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Photocatalysis and Blue Light in Swimming Pools Delay Corrosion in Concrete and Metal Parts and Improve Indoor Air Quality



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ABSTRACT

Västertorpsbadet aquatic center in Stockholm, Sweden, opened in 1967, had its original hypochlorite-based water treatment system combined with a photocatalysis treatment for the water and blue light in the pool hall. This case study follows up the outcome of these installations. When chlorine was reduced from 0.8 to 0.4 mg Cl₂/l levels of culturable bacteria did not raise, and also all other indicators remained well within the Public Health Agency of Sweden's guideline values. In addition, air quality in the pool hall was much improved because concentration of trichloramine in the air was reduced. When chlorine and chloride in the pool

water is reduced, risk for corrosion is reduced, which will give extended service life both for reinforced concrete in the pool and in the building and in all steel details such as ducts, pipes and fixtures. In our literature research, we have not found any other similar approach to reduce chlorine addition in a swimming pool. In conclusion we found a good technical effect from supplementing the hypochlorite addition with these methods.

Keywords: swimming pool, concrete corrosion, photocatalysis, blue light, trichloramine

1. INTRODUCTION: SWIMMING POOLS AND AQUATIC CENTERS

Aquatic centres have a very long history [1]. Obviously, they fulfil basic human needs related to hygiene, pleasure and wellbeing. They also are important for development and upkeep of the ability to swim. It is a very clear demand for indoor pools. For example, in Sweden there are at about 400 establishments shared by a population of 10 million people [2]. In Germany there are 3184 establishments shared by a population of 83 million people [2, 3].

In aquatic centers cleaning of the water and also of all the floors and spaces is very important. The literature reports on a number of cases where people have become infected in swimming pools [4-8]. The majority of microorganism present in swimming pools come from the bathers. Exposure to microorganisms when swimming in pools can happen via mouth, eyes, ears, wounds on skin or via inhaled air. If conditions regarding moisture, nutrition, temperature, oxygen and pH are favourable, bacteria can grow quickly. A favourable water temperature for pathogenic bacteria is around 30 – 40 °C, which corresponds to the temperature in a warm pool [9]. One notation is that bacteria can accumulate on the water surface [10-12]. So, one important way of exposure concerns the water surface with possible entrance via mouth, eyes, ears and wounds. This makes it relevant to make sampling of bacteria from the surface water.

The culturable bacteria are one important reason for outbreaks of diarrhea [5, 6]. *Pseudomonas aeruginosa* is a bacterium known to cause skin problems related to pool and spa-environment in healthy people such otitis externa (infection in the outer ear canal) and folliculitis (infections in the hair follicles) [4].

There are a number of methods available for the disinfection of swimming pool water [13]. One concept frequently used is hypochlorite in water. However, one important aspect is the health effects related to byproducts from the hypochlorite [14-16]. Another drawback is that chlorine is corrosive to the steel rebars in the structure and also to all other equipment made of steel in the building [17-20]. Corrosion in the pools and in other parts of the structure is a process that limits service life.

So, there are two main reasons for lowering the chlorine content. First, to reduce the amount of disinfection by-products formed and so reduce the user's and the staff's health problems related to chlorine and secondly to delay degradative or corrosive processes in the structure and in the equipment and so extend their service life.

The Public Health Agency of Sweden states: “In some cases, it may be acceptable for a swimming hall operator to keep the free chlorine content slightly below the guideline values under controlled conditions” [9]. However, it is very important not to impair hygienic quality of the water. If free chlorine content is reduced below what the guideline states, it is important that the chemical and microbiological parameters are followed carefully. Sampling may also need to be done more frequently. The guideline values are presented in Table 1. The follow-up presented in this report was actually a prerequisite for permittance of the lowered chlorine levels.

Table 1 – Guideline values for chlorine addition at different pH values and different water temperatures [9].

pH value	Free chlorine T below 35 °C	Free chlorine T above 35 °C	Unit
pH 7.2	not below 0.4	not below 0.8	mg Cl ₂ /l
pH 7.4	not below 0.5	not below 0.9	mg Cl ₂ /l
pH 7.6	not below 0.6	not below 1.0	mg Cl ₂ /l

2. AIM OF THIS STUDY

The aim of this study was to investigate the possibility of lowering the chlorine content in a swimming pool, while bacteria levels still remain on acceptable levels, by combining the ordinary cleaning system with using photocatalysis in the treatment plant and blue light illumination in pool halls. These methods will be described below. The inventor of this concept [21] was Bengt Simonsson at the company “Teknikmarknad” in Stockholm. The installations were done at the Västertorpsbadet aquatic center [22] in Stockholm, Sweden, which is managed and owned by the municipality of Stockholm. They made this investment in order to develop their competence and experience in swimming pool technology. This is relevant because the municipality of Stockholm is the owner of 15 aquatic centers [23]. Västertorpsbadet aquatic center was originally opened in 1967. It includes one bigger pool, 25x12,5 m, with a diving tower at the deep side of the pool, and a minor pool, 12,5x6,25 m. There are skylights on the sides of the bigger pool. The installations were done in 2020, just in the commence of the corona pandemic. This resulted in some delay in the evaluation presented in this report.

2.1 Photocatalysis

The photocatalysis was done in an AOT device [24] where the water is illuminated by a powerful UV-lamp as it flows through a pipe, which inside walls are coated with titanium dioxide (AOT stands for Advanced Oxidation Technology). The system acts as a catalyst for formation of free radicals, i.e. water molecules are split into hydrogen oxide (OH[•]) and hydrogen atoms (H[•]). These radicals kill and decompose all bacteria and other microorganisms. Furthermore, hydrocarbons in the water are decomposed to carbon dioxide and water [25]. These hydrocarbons (organic carbon) might be debris from the bathers, like skin flakes, or for

example, residues from skin care products. The AOT device is placed after the sand filters in the treatment plant, as indicated in the process scheme, Figure 1. Figure 2 is a photo of the equipment. For each circulation about 50% of the water flow passes the photocatalysis equipment, so in the long turn all the water will be treated. This type of photocatalysis was formerly tested in Sundbyberg aquatic centre in 2005, the outcome was said to be good [26], but no description or follow up was published.

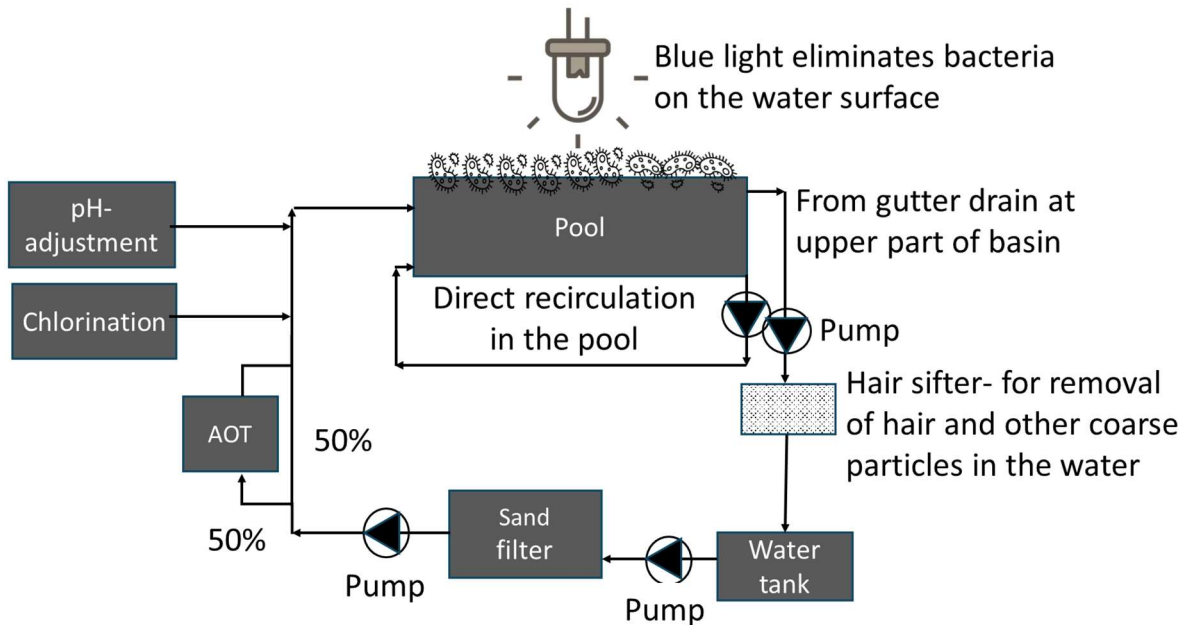


Figure 1 – Schematic flow chart of the water treatment plant in Västertorp aquatic center.



Figure 2 – This picture shows the AOT devices for photocatalysis installed in the treatment plant of Västertorp aquatic center.

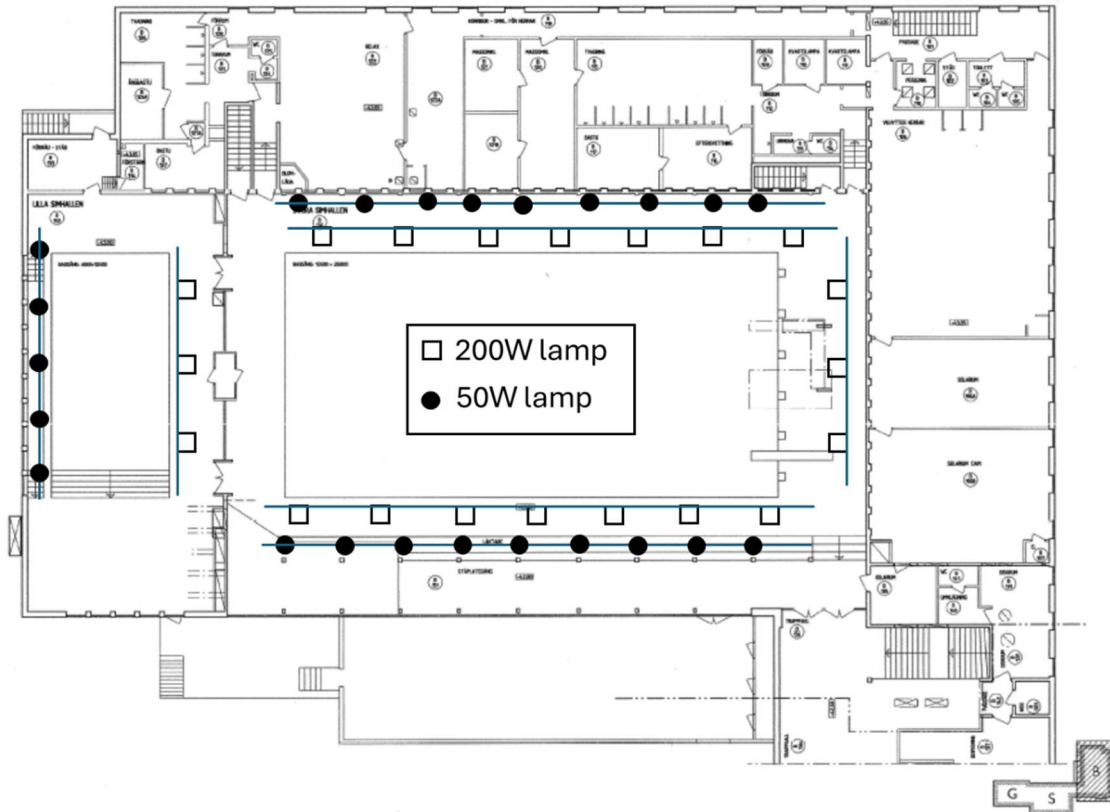


Figure 3 – Schematic description of the installation for blue light at Västertorp aquatic center.

2.2 Blue light illumination and its effect

Visible light has a wavelength range between 400 and 800 nm. Light with wavelength below 400 nm is UV light, which sorts into UV-A, UV-B, and UV-C. Wavelengths of UV-A are between 315 and 400 nm. Blue light of the wavelength 405 nm, which is close to UV-A light wavelengths, is interesting when it comes to kill bacteria. When this blue light hits porphyrin molecules inside a bacterium, reactive radical hydrogen oxide ($\text{OH}^\cdot$) is released [10]. These radicals destroy proteins; membranes etc. in the bacterium and kill it from inside. The technology is applied, for example, in acne treatment and in light locks into surgery rooms. Here the blue light illumination is supposed to kill bacteria on the water surface and on material surfaces in the hall and so protect bathers from infections. This is to complement the function of the regular water purification. For example, *Pseudomonas Aeruginosa*, do not develop resistance to this blue light but is found to remain sensitive through several generations [10]. The hall for the bigger pool has a row of windows with daylight admission located high up in the walls and there are fluorescent fixtures in the hall's ceiling. There were twenty blue light fixtures of 200 W (optical power 80 W) installed at the height of eight meters above the walkways and 25 blue light fixtures of 50 W (optical power 20 W) installed on the walls at a height of five meters. Placement of the fixtures are indicated in Figure 3. The blue light fixtures were delivered by UVTaoYuan [27]. The lamps were the 405 nm versions of the models TY-D-200W-FF, for 200W and TY-D-405/415nm-50W for 50W. The fixtures have reflectors, but

no lenses. All the fixtures shine towards different parts of the swimming pool and floor surfaces. The total floor and pool surfaces are approximately 550 square meters. Total illumination intensity for the blue light (optical power) is 2.1 kW, which in turn means 3.8 W/m². A timer supplements the installation, so the blue light is automatically turned off during daytime when bathers and personnel are in the premises. Figure 4 shows lamps in the hall.



Figure 4 – The photo shows blue light lamps in the bigger pool hall.

2.3 Indicators for water quality and hygiene

There are a number of indicators for water quality and hygiene in the facility in the regulations from the Public Health Authority of Sweden [9]. These indicators that are tested regularly are the basis for this case study.

pH-value and alkalinity

pH-value relates to the antimicrobial effect of chlorination. Hypochlorite is basic, which means that the bathing water needs to be acidified. Alkalinity is measured in mg HCO₃/l and gives an

indication of buffering capacity of water [9]. Alkalinity should stay between 60 and 120 mg HCO_3/l [28].

COD, TOC, turbidity and redox potential

COD in mgO_2/l (chemical oxygen demand) is a measure of the amount of oxygen needed to break down the organic substances that the water contains. TOC mg/l (total organic carbon) is a measure of dissolved and particle organic material in water. COD and TOC values indicate the amount of organic substance in bathing water, which can increase with bathing load. Organic substances consume chlorine and can cause a reduced disinfection effect. Organic substances also carry nutrients for bacteria. If the value of COD exceeds 4 mgO_2/l , it may be a sign that the capacity of the treatment plant is too low in relation to the number of bathers [9].

Turbidity is caused by small particles that are not separated during filtration and has the unit FNU (formazine nephelometric unit), which expresses how a light signal relates to that signal obtained from a formazine suspension prepared in a standardized manner [29]. If the turbidity has a value above 0.4 FNU, this can be a sign of problems in the filter system, or that bathing load is higher than what the purification system can handle with a poor disinfection effect as a result. It is therefore of utmost importance from a hygienic point of view that turbidity is kept as low as possible [9].

Redox potential is measured in millivolts with an Ag/AgCl 3.5 M KCl electrode [9], and is an indicator on free chlorine water. In addition to chlorine content, pH value and other chemical substances in the water also affect the redox potential. Monochloramine and dichloramine are also rather strong oxidants with high redox potentials [30]. When pH value and COD rise and other contaminants are present in the water the redox potential drops. A parameter limit value for redox is above +750 mV when measured in accordance with DIN 38404 [31].

Free and total chlorine

When the pool water is disinfected using chlorine the active part is free chlorine, which reacts with different molecules forming combined chlorine. Total chlorine is the sum of free and combined chlorine. Free chlorine, in Västertorp, is added to the pool water as sodium hypochlorite. Hypochlorite and hypochlorous acid are in a pH-dependent equilibrium with each other. Table 2 shows the guideline values for free chlorine at different pH-values.

Trichloramine

Trichloramine is an unhealthy gas which should be kept at as low level as possible [9]. Trichloramine in water evaporates easily. It irritates eyes and upper respiratory tract. Personnel in aquatic centers may develop asthma by exposure to trichloramine [32]. Some studies show that children with established allergies who often swim in public pools have asthma more often, while other studies have not been able to demonstrate such a connection. WHO has recommended a reference value of 0.5 mg/m^3 for trichloramine in air. However, in later studies, health effects have been noticed at concentrations in air down to 0.3 mg/m^3 i.e. below the WHO value [33]. Currently the Public Health Agency in Sweden has a guideline value that state that the trichloramine concentration should not exceed 0.2 mg/m^3 . Water with high

concentrations of free chlorine, high temperatures and low pH values form more trichloramine [9]. Combined chlorine levels above 0.3 mg Cl₂/l indicate a high input of nitrogenous pollutants to the pool water, often from bathers, or that the treatment plant is not capable of handling these pollutants. Therefore, the Public Health Agency of Sweden has guideline values for combined and total chlorine levels, see Table 2. One study [34] shows that urea CO(NH₃)₂ together with hypochlorous acid HClO forms tetrachlorourea CO(NCl₂)₂ by:



Tetrachlorourea together with more hypochlorous acid will then form trichloramine NCl₃ by:



The reactions (1) and (2) are not pH-dependent. However, trichloramine is not stable at pH around 7 and is transformed into dichloramine, with half-life of about three and a half hours. In a study about cooling towers, trichloramine was found to evaporate 300 times faster than dichloramine [35].

Circulation of the water in the pool

The water flow and the purification are described in Figure 1. When the hydraulics in the big pool were tested, by adding color to the water and following up the time until the color was washed away. It was found that time for water exchange in the pool was about six times longer than what should be anticipated in a normal pool. Nevertheless, in order to irrigate water in the big pool it is equipped with a direct recirculation where water is taken from the bottom of the pool and then directly pumped back to the pool without filtration or passage through the treatment plant. This direct circulation flow was about 50% bigger than the water flow through the treatment plant. This problem with hydraulics was one important reason for choosing this pool for the case study.

3. METHOD

This is a case study. The pools were used in the ordinary way during the test program. The technicians were acting in the ordinary way and did not change their way to work because of the test. Ventilation was operated in the ordinary way. This was also the case for cleaning of the facility.

Tests were done in 2021, after the peak of the Corona pandemic, when the swimmers were allowed to come back to the aquatic centre, and so the loads on the water treatment plant were normal. The tests were done in three rounds.

Round 1 free chlorine content – 0.8 mg Cl₂/l – this is the normal value

Round 2 free chlorine content – 0.6 mg Cl₂/l

Round 3 free chlorine content – 0.4 mg Cl₂/l

3.1 Test methods for water quality

Tests done on the water in the swimming pools are presented in Table 2, below.

Table 2 – Tests done on the water in the swimming pool

	Unit	Guideline value [9]	Method
Alkalinity	mg HCO ₃ /l	60-120 [28]	SIS-ISO 9963-2
pH	-	See Table 1	SS-EN ISO 10523
TOC (Total organic compounds)	mg/l	Less than 4	SS-EN1484: 1997
COD (Chemical oxygen demand)	mg O ₂ /l	Less than 4	SS-ISO 15705
Turbidity	FNU	Less than 0.4	ISO 2027-1 2016
Combined chlorine	mg Cl ₂ /l	Not above 0.3	SS-EN IS 7393-2
Total chlorine		Not above 2	
Chloride	mg Cl/l		SS-EN ISO 10304-1:2009
Redox potential		At least +750 mV	DIN 38404-6 [31].
Trichloramine	mg/m ³ indoor air	Not above 0.2	See section 3.2
Bacteria in the water.			
Enumeration of culturable micro-organisms	cfu/ml (cfu - colony forming units)	Less than 100	SS-EN ISO 6222 (36 °C for 2 days) Sampling is described in section 3.4.
<i>Pseudomonas Aeruginosa</i>	cfu/100 ml	Less than 1	SS-EN ISO 16266

3.2 Test of trichloramine in air

In the test for trichloramine in indoor air samples were collected by passing an air flow through two 37 mm quartz fibre filter (Whatman QMA, CAT No 1851-037) impregnated with arsenic trioxide and sodium carbonate. The air flow was 1 l/min, and the measurements were carried out for four hours. The flow was checked once every 15 minutes with flow meter. Furthermore, there were blank tests with no air flow. The filters were analysed by Environment and Health department at Örebro University using an ion chromatography method [36].

3.3 Tests of blue light intensity

The exploratory investigation of the blue light in the pool hall was carried out with a spectrometer (Thorlabs CCS200) with amplitude correction in the wavelength range 359-1019 nm. To get information about visible light a spectrometer developed for use in cinemas was

used, UPRtec CV 600 from UPR. A medical retinal laser at 532 nm was used for external calibration. The intensity of the blue light was measured in the pool hall and for comparison also the intensity of the natural outdoor light from the clear sky was measured, in the morning and in the shadow, so any direct sunlight was excluded. The results were compensated with the risk factors given in the EU-directive about artificial optical radiation values [37].

3.4 Tests for bacteria

Sampling of bacteria in the pool water is part of the regular quality control of the pool. Here a deviation from the normal test program occurred. The common way to take water samples for bacterial growth is from pool surface water, which is relevant since the greatest risk of infection is where water can be swallowed etc. [9]. However, the technician's routine was to do sampling from a tap in the treatment plant in the basement after the water had passed in pipes from pool. This was not noted until test round 2 when the free chlorine content was 0.6 mg Cl₂/l. The sampling point was hereby changed to the surface, at a point where circulation of water was slow according to hydraulic test, but for comparison also some tests at this round were taken from the tap in the basement. Hence in this study the sample points were:

- P – The water was taken from taps, which was flushed for a short while before the sample bottles were filled.
- S – From surface water of the swimming pool, excluding suspected bacterial incidents. The sample water was taken while the bottle was moved slowly forward in the water to avoid contamination from the sampler's hand.
- S-OO – For the 0,4 mg Cl₂/l 55 samples were tested. Two of these were outliers with high levels of CFU, which indicate some kind of contamination, see Section 5.1. Results where these two data points are omitted are also presented, as S-OO.

All sampling at chlorine content of 0.8 mg Cl₂/l were carried out as “P”. Measurements at 0.6 mg Cl₂/l were carried out both as “P” and “S”. All measurements at 0.4 mg Cl₂/l were carried out as “S”. The water from all these samples were also tested for *Pseudomonas Aeruginosa*.

4. RESULTS

The results are presented in diagrams where the mean value is presented by an arrow, and the 95% standard deviation is indicated by a box. The number of tests is indicated by N. Results for COD, TOC, turbidity and redox potential are presented in Figure 5. Results for alkalinity and pH-value are presented in Figure 6. Results from measurement of free chlorine, combined chlorine and total chlorine are presented in Figure 7. Results of measurements of bacteria are presented in Figure 8. All these samples were also tested for *Pseudomonas Aeruginosa* and the result were always zero, why no diagram was done. Results of measurement of trichloramine in air are presented in Figure 9. Results for measurement of chloride ions are presented in Figure 10. The risk values calculated the measurements of light intensity are presented in Figure 11.

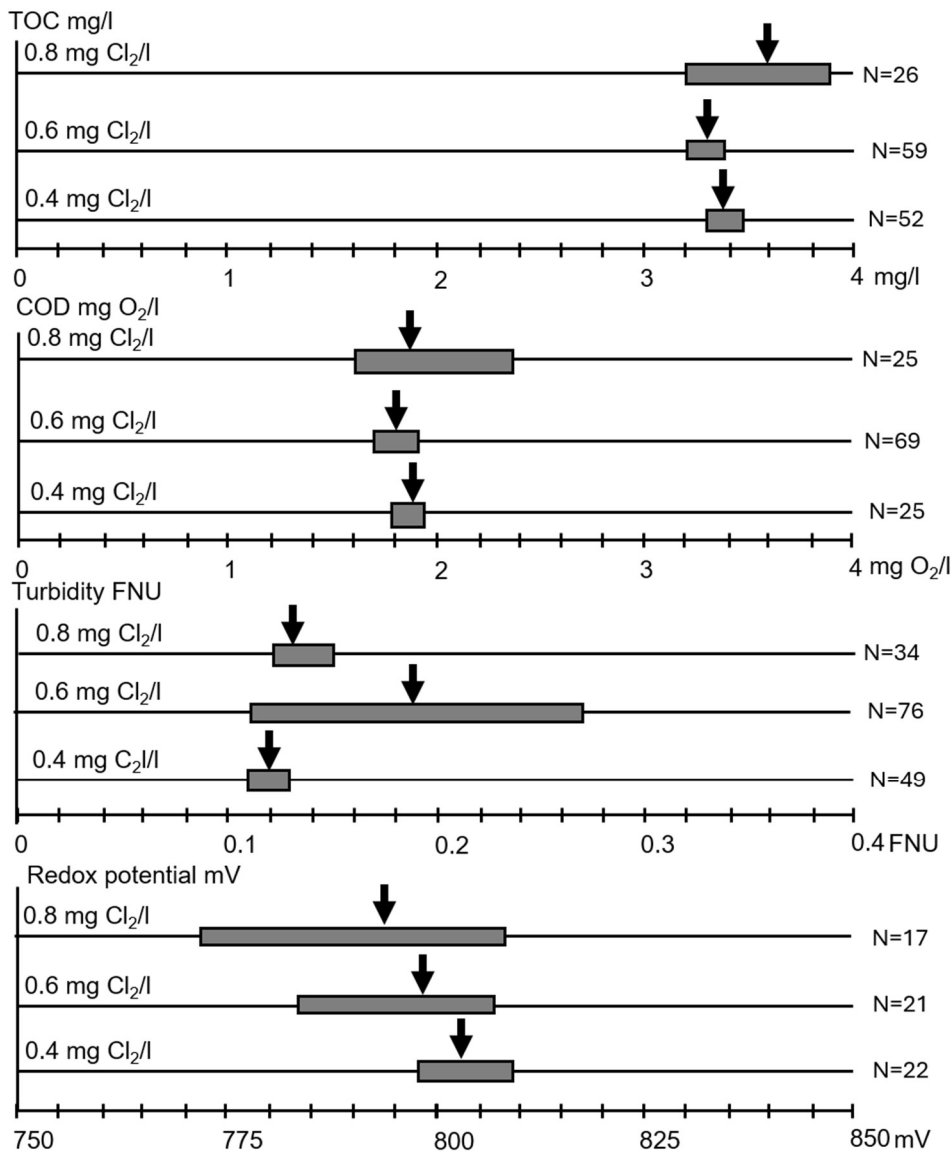


Figure 5 – TOC, COD, turbidity and redox potential at different chlorine levels. N is number of tests.

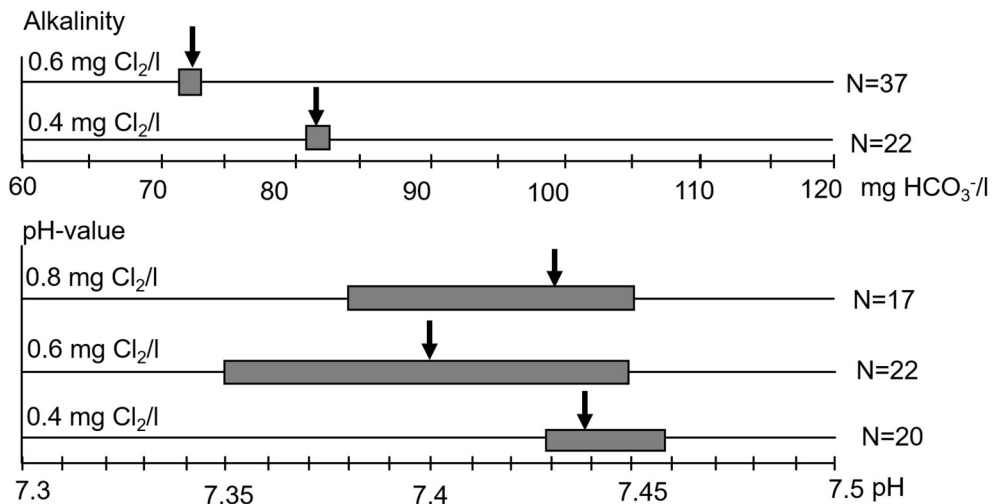


Figure 6 – Average values and confidence intervals for alkalinity and pH at different chlorine levels.

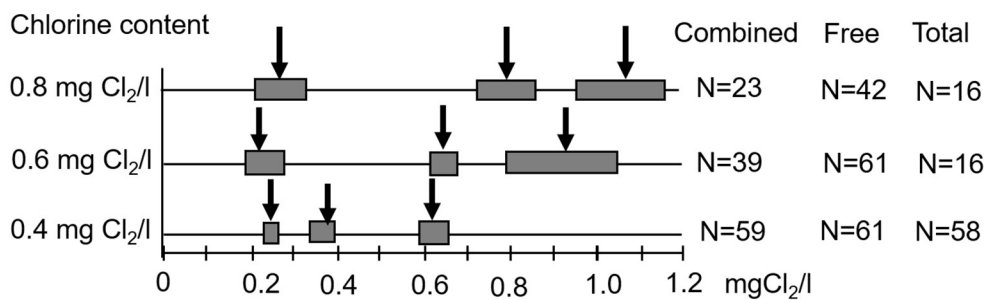


Figure 7 – Average values and confidence intervals for combined chlorine, free chlorine and total chlorine. Combined chlorine is to the left of the line, free chlorine in the center and total chlorine to the right.

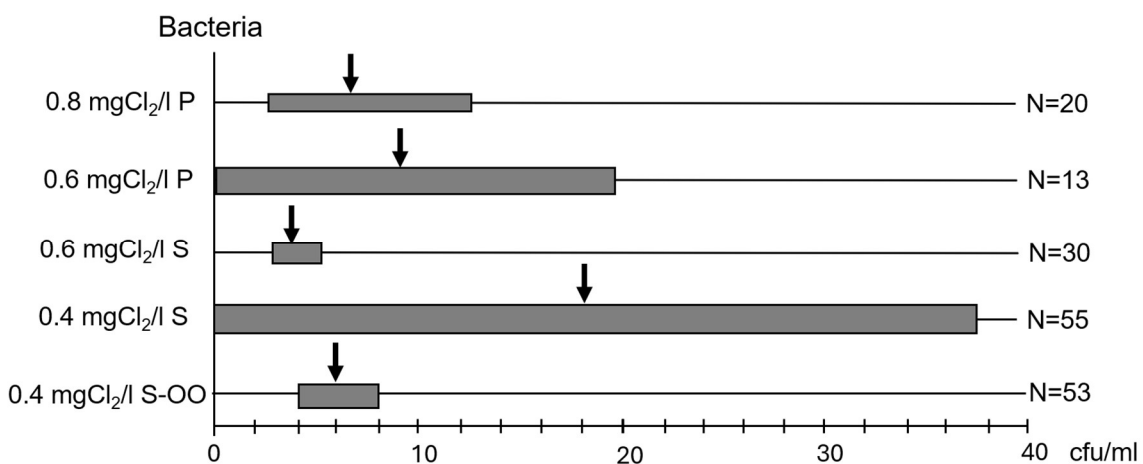


Figure 8 – Results of bacteria tests, culturable bacterial at different chlorine concentrations. P=sample from tap in water treatment plant, S=surface sample, S-OO=surface sample without outliers.

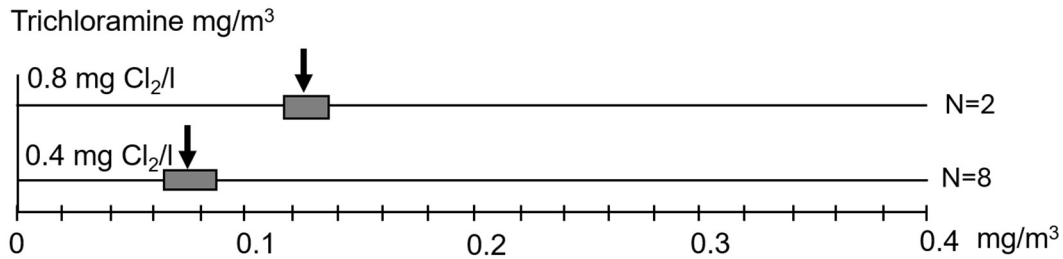


Figure 9 – Concentration of trichloramine in air at high and low levels of chlorine content.

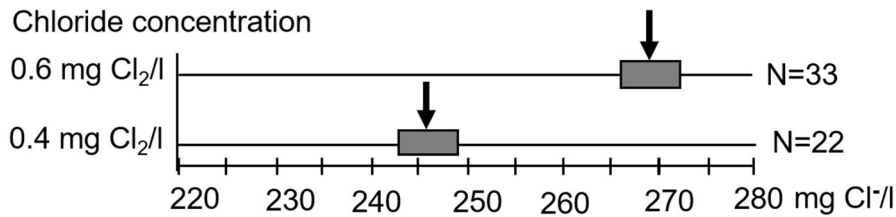


Figure 10 – Concentration of chloride ions at the two lower chlorine concentrations.

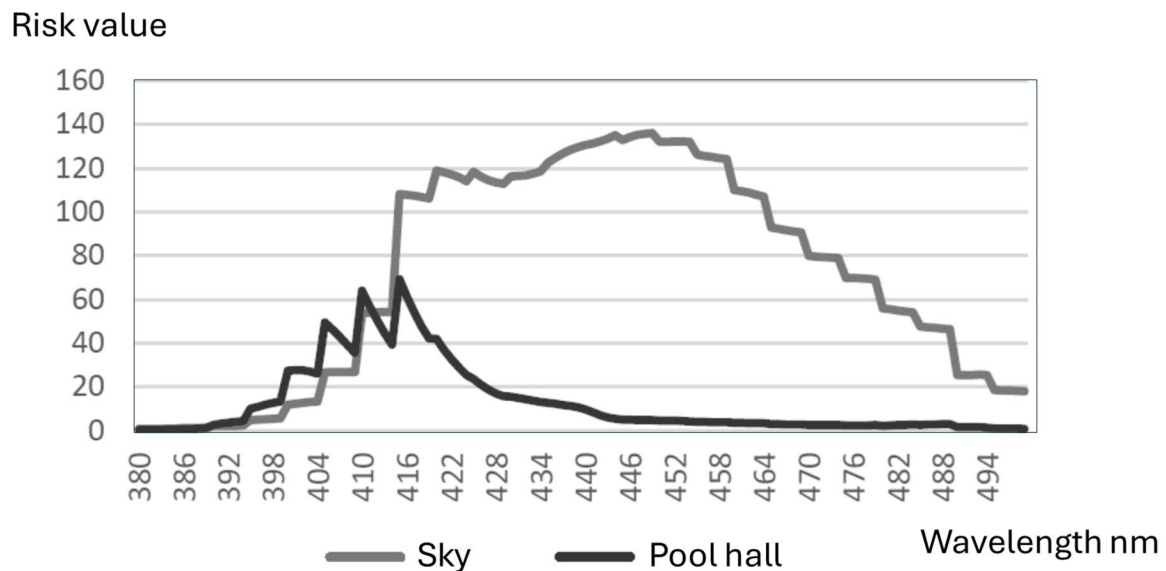


Figure 11 – Intensity of radiation from the blue light in the pool hall and from a clear blue sky in the morning, compensated with risk factors [28].

5. DISCUSSION

5.1 Bacteria and chlorine

Free chlorine is supposed to kill bacteria, and the chlorine content is therefore interesting to relate according to the bacteria content. Results of these measurements are presented in Figure 7. Combined chlorine is to the left of the line, free chlorine in the center and total chlorine to the right. The data confirms the reduction of chlorine content.

Figure 8 shows results from evaluation of culturable bacteria from different free chlorine levels. Sampling from the tap in the water treatment plant (routine P) probably gave a systematic error in high values. This might be understood when we compare the outcome of tests at round 2, where both samplings were used. The mean value of the routine P (from the tap) was somewhat higher than the mean value for routine S (from the pool surface).

The levels of culturable bacteria were in all cases well below the guideline level 100 cfu/100ml. In the 0.4 mg Cl₂/l data there were two outliers, with the values >500 and 140 cfu/100ml respectively. When these two outliers were removed (S-OO) the number of culturable bacteria at 0.4 mg Cl₂/l was in the same range as for the higher chlorine concentrations. The extra high readings could be explained by contamination during sampling or by some special behavior from the bathers. Regarding *Pseudomonas Aeruginosa* all results were below the guideline value of 1 cfu/ml, actually they were zero. In conclusion the bacteria levels remain acceptable also for the 0.4 mg Cl₂/l level.

5.2 Other tests for water quality

TOC, COD, turbidity and redox potential

The values for TOC, COD, turbidity and redox potential, presented in Figure 5, all remain within the guideline values shown in Table 2 when free chlorine was reduced to 0,6 and 0,4 mg Cl₂/l.

pH and alkalinity

Hypochlorite is basic, which means that the bathing water needs to be acidified. This is done regularly in Västertorp with carbonic acid. Results from these measurements are presented in Figure 6. The pH values in Västertorp pool are stable around 7.4. The measurement in Västertorp shows that pH has remained stable and in the same confidence interval throughout all the three test rounds. Alkalinity should be between 60 and 120 mg HCO₃/l. Mean values of alkalinity have increased with lower chlorine levels. At 0.4 mg Cl₂/l level the mean value of alkalinity level reaches above 80 mg HCO₃/l. In conclusion the pH and alkalinity still remain acceptable also at 0,4 mg Cl₂/l. One thing to notice is that according to the guideline values presented in Table 1, free chlorine should not be below 0,5 mg Cl₂/l when pH is 7,4. However, in this follow up water quality remain acceptable at 0.4 mg Cl₂/l , probably thanks to AOT and blue light.

Trichloramine in air

Concentration of trichloramine in air, Figure 9, was lower than the guideline value of 0.2 mg/m³ [9]. The reduction of free chlorine to 0.4 mg Cl₂/l reduced the trichloramine by 40%. In conclusion, the reduction in free chlorine was beneficial for the air quality with regard to trichloramine.

5.3 Chlorides and corrosion

The environment in pools is considered to be corrosive, which causes damage to reinforcement bars in concrete structures, such as the pool [19, 38] and also in other details such as pipes [18, 39] ladders, hangers for suspended ceilings [20], ventilation systems with their ducts and other items [17]. There are cases where the corrosion process has resulted in total collapse of an aquatic center building [40]. The chlorine compounds and the chlorides are the drivers for these processes.

It is an equilibrium in the pool water including elemental chlorine, chlorides and hypochlorous acid, given in reaction 3 [41]. This turns out to be far to the right when pH is around 7.4, as in Västertorp aquatic center. However, some dissolved elemental chlorine (Cl_2) is present also at this pH. Elemental chlorine (Cl_2) is a strong oxidation agent, and for this reason a driver for corrosion in steel. The process is described by reaction 4.



Hydrochloric acid is formed in reaction 4, which makes the solution more acidic, which in turn shift the reversible reaction 3 further to the left, creating more elemental chlorine, and the corrosion accelerates. This can be especially true in a micro perspective, for example in pore water close to a reinforcing bar. Another aspect on corrosion in concrete is the chlorides. There are studies that show how rate of corrosion is ruled by a threshold value of chloride concentration in the pore water [42-44]. The level of this threshold value is reduced by reduced pH-value. All these aspects say that less chlorine, less hypochlorite and less chloride ions will result in less corrosion both in the structure of the pool and in the building with the finish work and HVAC system.

In conclusion, problems with corrosion related to chlorine and chlorides in swimming pools and in ancillary equipment are very well documented. When the concentration of these are reduced, we can anticipate delayed corrosion and an extended service life for the pool, the building and all technical details such as ducts, pipes and fixtures.

5.4 Blue light intensity

The results from measurement of the blue light in the pool hall with the blue light turned on and for comparison the light from the clear sky in the morning with the equipment sheltered from direct sunlight, are shown in Figure 11. The data are compensated with the risk factors given in the EU-directive about artificial optical radiation values [37]. The cumulative risk is the area under the curves. Blue light is a known risk factor for damage to the central part of the retina. It is therefore important that the eye is not exposed too strongly and that limit values [37] are followed. In this case intensity compensated for risk in the realm around 400 to 405 nm is higher

in the pool hall than outdoors. But the cumulative risk over a wider range is much lower in the pool hall than outdoors. The calculated values of UV-light and blue light as measured in the floor level are around $2,8\text{W/m}^2$. The need for protection for people when blue light lamps are turned on should not be questioned, but it is not obvious that the risk is very high. In an overview paper over standardised tests for evaluation of risks with lamps it is noted that the risk of damage because of visible light is quite small because people usually avoid looking into the lamps because of glare [45]. So, perhaps blue light could be used all day when experience about the risk has developed. More time with blue light turned on should give more disinfection.

6. CONCLUDING REMARKS

This is a case study where we evaluate these two methods as a unit. We believe the place for the test is a very normal aquatic center in Sweden. The hydraulics for water exchange are actually not very good, and the water treatment plant is normal for its time, but not better than so. The water in an indoor swimming pool is obliged to fulfil a number of indicators related to hygiene, stated by the Public Health Agency of Sweden [9]. In the evaluation of this concept where the AOT photocatalysis method was combined with illumination with blue light at 405 nm all these criteria were fulfilled. Most important, the criteria for bacteria in the water was fulfilled also when the free chlorine was as low as $0.4\text{ mg Cl}_2/\text{l}$ which is actually below the value stated by the Health Agency of Sweden [9] when water has a pH-value of 7.4. This means that in this case it is possible to reduce the chlorine content used for the hypochlorite process by combining photocatalysis and blue light. Chlorine is the main risk factor for corrosion in reinforced concrete in the pool and the building and also for technical details such as ducts, pipes and fixtures. So, this is a way to extend service life of the aquatic center. This reduction in chlorine content in the pool water also resulted in a decrease in concentration of trichloramine in the air. This is beneficial for the health both for the swimmers and for the personnel. In our literature research, we have not found any other similar approach to reduce chlorine addition in a swimming pool. We also see a good technical effect from supplementing the hypochlorite addition with these methods. We believe the result from this case study can be generalized and that the effect would be the same if this system was installed in other similar aquatic centers. A final notation is that Västertorpbadet aquatic center still, four years after the test period still operate with blue light and AOT, and keep free chlorine at $0.4\text{ mg Cl}_2/\text{l}$, which is appreciated by the swimmers.

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