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 about 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 estimating water consumption have also been proposed to enable enhanced water management guidance to be developed.

Key words | consumption prediction, performance indicators, swimming pools, water consumption, water management guidance

NOMENCLATURE

ρ<sub>W</sub> density of air saturated at water temperature (lb/ft<sup>3</sup> dry air)
ρ<sub>r</sub> density of air at room condition (lb/ft<sup>3</sup> dry air)
E<sub>0</sub> evaporation rate from unoccupied pool (lb/hour/ft<sup>2</sup>)
F<sub>b</sub> bather number correction factor
F<sub>ns</sub> proportion of bathers not showering
N number of bathers
p<sub>r</sub> water-vapour pressure in air, air at room condition (in Hg)
p<sub>W</sub> water-vapour pressure in air, air saturated at water temperature (in Hg)
U utilisation factor (number of people in pool area × 48.4/池 area)
W<sub>b</sub> water exchange rate for bathers (m<sup>3</sup>/bather/day)
W<sub>bc</sub> water exchange rate for continuous bather contamination (m<sup>3</sup>/bather/day)
W<sub>c</sub> water exchange rate for chemical base load (m<sup>3</sup>/day)
W<sub>ex</sub> volume of water to replace disposal (m<sup>3</sup>/day)
W<sub>ev</sub> volume of water to replace evaporation (m<sup>3</sup>/day)
W<sub>p</sub> volume of water required by a pool (m<sup>3</sup>/day)
W<sub>r</sub> humidity ratio, air at room condition (lb/lb)
W<sub>wa</sub> humidity ratio, air saturated at water temperature (lb/lb)

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 & 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 (Ofwat 2009; DECC 2011). The development of new treatment technologies presents an opportunity to reduce the resource consumption of swimming pools while maintaining a healthy and inviting environment for the users (Sun et al. 2011). 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 little academic interest in the operational aspects of swimming environments.

Forrest & Williams (2010) conducted a study that included a review of sources of water consumption for domestic pools in the USA. Many of these aspects are relevant for large public 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 & Williams 2010). This paper considers only the direct processes.

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 L 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, 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.

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 filters can effectively remove free chlorine and disinfection by-products (DBPs) 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 2010), 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 and reverse osmosis 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 design is required and therefore they may not have a broad applicability to the industry.

This study reviews the overall water consumption of a fully operational modern swimming pool facility in the UK and uses 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 analyses are presented in this paper and proposals are made in relation to a new relationship that can be used to estimate 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 which contains a number of sports arenas, well-being rooms, offices and catering facilities, in
addition to an indoor eight lane, 50 m swimming pool with a surface area of 1,000 m² which is the focus of this study. The pool hall is approximately 60 m long and 30 m wide with an undulating roof resulting in an enclosed air volume of approximately 20,000 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. The facility also has a number of external grass and artificial sports areas and is open 7 days a week. 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 facility incorporates many common features of modern pools in the UK including automatic controllers 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. Other aspects of the pool operation can be adjusted manually using various control panels including the water circulation rate and the dosage of the ultra-violet treatment unit. The discharge of water is also a manual process, although a controller ensures that the pool tank level is maintained by automatically managing the addition of fresh water. The water used within the facility is currently sourced completely from the mains system. Three further 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 including the use of water for cleaning, showers, drinks fountains, hand basins and catering.

The water meters are not directly connected to the building management system and therefore they required manual logging in order to track trends in use. This was undertaken by the E&FM team on a daily basis 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.

This study 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 Equations (1) and (2).

\[
E_0 = 290D_w \times (D_t - D_w)^{1/3} \times (W_w - W_t) \quad (1)
\]

\[
E_0 = 0.0346 \times (p_w - p_r) \quad (2)
\]

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

\[
E = 0.023 - (0.0000162/U) + (0.041 \times (p_w - p_r)) \quad (3)
\]

The definition of each of the parameters is listed in the nomenclature at the start of this paper.

In addition to calculating the direct cost of water consumption attributed to operating the facility, secondary costs associated with the energy consumption linked to the evaporation and replenishment of water were also investigated. The energy required to heat the new incoming water as well as that required for compensating against the heat

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METHODOLOGY

The consumption of water is recorded by a number of inline water meters. The flow meter on the mains inlet for the
lost through evaporation were quantified. A third secondary cost is associated with the energy demand of the air conditioning processes that are required to maintain the indoor environment. It was not possible to quantify this aspect during this study due to a lack of information on the system.

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.

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. In addition, the pool volume included a complete fill of the pool tank which added a one-off consumption of 2,413 m³.

SWIMMING POOL WATER CONSUMPTION RESULTS

The water consumption of the pool (\(W_p\)) was subsequently analysed in greater detail. The swimming pool water consumption is made up of three 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 relates the amount of fresh water added to the swimming pool to 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 L per bather per day, is also shown for comparison (PWTAG 2009). As shown in Figure 2, the actual daily refresh rate, in litres per bather, was highly variable.

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 of the study. 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 inaccurate

Figure 1 | Water consumption of the facility from May Year 1 to October Year 2.
variation of discharge volumes by the E&FM team. The manual basis of the backwash process made it difficult for the E&FM team to control the amount of water discharged. Changes to the maintenance procedures were undertaken in November Year 1 to address some of the underlying issues. 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, an average of the amount of water exchanged daily during a month, 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

![Figure 2](https://iwaponline.com/ws/article-pdf/15/5/965/414081/ws015050965.pdf)  
*Figure 2* | Actual and recommended volumes of fresh water added to the pool for May Year 1 to October Year 1.

![Figure 3](https://iwaponline.com/ws/article-pdf/15/5/965/414081/ws015050965.pdf)  
*Figure 3* | Monthly averaged actual and recommended daily refresh rates based on actual monthly bather numbers for the facility between May Year 1 and March Year 3.
recorded bather numbers. This highlights the importance of a robust communication procedure between operational and maintenance teams.

**Pool water evaporation**

Water is continuously lost from the pool through 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 and 4 m³.

Using the look-up tables published by Shah (2011), operational set points and the pool dimensions, the theoretical volume of water expected to evaporate daily is between 3.42 and 3.87 m³/day. This is in close agreement with losses observed at the facility during this study and validates the equations published by Shah (2011).

**DISCUSSION**

At present all of the water demands for the study 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, the cost of the water consumption during the 18-month study period was approximately £41,700. This was just over 10% of the total utility costs of the facility and therefore water consumption is of moderate concern in relation to the operating costs of the facility. The carbon emissions associated with the water consumption were calculated to be 31,300 kgCO₂. This is close to 100 times smaller than the emissions calculated for the fuel consumption at the facility during the same period.

At present the carbon emissions associated with the off-site supply and disposal of water are not included in the scope of the facility’s carbon footprint for carbon reduction commitment reporting purposes and therefore only the financial implications are currently of concern to most facilities (DECC 2012). The manual nature of water data collection at most facilities, combined with the comparatively low significance of water consumption on the operating costs or environmental performance of a facility, means that data are not currently available to generate operational benchmarks.

**Financial implications of pool water consumption**

The cumulative water consumption for pool replenishment between May Year 1 and March Year 3 was 8,374 m³ at a direct utility cost of £10,240. The energy required to heat this volume of water from an average mains temperature of 15 °C to the desired pool temperature of 28 °C via the biomass boiler system installed at the facility adds an additional cost of £3,820 over this period. More significantly, the evaporation of approximately 3.5 m³/day during this period is associated with an energy cost of £44,610. This highlights that the costs associated with water management at a swimming pool are far larger than the direct cost of the water itself and therefore should be considered by pool operators as a significant concern.

**Development of water management practices**

The in-depth investigation into the water consumption of the swimming pool was used to review the current water management practices employed by typical facilities in the UK. 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 based on 30 L per bather per day. An increase in the WED is likely to result in increases in the concentrations of 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 provide evidence of an 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 increased again between March Year 2 and July Year 2 before remaining fairly stable until September Year 2. Further increases in the WED can be observed from October Year 2 to March Year 3.

Unfortunately there were no water quality 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 which 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 potential overestimate of bather numbers means that the amount of water recommended to be exchanged is also potentially overestimated. The user group study undertaken for the facility 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 suggest 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 30 minute observation method as shown in Equation (4), where $W_b$ is the PWTAG guidance value of 30 L per bather per day.

$$W_{ex} = F_b \times N \times W_b$$  \hspace{1cm} (4)

Additional surveys would be required to verify that the appropriate correction factor was used for the facility.

The 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.

$$W_p = W_{ex} + W_{ev}$$  \hspace{1cm} (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 which means that 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.

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 which 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 water exchange requirement of a swimming pool facility, Equation (6), is therefore generated by combining these developments with the modifications for bather numbers and evaporation losses.

$$W_p = (F_b \times N \times (F_{ns} \times W_{bi}) + W_{bc}) + W_c + W_{ev}$$  \hspace{1cm} (6)

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 the determination of the values for the three new parameters $W_c$, $W_{bi}$ and $W_{bc}$ before the proposed relationship could be implemented. A major challenge in the implementation of the proposed relationships in Equations (5) and (6) is in the willingness of operators to invest in the measurement of the data required. It is therefore also recommended that an overarching framework for the industry that would encourage the future adoption of improved practices to be developed.

**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 management aspects were shown to be a significant contributor to the operational cost of the facility with significant costs attributed to the evaporation and replenishment of water.

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 the number of bathers

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and therefore the use of a correction factor is required to prevent overestimation of water exchange requirements.

Evaporation is a primary concern for swimming pools in relation to water quality and energy consumption. The study has validated published theoretical equations which have been proposed for predicting evaporation in swimming pools. An improved relationship has been proposed for calculating the required water exchange requirements based on these equations.

A more enhanced relationship has also been proposed for calculating water exchange requirements which enables a broader range of factors to be incorporated. Further work is required to establish appropriate values for the water exchange parameters and also to develop the framework of the industry to encourage greater scrutiny of water management procedures.

REFERENCES


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