2016 Annex to the Model Aquatic Health Code

Scientific Rationale

APPENDICES

CS267224A

8.0 Appendices

Appendix 1: Summary of Health and Exposure Data for Chemical and Biological Contaminants

TRICHLORAMINE threshold research reference synopses:

- TRICHLORAMINE has a pungent CHLORINE odor, is a strong irritant, and causes excessive tearing of the eyes.[530]
- Methods for sampling include[531]
  - INRS method *[INRS 2007]*,
  - NIOSH draft methods *[method not published]* using ion chromatography *(IC),* and
  - Inductively coupled plasma atomic emission spectroscopy *(ICP-AES)*.
- Based on concentration-response data in mice, the author recommends TLV for a short-term exposure limit *(TLV-STEL532)* of 1.5 mg/m^3 and an allowable time weighted average *(TLV-TWA533)* of 0.5 mg/m^3 for TRICHLORAMINE.[534]
- Health complaints from teenage swimmers and soccer players showed a significant increase in respiratory complaints at chloramine concentrations of 0.37 mg/m^3 or greater.[535]
- Symptoms, in a separate study, were not observed until the chloramine concentrations reached 0.5 mg/m^3, and everyone reported symptoms when the levels reached 0.7 mg/m^3.[536]
- In a study of 334 lifeguards and 63 indoor POOLS, the prevalence of mucous membrane irritation among lifeguards exposed to TRICHLORAMINE levels above 0.5

530 Barbee SJ, et al. Acute inhalation toxicology of nitrogen trichloride. Am Ind Hyg Assoc J. 1983;44(2):145-6.
531 Hery M, et al. Exposure to chloramines in the atmosphere of indoor swimming pools. Ann Occup Hyg 1995;39(4):427-439.
532 The short-term exposure limit or maximum concentration for a continuous exposure period of 15 minutes (with a maximum of four such periods per day, with at least 60 minutes between exposure periods, and provided that the daily TLV-TWA is not exceeded.)
533 The allowable time-weighted average concentration for a normal 8-hour workday or 40-hour week to which a person can be repeatedly exposed for 8 hours a day, day after day, without adverse effect.
534 Gagnaire F, et al. Comparison of the sensory irritation response in mice to chlorine and nitrogen trichloride. J Appl Toxicol. 1994;14(6):405-9.
535 Lévesque B, et al. The determinants of prevalence of health complaints among young competitive swimmers. Int Arch Occup Environ Health. 2006;80(1):32-9.
536 Hery M, et al. Exposure to chloramines in the atmosphere of indoor swimming pools. Ann Occup Hyg 1995;39(4):427-439.

mg/m^3 was 86% for eye irritation, 61% nose irritation, 29% throat irritation, and 42% dry cough.[537]

- Airborne TRICHLORAMINE was measured at six indoor swimming facilities and researchers found an elevated prevalence of respiratory symptoms in swimming POOL workers. Mean TRICHLORAMINE concentration of 0.56 mg/m^3, with the highest concentration reaching 1.34 mg/m^3. General respiratory symptoms were significantly higher in POOL employees compared to the Dutch population sample *(odds ratios ranged from 1.4 to 7.2)*.[538]
- Researchers generated TRICHLORAMINES at 0.5 mg/m^3 in a challenge chamber and exposed the participants to a series of 10-minute exposures followed by spirometry. Results showed a decrease in pulmonary function.[539]
- TRICHLORAMINE is the most volatile and prevalent chloramine compound in the air around swimming POOLS[540], has low solubility, and decomposes rapidly in sunlight.
- The World Health Organization proposes a 0.5 mg/m^3 provisional value although it states that more research is needed to investigate health effects in people who use the POOL for extended periods of time and the role of TRICHLORAMINE in possibly causing or exacerbating asthma.[541]
- Although proposed STANDARDS and past studies indicate that a comfort level for indoor POOL areas would be to keep TRICHLORAMINE concentrations below 0.5 mg/m^3, there have been some concerns that this level may not be low enough to prevent symptoms.[542]

THM threshold research reference synopses:

- Animal toxicity studies demonstrate and characterize hepatotoxicty and nephrotoxicity.[543]
- Investigation of THMs in tap water and swimming POOL water. The concentrations of total THMs in swimming POOL water was higher than those in tap water, particularly, brominated-THMs. This poses a possible cancer risk related to exposure.[544]
- Environmental and biological MONITORING of THMs was performed in order to assess the uptake of these substances after a defined period in five competitive

537 Massin N, et al. Respiratory symptoms and bronchial responsiveness in lifeguards exposed to nitrogen trichloride in indoor swimming pools. Occup Environ Med. 1998;55(4):258-63.
538 Jacobs JH, et al. Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers. Eur Respir J. 2007;29(4):690-8.
539 Thickett KM, et al. Occupational asthma caused by chloramines in indoor swimming-pool air. Eur Respir J. 2002;19(5):827-32.
540 Thickett KM, et al. Occupational asthma caused by chloramines in indoor swimming-pool air. Eur Respir J. 2002;19(5):827-32.
541 WHO. Guidelines for Safe Recreational Water Environments: Vol. 2- Swimming Pools and Similar Environments. 2006. WHO Press, Geneva, Switzerland. Available at http://www.who.int/water_sanitation_health/bathing/bathing2/en/. Accessed on April 24, 2016.
542 Massin N, et al. Respiratory symptoms and bronchial responsiveness in lifeguards exposed to nitrogen trichloride in indoor swimming pools. Occup Environ Med. 1998;55(4):258-63.
543 Lilly PD, et al. Trihalomethane comparative toxicity: acute renal and hepatic toxicity of chloroform and bromodichloromethane following aqueous gavage. Fundam Appl Toxicol. 1997;40(1):101-10.
544 Panyakapo M, et al. Cancer risk assessment from exposure to trihalomethanes in tap water and swimming pool water. J Environ Sci (China). 2008;20(3):372-8.

swimmers. Analyses were performed by gas chromatography. In relation to biological MONITORING, $CHCl_3$, $CHBrCl_2$ and $CHBr_2Cl$ were detected in all alveolar air samples collected inside the swimming POOL.[545]

- Methods for testing halogenated hydrocarbons: NIOSH method 1003 halogenated hydrocarbons: http://www.cdc.gov/niosh/docs/2003-154/pdfs/1003.pdf; experimental method for sampling THMs - Membrane introduction mass spectrometry[546]. *Standard Method* 6232 C Trihalomethanes and Chlorinated Organic Solvents (Purge & Trap/Gas Chromatographic/Mass Spectrometric Method) in water found at: http://www.standardmethods.org/store/ProductView.cfm?ProductID=161.

Biologicial contamination research reference synopses:

- *Mycobacterium avium* complex *(MAC)* is reduced with higher halogen presence and higher TURNOVER RATE in hot tubs.[547]
- Mycobacteria are prevalent in POOL water and in air. They tend to aerosolize more than other POOL water CONTAMINANTS.[548]
- *Legionella* presence increased in HOT WATER, in water with pH greater than 7.8 and CHLORINE less than 0.2 ppm.[549]
- *Legionella* was more prevalent in SHOWERS than POOLS[550]. Low temperatures in SHOWERS showed higher *Legionella* prevalence. Over 109°F *(43oC)* resulted in no *Legionella*.
- For Gram negative bacteria - endotoxin levels of 14,400 in hot tub were considered a contributing factor to acute illness of BATHERS in Wisconsin.[551]
- 45 - 400 EU *(endotoxin units)*/m^3 was associated with acute airflow obstruction, mucous membrane irritation, chest tightness, cough, shortness of breath, fever, and wheezing.[552, 553, 554, 555]

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545 Aggazzotti G, et al. Blood and breath analyses as biological indicators of exposure to trihalomethanes in indoor swimming pools. Sci Total Environ. 1998;217(1-2):155-63.
546 Li J, et al. Volatile disinfection byproduct formation resulting from chlorination of organic-nitrogen precursors in swimming pools. Environ Sci Technol. 2007;41(19):6732-9.
547 Glazer CS, et al. Nontuberculous mycobacteria in aerosol droplets and bulk water samples from therapy pools and hot tubs. J of Occup Environ Hyg. 2007;4(11):831-40.
548 Angenent LT, et al. Molecular identification of potential pathogens in water and air of a hospital therapy pool. PNAS 2005;102(13):4860-5.
549 Goutziana G, et al. Legionella species colonization of water distribution systems, pools and air conditioning systems in cruise ships and ferries. BMC Public Health. 2008;8:390.
550 Leoni E, et al. Prevalence of Legionella spp. in swimming pool environment. Water Res. 2001;35(15):3749-53.
551 Fields BS, et al. Pontiac fever due to Legionella micdadei from a whirlpool spa: possible role of bacterial endotoxin. J Infect Dis 2001:184(10):1289-92.
552 Castellan RM, et al. Inhaled endotoxin and decreased spirometric values. An exposure-response relation for cotton dust. N Engl J Med. 1987;317(10):605-10.
553 Smid T, et al. Dust- and endotoxin-related acute lung function changes and work-related symptoms in workers in the animal feed industry. Am J Ind Med. 1994;25(6):877-88.
554 Milton DK, et al. Worker exposure to endotoxin, phenolic compounds, and formaldehyde in a fiberglass insulation manufacturing plant. Am Ind Hyg Assoc J. 1996;57(10):889-96.
555 Milton DK, et al. Endotoxin exposure-response in a fiberglass manufacturing facility. Am J Ind Med. 1996;29(1):3-13.

- Chronic health effects associated with airborne endotoxin exposures include chronic bronchitis, bronchial hyper-reactivity, chronic airways obstruction, hypersensitivity pneumonitis, and emphysema.[556]
- “Lifeguard lung" has been associated with indoor swimming POOL use.[557]
- A permanent decrease in pulmonary function, along with respiratory symptoms, has been reported in epidemiological studies.[558]
- The *Limulus* amebocyte lysate *(LAL)* assay used to analyze for endotoxin LAL assay, is a comparative bioassay.[559] However, changes in the LAL test procedures themselves can erroneously appear as changes in the measured endotoxin activity levels. Until problems with the LAL test are resolved, endotoxin results cannot be compared to samples collected at different times or analyzed by different laboratories. For these reasons, the American Conference of Governmental Industrial Hygienists *(ACGIH)* has proposed that RLVs[560], rather than the more usual TLVs, be used as a reference for endotoxin.[561]

Appendix 2: Air Quality Formula

NOTE: INCLUDED FROM 2014 MAHC (1ST EDDTION)*Significant numbers of public comments were received regarding the proposed increase, above ASHRAE 62 STANDARDS of required outdoor air. The commenters noted that the requirements will result in increased costs for equipment and operation while lacking adequate data to support the increase. Based on the potential negative impact and the need for additional research and data to differentiate the causes and sources of indoor air quality problems on design criteria (e.g., design, inappropriate operation, inadequate maintenance), the MAHC Committee decided to defer to ASHRAE outdoor air requirements in this version of the MAHC. The Committee thought it important to preserve the work done by the Technical Committee, so the proposed CODE language for additional outdoor air has been moved to Appendix 2 in the MAHC along with preserving the corresponding annex discussion. A research agenda should be developed and should be a priority to better address the contributing*

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556 Castellan RM. Respiratory health effects of inhaled endotoxins: byssinosis and beyond. In: McDuffie H, Dosman J, Semchuk K, Olenchock S, eds. Agricultural Health and Safety - Workplace, Environment, Sustainability. Boca Raton, FL: CRC Press, 1995; 97–100.
557 Rose CS, et al. "Lifeguard lung": endemic granulomatous pneumonitis in an indoor swimming pool. Am J Public Health. 1998;88(12):1795-800.
558 Milton DK. Endotoxin and other bacterial cell-wall components. In: Macher J, ed. Bioaerosols: assessment and control. Cincinnati, OH: American Conference of Governmental Industrial Hygienists. 1999; 23–1 to 23–14.
559 Milton DK. Endotoxin and other bacterial cell-wall components. In: Macher J, ed. Bioaerosols: assessment and control. Cincinnati, OH: American Conference of Governmental Industrial Hygienists. 1999; 23–1 to 23–14.
560 Relative Limit Values require that samples be collected from an area considered to represent background levels of endotoxin and be analyzed at the same time as the samples from areas of interest. The RLV is a comparison between the environment in question and background levels. ACGIH states that if health effects are consistent with endotoxin exposure, and if the endotoxin exposures exceed 10 times the simultaneously determined background levels, then the RLV action level has been exceeded, and action should be taken to reduce exposure. The proposed maximum RLV rises to 30 times the background level in an environment where no symptoms are reported. When exposures exceed the RLV action level or maximum RLV, remedial actions to control endotoxin levels are recommended. It is important to note that the nature of the relationship between the RLV and health effects has not been elucidated at this time.
561 Milton DK. Endotoxin and other bacterial cell-wall components. In: Macher J, ed. Bioaerosols: assessment and control. Cincinnati, OH: American Conference of Governmental Industrial Hygienists. 1999; 23–1 to 23–14.

factors to indoor air quality problems and the appropriate design and operational requirements needed to address those factors.

INDOOR AQUATIC FACILITY AIR HANDLING SYSTEM should have a design capability to supply the minimum outdoor air requirements using MAHC Appendix 2 Table below in addition to ASHRAE 62.1:

$$R_{MAHC} = R_a + \frac{R_p}{\text{Density (ft}^2\text{ / person)}}$$

Appendix 2 Table: Factors for Calculating Outdoor Air Requirements for Indoor Aquatic Facilities

Factors	*Flat Water*	*Agitated Water*	*Hot Water*	*Deck*	*Stadium Seating*	*Modifier*
ASHRAE R_a	0.48	0.48	0.48	0.48	0.06	None
Additional CFM per person (R_p)	10.0	25.0	60.0	10.0	7.5	None
Average density in the pool (sq ft/person)	20.0	15.0	10.0	50.0	6.6	Based on designer / engineer rationale
cfm / person / ft^2	0.5	1.67	6.0	0.2	1.14	
R_{MAHC} (Total cfm / sq ft)	0.98	2.15	6.48	0.68	1.2	

R_a = ASHRAE 62.1 Equivalent *(cfm / square foot)*

R_p = Occupant driven cfm/person

R_{MAHC} is the number of cfm of outdoor air required for the area.

For Example:

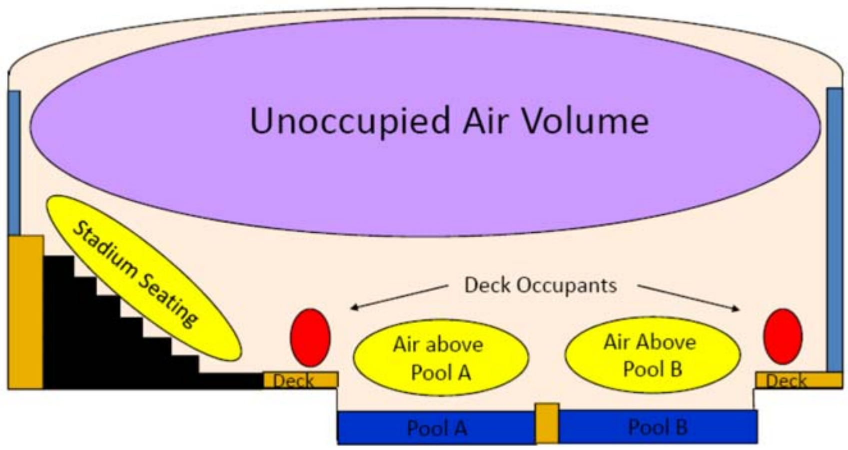
$$R_{MAHC} = R_a + \frac{R_p}{\text{Density (ft}^2\text{ / person)}}$$

R_{MAHC} (FLAT WATER)=.48 + $\frac{\text{10 cfm/person}}{}$ = .98 cfm/ft^2

20 ft^2/person

The additional cfm per person addresses the CONTAMINANTS contributed to the air from the individuals in the POOL. This number varies based on the release of CONTAMINANTS to the air, which is dependent upon the agitation of the POOL surface and the occupant density of the various locations within the INDOOR AQUATIC FACILITY as described below and the in Appendix Figure 1.

Appendix Figure 1: Side view of a typical indoor aquatic facility



- FLAT WATER – area of an AQUATIC VENUE in which the water line is static except for movement made by users. Diving spargers do not void the FLAT WATER definition.
- AGITATED WATER – area of an AQUATIC VENUE with mechanical means *(AQUATIC FEATURES)* to discharge, spray, or move the water's surface above and/or below the static water line of the AQUATIC VENUE. Where there is no static water line, movement shall be considered above the DECK plane.
- HOT WATER – area of an AQUATIC VENUE with a water temperature over 90 degrees Fahrenheit *(32°C)*.
- DECK – area of floor spaces at or near the same elevation as POOL surfaces often used for observation and access.
- STADIUM SEATING – area of high-occupancy seating provided above POOL level for observation. Generally bleacher style at a higher elevation than the POOL surfaces.

The Density factor in Appendix 2 Table could be modified if the designer/engineer of the INDOOR AQUATIC FACILITY can document the intended use is different *(i.e., a swimming POOL is a FLAT WATER venue and is normally 20 ft^2 (1.9 m^2) per person, but when designing a FLAT WATER WADING POOL, which has a higher density of BATHERS, the number could be modified to15 ft^2 (1.4 m^2) per person)*.

For INDOOR AQUATIC FACILITIES with more than one type of water or seating, the total outside air required is calculated by adding together the air required for each type.

The number of cfm of outdoor air for an INDOOR AQUATIC FACILITY shall be calculated with the following equation:

Area of FLAT WATER in ft^2 x FLAT WATER R_{MAHC}
+
Area of AGITATED WATER in ft^2 x AGITATED WATER R_{MAHC}
+
Area of HOT WATER in ft^2 x HOT WATER R_{MAHC}
+
Area of DECK in ft^2 x DECK R_{MAHC}
+
Area of STADIUM SEATING in ft^2 x STADIUM SEATING R_{MAHC}
=

Total cfm of required outdoor air for INDOOR AQUATIC FACILITY

Appendix 2 Table above was established to provide a guide for designers to achieve acceptable air quality while considering the main factors that affect air quality: Water treatment, THEORETICAL PEAK OCCUPANCY, and water surface area *(splashing, aeration)*.

The following outlines the discussion by the MAHC Committee. One of the goals was to establish a more comprehensive formula than is currently published in the ASHRAE 62 ventilation document *(e.g., adding additional air requirements to the minimum ASHRAE STANDARDS)*. The formula should include consideration for the type of feature as well as what type of water treatment is being utilized to maintain the water chemistry. The Committee realized early on that there is very little research in the off-gassing of chemicals for INDOOR AQUATIC FACILITIES. ASHRAE completed a preliminary research project[562] but did not perform detailed research on various AQUATIC VENUES and treatment methods. The Committee had to use the experience of its members on what was working in the real world and what was not working to modify the formula used in ASHRAE 62. In other words, the Committee had the final answer and developed a modified formula that yielded the desired results. This formula calculated the minimum air required in ASHRAE 62 and then added additional air TURNOVER requirements depending on the type and area of AQUATIC FEATURE or DECK/spectator area.

The matrix was set up with three types of AQUATIC VENUES: FLAT WATER, AGITATED WATER, and HOT WATER as each type of AQUATIC VENUE differs in how it affects air quality. One of the key drivers that the Committee identified that made these AQUATIC VENUES different was the expected THEORETICAL PEAK OCCUPANCY density. With increased BATHERS per unit volume of water, there is an increase in the organic contamination from the POOL users and thus the presence of combined CHLORINE or combined bromine. The second factor was how much surface area of the AQUATIC VENUE water would come in contact with the air to increase the expected off-gassing of chemicals.

562 Cavestri, RC, et al. Chemical off-gassing from indoor swimming pools [Internet]. Dublin (OH): American Society of Heating, Refrigerating, and Air Conditioning Engineers; 2008 Ju [cited 2011 Mar 3]. 40 p. Available from: http://rp.ashrae.biz/page/RP1083.pdf.

The rationale for developing guidance related to density and AQUATIC VENUE types is as follows:

1. FLAT WATER
   a. Contribute to poor air quality only when there are BATHERS splashing, releasing TRICHLORAMINE and other DBPs into the air.
   b. These AQUATIC VENUES generally are for swimming.
   c. The density was established at 20 ft^2 *(1.9 m^2)* per person. This represents an average horizontal swimmer occupying a 5 foot by 4 foot area.
   d. Assuming a person is swimming horizontally; a full body length is an average 5 feet *(152 cm)* with a 5 foot span to equal 25 ft^2 *(2.3 m^2)*. There was a need to account for higher density in shallow areas where users wade vertically versus swim horizontally. The middle ground was decided to be 20 ft^2 *(1.9 m^2)*.
2. AGITATED WATER
   a. These are AQUATIC VENUES with AQUATIC FEATURES that mechanically disturb the water surface such as spray features, WATERSLIDES, etc. They contribute to poor air quality any time those AQUATIC FEATURES are operating. This constant introduction of DBPs into the air requires more fresh air for these venues.
   b. These AQUATIC VENUES generally are for wading and enjoyment of features without swimming.
   c. The density was established at 15 ft^2 *(1.4 m^2)* per person. This represents an average vertical user occupying a 5 foot *(152 cm)* by 3 foot *(91 cm)* area. This also complies with the Illinois State Pool Code.
3. HOT WATER
   a. These AQUATIC VENUES require more chemicals and release more DBPs due to increased chemical demand, increased introduction of BATHER waste, and increased evaporation, which deposits more DBPs into the air per square foot than any other AQUATIC VENUE. This type of feature requires the most outside air.
   b. These AQUATIC VENUES generally are for lounging such as hot tubs, warming POOLS, etc.
   c. The density was established at 10 ft^2 *(0.93 m^2)* per person. This represents an average user sitting in a 3 foot *(91 cm)* by 3 foot area.
4. DECK and Spectator Areas
   a. For leisure POOLS, one can assume 50 ft^2 *(4.6 m^2)* per person based on Illinois Pool Code. Adding seating and tables, which separates groups, the square footage allows for less density.
   b. For spectator area, the Committee used 6.6 ft^2 *(0.61 m^2)* per person for STADIUM SEATING from the ASHRAE 62.1 Table. This seating is generally well above the water level.

Using the ASHRAE 62.1 definitions for outside air as a baseline, and utilizing the ASHRAE method to determine minimum outside air requirements, plus adding additional fresh air depending on feature type from Appendix 2 Table, the formula is:

Minimum outside air in cfm = (R_a X AQUATIC VENUE and DECK area in ft^2) + [AQUATIC VENUE A area in ft^2 X (R_p / Density factor)] + [AQUATIC VENUE B area in ft^2 X (R_p /Density)] + [DECK area in ft^2 X (R_p/Density factor)]+ (R_a X Spectator area in ft^2) + [Spectator area in ft^2 X (R_p / Density factor)]

- **R_a** = cfm of outside air needed for an aquatic space of any type without PATRONS. Using factor from ASHRAE 62.1 See Appendix 2 Table for R_a value.
- **R_p** = additional cfm needed per person occupying the AQUATIC VENUE above that calculated with R_a and ASHRAE 62.1. R_p value is based on type of AQUATIC VENUE for reasons stated above. See Appendix 2 Table for appropriate R_p value.
- **R_p** = additional cfm needed per person occupying DECK or spectator space above that calculated with R_a and ASHRAE 62.1. Occupant density differs based on DECK or spectator usage. See Appendix 2 Table for appropriate R_p value.

This calculation allows for calculating minimum outside air required for an AQUATIC FACILITY that has varying sizes and types of AQUATIC VENUES. Engineers can calculate for individual AQUATIC VENUES and DECK spaces and add them together for the entire facility.

Design professionals experience factored into the final cfm/ft^2. Design professionals knew from experience where the final number needed to be, added in reasonable density factors and then addressed the individual characteristics of the AQUATIC VENUES to include splashing at the surface and the temperature of the water.

To calculate the minimum cfm of fresh air required:

Minimum number of cfm of fresh air for AQUATIC FACILITY by type =

(R_a X AQUATIC VENUE and DECK area in ft^2) + (AQUATIC VENUE A area in ft^2 X (R_p / Density factor))+ (AQUATIC VENUE B area in ft^2 X (R_p /Density)) + *(DECK area in ft^2 X (R_p/Density factor))*+ *(R_a X Spectator area in ft^2) + (Spectator area in ft^2 X (R_p/Density factor))*

Example 1: Aquatic Facility with Flat Water Feature

Aquatic Venue	***Area (ft^2)***	***Fresh Air Required (cfm)***
Deck Minimum	30,000	14,400
Water=Flat	15,000	7,500
Water=Agitated	0	0
Water=Hot	0	0
Deck Area Only	15,000	3,000
	Feature Area Subtotal	24,900

Total cfm / ft^2 feature / deck area	**0.83**

Aquatic Venue	*Area (ft^2)*	*Fresh Air Required (cfm)*
Spectator Area minimum	6,500	390
Spectator additional	6,500	7,386
	Total cfm	32,676
Total cfm / ft^2 w/ spectator area		**0.90**

Example 2: Aquatic Facility with Agitated and Hot Water Venues

Aquatic Venue	*Area (ft^2)*	*Fresh Air Required (cfm)*
Deck Area	60,000	28,800
Water=Flat	0	0
Water=Agitated	25,000	41,667
Water=Hot	2,000	12,000
Deck Area Only	33,000	6,600
	Feature Area Subtotal	89,067
Total cfm / ft^2 feature / deck area		**1.48**

Aquatic Venue	*Area (ft^2)*	*Fresh Air Required (cfm)*
Spectator area minimum	2,500	150
Spectator area additional	2,500	2,841

	Total cfm	92,058
Total cfm / ft² w/ spectator area		**1.47**

Appendix 3: Dye Test Procedure

Dye testing should be performed to determine and adjust the performance of the RECIRCULATION SYSTEM. Dye studies tend to be qualitative in nature.[563]

Some judgment is generally required to determine whether a dye study should be classified as passing or a failing. In general, dead zones *(or areas of poor circulation)* would indicate a failure that could be fixed by adjusting the INLETS or other system hydraulics. If the POOL does not reach a uniform color within 15 minutes, then adjustments are required.

Materials

- Crystal violet *($C_{25}N_3H_{30}Cl$)(20 g/ 50,000 gal)*
- Sodium thiosulfate penta-hydrate *($Na_2S_2O_3 \cdot 5H_20$) (1.2 oz/ 1 ppm free chlorine/ 10,000 gal)*
- Sodium hypochlorite *(Bleach 5.7% AVAILABLE CHLORINE) (6.64 L/ 50,000 gal)*
- Two containers *(20 L or 5 gal)*
- Video camera
- Photo camera *(optional)*
- Tripod
- CHLORINE detection kit
- Pump *(capable of 700 mL/min or 0.18 gpm)*
- Tubing *(~6.4 mm or 1/4 inch ID)*
- Tubing clamps
- Fittings, adapters, and Teflon tape *(for threaded connections)*
- Scale
- Gloves
- Timer

Procedure

1. Use a scale to weigh out the correct amount of crystal violet needed. Be sure to wear proper SAFETY equipment when handling any chemicals.
2. Make the stock crystal violet solution by mixing the crystal violet and three gallons of non-chlorinated water in a container.
3. If you do not plan to use the POOLS existing DISINFECTION system during the dye removal process, then it will be necessary to prepare a sodium hypochlorite solution. To do this follow the recommended dose of 6.64 liters of bleach *(5.7%*

563 Alberta. Pool Standards, 2006 for the Swimming Pool, Wading pool, and Water Spray Park Regulation. (Last accessed July 6, 2016).http://www.health.alberta.ca/documents/Standards-Pools.pdf.

AVAILABLE CHLORINE) per 50,000 gallons of POOL water. Place the correct amount into a separate container.

4. Two days prior to the dye study, cut off the POOL's DISINFECTION system, and then measure the CHLORINE concentration of the POOL. On the same day as the DISINFECTION system is turned off, weigh out enough sodium thiosulfate penta-hydrate to neutralize the CHLORINE that is present and dump it around the perimeter of the POOL. It is necessary to neutralize the CHLORINE because it will react with the dye. Come back the following day to make sure there is no CHLORINE, and likewise on the day of the dye study.
5. Prepare the pump by attaching the tubing to the existing piping and calibrate the flow rate to 700 mL/min. At this flow rate, the stock solution of dye will be injected into the POOL over a 16 minute period. Tube clamps may be used to secure the connection between the tubing and the connectors.
6. Prepare the filter room by laying down a trash bag *(or similar item)* as protection from a potential chemical spill/leak. Then place the pump and containers containing the dye stock solution and sodium hypochlorite solution on the plastic cover.
7. Prepare a location in the pipe network *(preferably after the filter)* to inject the chemicals. If a location does not already exist *(e.g., an existing CHLORINE feed or acid feed point)* then one will need to be made by tapping the pipe and inserting the proper fitting.
8. Attach the tubing from the pump to the existing or newly created injection point. Depending on what fitting is present you might need an adapter for the tubing. The other end of the tubing should be placed in the chemical container holding the dye.
9. Make sure all assistants are in place to record video, take pictures, collect data, and time injection to 15 minute pass/fail observation point.
10. When ready to start, turn on the pump. The dye should begin to flow into the POOL. Start the timer at the same time as the pump is turned on *(pump on, time (t) = 0 min)*. The stock dye solution should be depleted in 16 minutes. After 16 minutes, turn the pump off so that air will not be introduced into the system.
11. Record the time when the dye is first observed coming into the POOL.
12. Record the time when the POOL water is completely dyed *(having uniform color)*.
    a. *Most POOLS should be uniformly dyed within 15-20 minutes (and generally no more than 30 minutes) when the RECIRCULATION SYSTEM is hydraulically balanced.*
13. Record any observations or patterns, including dead spots and/or short circuiting, and the corresponding times that they were noticed throughout the test.
    a. *Adjustments should be made to the RECIRCULATION SYSTEM to correct for any problems observed. Adjustments could include the following:*
        i. *the direction of INLETS (up and down as well as left and right),*
        ii. *the velocity of water through the INLETS (when adjustable by INLET modification or TURNOVER time adjustment), and*
        iii. *the proportion of water from the surface overflow and main drain components of the RECIRCULATION SYSTEM.*
14. Remove the dye by re-chlorinating the POOL. Switch the tubing from the container of dye to the one containing the sodium hypochlorite and turn the pump back on. Another option would be to restart the POOL's current DISINFECTION system.

15. Observe and record what you see as the dye is removed from the POOL through chlorination.