Executive Summary

Introduction

The swimming industry is facing increasing scrutiny as a consequence of a combination of tightening financial pressures and a rise in the profile of potential health issues associated with the activity. Historically the industry has been very loosely regulated with the main emphasis of management requirements placed on ensuring that participants are kept from physical harm. A growing awareness of the health implications associated with traditional pool water treatment practices has resulted in a multitude of new technological solutions and a greater interest in the exposure of bathers to chemicals to be developed (Oesterholt *et al.* 2009; PWTAG 2010).

Alongside this, the rise in utility prices, combined with the realisation of the environmental impact of energy use, has driven the industry to implement new efficiency measures for its facilities (Carbon Trust 2006). These developments have been piecemeal and poorly integrated to date, resulting in an industry relying on voluntary guidance that has formed organically over time. There is therefore a need to systematically appraise the current state of the industry, as a whole, and develop integrated guidance that considers all aspects related to swimming pool operation in order to ensure the sustainability of the industry as it develops.

The research presented in this thesis is the first to undertake a root and branch assessment of the industry. A strategy for addressing the major issues requiring resolution is recommended based on the analysis of primary data obtained through a series of targeted studies into the key interactions identified within indoor swimming facilities. The research was undertaken in conjunction with the Surrey Sports Park (SSP), the Department for Environment, Food and Rural Affairs (DEFRA) and the University of Surrey.

Identification of the Research Objectives

The initial phase of the research involved compiling all the interactions taking place within a swimming pool, as research published to date had focused on individual considerations in isolation. The interactions within the pool were categorised into five distinct aspects (Users, Employees, Water Quality, Air Quality and Energy Consumption) and a conceptual model for an indoor swimming pool facility was developed as shown in Figure 0-1.

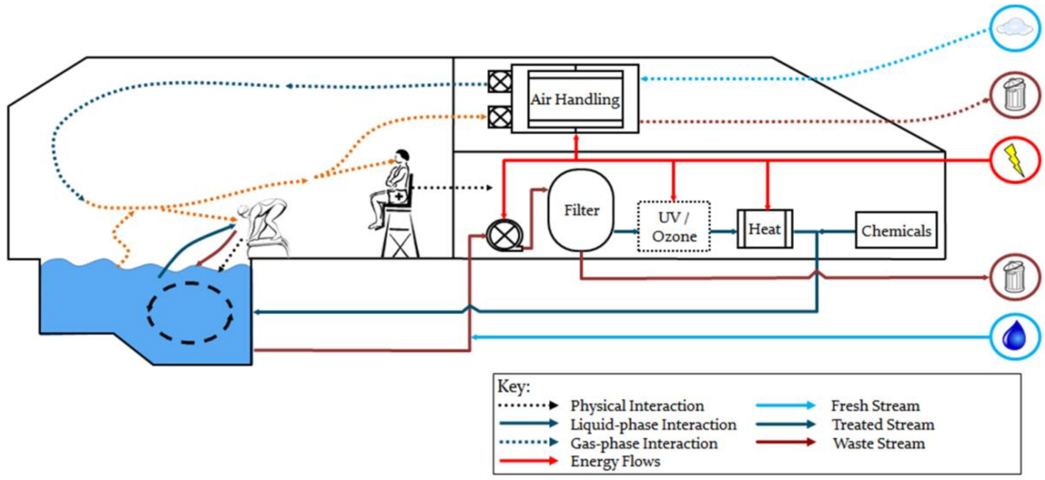

Figure 0-1 – Conceptual model for an indoor swimming pool

The generated conceptual model and these five aspects were used as the framework around which the initial scope of the research was formed. Key areas of existing knowledge that required strengthening in order to enhance current industrial guidance in the UK were identified through a review of existing guidance and in-depth discussions with the Pool Water Treatment Advisory Group (PWTAG), the primary body responsible for providing guidance to the industry.

The interactions relating to the water quality associated with swimming pools were considered to be of greatest importance during the literature review and discussions and were therefore selected as the focus for the research. These interactions included the relationship between user activity and water quality, as well as the impact of current UK guidance, prescribed for maintaining water quality, on the operational cost and environmental impact of a facility.

Employed Research Techniques

The broad nature of the area of research meant that a variety of research methods were required. An in-depth review of current guidance and regulation was required to gain an understanding of the existing information disseminated to the industry. To deepen the knowledge of the current state of the industry, several meetings and conversations with representatives of the industry were also undertaken. This provided a good insight into the challenges facing, and perceptions held by, practitioners in the industry. A review of academic literature relating to the sector was also undertaken to assess the existing supporting evidence available to the industry. As the industry has not been overly engaged with academic research, the range of pool-specific information available in academic journals was limited in many areas. To broaden the academic knowledge base from which to draw information, research findings based on closely-related industries, such as the drinking-water industry were also reviewed.

In addition to the review of available literature, primary data were collected during the research from a number of sources. Water quality data were generated by undertaking a programme of microbiological and chemical water sampling at an operational facility. Operational data for the facility were collected from the building management system installed at the facility as well as from the records held by the operational and maintenance teams. Statistical analysis of the data was undertaken and evaluation and discussion of the results were used to formulate conclusions in relation to the objectives set out in the scoping phase of the research. Computational software and small-scale physical experiments were also used to provide data which could be used to assess proposed hypotheses in relation to the impact of changes to operational aspects.

Contributions to Knowledge

Although a large amount of data has been reported in relation to swimming pool water quality to date, it has often been either reported with minimal information on the operational conditions of the facility or in relation to a restricted sample range (Lakind *et al.* 2010). In the current research, a substantial survey of the chemical and microbiological characteristics of the swimming pool water at Surrey Sports Park was undertaken, over an 18 month period, to generate the data required to assess the relationships between users and water quality. The range of parameters, sampling locations and sampling dates used in this survey, together with the access to associated occupancy and operational data, has provided a more substantial knowledge base than has been previously made available in the literature. This knowledge base enabled the impacts of different pool-based activities on water quality to be assessed. Activity type was found to be a factor in the degree of water contamination occurring during pool operation, not just the numbers of participants involved, as current guidance assumes. The relationship between activity type and water quality, as reported at the International Pool and Spa Conference held in Porto and the Engineering Doctorate Conference in 2011, is the first contribution to knowledge that was achieved during this research (Lewis et al. 2011a; 2011b).

The water quality survey also highlighted issues with the existing operational practices at the facility, namely the accumulation of dissolved non-reactive contaminants. Discussions with industry experts revealed that this issue was common throughout the industry and not specific to the facility involved in this research (PWTAG 2010). The investigation into operational practices at the research facility highlighted that a lack of performance indicators contributed to the mismanagement of the water replenishment. The Water Exchange Deficit, defined as the cumulative difference between the recommended and actual volume of water exchanged, is proposed as a new performance indicator. This is the second contribution to knowledge generated through this research.

The assessment of operational practices and current industry guidance identified that they were not effective at encouraging designers and operators to make sustainable decisions. Swimming pool facilities are large consumers of water, however, very little consideration for methods of reducing water demand has taken place to date. The over-simplification of current water management guidance, as published by PWTAG (2009), was proposed as a contributing factor. The current water management guidance does not clearly present operators with the potential benefits of utilising opportunities for improvements in water efficiency. It is recommended that the industry moves away from the current strategy that is based on a simple fixed water exchange rate to one that takes into account variations in the contributing factors behind the need for fresh water addition. These factors include the rate of evaporation from the pool (W_{ev}), the amount of contaminants introduced by the users (W_b) and the amount of contaminants introduced or formed as part of the water treatment process (W_c). An enhanced relationship for water consumption (W_p), as shown in Equation 0-1, is proposed in this research.

$$W_p = (F_b \times N \times ((F_{ns} \times W_{bi}) + W_{bc})) + W_c + W_{ev} \quad \textbf{Equation 0-1}$$

Where F_b is a factor accounting for errors in the calculation of bather numbers (N) via the half-hourly head count method, F_{ns} is the proportion of bathers not showering prior to participation and W_{bi} and W_{bc} are the water exchange requirements associated with the initial and continuous contaminants introduced by the bathers respectively. This is the third contribution to knowledge that has been made during this research.

The final contribution to knowledge that has resulted from the current research is in relation to the overall structure of the UK swimming industry. The disjointed and un-regulated approach of the industry to date has not been effective in delivering sustainable swimming pools that minimise the life cycle cost and associated health risks of facility operation whilst continuing to offer a welcoming environment and varied activity schedule to the public. A new framework for the industry has been proposed in this thesis.

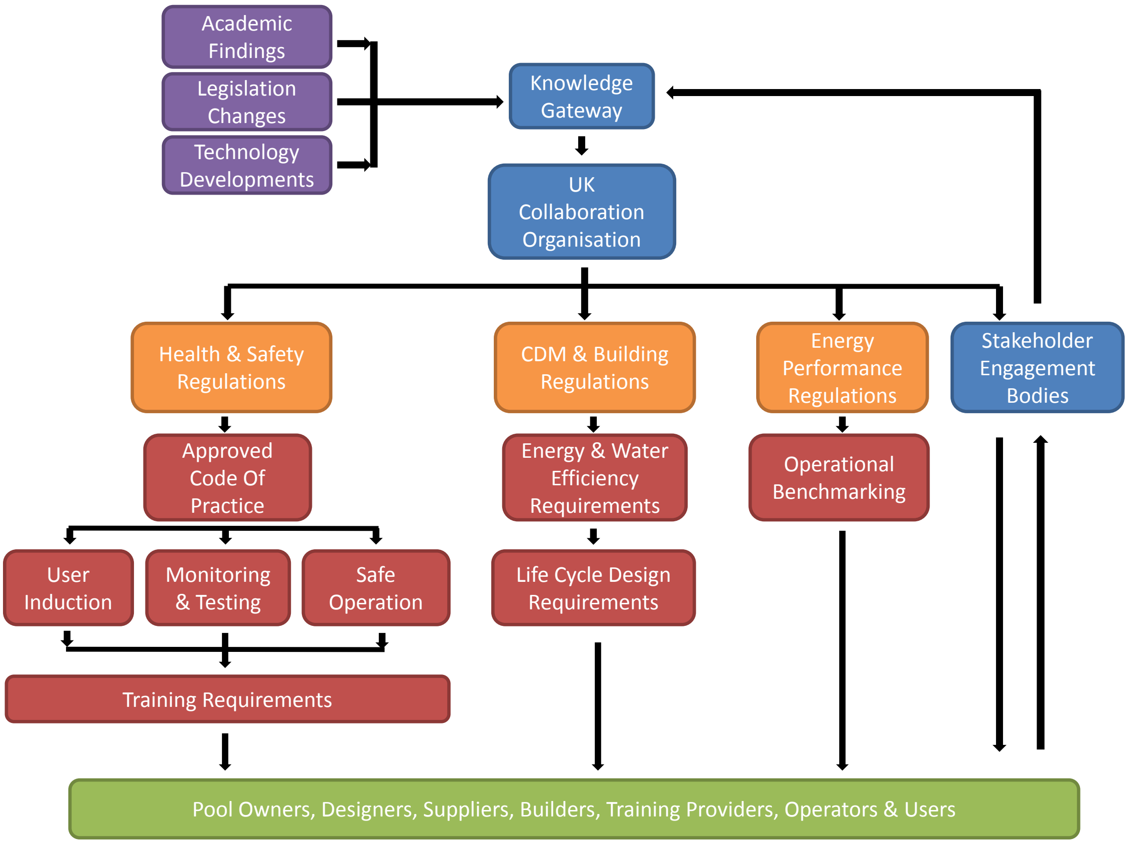

Figure 0-2 – A proposal for a new conceptual framework for the recreational water industry

The developed framework, shown in Figure 0-2, is based on the integration of the use of new approved documents under existing legislation with improved stakeholder collaboration and information sharing through a new knowledge gateway. The aim of the new framework is to encourage collaborative innovation and improved facility operation by enforcing minimum standards for fundamental aspects of the industry, such as requirements for training and water quality parameters, whilst leaving other aspects unrestricted, such as water treatment methodologies. One aspect that has been identified as needing substantial improvement is the promulgation of information to all stakeholders. Although the generation of industry guidance and regulation may be sufficient for those stakeholders who keep a close interest in industry publications, such as pool design companies, others will require active targeting and education, especially the general public. The addition of the requirement for user inductions and the formation of stakeholder engagement bodies as part of the proposed policy framework aims to address this issue. The framework also looks to encourage the use of risk-based assessments in the swimming industry through the adoption of Water Safety Plans similar to those used for drinking-water (WHO 2009).

Other Industry-Related Contributions

Aside from the four contributions mentioned above that are relevant to the industry as a whole, the research also involved studies that resulted in the development of the understanding of aspects relevant to the case of the Surrey Sports Park or the basis upon which future contributions to the industry could be made.

The research into the potential for modelling techniques to support the design and optimisation of swimming pool facilities was undertaken using the Surrey Sports Park as a test case. Both computational and physical modelling experiments were used to develop an initial modelling strategy for the swimming pool context. The modelling strategy enabled the existing hydraulics of the Surrey Sports Park swimming pool to be examined. More specifically, the ability for the current circulation rate to distribute disinfectants effectively and to remove water in a uniform fashion within the pool tank was investigated.

The distribution of disinfectant within the tank was simulated in the computational fluid dynamic modelling using a multi-phase time-accurate solver together with a Reynolds-averaged Navier-Stokes (RANS) based turbulence model. The results were validated using a combination of published data for several jet flow scenarios and dye visualisation results generated using physical experiments on a 1:50 scale model of the pool tank. The modelling showed that the current hydraulic strategy of the pool was effective at achieving disinfectant distribution throughout the tank within the currently recommended maximum time of 15 minutes. The pool turnover rate, defined as the time taken to exchange the water volume, was observed to be far longer than the estimated time calculated using the current guidance method. This is because of the guidance method assuming that the pool hydraulics is plug flow in nature whilst the requirement for disinfection distribution leads to well-mixed hydraulics to be adopted. The contradiction between the two recommendations in the current guidance needs to be addressed. The recent increase in implementation of ex-situ treatment technologies, such as UV and ozone, within the treatment plant opens the possibility to change the strategy used for pool hydraulics fundamentally as less emphasis is placed on traditional disinfection techniques within the main pool tank.

The specification of a modelling approach for the swimming pool requires further development in order to increase the confidence that can be placed on pool tank flows generated in this way. The work undertaken in this study provides a basis for this recommended future work. It is also advised that greater engagement with industries that currently use the technique in design processes is achieved to improve knowledge transfer into the swimming industry on a practical level. The addition of chemical reactions into the hydraulic simulations would be a useful tool to enable risk-based analysis of pool design and operation options.

The utility consumption of the entire facility was also evaluated during the research in order to put the swimming pool operation into the wider context of an entire multi-use leisure facility. Electrical consumption was observed to be the most significant factor in the overall cost of operating the SSP facility. The swimming pool was identified to contribute approximately 25% of the electrical consumption with water circulation and air conditioning making up the majority of this demand. The heating of the water in the facility is achieved using a biomass boiler which, although associated with a higher fuel cost, effectively reduced the carbon emissions of the facility. The reductions achieved were small compared to the emissions of the facility attributed to the electrical consumption. This high level review indicates that it could potentially be more beneficial to prioritise financial investment on the aspects that reduce the electrical demand of the facility. As water circulation is a fundamental requirement of swimming pool management and the facility already employed variable speed drives on the pumps, the opportunity to reduce the electrical consumption of this aspect further was limited. The evidence collected in the activity survey did indicate that it may be possible to use lower circulation rates during some activities, however, further research into the impacts of reduced circulation rates is required.

The review of operational procedures of the facility also showed that there were potential opportunities for efficiency savings to be realised through improving the understanding of the use of the facility in more detail. Trends in bather visits were analysed and the results showed that applying a uniform approach to pool management at the facility was not an efficient practice. The facility was observed to have a highly varied usage profile. The number of bathers using the pool followed both schedule-based variation and seasonal variation. Adapting the operating procedures to account for this variation could result in efficiency savings by modifying treatment intensity to suit pool usage. Again further research into the impacts of reduced treatment intensity is required alongside this recommendation.

The case study showed therefore that although water quality-related aspects are of importance when considering the welfare of bathers, the operational sustainability of large facilities is more affected by aspects that are related to the air handling system. Opportunities to improve the sustainability of SSP were identified during the research and were used to formulate a sustainability review for the facility. The documented opportunities included those that involved the modification to the infrastructure of the facility as well as those that focused on using the existing infrastructure in a more efficient manner. Key recommendations included the installation of a pool cover, the installation pool side controls for the treatment systems, the reuse of backwash water, the enforcement of pre-swim showers and increasing the temperature differential between water and air to 2^{o}C. The combination of these opportunities could realise cost savings of over £20,000 per year to the facility. The review also recommended that the potential for solar collectors, either for hot water or electricity generation, to be installed on the roof was re-assessed. The onsite generation of renewable electricity is likely to be the only way to make significant improvements in the environmental performance and operational cost of the facility.

Assessing the Research in the Context of the Engineering Doctorate in Sustainability for Engineering and Energy Systems

The research objectives and contributions to knowledge were also assessed in the context of the requirements for the Engineering Doctorate in Sustainability for Engineering and Energy Systems. The research objectives aimed to address the current challenges relating the sustainability of swimming pool facilities by evaluating the impacts of existing guidance and assessing the potential for policy developments to improve the efficiency of facility operation through the use of “industry-focused engineering” research. It is therefore considered that this work has met the requirements of the Engineering Doctorate in Sustainability for Engineering and Energy Systems by addressing both the “Engineering for Sustainability” and “Sustainable Energy and Low Carbon Systems” research themes.