Modifications for water management guidance based on an assessment of swimming pool water consumption of an operational facility in the UK

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Abstract

Water use is a significant operational cost factor for large swimming pool facilities, however it has been overshadowed by the recent focus on energy consumption and carbon emissions. Currently it is difficult for operators to make decisions in relation to water efficiency due to the lack of information on the relationship between pool operation and water use. This study has started to address this issue by reviewing water use at a fully operational facility. The analysis of the consumption data has led to a proposal for a new water performance indicator, the Water Exchange Deficit. Modifications to the method of predicting water consumption have also been proposed to enable enhanced water management guidance to be developed.

Introduction

The efficiency of energy and water use has become an increasingly important aspect of building operation in the UK and especially for publicly operated buildings during the current era of funding cuts. Swimming pools in particular are a significant consumer of both energy and water resources (Carbon Trust 2006, Forrest and

Williams 2010). The cost of energy and water has increased significantly in the UK in recent years causing facility operating costs to rise dramatically and increasing the pressure on operator budgets (DECC 2011, Ofwat 2009). The development of new treatment technologies presents an opportunity to reduce the resource consumption of swimming pools whilst maintaining a healthy and inviting environment for the users (Sun et al. 2011).

Many aspects of a swimming pool facility can be affected by the actions of the facility operators and water efficiency is one of them. An understanding of the water use associated with design options and operator decisions is fundamental to enabling future guidance for sustainable swimming pool design and operation to be developed. There has been significantly less academic interest in the operational aspects of swimming environments than there has been in the health related aspects. In general, the research that has been undertaken has focused on reducing the energy consumption of swimming pools, however, limited studies have focused on the water burden associated with swimming pools.

Forrest and Williams (2010) conducted a study that included a review of sources of water consumption for domestic pools in the US. Many of these aspects are relevant for larger facilities as well. As identified in that research, water is consumed through direct processes such as backwashing and evaporation as well as indirectly as part of the chemical or power production process (Forrest and Williams 2010). It is difficult to assess the impacts of the indirect processes on the overall water consumption, therefore these are not considered here and only direct water-consuming activities are discussed.

In order to maintain the quality of the pool water, fresh water is required to be added at regular intervals. This prevents the accumulation of dissolved substances in the pool water. It is currently advised that 30 litres of fresh water is added to the system for each bather that uses the pool (PWTAG 2009) although this has not been reviewed since it was included in the first swimming pool guidance in 1999. As the pool water treatment system is a closed loop, during operation the addition of fresh water requires the discharge of existing pool water. The process of backwashing provides an ideal opportunity to discharge the required water volume to allow addition of fresh water (PWTAG 2009). This is the extent to which current UK guidance covers water consumption expectations for swimming pools and is wholly inadequate for ensuring efficient water management practices.

There have been some studies published on the subject of evaporation of water in swimming pools. Prevention of evaporation through the use of pool covers was observed to result in a 50% reduction in pool water consumption in a study

reported by the US Department of Energy (2009). Shah (2011) developed a set of equations to approximate the water evaporation rate for both occupied and unoccupied pools and Asdrubali (2009) reported on experimental results of evaporation from a model swimming pool. All of these studies, however focused on the energy aspects of evaporation not the impact on the buildings' water efficiency.

Perhaps the most widely studied subject area is that of potential opportunities to reuse backwash water. The reuse of swimming pool backwash water will require varying levels of treatment depending on its final use (Carbon Trust 2006). Skibinski et al. (2009) showed that simply using granular activated carbon (GAC) filters can effectively remove free chlorine and disinfection by-products (DBP) from the water to enable its use in low level applications such as toilet flushing. Additional treatments would be required for other applications such as irrigation or reuse in swimming pools (PWTAG 2010b). McCormick et al. (2010) and Walsh et al. (2008) highlighted that there is a risk of increased DBP generation during the treatment of backwash water than during the treatment of pool water. Reißmann et al. (2005) undertook a study to evaluate the potential benefits of using a combination of ultra-filtration (UF) and reverse osmosis (RO) to enable backwash water to be reused within the swimming pool itself. The study showed that significant water savings could be achieved through this methodology. For many of these options a significant investment in equipment or plant redesign is required and therefore they may not have a broad applicability to the industry.

This study aimed to review the overall water consumption of a fully operational facility in the UK and use the collated data to identify opportunities for efficiency improvements in relation to the swimming pool through modifications to existing practices. The data gathered during the study and subsequent analysis is presented in this paper and proposals are made in relation to a new relationship that can be used to predict the impact of operational parameters on the water consumption of a swimming pool.

Facility Overview

The facility used in this study is a multi-sport venue offering a range of activities including swimming. The facility consists of a main building that contains a number of sports arenas, well-being rooms, offices and catering facilities, in addition to the swimming pool which is the focus of this study. The facility also has a number of external grass and artificial sports areas. The facility is open 7 days a week and is regularly used by a range of amateur and professional sports teams as well as the general public.

The swimming pool is run by the facility operations staff, however the maintenance and operation of the associated plant is the responsibility of the Estates and Facility Management (E&FM) team. The operation of the system is mostly automatic with controllers installed to assist with the operation of the pool water treatment system. These controllers manage the addition of the pool chemicals including disinfectants, coagulants and pH regulators. The settings for these automated controllers are the responsibility of the E&FM staff. Other aspects of the pool operation can be adjusted manually using various control panels. These include the pump speeds and the dosage of the Ultra-Violet treatment unit. The discharge of water is also a manual process, although a level controller ensures that the addition of fresh water is managed automatically.

Current guidance recommends that the water exchange rate should be directly linked to bather numbers (PWTAG 2009) with 30 litres of water disposed of daily for every bather using the facility. This is undertaken at the facility through the backwashing of the sand-filters. This reduces the overall amount of water that needs to be discharged by combining the removal of accumulated solids in the filter with the removal of dissolved compounds from the pool water.

Methodology

The water used within the facility is currently sourced completely from the mains system. Although the facility was initially designed to enable grey water use for sanitation, the system was removed during construction. The consumption of water is recorded by a number of inline water meters. The flow meter on the mains inlet for the building records the total consumption of water by the facility. Three further flow meters within the facility record the volumes of water used for sanitation, the swimming pool and irrigation. The difference between the mains water meter and the sum of the segregated meters was assigned to general applications. The general applications include the use of water for cleaning, showers, drinks fountains, hand basins, the bar, the kitchen and the coffee shop.

The water meters are not directly connected to the building management system (BMS) and therefore they required manual logging in order to track trends in use. This was undertaken by the E&FM team for the pool water flow meter in order to record the amount of water discharged during the backwash process. These manual recordings were collated and used to analyse the overall water consumption of the facility. In addition, the swimming pool water meter records were used in conjunction with operational records to investigate the water consumption of the swimming pool in more detail.

The study also used theoretical relationships published by Shah (2011) for evaporation from occupied and unoccupied pools to calculate expected volumes of water to be lost at the facility. These values were then compared to the actual consumptions recorded at the facility. For unoccupied pools Shah (2011) defines the evaporation rate (E_0) as the larger of the results of Equation 1 and 2.

$$E_0 = 290D_w \times (D_r - D_w)^{1/3} \times (W_w - W_r) \quad \text{Equation 1}$$

$$E_0 = 0.0346 \times (p_w - p_r) \quad \text{Equation 2}$$

For occupied pools Shah (2011) defines the evaporation rate (E_1) using Equation 3.

$$E = 0.023 - (0.0000162/U) + (0.041 \times (p_w - p_r)) \quad \text{Equation 3}$$

The definition of each of the parameters is listed in the nomenclature at the end of this paper. For ease of use Shah (2011) has generated look-up tables in SI units based on the above equations for a wide range of common pool water and air conditions. The evaporation rate look-up tables for unoccupied and occupied swimming pools are shown in Table 1 and Table 2 respectively.

		Space air temperature, degrees Celsius, and relative humidity, percent											
		25°C		26°C		27°C		28°C		29°C		30°C	
		50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
Water temperature, degrees Celsius	25	0.1085	0.0809	0.0918	0.0636	0.0732	0.0515	0.0498	0.0450	0.0583	0.0382	0.0523	0.0311
	26	0.1355	0.1042	0.1171	0.0872	0.0997	0.0693	0.0806	0.0547	0.0575	0.0479	0.0626	0.0479
	27	0.1579	0.1290	0.1433	0.1118	0.1262	0.0941	0.1081	0.0753	0.0885	0.0582	0.0723	0.0510
	28	0.1877	0.1556	0.1711	0.1380	0.1539	0.1200	0.1360	0.1014	0.1171	0.0818	0.0960	0.0618
	29	0.2174	0.1841	0.2006	0.1661	0.1831	0.1477	0.1651	0.1287	0.1644	0.1092	0.1268	0.0888
	30	0.232	0.2146	0.2143	0.1962	0.1960	0.1773	0.1772	0.1579	0.1576	0.1380	0.1372	0.1176
	31	0.2831	0.2474	0.2655	0.2285	0.2475	0.2091	0.2289	0.1892	0.2098	0.1688	0.1900	0.1480
	32	0.3192	0.2825	0.3013	0.2631	0.2829	0.2432	0.2639	0.2228	0.2445	0.2019	0.2445	0.1805
	39	0.6461	0.6035	0.6256	0.5808	0.6045	0.5575	0.5827	0.5334	0.5604	0.5087	0.5379	0.4833
40	0.7051	0.6617	0.6842	0.6386	0.6627	0.6148	0.6405	0.5903	0.6177	0.5655	0.5943	0.5391	

Table 1 – Evaporation rate (kg/hr/m²) look-up table for unoccupied pools based on the formulas proposed by Shah (2011)

		Space air temperature, degrees Celsius, and relative humidity, percent											
		25°C		26°C		27°C		28°C		29°C		30°C	
		50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
Water temperature, °C	25	0.2065	0.1878	0.2007	0.1809	0.1947	0.1737	0.1884	0.1660	0.1817	0.1580	0.1747	0.1496
	26	0.2179	0.1992	0.2122	0.1923	0.2062	0.1851	0.1998	0.1775	0.1932	0.1695	0.1861	0.1611
	27	0.2300	0.2113	0.2242	0.2044	0.2182	0.1972	0.2119	0.1895	0.2052	0.1815	0.1982	0.1731
	28	0.2427	0.2239	0.2369	0.2171	0.2309	0.2098	0.2246	0.2022	0.2179	0.1942	0.2109	0.1858
	29	0.2560	0.2373	0.2503	0.2304	0.2442	0.2232	0.2379	0.2156	0.2312	0.2076	0.2242	0.1992
	30	0.2700	0.2513	0.2643	0.2445	0.2583	0.2372	0.2519	0.2296	0.2453	0.2216	0.2383	0.2132

Table 2 – Evaporation rate (kg/hr/m²) look-up table for occupied pools based on the formulas proposed by Shah (2011)

Overall Facility Water Consumption Results

The total consumption of water by each of the four categories of application was recorded between May Year 1 and October Year 2 in order to assess the water footprint of the facility over an 18 month period of operation. The distribution of water consumption over this period is shown in Figure 1.

Figure 1 - Water consumption of the facility from May Year 1 to October Year 2

The pool water consumption accounted for 22% of the total water consumption during this period compared to 15% for sanitation and 38% for irrigation. The remaining water consumption of the facility was largely associated with applications requiring potable water such as in the kitchen, bar and coffee shop. The amount of water used for irrigation is believed to be inflated due to an international sports tournament that took place during the summer of Year 1 and required very heavy water use to maintain the quality of numerous grass pitches.

At present all of the water demands for the facility are met through the use of mains water. The water used in all applications with the exception of irrigation is liable to both supply and sewerage charges. CO₂ conversion factors were taken from the DEFRA guidance for Year 1 (Defra 2014) and utility pricing information was supplied by the facility on the condition that it was anonymised.

Using the consumption data shown in Figure 1 and the above pricing information, the cost of the water consumption during the 18 month study period was approximately £41,700. This is just over 10% of the total utility costs of the facility and therefore water consumption is a significant factor in the overall operating costs. The carbon emissions associated with the water consumption was approximately 31,300 kgCO₂. This is roughly 100 times smaller than the emissions

associated with fuel consumption at the facility. At present the carbon emissions associated with the off-site supply and disposal of water are also not included in the scope of the facility's carbon footprint for carbon reduction commitment (CRC) reporting purposes and therefore only the financial implications are currently of concern to the facility (DECC 2012).

Swimming Pool Water Consumption Results

The water consumption of the pool (W_p) was subsequently analysed in greater detail. As mentioned previously, the swimming pool water consumption is made up of 3 different elements: the disposal of water to maintain water quality and filter efficiency (W_{ex}), the evaporation of water from the pool tank (W_{ev}) and carry-out via bathers' clothing. The bather carry-out is considered to be very small and has therefore not been included in this study.

Pool Water Disposal

The most significant cause of water consumption is the disposal of water as part of the water exchange required to maintain the pool water quality. Figure 2 below relates the amount of fresh water added to the swimming pool with the number of bathers using the pool during the day for the first 6 months of the study period. The water exchange rate (W_b) required to meet the PTWAG recommendations, 30 litres per bather per day, is also shown for comparison (PWTAG 2009). As can be clearly seen in the figure, the actual daily refresh rate in litres per bather was highly variable. This was due to a combination of the manual process of exchanging water and the variable daily bather load.

Figure 2 – Actual and recommended volumes of fresh water added to the pool for May Year 1 to October Year 1

In the first 6 months of the study period the amount of fresh water added to the pool was significantly less than the recommended volume on 77% of the days. This lack of water exchange was due to a combination of infrequent backwashing being required, due to the low amount of solids present in the water, as well as scaling errors by the E&FM team. The issues were addressed in November Year 1 and the maintenance procedures updated. Large volumes of water were also exchanged throughout December Year 1 and January Year 2 to resolve issues with high chloride concentrations in the pool water.

A monthly-averaged daily water refresh rate was considered to be a more suitable measure to use than an actual daily water refresh rate as the pool water composition was observed to change relatively slowly, as reported by Lewis et al. (2011), and it enabled some of the variability to be moderated. The monthly-averaged daily refresh rate for the swimming pool is shown in Figure 3. Although significantly more water was exchanged following the operational changes in November Year 1, the average daily refresh rate fell below recommended values soon afterwards, due to the E&FM team not being aware of significant increases in recorded bather numbers. This highlights the importance of a robust communication procedure between operational and maintenance teams.

Figure 3 – Monthly-averaged actual and recommended daily refresh rates based on actual monthly bather numbers for the facility

The consistent inadequate exchange of water can cause operational issues in a pool facility. A new performance indicator was created to enable the E&FM team to monitor long-term trends in the rate of water exchange. The Water Exchange Deficit (WED) was defined as the difference between cumulative actual water consumption and cumulative recommended water consumption. An increase in the WED is likely to be the cause for the recorded increases in the concentrations in stable dissolved compounds such as chloride, as these are only removed through the water exchange process. Observations of equipment corrosion that were recorded between September and November Year 1 also provided evidence of the increase in chloride concentrations.

The WED for the facility from May Year 1 to March Year 2 is shown in Figure 4 together with the actual cumulative water consumption and the recommended cumulative water consumption based on recorded bather numbers. The data shows that the WED rapidly increased from May Year 1 to November Year 1. The WED was then significantly reduced following the adjustments made to the operational procedures at this time. The WED was then seen to increase again between March Year 2 and July Year 2 before remaining fairly stable until September Year 2. Further increases in the WED were observed from October Year 2 to March Year 3. This was as a result of the E&FM team not adequately adjusting the water exchange rate with respect to bather numbers.

Figure 4 – Actual and recommended cumulative water consumption and water exchange deficit for the facility between May Year 1 and March Year 3 with and without bather number correction

Unfortunately there was no water analysis data available for the period between November Year 2 and March Year 3, however, there were no further observations of the corrosion issues that had been present in Year 1 despite the WED being higher. This therefore prompted further investigation into the water exchange requirements.

In November Year 1, a user group study was undertaken at the facility. During this study, the number of bathers was recorded in real time. When the total number of bathers was compared to the number of bathers documented by the facility staff, there was a discrepancy of over 20%. Following this discrepancy, the method of bather counting used by the facility staff was investigated. The facility staff calculated the bather load through the summation of headcounts taken every 30 minutes during pool opening hours, a common method used by facilities in the UK (PWTAG 2011). Many of the activities that take place in the pool last for an hour or longer, therefore, some bathers could be double counted. At some times, for example during swimming club sessions, the recorded bather count can be up to four times higher than the actual number of bathers.

This overestimate of bather numbers means that the amount of water recommended to be exchanged is also overestimated. Assuming that the user group study was undertaken on a representative day for the facility, it suggests that the bather count, as calculated by the facility staff could be reduced by 20% when calculating the amount of water that should be exchanged daily. The effect of this

modification to the cumulative water consumption data for the facility is also shown in Figure 4.

After taking account of the overestimates in bather numbers, the amount of water that was added to the pool between May Year 1 and November Year 1 can be seen to remain significantly less than the recommended volume. However, the WED for the period following the operational changes is observed to remain close to zero. This provides a potential explanation for why the corrosion issues were not observed in Year 2 onwards even though the raw data suggests the WED was higher than in Year 1. It is recommended that for the water exchange requirement (W_{ex}) a correction factor (F_b) is applied to the bather number (N) calculated using the Half-Hour observation method as shown in Equation 4. Additional surveys would be required to verify that the appropriate correction factor was used for the facility.

$$W_{ex} = F_b \times N \times W_b$$

Equation 4

In this equation, W_b would remain at the PWTAG guidance value of 30 litres per bather per day.

Pool Water Evaporation

Water is continuously lost from the pool thorough evaporation. The water level in the balance tank is automatically controlled at the facility used for this study so that fresh water is added to compensate for these losses. The review of water consumption data and backwashing records enabled the amount of water lost through these routes to be determined. During periods of operation when backwashing was not undertaken, the daily water consumption was recorded to be between 3 m³ and 4 m³.

The pool water at the facility is maintained at 28°C with the air temperature maintained at 29°C. The humidity of the air in the pool hall is set to 60% and the pool is in use between 13 and 17 hours each day. Using the look-up tables published by Shah (2011), the above settings and a pool surface area of 1000m², the theoretical volume of water expected to evaporate daily is between 3.42 m³/day and 3.87 m³/day. This is in close agreement with losses observed at the facility during this study and acts as validation of the equations proposed by Shah (2011).

This addition of water to compensate for evaporation does not affect the concentrations of the dissolved compounds in the pool water as many of them are non-volatile. This means that an additional volume of water (W_{ev}) based on pool surface area and hours of use should be added to the water exchange requirement (W_{ex}), as shown in Equation 5, to account for the evaporative losses when calculating expected pool water consumption.

$$W_p = W_{ex} + W_{ev}$$

Equation 5

Further Developments

A main source of dissolved contaminants in the pool water is through the use of pool chemicals. The volume of chemicals added to the pool at the facility in the study is controlled automatically. The activity study by Lewis et al. (2011) showed that although the type and number of users affected the rate at which disinfectant was consumed, chemical dosing was found to still occur during unoccupied periods as well. Accordingly there is a base load of chemical addition that means an amount of water (W_c) is required to be exchanged regardless of bather load in order to prevent accumulation of impurities, such as chlorides, in the pool water.

The study by Keuten et al. (2012) reported that a large proportion of bather-related contaminants (60%) are usually introduced upon initial entry to the pool or through preventable releases that can be significantly reduced through good pre-swim hygiene practices. The amount of water required to meet the bather load demand will therefore depend on the bather management of the facility. Including the proportion of bathers not using a shower before entry (F_{ns}) would enable the water exchange value for bathers to be broken down further into a requirement for initial bather contaminant loading (W_{bi}) and a requirement for continuous bather contaminant loading (W_{bc}).

The following proposal for a modified methodology for calculating the expected water consumption of a swimming pool facility, Equation 6, is therefore generated by combining these developments with the modifications for bather numbers and evaporation losses.

$$W_p = (F_b \times N \times ((F_{ns} \times W_{bi}) + W_{bc})) + W_c + W_{ev}$$

Equation 6

This relationship takes account of the variety of uses of water within the facility and also incorporates factors that are affected by the operational management of the facility. By adopting this approach it would enable operators to better understand the impact operational changes would have on their water consumption. Further work is required however to enable a mass balance approach to be used in determining the values for the three new parameters W_c , W_{bi} and W_{bc} .

Conclusions

This study has presented the outcomes of an in-depth review of the water use associated with the swimming pool at a fully operational multi-use leisure facility in the UK. Water consumption was shown to be a significant contributor to the operational cost of the facility with a significant proportion attributed to the swimming pool.

The main consumption of water in the swimming pool was associated with water quality requirements. The study showed that poor communication at facilities can result in inadequate water exchange to be undertaken. A new performance indicator, Water Exchange Deficit, was proposed to assist with identification of long-term trends in water exchange. The correct accounting of bather numbers was also shown to be important in the efficient operation of a swimming pool. Current counting methods were found to overestimate the amount of water required to maintain the water quality of the swimming pool and therefore the use of a correction factor is required.

Evaporation is also a primary concern for swimming pools. The study has validated published theoretical equations that have been proposed for predicting evaporation in swimming pools. Subsequently a simple relationship has been proposed for calculating expected water consumption for a facility based on these equations and the modification to the existing water exchange guidance.

A more enhanced relationship has also been proposed for calculating expected water use that enables a broader range of factors to be accounted for. This relationship requires further work to be undertaken to establish appropriate values for the water exchange parameters.

Nomenclature

ρ_w = Density of air saturated at water temperature (lb/ft³ dry air)

ρ_r = Density of air at room condition (lb/ft³ dry air)

E_0 = Evaporation from unoccupied pool (lb/hr/ft²)

F_b = Bather number correction factor

F_{ns} = Proportion of bathers not showering

N = Number of bathers

p_r = Water-vapor pressure in air, air at room condition (in Hg)

p_w = Water-vapor pressure in air, air saturated at water temperature (in Hg)

U = Utilization factor (number of people in pool area x 48.4 / pool area)

W_b = Water exchange rate for bathers (m³/bather/day)

W_{bi} = Water exchange rate for initial bather contamination (m³/bather/day)

W_{bc} = Water exchange rate for continuous bather contamination (m³/bather/day)

W_c = Water exchange rate for chemical base load (m³/day)

W_{ex} = Volume of water to replace disposal (m³/day)

W_{ev} = Volume of water to replace evaporation (m^3/day)

W_p = Volume of water required by a pool (m^3/day)

W_r = humidity ratio, air at room condition (lb/lb)

W_w = humidity ratio, air saturated at water temperature (lb/lb)

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