THE EFFECTS OF USER GROUPS AND REST PERIODS ON SWIMMING POOL WATER QUALITY

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ABSTRACT
A study into the effects of different bather types on the water quality at a multi-use swimming pool facility was undertaken. The aim of the work was to assess whether activity type should be considered when deciding on the pool schedule and operational parameters. Samples were taken before and after ten different activities ranging from lane swimming to aqua fitness classes. The samples were analysed for free and combined chlorine using a photometric water testing unit. In addition real-time logging of pH, free chlorine, temperature and conductivity was undertaken at the sampling locations using submersible amperometric sondes. Bather count and pre-swim habits were also recorded together with any pool configuration changes. Large discrepancies in the proportion of bathers using the shower prior to entry were observed between activity types. Free chlorine concentrations appeared to increase during the busy parts of the day. This is potentially due to the automatic controller overcompensating for the reduced levels in the pool outflow. The constant addition of pool chemicals is likely to be the cause for the steady increase in conductivity that was observed. No significant variation in pH was observed and the type of activity did not affect the rate of temperature loss. Potential issues relating to floor repositioning were observed and support the need for further research into the effects of internal structures on the water circulation. The most significant observations were in the variation in combined chlorine. Chloramine concentrations were observed to be strongly associated with bather load. Elite swimming, aqua fitness classes and water polo were found to have disproportionate effects on the chloramine levels. Rest periods were observed to be effective at allowing water quality to recover. The data suggests that activity type should be a factor in specifying pool operating parameters and the activity schedules.

Keywords Bather Load, Chloramine, Rest Periods, User Type, Water Quality

BACKGROUND
Swimming is an extremely popular form of physical exercise in the UK. There are about 350 million visits to UK public swimming pools each year (National Statistics, 2004). Recent success and publicity of UK athletes in international competitions has significantly raised the profile of the sport and, together with the increased availability of swimming pools in the UK, has helped to increase participation.

This increase in bather numbers makes it even more important that pool designers and operators have in place soundly based arrangements for mitigating the potential risks inherent in various aspects of pool design and use. At present there are a wide range of guidance documents and design standards published in the UK relating to the safe design of swimming pools (BSI, 2008a; BSI, 2008b; HSE, 2007; PWTAG, 2009; Sport England, 2008; WHO, 2006). The focus of these documents is the safe management of visitor and staff movements around poolside. The driver for the generation of these standards has been the increased health and safety culture present in the UK and the associated increased risk of litigation.

The emphasis has therefore been placed on the prevention of physical injuries. There are currently no regulations for water quality in the leisure industry, however, generic guidance has been published. The PWTAG publication, Swimming Pool Water: Treatment and Quality Standards for Pools and Spas, is widely used as the benchmark for swimming pools in the UK and forms the basis for pool operator training programs (ISRM, 2010). Many of the recommended operating parameters and water quality ranges have been suggested based on reviews of historical incidents and observations.

Nowadays pools come in all shapes and sizes. The designs are far more complex than the rectangular tank on which all the traditional science of pool design and operation has been based. The demand for flexible, multi-configuration pool facilities has increased as operators aim to increase their revenue by offering a widening range of water based activities. The introduction of moveable floors and booms to alter the length and depth of pools invariably raises questions regarding the effect of water flow around these structures. There is very limited advice currently published relating to the operation of pools in different configurations or for different pool activities and the advice that is available has generally been based on perceived user preferences.

In order for better guidance to be developed and the requirement of regulatory controls to be assessed, it is necessary to obtain an in-depth understanding of pool water behaviour. A series of analytical and theoretical research projects are currently being undertaken at the University of Surrey to increase our knowledge. The first of these projects is intended to evaluate the effects different activities have on the pool water quality – the results of which are presented in this paper.

THE RESEARCH CENTRE

The user group evaluation was undertaken at the Surrey Sports Park facility at the University of Surrey, UK. Surrey Sports Park was opened in 2010 and is one of Europe's premiere sites for elite sport, physical activity, well-being and leisure providing a venue for all types of users from world class athletes to grassroots beginners. The Surrey Sports Park incorporates an indoor 50m 8-lane deck level swimming pool with the ability to adopt multiple configurations, see Figure 1.

Figure 1 Surrey Sports Park Facility

The pool has a traversable boom and a moveable floor. The boom travels horizontally and can lock into three positions creating a 1 x 50m pool, 2 x 25m pools or a 33m and 17m pool. The moveable floor measures 13m x 20m and can be set at any depth from 0 to 2m. This enables the pool to accommodate as wide a programme of use as possible. The main pool is 50m long and 20m wide with a total capacity of 2,000 m^3. The water treatment plant consists of a coarse strainer, medium rate sand filters and a medium-pressure UV unit. The pool operates on a 3.7 hour turnover during opening hours. Sodium hypochlorite is added to the water through an automatic dosing system to maintain a free chlorine residual of 1 ppm.

In addition, hydrochloric acid is used for pH amendment and poly-aluminium chloride is used as a coagulant. The pool temperature is automatically controlled at 28°C.

The variety of water-based activities that take place at Surrey Sports Park makes it an ideal venue to assess the impacts of different user groups on water quality. These activities range from learn-to-swim and aqua aerobics classes to elite swimming and water polo training sessions.

Access to both the pool tank and the associated treatment plant was possible at all times allowing unrestricted sample collection.

METHODOLOGY

The purpose of this study was to assess whether the various water-based activities that take place at the Surrey Sports Park have different effects on the pool water quality. Fourteen different activities take place in a typical week. Of these activities, four were not assessed due to either very low expected bather loads (< 5 people in the pool) or equipment availability issues. The activities that were examined are listed in Table 1 together with their durations. In addition to the various activities it was considered that the periods when sections of the pool were closed should also be examined to establish the effects of rest periods. The canoe club session on the 16th November 2010 was used to trial the set-up of the equipment as preparation for the main study on 18th November 2010.

Table 1 List of Activities Studied

Day of Assessment	Activity	Duration
Tuesday	Canoe Club	1.5 hours
Thursday	50m Lane Swimming – Public	4 hours
	50m Lane Swimming – Elite	2 hours
	25m Lane Swimming - Public	8.5 hours
	25m Lane Swimming – Elite	2 hours
	Aqua Fitness – Zumba	0.75 hour
	Aqua Fitness – Power Workout	0.75 hour
	School Swimming	0.5 hour
	Learn to Swim	2.5 hours
	Water polo	1.5 hours
	Rest Period	2 hours

Current guidance advises operators to monitor the pH, total dissolved solids (TDS), free chlorine and combined chlorine levels in the pool on a regular basis to ensure that there are adequate disinfecting properties. (PWTAG 2009) It is suggested that an increase in bather load will increase the concentration of contaminants in the water. This higher contaminant loading will reduce the free chlorine available for disinfection. The initial phase of the research consisted of monitoring these parameters before, during and after each of the activities. This was undertaken using a combination of photometric testing of grab samples and in-situ amperometric measurements.

The study was conducted on a day when the majority of pool activities took place. The pool configuration is altered during the day to enable multiple activities to be offered. This includes moving the boom from 50m to 25m as well as raising the floor from 2m to 0.5m. The water quality was therefore monitored at two different locations. The sampling locations were located on the side of the pool 15m from either end of the pool (See Figure 2). Both locations were checked to make sure that they were not near any inlets or outlets. Table 2 shows the pool schedule for the day of the study and indicates which sample location is most appropriate for each activity.

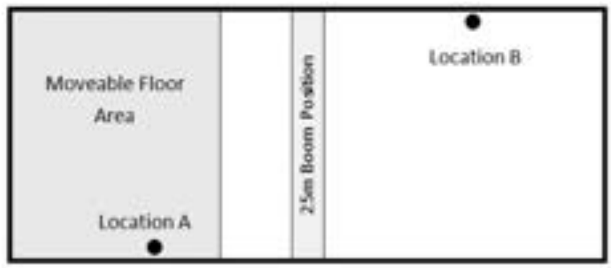

Figure 2 Sample Locations

Table 2 Pool Schedule – 18th November 2010

Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00
Sonde A	GCSC 50m		Closed		Boom Move / Aqua	Closed		School	Closed
Sonde B	Public 50m				Boom Move / Public 25m				
Time	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Sonde A	Closed / Learn to Swim			Aqua	GCSC 25m		Public 25m	Closed	
Sonde B	Public 25m				GCSC 25m		Water Polo	Closed	

In order to allow comparison of the effects on water quality between different activities, samples were taken before and after each activity. In addition to the grab samples, in-situ measurements were taken at both locations in 60 second intervals throughout the study.

Bather load, time of entry and the activity undertaken was recorded throughout the day. In addition the number of people entering the pool without using the showers was recorded.

THE MEASURING EQUIPMENT

The photometric testing was undertaken using a Palintest Pooltest 25 photometer (See Figure 3). This unit was used to assess the free and combined chlorine of the pool water at specific times during the study. A grab sample was taken from the pool and a specific reagent added to cause a colour change. Free chlorine and combined chlorine concentrations were measured using DPD No. 1 and DPD No. 3 respectively. In the photometer, light is passed through the sample, then through an optical filter onto a photodetector. The concentration is calculated from the difference in absorbance of the water sample at 530 nm compared to a blank sample.

The in-situ monitoring was carried out using a pair of YSI 6920DW sondes (See Figure 3). These sondes have been specifically developed for the monitoring of key parameters of drinking water systems. They are capable of measuring and recording values for pH, conductivity, temperature and free chlorine. Each of the parameters was measured using dedicated probes located within the sonde housing. They are powered using an internal power supply and the sampling rate is fully customisable. This allows them to be configured in advance and then deployed and left to monitor the water unattended. The free chlorine was measured using an amperometric free chlorine sensor. The probe was calibrated by measuring the current in a solution of known free chlorine concentration and adjusting the output accordingly. This was achieved by taking a grab sample and measuring the free chlorine concentration using a Palintest Pooltest 25 photometer and the DPD No.1 test reagent. The pH probe is a combination electrode consisting of a proton selective glass reservoir filled with buffer at approximately pH 7 and a reference electrode with a gelled electrolyte. The pH probe was calibrated using a 3 point procedure with solutions of known pH as recommended by the manufacturer. The pH measurement is affected by temperature and therefore the probe incorporates a thermistor to allow automatic adjustment. The thermistor exhibits a known variation in resistance with temperature changes and is factory set. The conductivity probe consists of four nickel electrodes that measure the voltage drop and convert it into a conductance value. The exact value of the conversion factor is automatically identified by the sonde during the calibration process using solutions of known conductivity.

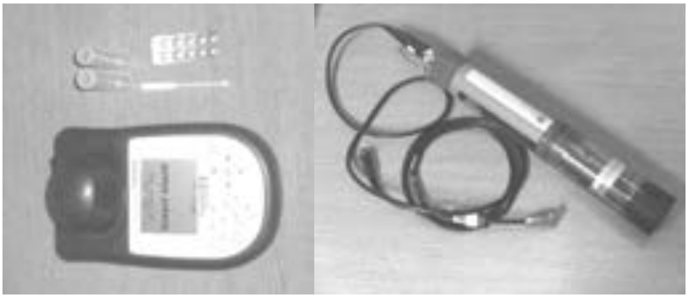

Figure 3 Palintest Photometer and YSI Sonde

RESULTS AND DISCUSSION

BATHER LOADING AND HABITS

Bather load is considered to be a potentially significant factor on the quality of the water (PWTAG, 2009). An increase in bather load is likely to result in the increased amount of materials of human origin (MHOs) to enter the pool, including sweat, hair, faecal matter and cosmetics. The average bather loading for each activity varied significantly, ranging from 9 during the aqua fitness class to 59 during the school swimming session. The bather load during the activities remained fairly constant with the exception of the public swimming sessions. Public swimming sessions are subject to a decreased demand during working hours. This was observed during the study as the number of public swimmers significantly declined between 9am and 12pm and between 1pm and 5pm. The bather load in each of the monitoring locations is shown in Figure 4 together with the cumulative visitor count.

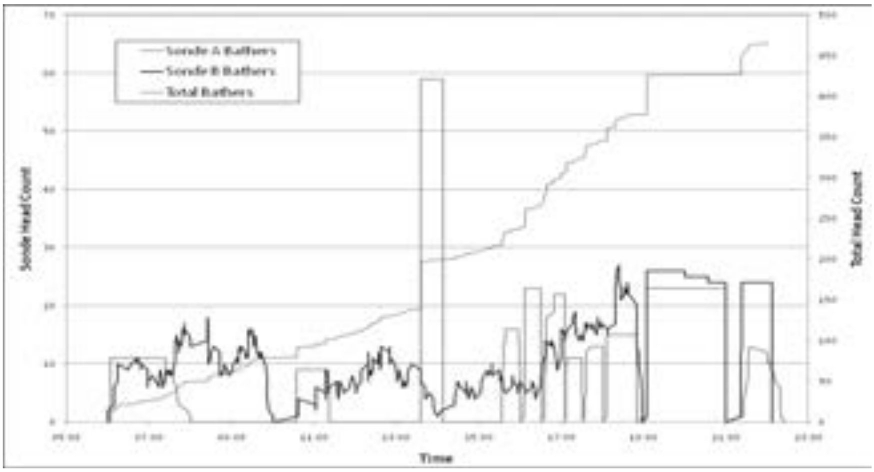

Figure 4 Bather Load at SSP – 18th November 2010

During the study observations of bather habits were also documented as poor pre-swim hygiene is a known issue in the UK. Each bather was monitored as they entered the pool hall and their use of the pre-swim showers was recorded. Table 3 shows a breakdown of the types of user that visited the pool during the study and the proportion of them that used the shower before entry. There was significant variation between the different user groups with the learn-to-swim and aqua classes having the lowest proportion of people using the showers. The highest pre-swim shower rates were observed with the water polo and school groups. The school group was actively controlled at the point of entry to the pool hall by the group organiser. However, when the organiser had moved from the shower area to the poolside with the initial group of children there was no one encouraging the remainder to shower. It was also observed that a significant amount of people who did use the shower only did so for a matter of seconds and failed to wet their hair, which is believed to be a significant source of pollutants (Kim et al., 2002). A short pre-swim shower has been reported to result in a significant reduction in the level contaminants introduced to the pool by bathers (Lakind et al., 2010). Increasing the proportion of bathers using pre-swim showers could reduce the impact on the water quality.

Table 3 User Distribution and Pre-Swim Shower Data

Activity	Number of Bathers	Number Showered	% Showered
Public Swim	208	125	60%
Learn To Swim	85	11	13%
Swimming Club	68	39	57%
School Swim	59	45	76%
Canoe Club	20	17	85%
Aqua Classes	24	2	8%
Water Polo	24	24	100%
Total	**488**	**263**	**54%**

In addition other general observations were recorded. The use of swimming hats and dedicated swimming costumes appeared to vary with user group. They were very common amongst the swimming club, learn-to-swim and water polo club bathers, however, they were far less common amongst the other groups. Other potential sources of contaminants were observed during some activities. Many of the activities involve the use of equipment such as swimming aids and canoes. These can potentially introduce contaminants into the water if they are not stored and cleaned appropriately. The canoe club at Surrey Sports Park are required to use different canoes in the pool from the ones they use for outdoor activities, however, the storage location and cleaning procedures followed is unknown. A number of parents were observed escorting their children to poolside for the swimming lessons. Many of these did not remove their shoes resulting in the transfer of dirt through the showers and onto poolside. Finally, the swimming instructors were observed to enter the pool without showering. As the instructors wear clothing during the lessons there is potential for these items to introduce contaminants to the water.

FREE CHLORINE

Grab samples were taken before each activity started, 30 minutes into the activity and after the activity had finished. Each sample was analysed for free chlorine using the DPD test method and a Palintest Pooltest 25 unit. It was not possible to identify any correlation between the activities and the change in free chlorine concentration with contrasting variations observed during similar activities. The free chlorine in the pool is automatically controlled by an amperometric monitoring unit in the plant room. The controller automatically adjusts the dosing of the sodium hypochlorite based on the free chlorine concentration in the balance tank outlet water. This is believed to cause the fluctuations identified during the study.

The fluctuations are more clearly observed in the data collected using the sondes. The data from Sonde A is shown in Figure 5 together with the data from the grab samples. The chlorine probe within Sonde B malfunctioned during the study and has therefore been omitted. Although the frequency of the oscillations makes it impossible to identify any small scale effects of the activities, a general increase was visible during the two peak periods, before 9am and after 5pm. The fluctuations were greatest during the off-peak period. This is most likely due to a combination of the significant water movements caused by the floor movements and the large variations in bather loads associated with the afternoon groups.

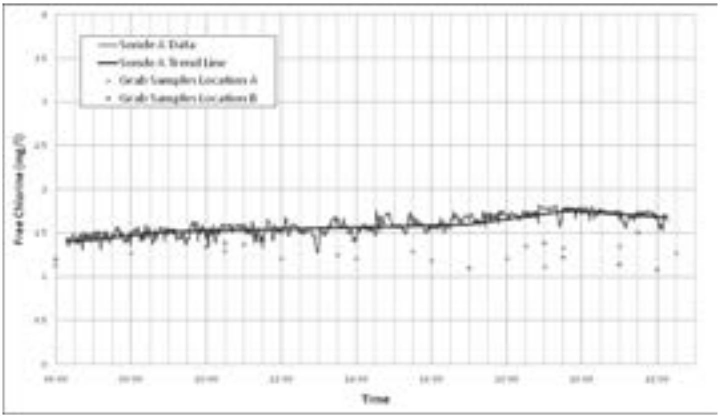

Figure 5 Free Chlorine Concentrations – 18th November 2010

COMBINED CHLORINE

The combined chlorine concentration of grab samples taken before and after each activity was measured using the DPD method. The change in combined chlorine concentration was then assessed at each monitoring location. The data is presented in Table 4 together with the associated number of bathers attending each activity. The pool water at the start of the day had an elevated concentration of combined chlorine. This is possibly a result of the reduced turnover rate used overnight. A net reduction in combined chlorine levels was observed at both monitoring locations during the initial activities. The increased water agitation from the faster turnover rate and bather activity is the most probable reason for this change. The reduction in Location A is logical considering the low numbers of bathers in the swimming club session. Significantly more bathers attended the public session, however it appears not to have been significant enough to maintain the combined chlorine concentration. The reduction in Location B may have been exaggerated by the movement of the boom from 50m to 25m.

Table 4 Combined Chlorine Concentrations – 16th & 18th November 2010

	Time	Activity	Number of Bathers	Initial Concentration (mg/l)	Final Concentration (mg/l)	Net Change (mg/l)
Location A	21:00	Canoe Club 1	20	0.27	0.14	-0.13
Location B	21:00	Canoe Club 2	20	0.47	0.08	-0.39
Location A	06:00	GCSC 50m	11	0.16	0	-0.16
	08:00	Rest 1	0	0	0.04	0.04
	10:30	Aqua Class 1	9	0.04	0.04	0
	11:30	Rest 2	0	0.04	0.04	0
	13:30	School Swim	59	0.04	0.12	0.08
	14:00	Rest 3	0	0.12	0.04	-0.08
	15:30	Learn to Swim	85	0.04	0.2	0.16
	18:00	Aqua Class 2	15	0.2	0.26	0.06
	19:00	GCSC 25m 1	23	0.26	0.18	-0.08
	21:00	Public 25m 1	16	0.18	0.02	-0.16
Location B	06:00	Public 50m	68	0.1	0	-0.1
	10:30	Public 25m 2	107	0	0.24	0.24
	18:00	Uni/Public 25m 1	25	0.24	0.06	-0.18
	19:00	GCSC 25m 2	26	0.06	0.28	0.22
	21:00	Water Polo	24	0.28	0.5	0.22

During the afternoon, increases in combined chlorine concentrations were linked with the school swimming, learn-to-swim and public swimming sessions. The first two activities are associated with high instantaneous bather loads, however, the impacts are potentially exacerbated by the floor being raised to 0.75m and 0.5m respectively. Although the total number of bathers during the public session is high, the instantaneous bather load varies significantly over the session. It is not possible to identify whether the increase was gradual throughout the entire session or concentrated towards the end when bather load was higher. The level of combined chlorine at Location B was found to decrease during the combined public and university club session despite the increase in instantaneous bather load. In contrast the concentration rose further during the evening aqua class. Two parallel swimming club sessions took place in the evening, on either side of the boom. The final combined chlorine concentrations were similar at both locations despite starting from very different levels. The combined chlorine concentration continued to rise during the water polo. As highlighted previously the free chlorine concentration was higher towards the end of the day, increasing the potential for by-products to form. The low bather loads in the late public swimming sessions allowed the water quality to recover at Location A before the end of the study. The water overflow from the pool was significantly greater during the canoe club session compared to the other activities. This was as a result of both the disturbance from the canoes and there being no lane ropes restricting surface flows. The outcome of this increased removal of the surface water was a significant reduction in combined chlorine concentration.

When the combined chlorine concentrations are plotted against the bather loads it becomes apparent that, when the pool is in the 50m configuration, the presence of combined chlorine is significantly lower (Figure 6). It would also appear that during activities in the 25m configuration, with the exception of water polo, the swimming club sessions and the aqua fitness class, the concentration of combined chlorine is strongly associated with bather load. From this analysis it would appear that the swimming club, water polo and aqua fitness sessions have a higher than expected impact on the pool water quality.

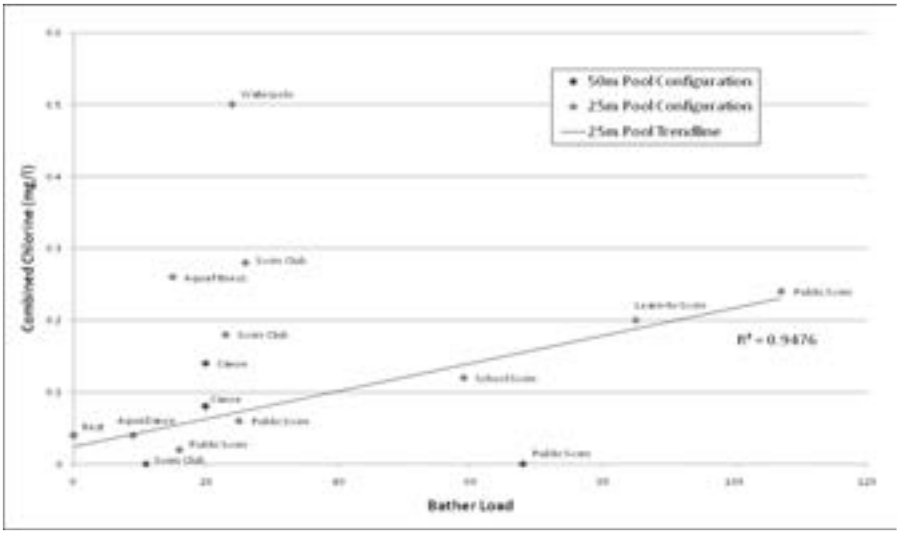

Figure 6 Combined Chlorine Concentration vs Bather Load

PH

The pH of the pool water was maintained in the target range by an automated hydrochloric acid dosing pump. This constant pH correction resulted in minimal variations being observed in the data. A slight decrease was recorded during the evening peak sessions. The drop in pH from 7.44 to 7.39 at Location B was the largest variation identified but is of little significance to the overall pool water quality.

CONDUCTIVITY

The specific conductivity at both locations was automatically recorded by the sondes. An unknown issue occurred between 9:30am and 1pm resulting in significant oscillations in the recorded values. Following this period of oscillations, the conductivity appeared to steadily increase at both locations until the end of the study. The data suggests that the activities during the day resulted in an overall increase in the conductivity of between 10 µS/cm and 15 µS/cm. A rate of increase of this order is in line with recently recorded monthly increases of water conductivity value, 285 µS/cm in October. An extended period of monitoring and some independent validation sampling are required to identify whether this is an accurate trend or whether the sondes were suffering from measurement creep.

TEMPERATURE

The water temperature at both locations during the study is shown in Figure 7. On first inspection of the data gathered by the sondes it was apparent that, although there was a general reduction in temperature, some activities were causing the temperature to increase at specific times during the study. On closer inspection of the data it was identified that the spikes in water temperature coincided with times when the pool had been reconfigured. The anomaly in the Sonde B data at 10:15am was when the sonde was removed from the water to allow the boom to move to its 25m position. The other step changes in temperature appeared to be linked to the movement of the floor. Sonde A was located directly above the floor whilst Sonde B was located on the other side of the boom. This is believed to be the reason for the sharper response identified in the Sonde A data. The step change appears to be more significant when the floor is lowered than when it is raised. The temperature of the floor is also automatically maintained at the set-point by adjusting the flow of water through the heat exchangers. This is controlled by a pair of temperature probes located on the return line in the plant room. It is possible that the larger step changes observed at 2pm and 6pm are due to the lower temperature limit being reached and additional heating occurring.

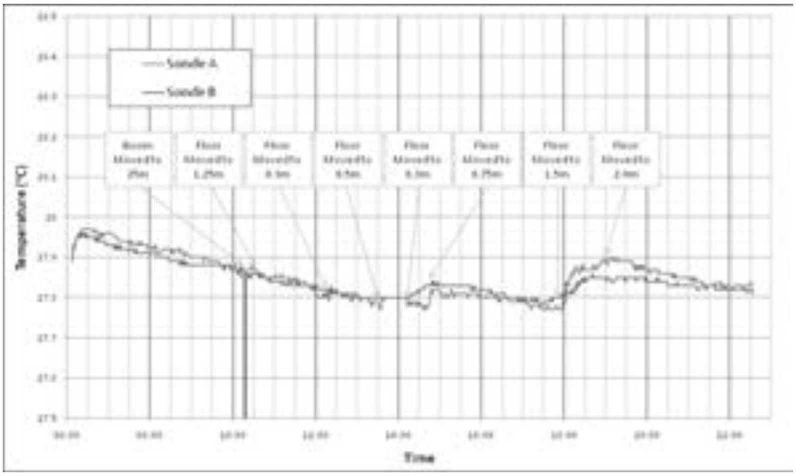

Figure 7 Pool Water Temperature – 18th November 2010

The temperature at the start and end of each activity was taken from the series of data and used to compare the relative rates of temperature change caused by each activity. When the raw data is used a number of the activities appear to result in a net increase in the water temperature. However, if the data is adjusted to account for the step changes experienced following the movement of the floor, the data indicates that the rate of temperature loss is independent of activity. The water temperature decreased at an average rate of 0.02°C/hr.

CONCLUSIONS

This study highlighted the need for a further study and an awareness campaign concerning pre-bathing habits of user groups in the UK. Failure to shower before entry to the pool is likely to be a contributory factor behind the increase in combined chlorine concentrations identified following some activities (aqua and learn-to-swim classes) despite relatively low instantaneous bather loads. Although a high proportion of the school group using the pool went through the showers before entry, the extremely high bather load during this activity resulted in a significant increase in combined chlorine levels. The use of the moveable floor to reduce the depth of pool is likely to exacerbate the concentrations present in the water. The effects of the floor positioning on the water circulation needs to be investigated to ensure that the water turnover rate is appropriate for these activities. Significant levels of combined chlorine were also observed after other high load activities such as the late afternoon swimming club and public swimming sessions. For most activities observed in the study, chloramine formation had a strong dependence on bather load with identifiable quantities found when the bather load was 20 or greater (based on the 25m pool arrangement).

The study data suggests that rest periods are an effective way of maintaining good water quality. The combined chlorine concentrations were low after each of the rest periods. The use of equipment in the pool did not appear to cause any issue. The increased overflow of water during the canoe club session resulted in the greatest reduction in combined chlorine concentration during this study. A wider screening of water parameters is required to confirm these findings. Online monitoring of combined chlorine could identify a more complex relationship between activities and water quality than the discrete sampling allowed in this study.

The automated free chlorine, pH and temperature control system made assessment of the effects of the activities on these parameters more difficult. There was no evidence of the pool activities affecting the pH level of the water. Free chlorine levels were seen to increase during the busiest periods and remain fairly constant during the quieter ones. This could be potentially due to an overcompensation of the controller following reduction of free chlorine in the water leaving the pool. The rate of temperature loss was found not to be affected significantly by the nature of the activity. A series of temperature step changes appeared to coincide with the repositioning of the floor. This supports the need for the effects of internal structures on water circulation to be investigated further.

The conductivity of the pool water was found to increase slightly during the study period. This is most likely due to the continual addition of pool chemicals by the dosing system as well as the introduction of contaminants by the bathers. More detailed chemical and microbial analysis of the water would enable identification of any substances that are accumulating in the pool water. Without this information it is not possible to conclude what the full effects of the activities are on the pool water quality. This study, however, identified that elite swimming, aqua fitness and water polo sessions have a disproportionate impact on the water quality at Surrey Sports Park in comparison to the other activities. The scheduling of rest periods should therefore take into account activity type as well as bather loading.

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