for mapping the exposure of DBPs.

Correlation between tTHM and number of bathers has been shown in some studies [92], the amount of tTHM in the air and in the water is also shown to correlate in some studies [92, 93], and tTHM in the air are in many studies shown to be more concentrated than tTHM in the water [5, 6, 63, 75, 94]. It is also found a positive correlation between TCAM and tTHM, and the concentration of TCAM have a tendency to be higher [95]. HK and THM has in some studies also been shown to correlate [96]. In other words, there is reason to believe that at high THM concentrations, there will also be high concentrations by other DBPs.

Some studies have also tested for the correlations between tTHM in water and air and physicochemical parameters such as pH, water temperature, air temperature, free chlorine and combined chlorine in the water. These studied have high variations in their results and it is thus difficult to establish any clear correlations of THM and the physicochemical parameters just from searching in the available literature.

4.7 Solutions to remove DBP

There are several ways to reduce the amount of DBPs in the swimming pools. Several studies have mapped ways to treat bathing water to lower the formation of DBP, but there are few studies that have mapped the possibility of reducing DBP exposure in the air.

4.7.1 Water treatment

The high frequency of occurrence and concentration of Disinfection Bi-Products in bathing water shows that the conventional water treatment system (Circulation system including UV/filtration/etc.) cannot effectively remove or reduce DBPs to achieve a good water quality and thus a good air quality. DBP removal processes such as advanced oxidation processes and membrane filtration are beneficial to ensure the chemical safety of pool users. [18]

Advanced Oxidation Processes (AON) such as UV, H202 or O_3 generates hydroxyl radicals that helps degradation of organic matter, which is crucial for the formation of DBP. UV, for example, are widely used. Rudra et al. found completely degraded brominated THM after 70 minutes of UV irradiation, and 46 % removal of chloroform [97].

Membrane filtration is a common term for several separation processes in which one or more of the components of a liquid mixture are separated from the others by passing through semi permeable membranes. There are several membrane filtration techniques, but the most used for water is nanofiltration and reverse osmosos filtration. Compact membranes are used in which the apertures are in practice between 0.3 to 5 nm. With such membranes it is possible to separate small molecules and ions from a solution. Because the membranes are very dense, the pressure should be very high, around 100 bar. Membranes for nanofiltration have positively or negatively charged groups attached to the surface. For example, as similar charges repel each other. A negatively charged membrane surface rejects negative ions, while positive ions are attracted, resulting in an additional separation effect. [98]

Adsorption is also one alternative that have been studied. This method has low costs and is a simple model. Absorption in a mass transfer process in while the compounds is transported and gathered at the interface between two phases [99]. The compounds bind to the surface of the solid phase and transform in an adsorbate, which is regenerated by a desorption process [100]. There are several types of adsorption, but some are more commonly: powered activated carbon (PAC), granular activated carbon (GAC), carbon nanotubes (CNTs), and ion-exchange resins (IERs).

Powdered activated carbon are carbon made in particulate form as powders less than 1 mm. Thus, they present a large surface to volume ratio with a small diffusion distance. PAC is generally added directly to process units such as raw water intakes, clarifiers and gravity fillers. One study conclude that PAC removed 62,4-75,8% of THM through carbon nanotubes [101]. GAC has larger particle size than PAC, which means it achieves a smaller external surface and it seems like the efficiency of GAC is less than PAC. CNTs are comparatively innovative adsorbents and have excellent potential for environmental protection applications. CNTs characteristics can be enhanced by acid treatment. This causes them to become hydrophilic and improves the adsorption of THM. CNTs with diameter < 5,5 nm have been shown to absorb all THMs in water, according to one study [102]. IERs is used for removal of THM precursors, but not THM itself [102].

Activated carbon acts as an efficient adsorbent to eliminate THMs and THM precursors [103]. Also, activated carbon can contribute to removing organic compounds from the water to prevent the reaction with chlorine that creates DBPs. It has also become the most commonly used adsorbent for THM precursors and THM removal [103]. Both GAC and PAC can be used to remove some of the THM precursors and THM.

Other more uncommonly methods are also used but are mainly tried in drinking water systems. Biodegradation is the degradation of water compounds by subsurface microorganisms. This method has proven to remove some THM precursors, but not THM itself. Biological filtrations are a process used to support the water treatment process. It uses bacteria in a large surface to break down the pollutants like THM. Soil aquifer treatment, biosand column and horizontal subsurface flow wetland are other processes that have been tested to remove precursors and THM. [103]

4.7.2 Air treatment

Filtration is the most commonly way to ensure that the air is free of particles and dust. Although classic particle filters cannot absorb the DBP gases in the air, it is possible to combine classic particle filters with carbon filters.

Normal filter classes have a new standard for classification of filters. This standard is based on how large particles and how much of the particles a filter arrest and trapped in the small pores in the carbon. The normal filters are categorized in four groups: ePM1, ePM2.5, ePM10 and Coarse, with 50 % or more efficiency in particle sizes 1 µm, 2.5 µm, 10 µm and under 50 % efficiency for 10 µm for the coarse filter. For example: a filter that absorbs 70% of 1 µm or bigger particles is classified as “ePM1 70%”. [104]

The finest filters are called HEPA (High Efficiency Particulate Air) filter. These filters arrest 95 % or more of all particles in the air and have a classification from ISO 15 E (which is less efficient, 95 %) to ISO 75 U (99.999995% efficient) [105]. These filters are very efficient to fine particles, but do not adsorbs gasses and odours like volatile organic compounds such as DBPs. To remove these compounds, a carbon filter is essential [106]

Carbon filters use a bed of activated carbon to remove contaminants and impurities, using chemical absorption. Each carbon particle provides a large surface pore structure. When contaminant is exposed to the active sites in the filter they are arrested. 450 g of carbon have approximately 40 hectar surface. Activated carbon filtrates through a process called absorption. The small pores in the carbon traps the molecular pollutants and filtered out of the air and water. The carbon is activated by injection of hot air and steam, which creates many more places for molecules to become trapped and makes the carbon much more efficient as a filter than normal carbon. A large amount of carbon is needed to remove all VOCs. Therefore, it may be high costs to use these filters as the only source of molecular removal. There are also major challenges to the lifetime of carbon filters. Particularly in humid climates, they have poor lifetimes because they are quickly saturated. [107]

Another method of removing airborne contaminants is by having an effective ventilation system with enough fresh air flow. This ensures that the pollutants like volatile DBPs are transported away from ambient air while fresh air is being supplied. As of today, as far as the undersigned understands, there are no ventilation systems in swimming pools that control the amount of ventilation according to the contamination of DBPs and other gases in the air. But even though it is not controlled by contaminants, an effective ventilation system is important to the air quality.

5 Field study object

In the field study in this thesis, a swimming pool finished in 2018 was investigated. This pool is a part of Pirbadet in Trondheim. The reason for choosing this swimming pool facility was due to the geographic suitability and the suitability for placing air purifiers. The swimming pool has a power supply in one corner that can be used by the electric air purifiers. Also, it has not been investigated for THM before since it is so new. The primary disinfectant is NaOCl, which has been shown to cause more formation of DBP compared to the disinfectants.

A blueprint is shown in Figure 3. The pool is 8.5x12.5 meters and is mainly used for educational purposes for younger school classes.

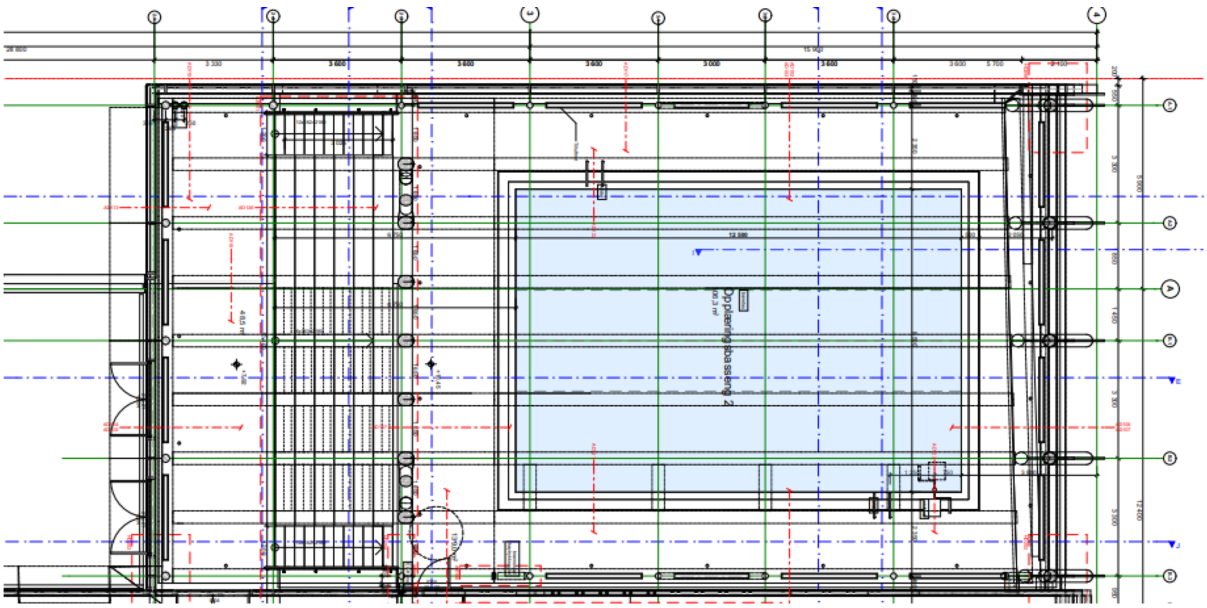

Figure 3. Blueprint of the swimming pool.

5.1 Facilities

In Pirbadet there are altogether seven swimming pools; a wave pool, a children's pool, a youth pool, a therapy pool, two training pools and a sports pool. This study focuses on one of the training pools which keeps a temperature around 31-33 ºC. There is a possibility to adjust the depth of the training pool according to the skills and age of the children who participate in swimming education.

5.2 Disinfectant and water treatment

The water in the swimming pool is 100% freshwater from the municipal pipeline network. The disinfectant used is liquid chlorine in the form of NaOCl, 15%. As a secondary disinfection, UV radiation is used. This radiation is continuously running in the circulation system to kill microorganisms. In addition, flocculant and carbon filtration of the water is used.

The chlorine is transported in tankers that pumps liquid NaOCl over to separate containers. This process prevents the staff from direct exposure of the disinfectant. NaOCl is basic, so H_2SO_4 is used to adjust the pH value. The filters are cleaned and flushed two times per week.

5.3 Ventilation system

The ventilation system in the swimming pool room is largely based on recirculated air at nighttime and larger fresh air volumes during the day. It is a mixing ventilation system with supply and exhaust ducts. In the frame of each window facing outside there are supply air ducts, and the exhaust duct is placed high on the wall at one short side, near the entrance to the swimming pool, see Figure 4. At daytime, an air flow of about 5000-7000 m^3/h is supplied with 70-100 % fresh air, depending on the relative humidity and temperature. At night only 3000-5000 m^3/h is supplied, with a fresh air amount of 0-70%. In swimming pools, it is a special ventilation demand because of the hot and humid air. The users do not wear more than swimming clothing and are therefore sensitive to cold environment. The heating of the swimming pool is mainly covered by heating of the water and the supply air. The air change per hour is therefore dependent on the humidity and temperature to keep satisfying indoor air quality, as well as avoiding condensation and evaporation problems.

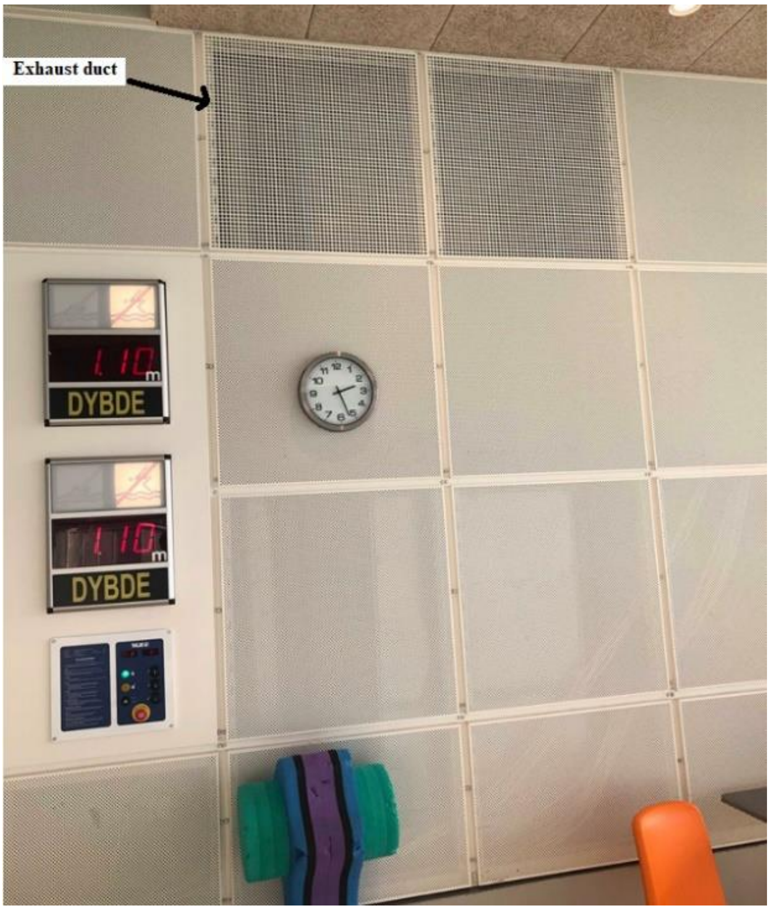

Figure 4. Exhaust duct.

5.4 Cleaning routines

Every day the floor area is cleaned as needed. In addition, four hours is set aside two days a week for more extensive cleaning. Since the pool was completed in 2018, the water has not yet been replaced and the bottom has not been cleaned yet. Both sand, hair and carbon filter clean the water continuously, and filter flushing is carried out twice a week in addition to the pool being bottom vacuumed every other day. In the wardrobes there are posters informing that showering is required before use of the swimming pool. To keep the water quality as good as possible, it is crucial that the users use the shower and clean themselves to avoid that skin and hair products is transported to the water and mixed with the disinfectant.

5.5 Usage

The swimming pool is, as mentioned, used for swimming lessons, but is open to the public from 4PM in the afternoon. Classes of 5-30 persons, excluding teachers, is common between eight o'clock to two o'clock in the morning. The activities vary from calm swimming to free activity with various toys. The children that uses the pool is mainly between 10 to 15 years.

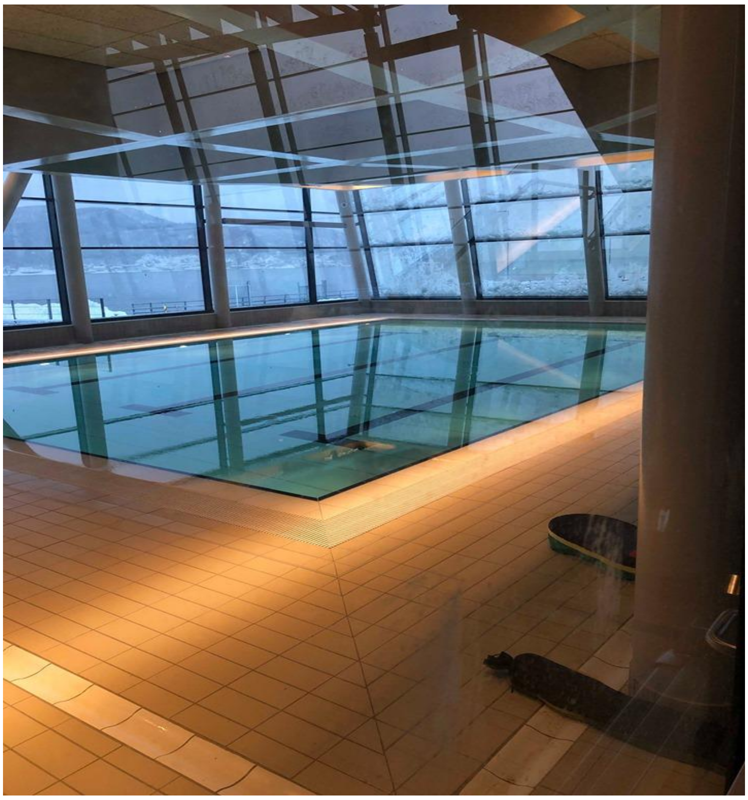

Figure 5. The swimming pool.

6 Method

In this chapter, the method for the measurements in Pirbadet is introduced. During the work with this thesis, it was given training in how to spike the sampling tubes, how to proceed when taking samples in the swimming pool according to the standards, and how to interpret the results from the analysis. The analyse itself was conducted by laboratory staff.

6.1 The swimming pool facility

As mentioned in chapter 1, the swimming pool room investigated in this study was built in 2018. It is built with the purpose of allowing primary school classes to use the pool for swimming lessons, in addition to being used for public swimming during weekends and afternoons. It was chosen to take measurements during the swimming lesson, from 10 AM in the morning, to about 3 PM in the forenoon. Thus, it was always possible to count the number of people in the pool. In addition, there was no one in the pool between the swimming lessons, which was interesting for the study in view of the relationship between bathing load and tTHM concentration. It was decided to take measurements two days a week, on Tuesdays and Thursdays, for four weeks. It takes about 7 minutes to prepare and spike one sorbent tubes before it can be used, so one day between the measurements (Wednesday) was necessary to make such preparations. The first two weeks the following was measured: THM, CO_2, bathers, relative humidity and temperature in the air. The last two weeks was the same, but with air purifiers from CAMFIL running at all time. The goal was, as mentioned in chaper 1, to investigate if there were any difference in THM concentration with and without air purifiers, and the correlation with CO_2 concentration.

6.2 Chosen method

6.2.1 THM

In the air there are very low concentrations of pollutions, and a sampling technique allowing us to identify such low concentrations are used. It was chosen to use the method that has been used in previous measurements of THM in Pirbadet. This method is well known and has shown good results. Generally, it consists of pumping a given amount of air through an absorbent that absorbs the contaminants in the air. Then, this absorbent is processed and analysed by an analyser machine [91]. This method is used in several studies where THM is measured in swimming pool arenas [95, 108, 109]. The method is described in the standard NS-EN ISO 16017-1:2000 and US EPA Method TO-17. The absorbent used in this study is called Tenax TA and was chosen because of the availability of the laboratory, and that it had been used in previous samples in Pirbadet. The experiences from the use of Tenax TA was in a previous study seen as good. Tenax TA is a hydrophobic material and is characterized by its high thermal stability, although it has not the highest throughput volume compared to other absorbents [110]. Other absorbents can also be used, such as Tenax GR, Chromosorb 102, Carbotrap C, Carbopack B, Anasorb 727, Anasorb 747 and Porasil C/*n*-octane, but Tenax TA proved to have the best properties considering the amount obtained, breakthrough and standard deviation during samples [111].

To determine the amount of air that will be pumped through the tube, it is important to consider type of adsorbent, air humidity, temperature and pressure. It is important to look at how much Tenax TA manages to absorb before it saturates and releases the contaminants through the tube. US EPA method TO-17 describes maximum pump speed like this: 70% of the pump speed that causes 5% of the contaminants to be detected in a secondary tube connected in series with the primary tube, and a pump speed over 10 ml/min for prevent other compounds to diffuse into the sorbent tube [112]. THM studies have been conducted at Pirbadet before and the analyse was done at the same laboratory. The laboratory staff suggested a pump speed of 40 ml/min for 20 minutes (0,8l) for each tube/sample, since that gave good results [3]. This speed and sampling period were used as setting for every samples in this study.

6.2.2 Instruments

6.2.2.1 CO_2 and air temperature

CO_2 concentration changes due to the number of breathing humans/animals and sometimes from combustion processes. Since the swimming pool does not have any combustion processes that affect the CO_2 concentration, it will mainly be affected by the person load inside the swimming pool arena. [113]

The equipment used for CO_2 measurements is KIMO AQ 200. AQ 200 is a device which can measure a lot of units, depending on which probe is connected to the device. In this field study, a CO_2/Temperature probe was used. This device runs on batteries, or directly connected to power.

Figure 6. KIMO, AQ 200. Measurement device for CO_2 and temperature. Picture from actoolsupply [114].

Specifications from producer’s website [114]:

- Range temperature: from -20°C to +80°C
  Range CO_2: From 0ppm to 5000ppm
- Accuracy temperature: ±0,3% of reading or ±0.25°C
  Accuracy CO_2: ±3% of reading or ±50ppm

6.2.2.2 *Relative humidity and Temperature*

In addition to CO_2 and THM, relative humidity and temperature was measured in three different places. The equipment used was EasyLog USB-2. One was placed next to the THM/CO_2 measurements and two were placed in each corner of the swimming pool, see Figure 9. EasyLog USB-2 is a USB stick with sensors for temperature and relative humidity measurements. The device is shown in Figure 7. This small device is easy to install in every zone in the swimming hall. The battery life of this instrument is 3 years. The measurements are downloaded from a memory card inside the device through a software special for EasyLog.

Figure 7. EL-USB-2, USB device with sensors for temperature and relative humidity. Picture from Lascarelectronics [115].

Specification from the producer website [115]:

- Range temperature: from -35°C to +80°C
  Range relative humidity: From 0% to 100%
- Accuracy temperature: ±0.55°C
  Accuracy relative humidity: ±2.25%

6.3 Measurement points

A test stand, adjusted to collect samples 0.3 m above the floor was used to attach the sorbent tubes and the other measurement instruments. The attachment of the sorbent tubes was adjusted to 0.3 m above the water surface in one corner of the pool, 2.8 meters from the water, see Figure 8. Thus, the samples were not disturbed from the activities in the pool. All samples were collected from the same height because of the possibility to look at changes in THM concentration under different external factors such as with/without air purifiers and with different number of bathers. The location of the test stand corner was also convenient because of the power supply close by. The temperature and relative humidity were measured in several places in the room before the sampling to investigate if the air in the room was well mixed.

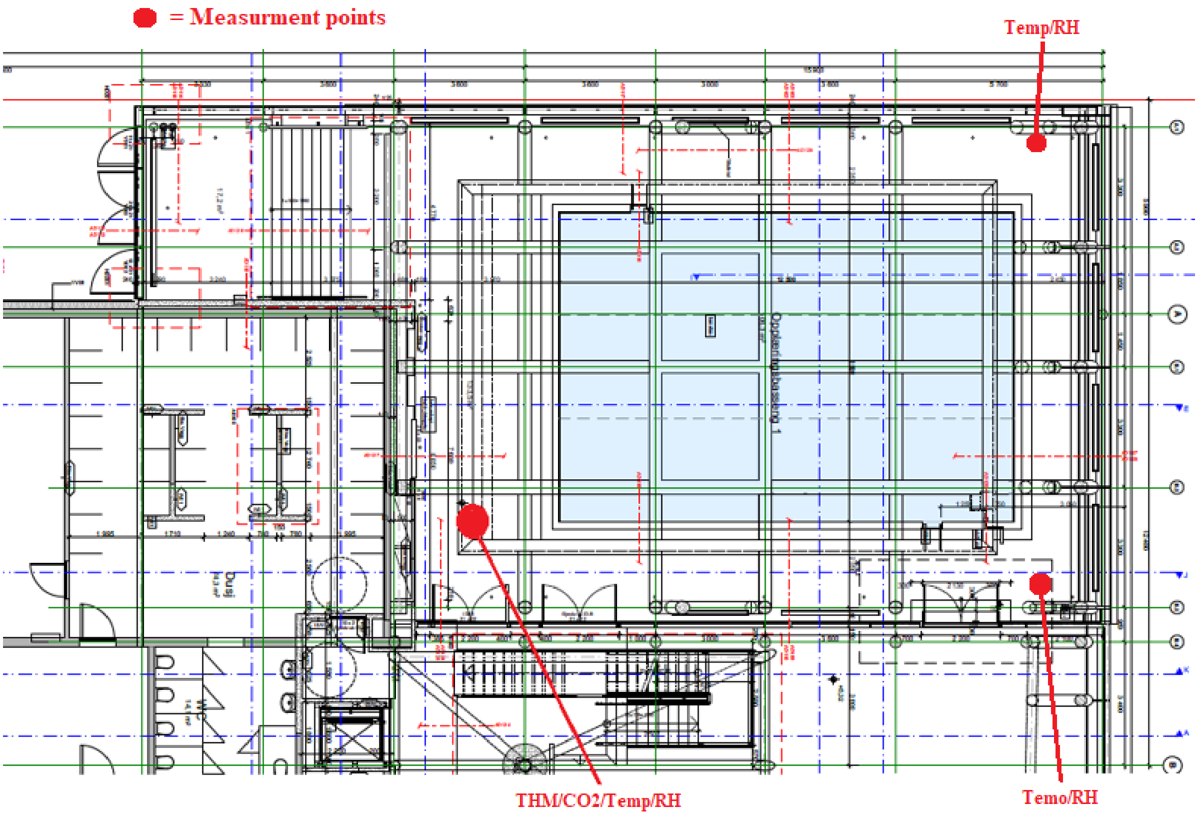

Figure 8. Measurement points.

During the days of sampling, from 10 AM to 3 PM, the equipment was always under personal supervision. This was to ensure that no one could harm or disturb the measurement equipment, and to look for external disturbances. There were also posters that informed about ongoing research, see Figure 9. The sensor for the CO_2 measurements was mounted a little higher than 30 cm, since the CO_2 concentration itself is not interesting in this study. It is the variations in concentration that is used to compare with other parameters such as THM.

Figure 9. Installation of equipment.

6.4 Conditioning and spiking of the tubes

Before the air samples could be collected, the sorbent tubes were conditioned by heating to 335 ºC for 15 minutes with helium as carrier gas and a speed of 70 ml/min. After conditioning, the sorbent tubes were spiked with 250 ng of internal standard mixture 2, including fluorbenzen, klorobenzen – D5 and 1,4-dichlorobenzen-d_4. Spiking was done using a 10 µl precision syringe (Hamilton Microliter ^{TM}). The syringe was rinsed with methanol ten times before use. The syringe has an uncertainty of ±1% of nominal volume. After spiking, they were flushed with helium with a speed of 100ml/min for five minutes, and then sealed with couplings (Swagelok with PTFE casing, see Figure 11) and packed in uncoated aluminium foil. Further, the tubes were placed in an airtight glass container with activated carbon inside to prevent the samples from being contaminated. The tubes were stored in room temperature in the glass before sampling. Figure 10 shows the machine used for analysing and conditioning of the sorbent tubes.

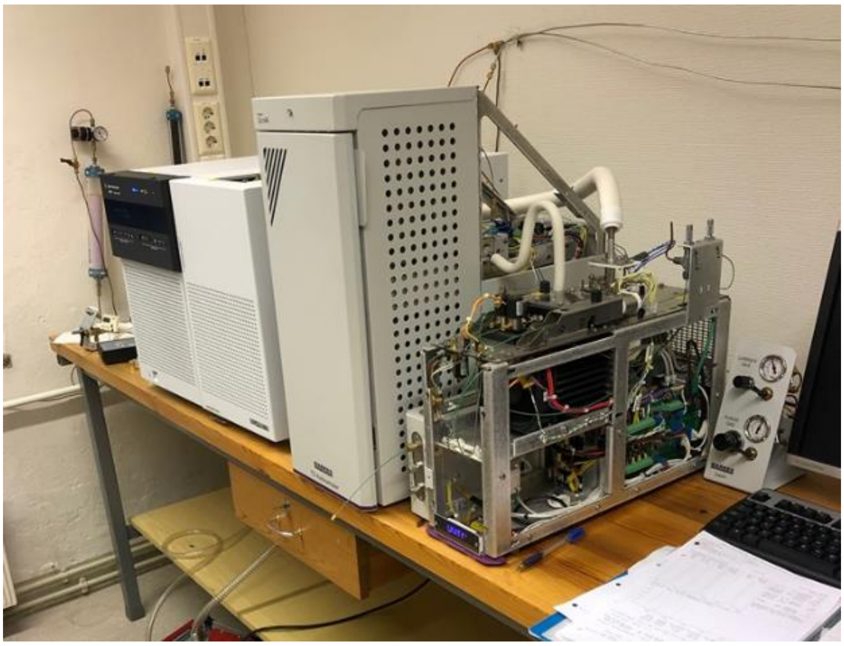

Figure 10. Station for spiking, analysing and conditioning. Gas chromatograph connected to the mass selective detector

Figure 11. Sorbent tubes with couplings.

6.5 Sampling

During sampling, a low flow pump pumped air through the sorbent tubes, containing 200 mg Tenax TA 35/60. The pump used was Markes International ACTI-VOC Low-Flow Pump. The tubes have the dimensions: external diameter 6.4 mm, internal diameter 5 mm, length 89 mm. The couplings were attached to the tubes before and after the sampling period, see Figure 11. Clean cotton gloves were used during the handling of the equipment. The airflow was measured by two different flow meters (Bios Defender 530 and TSI 4148) before and after every sampling and the flow was between 33 and 39 ml/min in every sample. To stabilize the flow meter, it was turned on at least 15 minutes before the first sample.

Between 0.65 l to 0.8 l air through was pumped through the sorbent tubes. According to EPA Method TO-17 the samples should be discarded if the air velocity differed more than 10% before and after sampling. The maximum differ in this study was only 2 ml/min, so no samples were discarded due to airflow. After the sampling, the sorbent tubes were sealed with the couplings, foiled with aluminium foil and put in a sealed glass with activated carbon, to ensure that they were not polluted by external sources. They were then transported to the laboratory and analysed the same day. EPA Method TO-17 requires blank and blind tubes to be treated the same way as the test tubes. These blank tubes were stored in the sealed glass during the samples and transported with the used samples to the laboratory for analyse. ISO 16017-1:2000 requires at least 10 % and more than one sample to be blank. In this study two to four of the samples were blank [116] every day air samples was conducted.

From 10 AM to 3 PM there were conducted ten samples with ten sorbent tubes every half hour. The last day of sampling, only five sorbent tubes were used, giving a total of 65 samples. CO_2 measurements were also conducted at the same time as THM measurements, while temperature and relative humidity from the EasyLog devices made measurements all the time from 10 AM to after the last air sample of THM around 15 PM. The number of bathers, the total number of peoples inside the swimming pool and type of activity was noted for every sample. Free chlorine, combined chlorine, pH value and ventilation values were obtained after the measurements from the technical manager of the swimming pool.

6.6 Analyse of THM samples

After the sampling in the swimming pool, the sorbent tubes were sent to the laboratory for analyse according to the standards NS-EN ISO 16017-1:2000 and US EPA Method TO-17. A gas chromatograph and a mass spectrometer (GC/MSD) was used for analyse. The GC-MSD uses approximately one hour for conditioning and analyse of each sorbent tube.

30 sorbent tubes were available in this study and between 12-15 were used each sampling day. As mentioned, ten of the sorbent tubes was used to sample the air in Pirbadet, while the rest was used as blanks. When analysing after the samples, Markes TD Autosampler was used (see Figure 10). Up to 100 tests could be analysed simultaneously.

To quantify and identify the different THMs on the sorbent tubes, a thermal desorption unit (Markes Int.) was connected to GC/ MSD (Agilent Technologies, 5975T LMT-GC/MS). See Figure 12 for illustration of the connection between the devices and Figure 10 for a real picture of the equipment in the laboratory.

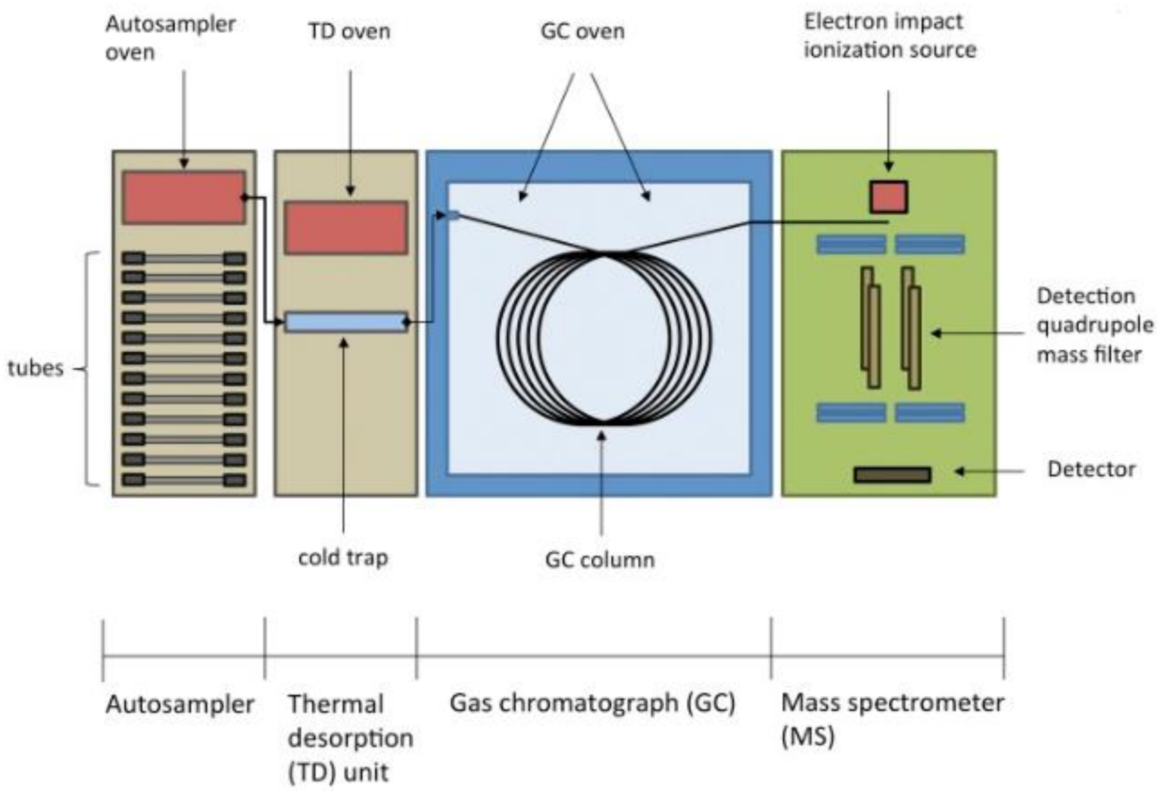

Figure 12. Autosampler connected to TD, GC and MS.

6.7 Calibration

All the sorbent tubes used in this thesis was calibrated in the laboratory according to the standards NS-EN ISO 16017-1:2000 and US EPA Method TO-17.

The CO_2 equipment was not calibrated before the samples. But some comparisons were made to ensure that the equipment was in order. The CO_2 instrument was compared with two other instruments that measured CO_2. There were no more deviations than 3%. Thus, it was assumed that the instrument was accurate enough. The most interesting for this study was to see the development and change in CO_2 concentration. The actual concentration itself was less interesting.

6.8 Filter

In the last two weeks of measurements, two air purifiers from Camfil AS called City M were used [117]. These are intended to provide better indoor climate by filtering away everything from dust and harmful particles to molecular contaminants and even odour by using a combination of HEPA and activated carbon filter. The HEPA is classified as H13 filter, or by ISO 29463 as ISO 25 H, and removes 99.9% of the particles in the air in a size down to 0.3-0.4 µm. The carbon used is called NXPP media Adsorbent G353V and absorbs molecular compounds in addition to removing odours. City M has a six-step control of the fan speed, and one alone is designed to improve the air for as big as 75 m^2 at the highest pump speed.

The airflow of the air purifiers is shown in Figure 13.

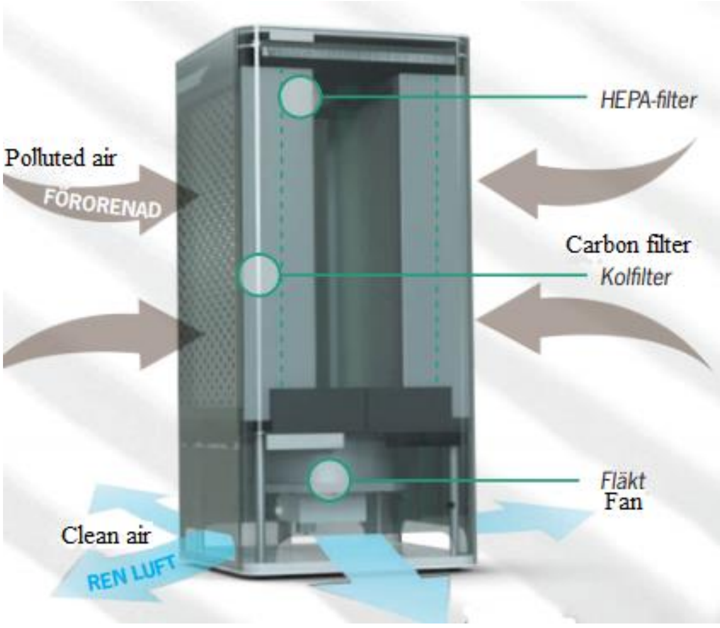

Figure 13. City M air flow [117].

The two air purifiers were placed next to each other, one and two meter from where measurements of THM were made, see Figure 14. The purpose was to take THM samples as close to the supply air from the air purifiers as possible to look at differences in concentration.

Figure 14. Air Purifiers and THM measurements.

One THM sample was conducted a few centimetres from the supply ("clean") air from one of the purifiers as shown in Figure 15. This was to look for significant changes in THM in the air that flew through the air purifiers.

Figure 15. Sorbent tube samples filtered air.

6.9 Analyse and statistics

To collect and organize all data from measurements and other information, Microsoft excel was used. The average of CO_2 concentration was calculated in excel for comparing with other values. All graphs were also made in excel.

To analyse correlations and other statistics, a programme called SPSS (Statistical Package for the Social Sciences version 25) was used. The mean with 95 % confidence interval, standard deviation, lower and upper bound and correlations was calculated. The variables such as weekdays and air temperature were numeric coded. For example: Tuesday=0 and Thursday=1. To test for correlations, Spearmans correlation coefficient was used. Spearmans correlation coefficients tests for correlations between two or more variables at the interval level and calculate with a 95 % confidence interval. Spearmans is also used in other studies, which makes these results more comparable.

7 Results and discussion

In this thesis, measurements are conducted in a new swimming pool facility in Pirbadet, Trondheim. This pool is built mainly for swimming education for school children. The disinfectant used is NaOCl which have a history of forming DBPs in swimming pools. Earlier, samples have been conducted in Pirbadet with results that indicate that DBPs like THM are formed in relatively high concentrations [3]. Therefore, this study investigates if there are some possibilities to reduce these DBPs to get a better indoor air quality in swimming pool facilities using a carbon filter. In addition, it has been investigated whether visitor number and CO_2 concentration in the air correlate with THM concentration. Correlations like this can help understand the exposure of THMs and thus answer the research question: *Are there any correlations between trihalomethane- and CO_2 concentration and how does an air purifier with carbon filter affect the concentration of trihalomethanes?*

In total, the results of this study are based on 64 samples of THM (chloroform, DBCM, BDCM, bromoform). 65 samples were conducted but one had to be rejected due to problems with the pump. The measurements were conducted over seven days. Each day, despite the last day, ten air samples of THM were taken, in addition to temperature, relative humidity and CO_2 measurements. Every sample, despite one, was conducted 30 cm above the water surface 2.8 meter away from the water. One sample was conducted 5 cm away from the supply air of the air purifiers to investigate if the air purifier worked properly. During the samples, different school classes had swimming training. Between the classes there were no one in the water, and maximum 4-5 persons present in the room.

In this chapter, the results and the accompanying discussion about the results are presented. Summary is first presented to give an overview of the main measurements. Essentially, the result will be shown through tables and graphs. Correlation analysis is also conducted to prove some of the important findings of this study. All the values from each day of measurements are presented in Appendix A. Results, and some descriptive statistics of the main results are presented in Appendix B. Statistics.

There are three main findings in the result that is presented and discussed:

- tTHM and CO_2 correlates significantly
- tTHM and combined chlorine correlates significantly
- The carbon filter test did not give expected results

7.1 Summary

Table 9 shows a short summary of the main result in this study. All parameters are average through the day.

Table 9. Summary of results.

Weekday	Date	Filter	Bathers	Combined chlorine	Free chlorine	pH	tTHM	CO_2	ACH
Tuesday	05.feb	no	6,9	0,12	0,8	7,2	111,05	626,2	5,8
Thursday	07.feb	no	14,4	0,15	0,8	7,2	116,27	641,4	5,1
Tuesday	12.feb	no	13,9	0,13	0,8	7,2	116,75	639,0	5,6
Thursday	14.feb	no	15,3	0,10	0,8	7,2	88,88	649,4	5,7
Tuesday	26.feb	yes	12,6	0,19	0,8	7,2	134,61	668,4	5,5
Thursday	28.feb	yes	5,1	0,20	0,8	7,2	126,80	620,1	5,6
Thursday	07.mar	yes	14	0,20	0,8	7,2	184,00	659,2	5,1

As shown in Table 9, the maximum average value is 184 µg/m^3 and the total average is calculated to be 121 µg/m^3 in this study. This is significantly lower than the average in the other swimming pools in Pirbadet, which has a arithmetic average of 410 µg/m^3, 492 µg/m^3 and 266 µg/m^3 [3]. This can be explained by the fact that the ventilation system is completely new and efficient, and that the pool is relatively new, and it may be that there are few inorganic contaminants. Anyway, in this study it is focused on what affects the THM and DBP exposure in the air, and thus discuss measures to improve the swimming pool air quality. Therefore, the exposure itself is not of interest and will not be considered in the analyse.

Both pH, free chlorine and water temperature was stabile during the four sample weeks:

- pH: 7.2
- Free chlorine: 0.8
- Water temperature: 31ºC

7.1.1 Correlations

There were also found some interesting correlations. These findings are presented in Table 10.

Table 10. Correlations.

Correlations		
Parameters	Spearmans correlation coefficient	n
tTHM vs CO_2	**0.378****	**64**
Chloroform vs CO_2	0.424**	64
Nr. of bathers vs CO_2	0.727**	64
BDCM vs CO_2	0.390**	64
DBCM vs CO_2	0.156	64
Bromoform vs CO_2	-0.071	64
tTHM vs Combined chlorine	**0.613****	**64**
tTHM vs ACH	0.209	64
tTHM vs RH	0,528**	40

**. Correlation is significant at the 0.01 level (2-tailed).
n = Number of samples, ACH = Air change per hour, RH = Relative humidity

To better understand the exposure of THM, measurements of CO_2 concentration were made at the same time as the THM samples were conducted. To look at correlations, analyses have been done using SPSS, as mentioned in 6.9.

By using Spearman's twotailed correlation factor several correlations were found.

As seen in Table 10, The correlation coefficient between the number of bathers and CO_2 is as expected high: 0.707**. The correlation between tTHM and CO_2 through all 64 samples is also proven to be significant and an analysis of chloroform and CO_2 gives even more significance (0.424**), which indicates that chloroform is formed in higher concentrations when the CO_2 concentration and the number of bathers is high. DBCM and bromoform has no proven correlation with CO_2. This can be explained by the fact that the bromine-containing THMs rely on airborne contaminants in the main hall containing saltwater pools and thus not necessarily are formed in significant amounts in freshwater pools. Water turbulence created by bathers seems to increase the amount of tTHM and chloroform especially. This means that by measuring CO_2 concentration in the air of a freshwater swimming pool, it can give an indication of the amount of THM, and especially chloroform.

7.2 tTHM and CO_2 correlates

Table 9 shows average values of the various parameters that were measured. What is more interesting, is to look at variations in terms of one day of measurements. Both the number of bathers and the CO_2 concentration appears to be related to the tTHM concentration. In six out of seven days, ten samples were carried out, so it is possible to see how the THM concentration changes in line with other parameters. Table 11 shows the results for the second day of measurements.

Table 11. Results Tuesday 12.02.2019.

Time	Sample nr.	Number of bathers	Combined chlorine [1]	TCM	BDCM	DBCM	TBM	tTHM ($\mu g/m^3$)	CO_2 (ppm)	ACH[2]
10:00-10:20	1	14	0,13	89,57	12,45	2,97	25,87	130,87	626,2	5,61
10:30-10:50	2	28	0,13	110,48	13,20	1,81	14,03	139,52	665,5	5,61
11:00-11:20	3	15	0,13	100,73	11,45	0,80	7,72	120,71	665,3	5,61
11:30-11:50	4	7	0,13	80,69	10,47	2,16	21,16	114,48	603,1	5,61
12:00-12:20	5	27	0,13	94,39	10,75	0,99	9,83	115,95	656,7	5,61
12:30-12:50	6	25	0,13	100,61	11,51	0,89	8,24	121,25	686,6	5,61
13:00-13:20	7	4	0,13	74,83	8,32	0,39	7,17	90,71	604,0	5,61
13:30-13:50	8	10	0,13	93,19	10,16	0,44	5,69	109,48	656,7	5,61
14:00-14:20	9	9	0,13	108,41	11,96	0,60	5,33	126,31	670,9	5,66
14:30:14:50	10	0	0,13	84,51	8,99	0,15	4,61	98,25	554,8	5,66

[1] Measured in mg/l, [2] ACH = Air change per hour

As Table 11 shows, the concentration of bound and free chlorine and ACH in the water are stabile through the whole day while both tTHM and CO_2 concentration changes relatively much throughout the day. Between 10:30 and 10:50 the tTHM concentration is 139,52 $\mu g/m^3$ and between 13:00 and 13:20 the tTHM concentration is 90.71 $\mu g/m^3$. The development of the tTHM and the CO_2 concentration during the day indicates that they correlate, and that is proven in the correlation analysis as shown in Table 10.

The results in Table 11 also shows that the largest part of THM is chloroform (average 80%). This may be because it is only freshwater in the swimming pool. As described in the theory chapter, the largest share of THM in freshwater pools is chloroform. Parameters such as combined chlorine, free chlorine, ACH, temperature and pH are stable throughout the day and therefore they have not any great influence on the variations of THM in terms of one day.

The only variation, beside THM, that occur within a day are the number of bathers and CO_2 concentration. During the samples there were alternating numbers of people in the water, so what is noted is the average number of bathers during the 20 minutes sampling period. Measurements of CO_2 indicate strong correlation with bather loading and operating characteristics of the pool, as expected since CO_2 comes from the breath of humans/animals. It also takes some time before the CO_2 concentration increases when it has just arrived a new class for swimming training. Therefore, the variation in the number of bathers and CO_2 concentration do not necessarily change at the same time. Anyway, Figure 16 shows a clear relationship between the two parameters. This is proven in the correlation analysis with a correlation coefficient of 0.727**, as shown in Table 10.

Worth mentioning is that the CO_2 concentration is reduced relatively quickly after the training lessons when there are no people present in the hall. This indicates that it is an effective ventilation, where old air is replaced with new air efficiently and quickly, see Figure 16. The same can be said about the tTHM exposure. Even if the tTHM is not reduced to the same extent, there is a decrease in exposure each time there are few bathers.

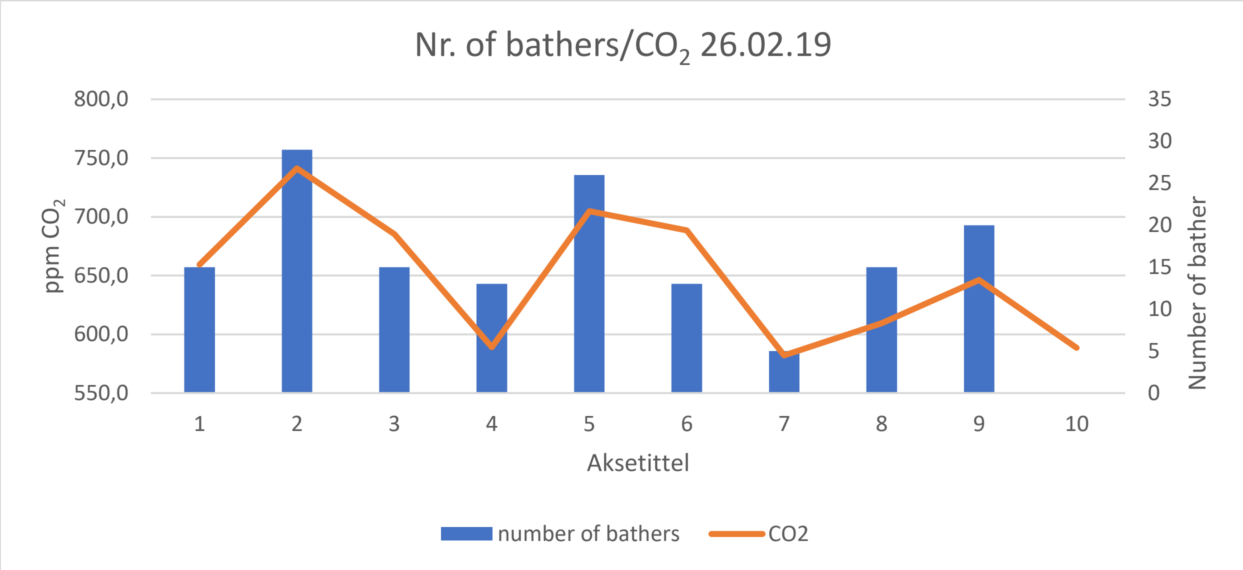

Figure 16. CO_2/Nr. of bathers 26.02.19.

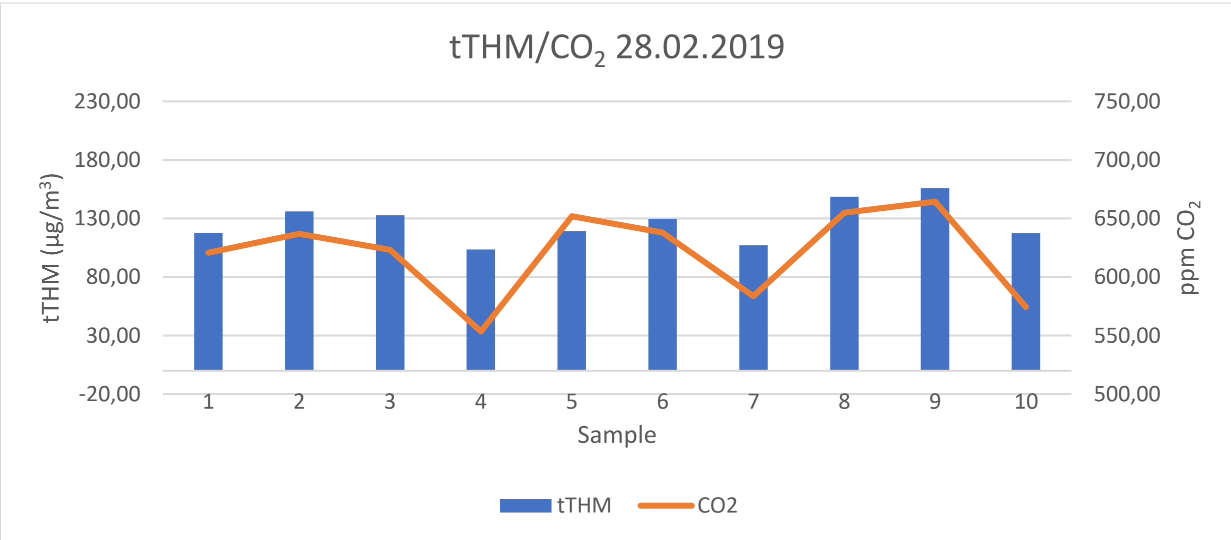

Figure 17. tTHM/CO_2 28.02.2019

What is interesting is to see that the THM concentration in the air increases as soon as there are increasing numbers of people in the water. Primarily, it is conceivable that it is due to an increase in the concentration of organic matter from the human body. But it may also be that by splashing and swimming more aerosols are sprayed into the room, and thus the volatile substances are more easily formed in the air. The volatiles are formed as a result of increasingly water turbulence, and thus more mixing of organic matter and chlorine, forming

THM and other DBPs. Increased organic matter and water turbulence is probably the two most important factors of the variations on tTHM in an hourly basis

7.2.1 Possible measures

As Figure 17 shows, there is a clear connection between the values of THM and the CO_2 concentration from hour to hour. CO_2 is easily measured with relatively cheap and accurate sensors. It may therefore be an opportunity to install such sensors to get an indication of the THM concentration. These sensors can further be used in controlling the ventilation system.

The ventilation system helps to replace old polluted air with fresh air. Today, they are two set points that determine the air supply in the swimming pool, and they are temperature and relative humidity. Regulating according to these two parameters is necessary to get an indoor climate that is comfortable to visitors but is at the same time important to avoid condensation and evaporation in the humid environment. Therefore, there are currently supply air ducts at the window frames that help keep the windows free of condensation.

However, what the control of the ventilation system does not consider is the amount of hazardous substances in the air and water. As shown in Table 10, ACH does not correlate with tTHM, which indicates that the air volume is not increased with increased amount of tTHM in the air. Besides increasing the amount of air in the day compared to the night, there is no regulation of how much contaminants are formed by the bathers. Of course, increasing numbers of bathers contribute to increased humidity and temperature, but it often takes a while before the airflow is adjusted so that air is kept within the specified values. It can therefore be a possibility to place CO_2 sensors in the swimming pool. CO_2 indicates how many people are present, and since the THM concentration increases in step with the CO_2 concentration, it may be appropriate to add CO_2 as a parameter in the control of fresh air supply and thus ACH. CO_2 concentration can thus be an indicator of the water and air quality. To lower the CO_2 concentration, it is essential that the fresh air supply increases, so that air from outside with low CO_2 concentration is mixed with the air inside the swimming pool. For example, if many people suddenly arrive in the swimming pool, the CO_2 sensors will react to that, and they will then inform the ventilation control which increases the supply air and air change. In this way, the THMs are transported away more efficiently. This may result in a lower average concentration of THMs and other volatile DBPs.

7.3 tTHM and combined chlorine correlates

By looking at all the measurements together, it is easier to draw conclusions on which factors affect the concentration of THM in terms of a longer period. Figure 18 presents a graph that shows the development of tTHM and combined chlorine. The correlation is significant, as proven in Table 10.

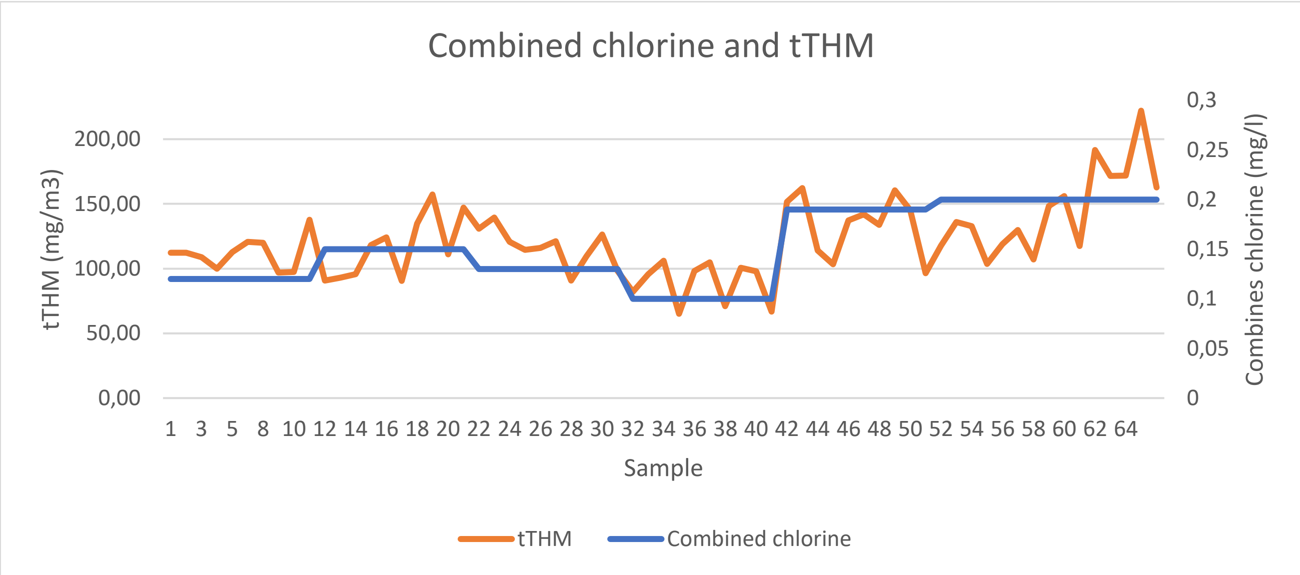

Figure 18. tTHM and combined chlorine.

Table 12 shows an overview of the parameters that vary greatly during the seven days of measurements over the four sampling weeks.

Table 12. Combined chlorine and tTHM.

Average values		
Day	**Combined chlorine (mg/l)**	**tTHM (µg/m³)**
Tuesday 05.feb	0,12	111
Thursday 07.feb	0,15	116
Tuesday 12.feb	0,13	117
Thursday 14.feb	0,10	89
Tuesday 26.feb	0,19	135
Thursday 28.feb	0,20	127
Thursday 07.mar	0,20	184

In the last three days, the concentration of combined chlorine is higher than the rest of the days. The same applies to the average concentration of tTHM. The amount of free chlorine is constant throughout the measurement period, so the amount of combined chlorine seems to be the parameter that affects the THM concentration in a long-term perspective. Between the dates 14.02 and 26.02 it was a winter holiday. In the winter holidays, historically speaking, there is many visitors in Pirbadet. In addition, there have been no swimming lessons during that week, so the pool has been open to the public. Increased visitor load and number of bathers also increases the amount of organic matter. Increased amount of organic matter can in turn lead to increased amount of reactions with chlorine and thus forming more THM and other DBPs. It is possible that the amount of combined chlorine affects the average value of THM over a longer time perspective (week / month / year), but that it has less to say about the variations for one day.

It seems like there are no differences in THM concentration on Tuesdays and Thursdays. Although the average concentration is slightly higher on Tuesdays, the differences are not large enough to draw conclusions that exposure varies widely over a week. Nevertheless, the slight difference may indicate that the number of bathers on weekends is greater, which gives more organic material to the water. The exposure on Tuesdays can therefore be slightly larger than Thursday because the exposure on the weekends gives a slight effect over the next week, such as the winter holidays affecting the exposure in the following weeks. The last week of measurements (07.03) was not included in the average value of tTHM because measurements were not made on Tuesday 05.03. The combined chlorine concentration also has no major variations on Tuesdays and Thursdays.

7.3.1 Possible measures

Not only CO_2 can work as an indicator of THM and DBP exposure. Combined chlorine can also be a parameter to include in the ventilation control, but this demands sensors that continuously measures the concentration, or optionally set an average fresh air supply due to the concentration of combined chlorine measured in the mornings. Today, only two measurements are conducted every day. The values considered in this study is from the sample taken 8 AM in the morning.

Since two measurements of combined chlorine are already taken every day, the measurement method is incorporated. Therefore, in testing the impact of this ventilation strategy no new sensors or other equipment is needed to measure the concentration. Since the correlation is significant with the tTHM exposure, it may be possible to test the supply of increased fresh air amounts when it is high concentrations of combined chlorine is measured. This can first be tested manually to look at the effect of it. If the effect of increased amount of fresh air on days of high concentration of combined chlorine lowers the average exposure of tTHM, it may be useful information for the ventilation providers to research further on an automatic regulation that can be implemented in the future.

7.4 The carbon filter test

In this thesis, in addition to looking at CO_2 concentration, a possible method for lowering exposure to harmful DBPs was studied. As mentioned in the method chapter, CAMFIL Trondheim lent out two air purifiers with a carbon filter for testing in the swimming pool. The two air purifiers were installed at the pool for the last two weeks of measurements to see if they could contribute to reducing the THM concentration.

The air purifiers were set at maximum speed just before the first sample Tuesday 26.02. It was then possible to look at changes in the exposure over the first hours after the air purifiers were turned on.

However, the results of the samples were not as expected, see Figure 19 and Figure 20

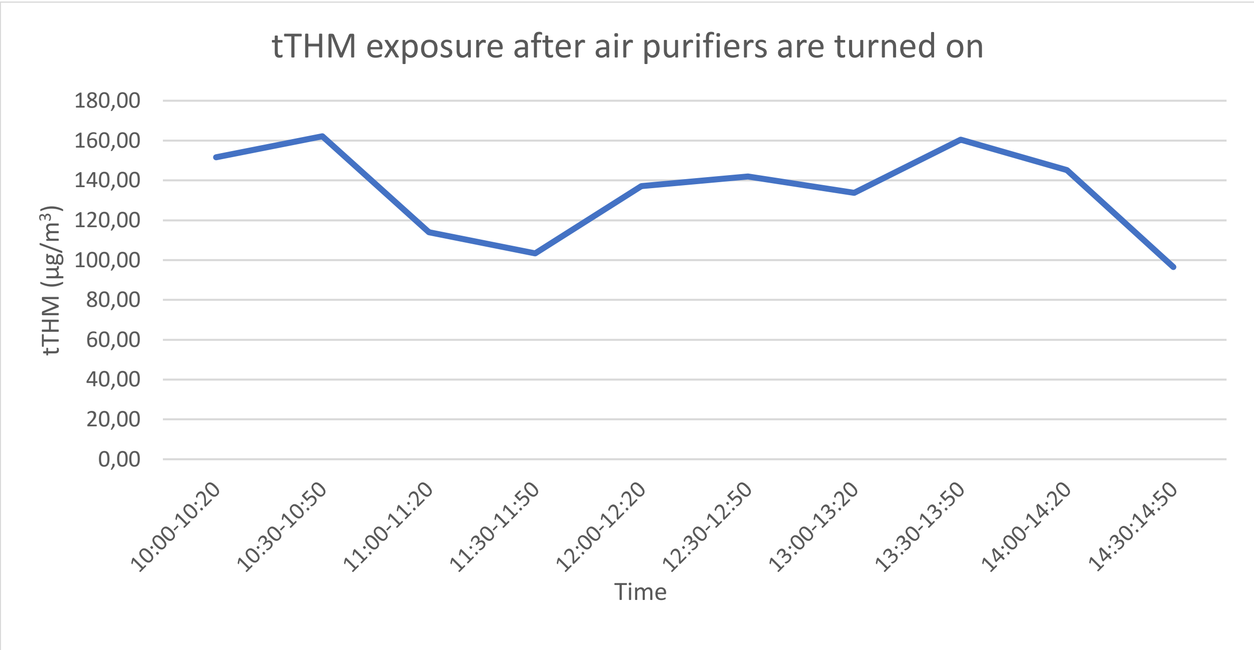

Figure 19. First samples with air purifier turned on.

It seems like the air purifier with the carbon filter does not affect the THM exposure in the first 5 hour after turning them on. Although they were turned on at maximum fan speed, there were no noticeable changes in concentration according to the results. This is proved in Figure 20, which shows the mean tTHM exposure before and after the air purifier was turned on.

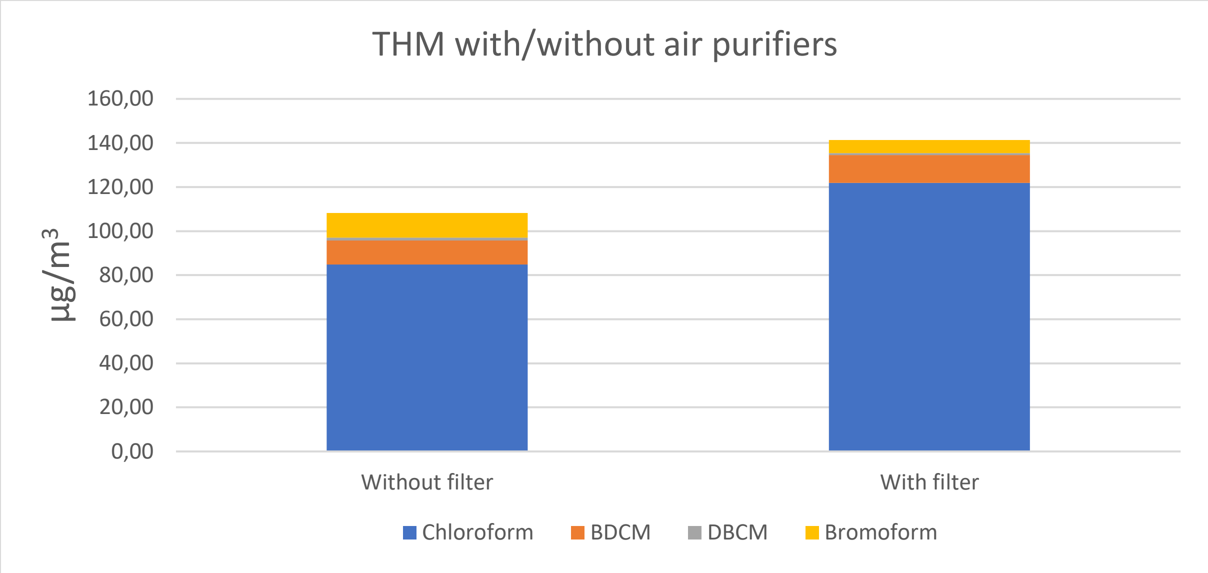

Figure 20. Mean exposure of THM with/without air purifiers.

The average value is higher with the use of air purifiers than without. In other words, it seems like the carbon filter in the air purifier does not have a particularly large impact on the THM concentration.

It is conceivable that this is primarily due to the after-effects of the increased visitor load during the winter holidays. As mentioned earlier, the THM concentration increased considerably after the winter holidays, probably due to increased amounts of chlorine and organic matter due to increased number of bathers. The result may have been different if they all the measurements were conducted the same week, with the same amount of combined chlorine and same average number of bathers.

The fact that two such air cleaners are unable to absorb enough to lower the exposure also says that the carbon used in the filter simply does not fit in such humid environments as in a swimming pool. It is also stated in the data sheet that a City M filters the air to about 75 m^2 effectively at maximum speed. That is about 150 m^2 in total with the two air purifiers. It is assumed that the area in the swimming pool is close to 300 m^2, which means that the air purifiers are not efficient enough in such large rooms. In addition, there are challenges associated with moisture. If moist particles reach the filter, the carbon will almost instantly be saturated by these particles instead of the capacity being used for what it really should be used for. Also, gases are dependent on a particular contact time with the carbon medium to get time to react with the carbon and thus be removed from the air. If the air velocity is too high, the reaction time will not be sufficient to remove the gases [118]. When the pump is at maximum speed, it may be conceivable that the air velocity of the carbon in the filter is too large to absorb the THMs. [118]

The one sample taken at the supply air from the air purifiers, see Figure 15 in chapter 6.8, did not result in an interesting finding. The concentration was 177.56 µg/m^3, which was on the average that day (28.02).

7.4.1 Possible measures

To investigate the effect of carbon filters, it may be more convenient to test over a longer period, with more constant outer parameters such as the number of bathers and the amount of combined chlorine. In addition, the sampling method should be changed. A method where all air that are sampled is pumped through a filter with different carbons over a longer period can be a better way to understand the different carbons ability to adsorb THM and other DBPs and the carbons lifetime before it gets saturated.

There is also the possibility to try other methods that include carbon filters in the air. Much of the air in a ventilation system in swimming pools is recirculated air. One possibility may be to place carbon filters in the air handling unit to look at the effect of the air being filtered for the different gases and molecules.

It is also possible to try out parallel samples. One air sample is taken as usual, while at the same time taking another air sample of indoor air that has passed a carbon filter. This can be done, for example, by using a small chamber with a carbon filter mounted in the entrance to the chamber. A pump provides airflow to the chamber where the samples are taken. In this way, it is possible to see the difference in THM with and without coal filter at the same time.

Another possibility is to improve the use of free-standing air purifiers in the swimming pool. The two City M air purifiers used in this study is maybe not big enough to cover the entire room of 300 m^2. A solution could be to install a bigger air purifier for industrial usage that can cover the entire swimming pool. Different carbon filters inside the air purifier can be tested for saturation time and absorption efficiency.

7.5 General discussion

In the first chapter, some hypotheses were presented that were to be evaluated using measurements and results. After this study, it is possible to confirm and dispel some of them, while others are still difficult to answer.

- CO_2 correlates with the number of bathers

The first hypothesis was basically a matter of course. CO_2 has been shown to vary with the number of occupants in several studies. Nevertheless, it is necessary to make measurements showing that the hypothesis is correct. It can be a ventilation system that is controlled by the number of visitors, resulting in a CO_2 concentration that will not vary to the same extent as the bathers loading. In this study, a statistics analysis showed a significant correlation between these two parameters. The measurements also showed that there is a ventilation system with an effective air distribution that quickly lowers the CO_2 concentration after people have left the pool. The ventilation values proves this by having been calculated to be between five and six ACH, where a large proportion of supplied air is fresh air in daytime when the samples were taken.

- THM concentration correlates with the CO_2 concentration

Variations in term of one day turn out to be the general use of the pool. The more bathers, the higher the concentrations of THM. The second hypothesis said that the THM exposure changes with the number of bathers. This hypothesis is correct as there is significant correlation between tTHM and CO_2. The reason can be increased amount of organic matter and increased water turbulence, forming more THMs and DBPs.

- Carbon filter absorbs THM and reduces the exposure significantly

The third hypothesis was that a carbon air filter absorbs the THM and reduces the exposure significantly. Measurements have been made both with and without air purifiers with carbon filters in the hope of seeing distinct differences in THM exposure. However, it turned out that the two air purifiers did not have enough capacity or the appropriate carbon to absorb enough to see significant differences in THM exposure. Since the carbon inside the sampling tubes (Tenax TA) manage to adsorb all the THM gases, the potential of carbon filter in the air are substantial.

In retrospect, it is necessary to use another method to check if carbon filters work for such purposes. First and foremost, it is important to have equal circumstances with and without the use of the filter to have a good basis for comparison. Then, the sampling method should allow all the air to pass through the filter. The method may need to be developed and tested in a laboratory under controlled circumstances first, and then tested in a swimming pool. During this project period it was difficult to obtain enough funds and resources to produce an indoor environment like the swimming pool in a laboratory.

In conversations with representatives from Camfil AS, it was concluded that the air purifiers City M were most current to use due to practical reasons. They were easy to assemble, making it feasible to test in a relatively short time. In retrospect, it might not be the best solution due to the results. Nevertheless, it is an experience to include in later research.

- THM concentration is reduced with high ventilation rate

The last hypothesis was that THM concentration is lower at high supply air volumes. Although it was difficult to distinguish the concentration due to slight variations in supply air in this thesis, it is logical to think that it should primarily be considered to supply fresh air to lower the exposure of THM and other DBPs. Firstly, it is easy to increase the airflow over shorter periods of time to look at its impact, and secondly, it is practically feasible because of low costs. This hypothesis can be seen in the context of the CO_2 concentration's correlation with tTHM. With increased fresh air volumes, the CO_2 level decreases faster, and with decreasing CO_2 levels, the tTHM exposure will decrease as shown in the correlation analysis and Figure 17.

It is also important that the ventilation changes the air in the occupant zone of the bathers. Today, air is added to the windows as mentioned. It may be that the supply air gets a kind of "short circuit" and flows straight up at the ceiling height and transported away by the exhaust duct by the roof. THM samples should therefore be conducted near the occupant zone with different air distribution solutions if this is to be investigated.

8 Conclusion

In this study, both THM, CO_2, temperature and RH were measured for four weeks to study the concentration of THM. In addition, it was examined whether two air purifiers with carbon filters could significantly reduce the THM concentration.

Regardless of which week or day the measurements were made, the results showed that short-term variations in THM concentration are probably due to the number of bathers and general usage of the pool. A correlation analysis showed significant correlation between the CO_2 and number of bathers and tTHM. Increased activity in the water leads to water turbulence and higher amounts of organic matter which is likely to cause increased concentration of the volatile THMs in the air.

Over a longer time-perspective, looking at all four sampling weeks, it is mainly the daily measured parameter called combined chlorine that affects the average tTHM concentration every day. The analyse proves a significant positive correlation between tTHM and combined chlorine. Especially after the winter holidays, before the last two sampling weeks, the combined chlorine concentration went form 0.1mg/l to 0.2 mg/l. This led to increased average THM concentration, and especially chloroform was correlated to the combined chlorine concentration.

The testing of the air purifiers with carbon filters did not yield expected results. In fact, the average THM concentration was higher when the air purifiers were in use. This is probably due to the extra visit load during the winter holidays, which gave higher values of combined chlorine the week after the measurements were taken. It may also be that the carbon filters were not suitable for the humid climate in a swimming pool. The capacity of the air purifiers was probably not large enough either. The carbon filter test method should be remedied to investigate the potential of air carbon filters.

Ways to lower the exposure of THM and other DBPs may be to use sensors that measure the CO_2 concentration. Then use that as an additional parameter to temperature and RH in the control of fresh air supply in the ventilation system. This will mean that the supply air flow will increase with increasing CO_2 concentration. Further, combined chlorine is also a parameter that could be included in the ventilation control.

The result of this thesis proves some factors which have a strong relationship to the THM exposure. The design and management factors of swimming pools should be given priority in exposure risk management.

9 Further work

To continue investigating the challenges of indoor air quality in swimming pools, further studies and investigations are essential. Some possible further studies are presented in this chapter.

The samplings and measurements in this study was conducted through four weeks, two days a week with 64 samples in total. It is preferable to take measurements over a longer period with more samples to get a better understanding of the factors that affect the THM concentration. Long term measurements also make it possible to look at seasonal variations, and look at relationships with weather conditions etc.

The variations in the THM concentration during the day are proven to correlate positively to the number of bathers, and thus the CO_2 concentration. It would have been interesting to look at a ventilation control, which in addition to RH and temperature, also adjusted the air volume in relation to CO_2 concentration. It is believed that this ventilation strategy can provide lower average exposure of THM, and thus also other DBPs. Furthermore, combined chlorine can also be a parameter for controlling the supplied fresh air flow as the correlation is significant to THM concentration.

Carbon filter testing did not provide the expected results. To further investigate the effects of carbon filter in the air, a new method for testing them are essential. One strategy that can be tested is to test the filter by taking parallel air samples where one air sample is taken in the swimming pool as usual, and the other is taken by air that has only passed the carbon filter. In order to test the lifetime of the filters before they get saturated, it is important to take samples over a longer period.

Further, a method for testing carbon filter may be to build a test chamber by recreate an indoor climate as in a swimming pool, only on a much smaller scale. That would make it easier to measure and test different carbon filter solutions both for adsorption properties and for duration before the filters become saturated. In addition, the surroundings are equal and stabile and ensures a good basis for comparison. In this method, it is also more cost-effective to try many filters. This makes it easier for suppliers to contribute to the research.

In the literature study there were found many studies that had mapped the THM exposure and other DBPs in swimming pools, but none stated which ventilation strategy and air distribution that were used. A further study may be to identify which ventilation strategies and air distribution principles that provide the lowest concentration of THM and other DBPs. If this is mapped, it provides useful information for building new swimming pools. It is conceivable that the air distribution can be improved by supplying air directly into the occupancy area, and not on the windows. The new supply air will then be better mixed with the old air.

It is recommended that in the testing of exposure-reduction measures, it is important to look at more DBPs than just THM. This applies especially to exposure-reducing measures involving chemicals and other disinfectants. Therefore, a comprehensive understanding of the formation of other DBPs should be established.

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Appendix

A. Results

In the appendices, all the results from the measurements are presented at tables from each day. Temperature is not included as there were only variations from 28.5-29 ºC in all measurements.

05.02.2019										
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH
10:00-10:20	1	18	0,12	84,33	11,49	1,87	14,68	112,37	688,8	5,85
10:30-10:50	2	21	0,12	91,20	11,72	1,19	8,27	112,37	716,0	5,85
11:00-11:20	3	0	0,12	82,81	11,16	1,69	13,08	108,75	610,5	5,85
11:30-11:50	4	3	0,12	74,21	10,09	1,59	13,97	99,87	615,8	5,85
12:00-12:20	5	7	0,12	86,27	11,80	1,77	12,96	112,80	635,9	5,85
12:30-12:50	6	4	0,12	91,47	13,17	2,04	14,13	120,81	617,3	5,85
13:00-13:20	7 *	8	0,12	-	-	-	-	-	-	5,69
13:30-13:50	8	8	0,12	76,56	10,32	1,09	9,05	97,03	624,1	5,63
14:00-14:20	9	0	0,12	73,13	10,75	1,65	12,03	97,56	577,1	5,63
14:30:14:50	10	0	0,12	97,53	15,96	3,52	20,85	137,87	571,1	5,63

* Rejected

07.02.2019										
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH
10:00-10:20	1	15	0,15	73,24	8,73	0,52	8,21	90,71	607,3	5,37
10:30-10:50	2	30	0,15	79,07	9,57	0,25	4,17	93,07	662,4	5,37
11:00-11:20	3	0	0,15	80,67	9,83	0,41	4,81	95,72	658,7	5,37
11:30-11:50	4	14	0,15	89,53	11,64	1,84	15,12	118,13	612,3	4,89
12:00-12:20	5	28	0,15	91,40	12,69	2,31	17,67	124,07	678,6	5,43
12:30-12:50	6	0	0,15	62,81	9,48	1,76	16,53	90,59	678,0	5,06
13:00-13:20	7	28	0,15	92,56	16,43	3,71	22,13	134,83	660,2	5,28
13:30-13:50	8	28	0,15	109,95	19,84	4,49	23,12	157,40	634,0	5,35
14:00-14:20	9	1	0,15	80,97	12,61	2,31	15,11	111,00	634,6	4,63
14:30-14:50	10	0	0,15	99,63	18,97	4,76	23,88	147,24	588,3	4,59

12.02.2019												
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH	RH
10:00-10:20	1	14	0,13	89,57	12,45	2,97	25,87	130,87	626,2	5,61	59,7
10:30-10:50	2	28	0,13	110,48	13,20	1,81	14,03	139,52	665,5	5,61	58,7
11:00-11:20	3	15	0,13	100,73	11,45	0,80	7,72	120,71	665,3	5,61	55,6
11:30-11:50	4	7	0,13	80,69	10,47	2,16	21,16	114,48	603,1	5,61	52,7
12:00-12:20	5	27	0,13	94,39	10,75	0,99	9,83	115,95	656,7	5,61	54,3
12:30-12:50	6	25	0,13	100,61	11,51	0,89	8,24	121,25	686,6	5,61	58,2
13:00-13:20	7	4	0,13	74,83	8,32	0,39	7,17	90,71	604,0	5,61	56,5
13:30-13:50	8	10	0,13	93,19	10,16	0,44	5,69	109,48	656,7	5,61	55,8
14:00-14:20	9	9	0,13	108,41	11,96	0,60	5,33	126,31	671,0	5,66	58,6
14:30:14:50	10	0	0,13	84,51	8,99	0,15	4,61	98,25	554,9	5,66	58,6

14.02.2019											
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH	RH
10:00-10:20	1	15	0,10	68,83	7,32	0,07	6,03	82,24	659,2	5,85	57,6
10:30-10:50	2	29	0,10	81,33	8,55	0,20	5,63	95,71	741,2	5,85	56,0
11:00-11:20	3	15	0,10	87,84	9,73	0,65	7,88	106,11	685,1	5,85	57,1
11:30-11:50	4	13	0,10	54,64	5,35	0,00	5,12	65,11	588,9	5,85	56,1
12:00-12:20	5	26	0,10	85,52	8,65	0,00	4,03	98,20	704,7	5,85	55,7
12:30-12:50	6	13	0,10	90,76	9,67	0,20	4,17	104,80	688,5	5,63	55,4
13:00-13:20	7	5	0,10	58,81	6,19	0,00	6,07	71,07	582,1	5,69	52,8
13:30-13:50	8	15	0,10	84,11	9,52	0,53	6,56	100,72	609,4	5,63	53,5
14:00-14:20	9	20	0,10	85,04	8,89	0,11	3,95	97,99	646,2	5,63	53,5
14:30:14:50	10	0	0,10	58,71	5,53	0,00	2,64	66,88	588,6	5,01	52,1

26.02.2019											
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH	RH
10:00-10:20	1	18	0,19	134,11	14,51	1,37	1,63	151,62	689,3	5,45	61,1
10:30-10:50	2	21	0,19	139,07	15,19	1,33	6,56	162,15	692,4	5,45	62,2
11:00-11:20	3	0	0,19	91,88	10,71	1,25	10,15	113,99	605,6	5,45	60,8
11:30-11:50	4	3	0,19	86,30	9,74	0,60	6,66	103,30	599,4	5,45	57,2
12:00-12:20	5	7	0,19	108,18	13,25	2,11	13,67	137,21	684,3	5,45	58,9
12:30-12:50	6	4	0,19	120,36	13,77	1,22	6,68	142,03	686,2	5,45	61,6
13:00-13:20	7	8	0,19	110,86	13,40	1,58	7,90	133,74	691,9	5,45	59,4
13:30-13:50	8	8	0,19	135,84	15,96	1,70	6,95	160,44	743,0	5,70	60,0
14:00-14:20	9	0	0,19	124,53	13,92	1,19	5,49	145,14	707,4	5,70	60,0
14:30:14:50	10	0	0,19	82,82	8,77	0,33	4,59	96,51	585,2	5,70	57,6

28.02.2019											
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH	RH
10:00-10:20	1	18	0,20	100,53	9,95	0,58	6,74	117,80	620,8	5,61	61,7
10:30-10:50	2	21	0,20	121,44	12,17	0,61	1,69	135,91	636,9	5,61	57
11:00-11:20	3	0	0,20	119,29	11,43	0,43	1,67	132,81	623,2	5,61	56,7
11:30-11:50	4	3	0,20	90,53	8,13	0,00	4,85	103,51	553,5	5,61	53,9
12:00-12:20	5	7	0,20	107,27	9,93	0,13	1,67	119,00	651,9	5,61	54,6
12:30-12:50	6	4	0,20	113,83	11,10	0,30	4,53	129,76	637,9	5,61	55,1
13:00-13:20	7	8	0,20	92,93	9,13	0,19	4,93	107,17	583,8	5,69	54,1
13:30-13:50	8	8	0,20	131,63	12,76	0,00	4,11	148,50	654,9	5,69	55,3
14:00-14:20	9	0	0,20	138,41	13,31	0,47	3,79	155,99	664,4	5,69	57
14:30:14:50	10	0	0,20	100,00	10,34	0,64	6,57	117,56	574,3	5,69	55,3

07.03.2019										
Time	Sample nr.	Number of bathers	Combined chlorine	TCM	BDCM	DBCM	TBM	tTHM	CO2	ACH
10:00-10:20	1	18	0,20	162,57	16,10	1,69	11,18	191,54	678,5	5,32
10:30-10:50	2	21	0,20	149,34	14,12	0,82	7,38	171,66	641,2	5,02
11:00-11:20	3	0	0,20	148,38	14,51	1,01	8,04	171,96	633,2	5,34
11:30-11:50	4	3	0,20	194,79	18,81	1,42	6,99	222,02	732,7	5,25
12:00-12:20	5	7	0,20	142,57	13,61	0,64	6,01	162,82	610,6	4,74

B. Statistics

The table shows descriptive statistics for THM, CO2, number of bathers and combined chlorine. All data is calculated in SPSS.

The mean with the lower and upper bound have been calculated with a 95% confidence interval.

Statistics									
						Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
tTHM	1	9,00	111,05	12,89	4,30	101,14	120,96	97,03	137,87
	2	10,00	116,28	24,41	7,72	98,82	133,73	90,59	157,40
	3	10,00	116,75	14,62	4,62	106,29	127,21	90,71	139,52
	4	10,00	88,88	16,05	5,07	77,40	100,36	65,11	106,11
	5	10,00	134,61	22,96	7,26	118,19	151,04	96,51	162,15
	6	10,00	126,80	17,02	5,38	114,63	138,97	103,51	155,99
	7	5,00	184,00	23,71	10,60	154,56	213,44	162,82	222,02
	Total	**64,00**	**121,14**	**29,32**	**3,67**	**113,81**	**128,46**	**65,11**	**222,02**
CO_2	1	10,00	626,24	45,17	14,29	593,92	658,56	571,05	715,95
	2	8,00	637,78	32,18	11,38	610,88	664,69	588,25	678,60
	3	10,00	638,99	40,91	12,94	609,72	668,26	554,85	686,60
	4	10,00	649,37	55,67	17,61	609,54	689,20	582,05	741,20
	5	10,00	668,43	52,55	16,62	630,84	706,02	585,15	743,00
	6	10,00	620,14	37,49	11,85	593,32	646,96	553,50	664,40
	7	5,00	659,22	47,78	21,37	599,89	718,55	610,60	732,65
	Total	**63,00**	**641,75**	**46,09**	**5,81**	**630,14**	**653,35**	**553,50**	**743,00**
Number of bathers	1	10,0	6,9	7,4	2,3	1,6	12,2	0	21
	2	10,0	14,4	13,3	4,2	4,9	23,9	0	30
	3	10,0	13,9	9,8	3,1	6,9	20,9	0	28
	4	10,0	15,3	9,5	3,0	8,5	22,1	0	29
	5	10,0	12,6	7,3	2,3	7,4	17,8	0	20
	6	10,0	5,1	3,0	1,0	2,9	7,3	0	9
	7	5,0	14,0	9,0	4,0	2,8	25,2	3	27
	Total	**65,0**	**11,6**	**9,4**	**1,2**	**9,2**	**13,9**	**0**	**30**
Combined chlorine	1	10,00	0,12	0,00	0,00	0,12	0,12	0,12	0,12
	2	10,00	0,15	0,00	0,00	0,15	0,15	0,15	0,15
	3	10,00	0,13	0,00	0,00	0,13	0,13	0,13	0,13
	4	10,00	0,14	0,00	0,00	0,14	0,14	0,14	0,14
	5	10,00	0,19	0,00	0,00	0,19	0,19	0,19	0,19
	6	10,00	0,20	0,00	0,00	0,20	0,20	0,20	0,20
	7	5,00	0,20	0,00	0,00	0,20	0,20	0,20	0,20
	Total	**65,00**	**0,16**	**0,03**	**0,00**	**0,15**	**0,17**	**0,12**	**0,20**

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