cally polluted water.

The operational bathing water forecast systems are currently used on a daily basis as decision support for bathing water managers to secure and minimize the risk of bathers becoming ill by avoiding contact with polluted waters and at the same time maximizing the recreational use of the bathing water whenever possible – the most frequent situation.

We are presently developing a system that couples the dynamic model approach from the bathing water system with Qualitative Microbial Risk Assessment (QMRA), in order to predict the risk of becoming ill through contact with faecally contaminated water. We foresee that this tool will be able to be used worldwide to estimate the burden of disease at a local scale and to estimate the effects of interventions on public health.

References

EPI-news (2010). Outbreak after triathlon. EPI News 42-43/10. http://www.ssi.dk/English/News/EPI-NEWS/2010/No%2042-43%20-%202010.aspx

Erichsen, A.C. and Rasch, P.S. (2001). Two and Three-dimensional Model System Predicting the Water Quality of Tomorrow. In: Proc. of the Seventh International Conference on Estuarine and Coastal Modelling. Eds. Spaulding, M.L., American Society of Civil Engineers.

Erichsen, A.C., Nielsen, J.B., Dahl-Madsen, K.I. (2003). Bathing Water Forecast covering for Copenhagen Harbour. Water 21, International Water Association (IWA), August 2003.

Erichsen, A.C. & Kaas, H. (2007). Modelling Noxious Micro-Organisms. In: Proceedings of the SHF Colloquium "Qualité des eaux marines". Paris, January 2007 (Published in issue 5/2007 of La Houille Blanche (in French)

Kaas, H., Erichsen, A., Kronborg, M. and Roberts, C. (2011). Early warning of bathing water quality – an operational water forecast service. In prep.

Lepesteur, M., McComb, A.J., and Moore, S.A. (2006). Do we all face the same risk when bathing in the estuary? Wat. Res. 40:2787 – 2795

Pond, K. (2005). Water Recreation and Disease. Plausibility of Associated Infections: Acute Effects, Sequelae and Mortality. World Health Organization. IWA Publishing, London, UK. ISBN 1843390663.

Prüss, A. (1998). Review of epidemiological studies on health effects from exposure to recreational water. Int. J. of Epidemiol. 27:1-9.

van Asperen, I.A., Medema, G., Borgdorff, M.W., Sprenger, M.JW. and Havelaar, A.H. (1998). Risk of gastroenteritis among triathletes in relation to faecal pollution of fresh waters. Int. J. of Epidemiol. 27:309-315.

Anders Chr. Erichsen

DHI Water, Environment & Health
Hørsholm, Denmark
aer@dhigroup.com

Hanne Kaas

DHI Water, Environment & Health
Hørsholm, Denmark
hka@dhigroup.com

Claus Jørgensen

DHI Water, Environment & Health
Hørsholm, Denmark
clj@dhigroup.com

Quality control of water and air in swimming pools

Abstract

The water and air treatment circuits in public swimming pools are controlled by the technical staff, automatic systems and by official or accredited laboratories. The controls are based on appropriate legislation and make use of the specialized experience and accumulated knowledge of several entities.

This paper presents a summary of the principles considered fundamental for the previously referred to contributions for the adequate control of swimming pools. The implementation of automatic control systems replacing manual monitoring is an interesting option, with economic benefits for operational costs.

The analytical control programme proposed in this work, or any other that may serve the same purpose, should be followed by all public swimming pools. This is essential to provide a high quality public service and also to ensure healthy competition among the providers of such services.

Key words – swimming pool, automatic control, water quality, air quality

Introduction

In every public swimming pool it is necessary to guarantee public health through the correct operation of water and air treatment systems. The adequate control of operational variables such as pH, disinfecting agent concentration in pool water, temperature, air humidity and the concentrations of the by-products of disinfection in water and air must also ensure the optimal operation of equipment, the required quality in water and air and minimization of operational costs.

Standard controls in swimming pools may include:
- Manual (immediate) controls performed by operators
- Automatic (inline) controls
- Analytical controls performed by external entities

Each type of control is important and none is dispensable. External entities verify if the swimming pool is being correctly controlled and if the legal requirements as well as the rules established by the Health Authority are being observed. Automatic controls ensure that the operational variables are within established ranges, ensuring optimal operational costs. Finally, the operator verifies whether automatic controls are operating correctly and if necessary may adjust their parameters. It is also the operator's responsibility to ensure the good operational condition of all the equipment.

A good control system implies:
- Good quality instrumentation and equipment;
- Adequate maintenance and calibration;
- Qualified staff.

The immediate control

The water and air treatment systems of a swimming pool require the supervision of one or more operators. However, with the technological means now available, supervision is not needed on a full-time basis in each swimming pool and one operator may easily supervize more than one swimming pool and rotate between the different installations.

In a public swimming pool the operator is responsible for maintaining a safe and pleasant environment for all users. The control of all equipment monitoring operating conditions is of the utmost importance and the operator is also responsible for the quality of the water and air, regardless of automatic controls that may also be available.

The operator's tasks start half an hour before the opening of the swimming pool and he must measure and register the values of the following parameters:

a) water: temperature, pH, free chlorine, total chlorine and turbidity
b) air: dry and wet bulb temperatures, that lead to the humidity value

Figure 1: Swimmingpool, "Piscina de cartes" Porto, Portugal, Photo: Porto Lazer, EEM

The control of these parameters must continue during the working period and must be repeated at least every four hours. All values must be registered and posted in a position visible to bathers.

The prompt measuring of water quality parameters may be performed with kits supplied by specialized companies. These give reliable and immediate results as long as their instructions are followed. In Table 1 a set of water quality parameters is presented, as well as their recommended limits.

Parameter	Units	Limit	Obs.
Free chlorine	mg/L Cl_2	0.50 to 1.2	6.9 ≤ pH ≤ 7.4
		1.0 to 2.0	7.5 ≤ pH ≤ 8.0
Total chlorine	mg/L Cl_2	Must not exceed in more than 0,50 mg /L Cl_2 of the free chlorine value	-
Bromine (b)	mg/L Br_2	2.0 to 4.0	-
Isocyanuric acid (b)	mg/L $H_3C_3N_3O_3$	≤75	-
Ozone (b)	mg/L O_3	≤0.01	
Turbidity	NTU	≤4	(a)
Temperature	°C	≤30	-

(a) The operator may use one of the following alternative methods: 1 – To see clearly the marking lines on the bottom of the pool; 2 – To see clearly a black disk (Secchi disk) with 155 mm diameter placed in the deepest part of the pool with a minimum horizontal distance of 10 m.
(b) Test only in cases where a product that contains it is in use.

Table 1: Water quality parameters and corresponding limits for the prompt control of water treatment systems according to the requirements of the Portuguese Health Authority (DGS – 2009)

Automatic control

Nowadays the automatic control of water and air treatment systems in swimming pools is very simple. The inline measurement of operational variables, and the registration and use of control units involves a small investment when compared with the total cost of building a swimming pool complex.

For air treatment there are four compulsory rules:

1) to renew a certain amount of the swimming pool air;
2) to limit the air velocity in the swimming pool space;
3) to guarantee an established temperature value;
4) to keep the humidity values between 55 % and 75 %.

The first two rules involve the measurement of flow rates and the establishment of a correct opening position for the related valves. The last two may be satisfied by two control systems: temperature and humidity. The flow chart in Figure 2 shows schematically an air treatment system, including the measurement points.

The humidity of the swimming pool atmosphere must be measured by means of two psycrometers placed on two walls that are distant from each other and far from the air entries and exits. The psycrometers should be placed at 1.5 m above floor level so that the operator may read the values easily. Temperature and humidity sensors must be installed inside the air piping, with signal outputs between 4 and 20 mA, compatible with the corresponding recording and control systems. The humidity value of the incoming piped air determines the operation of the heat pump. The temperature signal is used by the air heating system to make the required adjustments.

The pool water treatment may also be undertaken with only a minimum contribution by the operator. The circulating water pumps operate continuously and do not require close supervision. The management of water pumps, water heating and filter washing may be done automatically. The automatic control of pH and disinfectant concentrations is also easily applied to these installations. Figure 3 shows the flowchart of the swimming pool water treatment system and indicates the measuring points for important parameters, as well as the most important measurements to be made.

Chlorine inline measurement is normally done by amperometric sensors that quantify the electric current induced by the reduction reaction of hypochlorous acid. Knowing the pH value, the free chlorine may be determined using the equilibrium constant of the acid hydrolysis. The current produced is proportional to the hypochlorous acid concentration and the signal is sent to the controller and to the registering system. The controller uses this signal to operate a dosing pump for which the flow rate is variable and depends on the difference between the established and the measured value of free chlorine.

The inline pH meter is similar to those used in a laboratory. The value may be displayed or registered and if required it may be forwarded to a pH controller. In a swimming pool the pH variation often has only a tendency to increase or decrease Therefore, only one dosing pump will be necessary with a constant flow rate. Let us consider that in a certain swimming pool, the tendency is that pH rises. If the pH set point range is settled between 7.2 and 7.6, the acidic solution pump will start working if the pH exceeds 7.6 and will stop when the value gets to 7.2.

The water temperature in the swimming pool is the variable that causes the highest number of complaints from bathers. This means that the control and management of this variable is of the utmost importance. The temperature control systems must be reliable and have fast responses to the usual unwanted variations. The management of the swimming pool is directly concerned with this problematic. The makeup water that replaces rejected water causes lowering of the swimming pool water temperature. If the

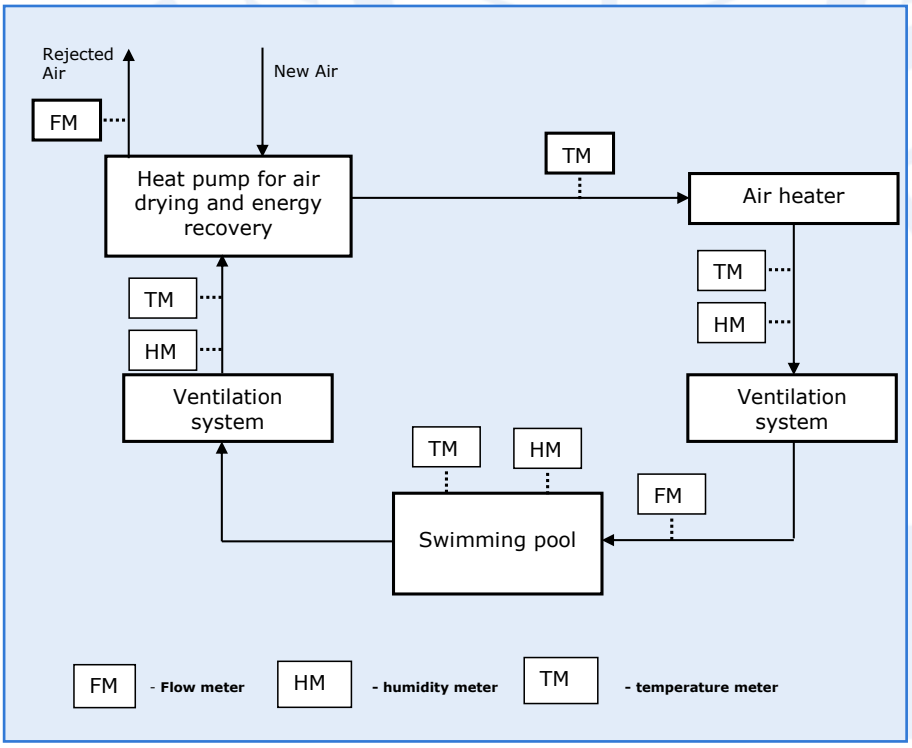

Figure 2: Flow chart of the air treatment system in a swimming pool

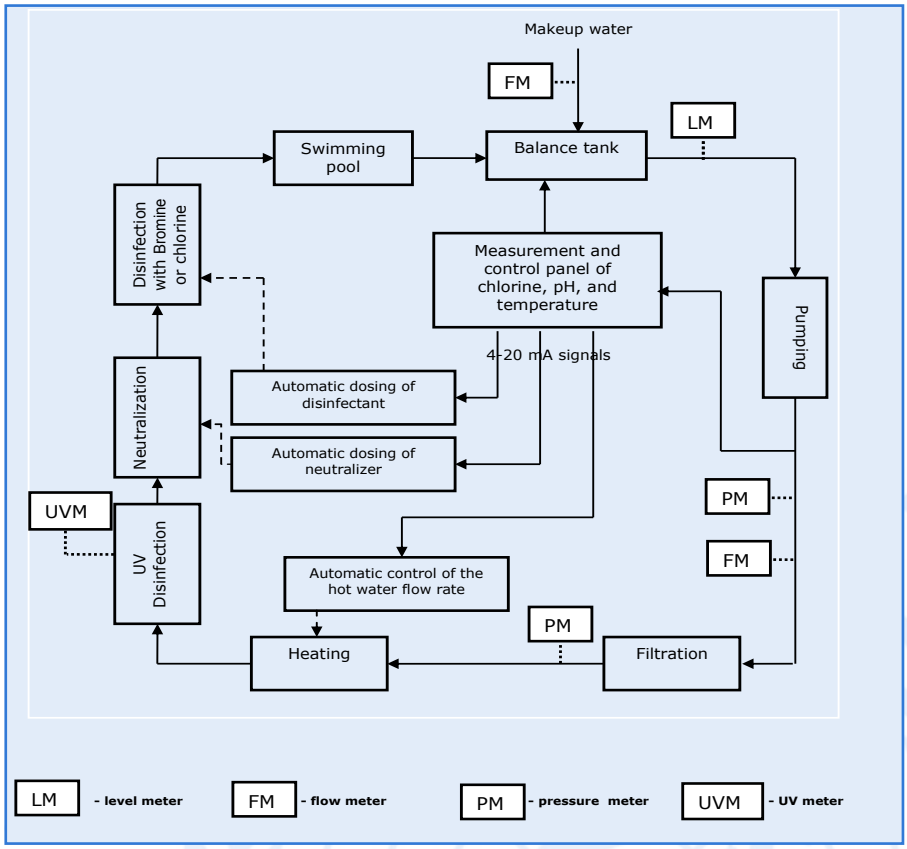

Figure 3: Flow chart of the water treatment system in a swimming pool

water heating system is not able to cope with sensible changes in water temperature, the schedule for filter washing should be programmed for a period while the swimming pool is not being used.

The variables already referred to are the most important for the automatic operation of the installation. However it is advisable to register other variables such as makeup and circulating water flow rates, pressures and ultra-violet radiation intensity (when applicable).

Control by external entities

Public swimming pools must have an external control programme performed by health authorities and by independent and reliable entities. In Portugal, health authorities periodically examine fractions of all public swimming pools. It is highly advisable that this type of control is done in all swimming pools to ensure healthy competition among them.

Portuguese law indicates that physical, chemical and bacteriological analyses must be undertaken twice a month, with no less than 10 days between analysis, by official or accredited laboratories. The reports produced must include a comment and the classification of the swimming pool water.

Parameter	Recommended value	Limit value	Periodicity
Heterotrophic plate count at 37 ºC (CFU/mL)	100 (a)	-	Each 15 days
Coliform bacteria (CFU/100 mL)	0	10	
Escherichia coli (CFU/100 mL)	-	0	
Enterococcus (CFU/100 mL)	-	0	
Pseudomonas aeruginosa (CFU/100 mL)	-	0	
Coagulase-positive *Staphylococcus* (CFU/100 mL)		0 (b)	
Staphylococcus spec. (CFU/100 mL)	≤ 20 (a)	-	
Legionella (CFU/L) (only in hydrotherapy tanks) (c)	-	*L. spp*: 10^3 *L. pneumophila*: 0	quarterly

(a) the recommended value may be exceeded once each season or calendar year
(b) 0 / 100 mL in 90% of samples. This analysis is the Public Health Unit responsibility (at the end of the season or the calendar year)
(c) if the results are systematically negative for Legionella for 6 months and if a control programme for Legionella is undertaken effectively, the Health Delegate may suspend the analysis

Table 2: Microbiological control parameters and corresponding periodicity according to the Portuguese Health Authority (DGS – 2009)

Parameters	Guideline values	Periodicity
Combined chlorine (mg/L Cl_2)	≤ 0.50	Monthly
Free chlorine (mg/L Cl_2)	0.50 – 1.2 (6.9≤pH≤7.4) 1.0 – 2.0 (7.5≤pH≤8.0)	
Cyanuric acid (mg/L $C_3H_3N_3O_3$) [(a)]	≤75	
Total bromine (mg/L Br_2) [(b)]	2.0 – 4.0	
Copper (mg/L Cu) [(c)]	2	
Turbidity (NTU)	0.5 – 4.0	
pH (Sörensen scale, 25ºC)	6.9 – 8.0	
Conductivity (µS/cm 20ºC)	1500	
Chlorides (mg/L Cl)	500	
Oxidability or TOC (mg/L O_2 or mg/L C)	6	
Temperature (indoor pools) (ºC)	≤ 30	
Total Trihalomethanes (indoor swimming pools) (µg/L)	100	

(a) Analyse only if the water disinfecting agent is a chlorine stabilized product
(b) Analyse only if the water disinfecting agent is bromine
(c) Analyse only if copper is used in the water disinfection

Table 3: Physical and chemical control parameters for water and their corresponding periodicity according to the Portuguese Health Authority (DGS – 2009)

The same question often arises: which parameters must be controlled?

The answer is obvious:

a) parameters that are influenced by the treatment processes, such as the disinfecting agent residual, pH and temperature;
b) parameters that may reveal the contamination of the water by nitrogen and other organic compounds;
c) parameters that may affect public health.

The simplest solution, but not necessarily the best one, is to follow strictly the official requirements now in use that are presented in Tables 2 and 3. In our opinion the makeup water should also be analysed simultaneously.

The analysis reports previously referred to must be posted in a location where they are visible to all users.

Air quality control

The air quality control in swimming pools has not received appropriate attention in the past. Temperature and humidity have been the only two parameters controlled and even these have not always been well-controlled. The well-being and health of the public also depend on other variables, such as chlorine and the concentration of disinfection by-products.

For indoor swimming pools, French Health Authorities suggest the limit for trichloramine in the air as being 0,5 g/m^3.

Portuguese law (Decreto-Lei nº 290/2001, partial altered by the Decreto-Lei nº 305/2007) limits the chloroform concentration for professional exposure to 10 mg/m^3 (weighted average over 8-hours). This value is hardly ever attained in the atmosphere in indoor swimming pools. OSHA (Occupational Safety and Health Administration – USA) stipulates the exposure limit for chlorine as 3 mg/m^3 and NIOSH (National Institute for Occupational Safety and Health – USA) established 1,5 mg/m^3 as the exposure limit for an 8-hour period. For ozone, OSHA fixed 0,2 mg/m^3 as the limit for the weighted-average concentration for an 8-hour exposure.

In the Portuguese law (Decreto Lei nº 79/2006) on indoor air quality requirements for service buildings, the air of indoor swimming pools, which are also included in that group, must be within the maximum reference concentrations presented in Table 4 for physical and chemical parameters. Air volume refers to temperature and pressure values of 293.15 K and 101.3 kPa respectively.

According to the same law, swimming pools must be audited every two years to verify the air quality parameters and also evaluate the hygiene conditions of the air treatment systems, including piping and filters.

Following on from Table 4, Table 5 presents proposed limits to extend air quality controls in indoor swimming pools. The proposed periodicity for those analyses is once every three months, simultaneously with a water control campaign performed by an external laboratory.

Figure 4: Analysis of a swimming pool
Photo: isep

Parameter	Unit	Maximum reference concentration
Suspended particles (PM_{10})	mg/m^3	0,15
Carbon dioxide	mg/m^3	1800
Carbon monoxide	mg/m^3	12,5
Ozone	mg/m^3	0,2
Formaldehyde	mg/m^3	0,1
Total volatile organic compounds	mg/m^3	0,6

Table 4: Physical and chemical indoor air quality requirements according to Portuguese law (Decreto-Lei nº 79/2006)

Parameter	Unit	Maximum reference concentration
Chlorine	mg/m^3	1,5
Chloroform	mg/m^3	2
Carbon dioxide	mg/m^3	1800
Ozone	mg/m^3	0,2
Trichloramine	mg/m^3	0,5
Relative humidity	%	55 to 75
Dry bulb temperature	ºC	1 ºC above the water temperature of the pool with lower temperature and with a maximum of 30ºC
Wet bulb temperature	ºC	>23

Table 5: Physical and chemical air quality requirements proposal for indoor swimming pools

Conclusions

Public swimming pools must have control procedures for water and air quality. The greater availability of technical means enables managers to make important savings in operational costs and contributes to the health protection and well-being of users.

The automatic systems simplify the control of the more important variables in the air and water treatment systems. However, they do not replace either the immediate controls to be performed by a qualified operator or the external controls undertaken by official or accredited laboratories. The customers must have easy access to the values obtained by the operator and the reports of external laboratories.

In the public interest, competent authorities must publish legal regulations for swimming pools or extend them to the existing regulation for aquatic parks. This will be an important contribution to health protection and will encourage healthy competition among the owners of public swimming pools.

References

Beleza, V. M., Santos, R., Pinto, M., 2007, Piscinas - Tratamento de Águas e Utilização de Energia, Edições Politema, Porto.

Decreto-Lei nº 305/2007, de 24 de Agosto, Diário da República, I Série, 163: 5728-5731, Lisboa.

Decreto-Lei nº 290/2001, de 16 de Novembro, Diário da República, I Série 266: 7330-7336, Lisboa.

Decreto-Lei nº 79/2006, de 4 de Abril, Diário da República, I Série-A, 67: 2416-2468, Lisboa.

DGS (2009), Circular Normativa 14/DA, Direcção Geral de Saúde, 21 de Agosto.

WHO (2006). Guidelines for Safe Recreational Water Environments, Volume 2 – Swimming Pools and Similar Environments", World Health Organization, Geneva.

Vitorino Beleza

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Isabel Pereira

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Margarida Ribeiro

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Teresa Esteves

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Marta Pinto

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Rosária Santos

Instituto Superior de Engenharia do Porto
Fundação Instituto Politécnico do Porto

Visit: http://www.isep.ipp.pt/