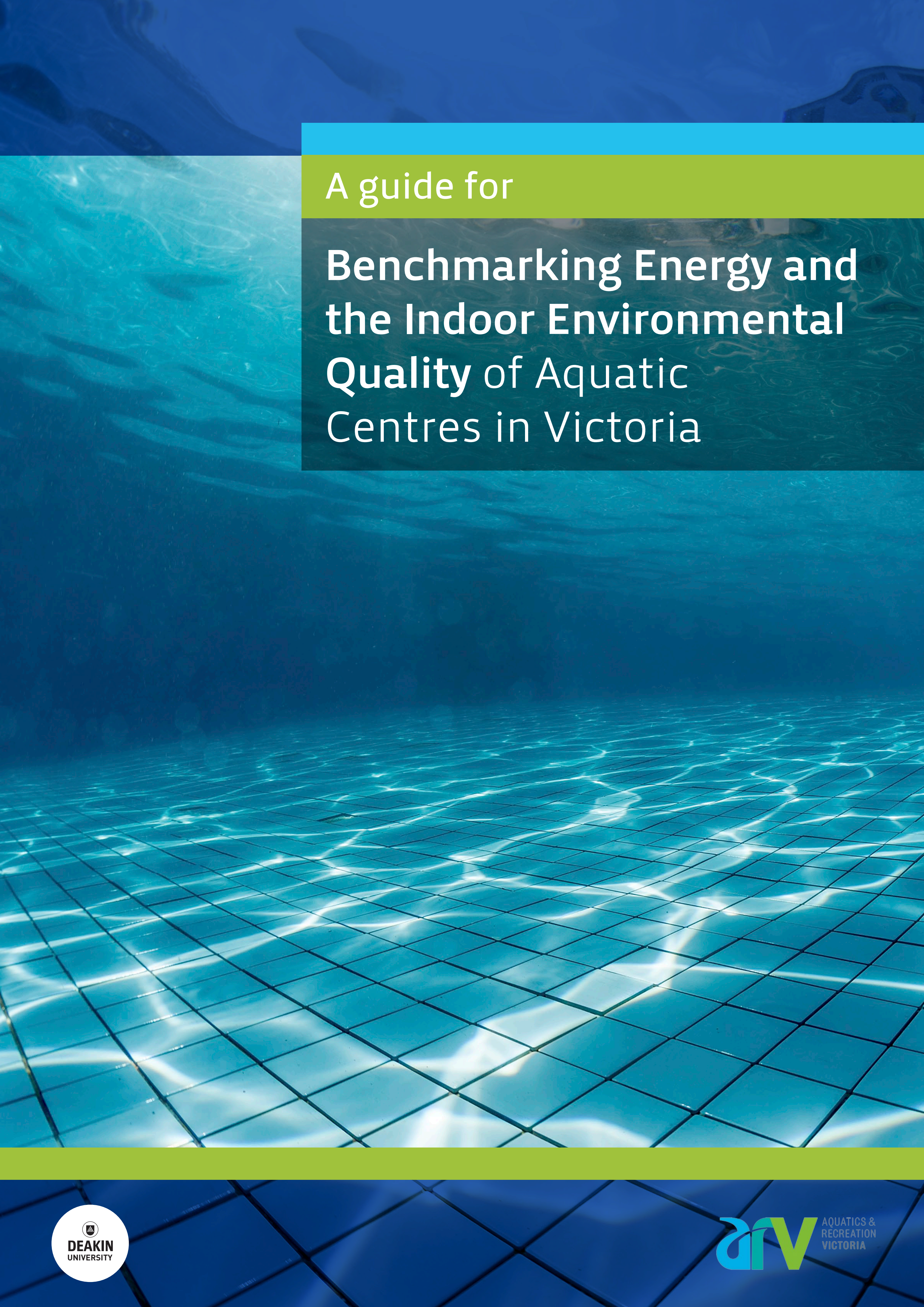


A guide for

Benchmarking Energy and the Indoor Environmental Quality of Aquatic Centres in Victoria

DEAKIN UNIVERSITY

ARV AQUATICS & RECREATION VICTORIA

DISCLAIMER

Published by Aquatic and Recreation Victoria
195 Wellington Rd, Clayton VIC 3168

Dr Priyadarsini Rajagopalan

School of Architecture and Built Environment

Deakin University

Mr Anthony McIntosh

Aquatic and Recreation Victoria

ACKNOWLEDGEMENTS

We thank the following individuals and organisations for providing critical and constructive feedback in developing the Guide for Benchmarking Energy and the Indoor Environmental Quality of Aquatic Centres in Victoria:

Ian Swan (Former CEO, ARV);

Sam Thorn (BRT Consultants);

Robert Quinn (EcoData);

Patrick Elliott (Umow Lai);

Grey Barton (Williams Ross Architects);

Mike McGrath (DWP Sutters);

David Newstead (Mantric Architecture);

Gordon Smith (Geoff Ninnes Fong);

Andrew Crellin (ADCO Constructions); and

Terry Mahoney (Air Barrier Technology).

We would also like to thank the following aquatic centres for agreeing to be case studies:

Splashdown Aquatic Centre (City of Greater Geelong);

Waves Leisure Centre (City of Kingston);

Peter Krenz (City of Greater Bendigo);

Glen Eira Sports and Recreation Centre (Glen Eira Council);

Pelican Park Recreation Centre (Morning Peninsula Shire);

Aqualink Boxhill (Whitehorse City Council); and

Warringah Aquatic Centre (Warringah Council)

Contents

Contents continued

Figures & Tables

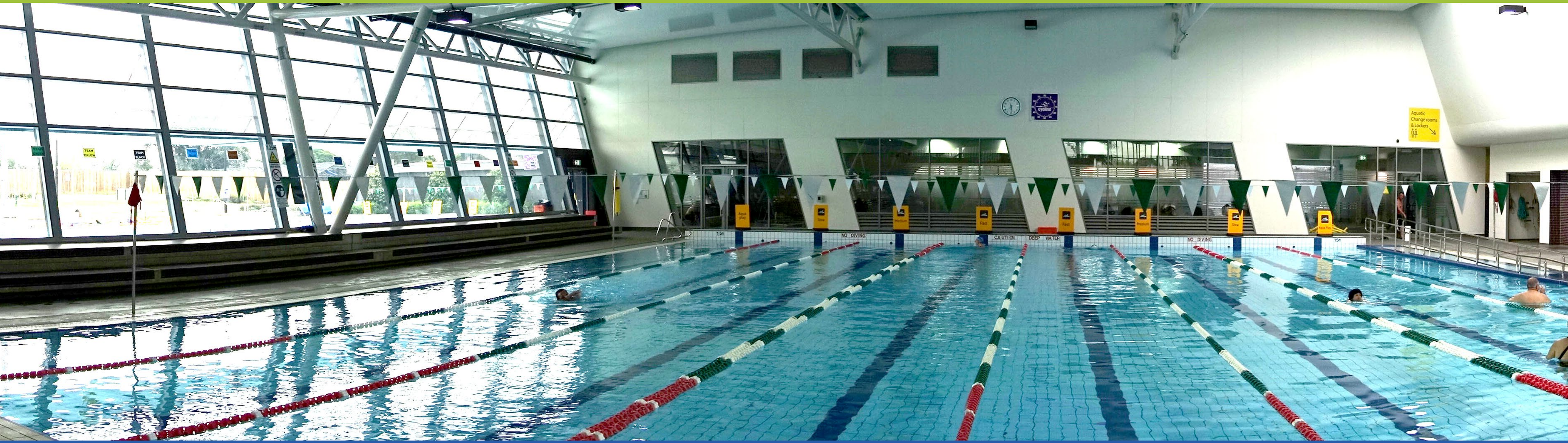
PAGE

List of Figures

List of Tables

1 INTRODUCTION

Over the past two years, Deakin University's School of Architecture and Built Environment has worked with Aquatics and Recreation Victoria (ARV) to undertake an energy benchmarking exercise with ARV's Facility Management Standing Committee and its member facilities and councils. The results of this research have been used to develop benchmarking guidelines for designing and operating aquatic centres in Victoria. These guidelines will assist local governments in the management of energy consumption by improving the day-to-day operations and guiding environmental decisions in the design of new infrastructure.



2 BACKGROUND

Recently, demands for sports facilities in urban areas have increased. Consequently, more attention is being directed towards creating healthy indoor environments for users. A growing desire for better Indoor Environmental Quality (IEQ) at indoor sports centres has resulted in marked increases in energy consumption in the building sector. Studies conducted in the United Kingdom (UK) have shown that £700 million is spent by sports sector buildings on energy every year with annual emissions amounting to 10 million tonnes of carbon dioxide (the principal contributor to climate change) (Building Research Energy Conservation Support Unit (BRECSU), 2001). Energy costs account for nearly 30 per cent of the total running costs of any typical sports centre and are second only to labour costs (Carbon Trust, 2006). Further, the types of activity conducted at sports centres have a significant effect on the energy requirements and costs of the building.

Aquatic centres represent popular recreational and sports facilities in Australia. During the early 1970s, Australian state and local governments implemented many programmes introducing new sports and aquatic facilities that emphasised the provision of indoor activities. Victoria's cold weather conditions created a need to enclose water bodies and led to Victoria having the largest number of indoor centres in Australia. Other Australian states with more sub-tropical/tropical climates have traditionally used open-air infrastructures or interactive spray parks and play spaces to take advantage of the warmer climate. Presently, many of these facilities lack integral environmental design strategies and thus have a large carbon footprint. Further, given the age of the existing buildings, a large number of the aquatic centres are due to be refurbished.

Victoria has an excess of 500 aquatic facilities, of which 277 (i.e., 55 per cent) belong to the local government. The remaining 233 (i.e., 45 per cent) are owned by private swim schools or educational institutions (ARV, 2009). The high-energy consumption of aquatic and recreation centres creates both challenges and opportunities for energy conservation and the improvement of indoor environmental conditions. However, environmental design standards for aquatic centres have generally been overlooked due to the complex nature of these buildings. Consequently, the sector lacks both qualitative and quantitative information and benchmarking guidelines. To identify opportunities for energy conservation and improve the environmental quality of indoor facilities, a comparison of the performance of aquatic centres was undertaken to establish benchmark data and best practice.

2.1 Why Benchmarking?

Energy benchmarking tools comparatively evaluate the energy performance of an existing building compared to similar buildings. Benchmarking allows buildings with similar functions and characteristics to be compared, reveals the relative standings of buildings in comparison to the group and sets achievable goals for improvements. It also allows facility managers to gain a deeper understanding of a building's energy needs and determine a building's relative performance in comparison to others to identify areas for improvement. However, before any effective measures can be taken, a clear understanding of the current energy use conditions must first be obtained. Knowledge of a country's building stock energy data and climatic zones is very important in the establishment of an energy benchmark.

Standardised methodologies can be used to benchmark the performances of buildings. The most commonly used energy benchmarking approaches include averages, medians, simple rankings and normalised rankings (Sharp, 1996). Some researchers have altered these approaches to accommodate special cases. Averages provide the most straightforward benchmark and allow for quick comparisons to be made between similar buildings in relation to energy efficiency. However, the use of averages for benchmarking requires careful consideration, as individual buildings with excessive energy intensity cause significantly higher averages. Medians are less sensitive to extremes; however, similar to averages, the information conveyed by this benchmark is limited. Conversely, normalised rankings consider differences in a building's functional and operational features and provide a more robust method of benchmarking. Energy Usage Intensity (EUI) (kWh/m^2/year) is the most commonly used indicator for benchmarking. However, a simple ranking based on floor area often masks functional and operational differences between buildings and has resulted in some buildings being unreasonably penalised and others being awarded undeservedly high grades; for example, aquatic centres with high occupancy have been penalised when directly compared to centres with much lower occupancy. Factors such as the number of occupants effect energy consumption, but are often inflexible. Thus, it is often beyond the ability of managers to alter these factors to make efficiency improvements. Accordingly, to make more equitable comparisons between buildings, these factors must be normalised. This usually involves collecting a list of potential 'drivers' of energy consumption from buildings and then applying regression techniques to identify the statistically significant factors for normalisation (Sharp, 1996, 1998).

2.2 Functional Spaces within an Aquatic Centre

Aquatic centres have many functional areas. Thus, it was necessary to define a clear boundary of what was to be included in the energy analysis. Swimming pools, sports halls and fitness centres cover the majority of floor areas in an aquatic centre. Requirements for these areas are discussed in further detail below.

2.2.1 Swimming pools

Centres with indoor swimming pools attract considerably higher visits than outdoor only centres. The energy consumption of a centre with an indoor swimming pool is approximately three times higher than that of an outdoor centre of the same size (International Centre for Energy and Environmental Technology (IECU), 1994). However, recent studies have shown that to improve financial viability and produce higher participation rates, decision-makers involved in the planning of public aquatic centres should aim to include multi-purpose facilities with indoor swimming pools and minimise facilities with outdoor swimming pools (Howat et al., 2005). Relatively, swimming pools have higher energy consumption than sports halls due to their specific requirements such as high latent, sensible and ventilation loads. The energy consumption of a typical indoor swimming pool facility comprises 45 per cent for space heating (including ventilation), 33 per cent for water heating, 10 per cent for heating and ventilating the remainder of the building, 9 per cent electricity for powering equipment and lighting and 3 per cent for hot water services (Trianti-Stourna et al., 1998). Swimming pool water evaporation increases the load for water heating. Additionally, the evaporated water increases indoor humidity levels that need to be controlled by increased ventilation rates. Further, if the indoor temperature is much higher than the water temperature, there may be complaints that the water temperature is too low, which may lead to higher evaporation rates. Thus, the temperature of the air and the water need to be linked and balanced to achieve the appropriate humidity, optimise user comfort and minimise the evaporation of swimming pool water.

Ma et al. (2006) suggested that 1–2°C is a suitable temperature difference between the water and the air. Indoor swimming pool facilities require large amounts of outside air to offset the amount of water in the atmosphere. Further, extensive water features will cause more evaporation and require more air change rates. The constant presence of moisture on glass and steel structures can also lead to corrosion, shortening the lifespan of a facility and can ultimately become dangerous. Any air circulation system should be able to distribute air effectively over the whole of the pool hall area to eliminate any chlorine odours, the risk of condensation and uncomfortable drafts. A smell of chlorine, high humidity and carbon dioxide levels are common at aquatic centres. Further, condensation on large glazed surfaces is not uncommon and promotes the growth of mould. Poor air quality at an indoor swimming pool centre can have a negative effect on the health of swimmers, coaches and swimming pool workers and can lead to respiratory problems. Fluctuations in relative humidity levels are an even greater concern, as relative humidity levels outside an appropriate range can result in increased human susceptibility to disease from bacteria, viruses, fungi and other contaminants and can potentially lead to respiratory problems (Baxter, 2012).

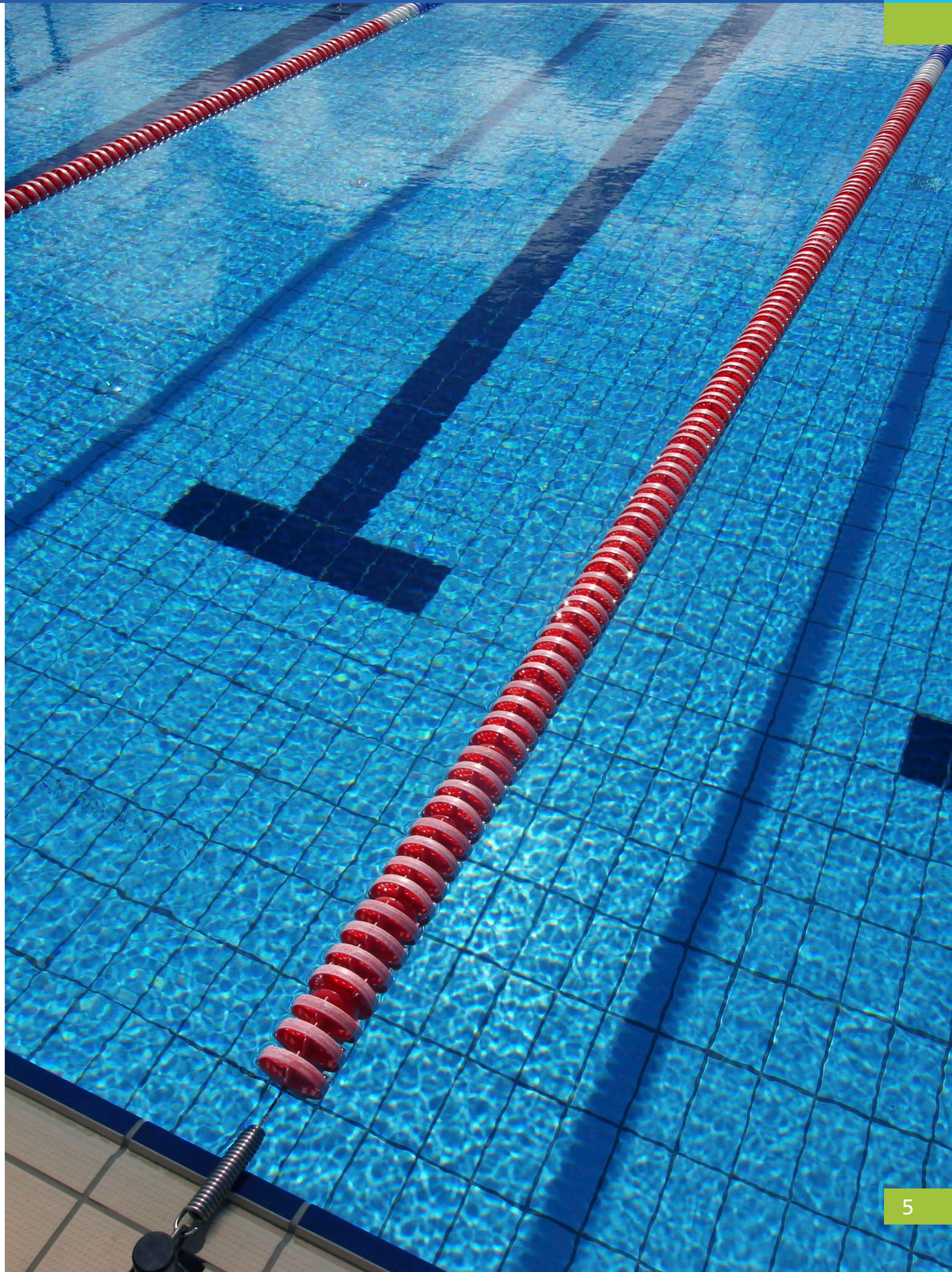
2.2.2 Sports halls and fitness centres

Indoor sports halls have different thermal requirements and are less energy intense than indoor swimming pool facilities. Sports halls generally have natural or hybrid ventilation systems whereas gymnasiums and fitness centres are air conditioned (using fan coil units or split units). In spaces such as stadiums and athletic halls, a large number of people may attend events and athletes may train and compete in a heavily polluted local environment (Stathopoulou et al., 2008). A numerical study using computational fluid dynamics revealed that significant thermal stratification occurs in gymnasiums and that annual cooling loads can be overestimated by 45.4 per cent for the best exhaust position if the effect of thermal stratification is not considered (Lam & Chan, 2001).

2.3 Challenges in Benchmarking Aquatic Centres

Benchmarking the energy performance and water usage of aquatic centres is a complex exercise, as the energy and water use pattern of aquatic centres differs completely to that of other building types. Further, every aquatic centre is different. Indeed, it is difficult to find two aquatic centres with similar amenities and consumption patterns.

Many studies have used floor area as an energy performance indicator for benchmarking. Floor area can include conditioned spaces and unconditioned spaces such as naturally ventilated stadiums or indoor sports halls. Combining these areas could affect the accuracy of the benchmark. Other studies have used usable area and water surface area as indicators. Using water surface area as a performance indicator makes energy comparisons between aquatic centres and other types of building (e.g., residential buildings, retail buildings and office buildings) difficult. As a performance indicator, water surface area might be appropriate if the benchmarking focuses on indoor swimming halls only. However, aquatic centres comprise several amenities, including gymnasiums, sport halls and cafés. Thus, using water surface area as a performance indicator could produce unreliable benchmarks.



3 SCOPE AND LIMITATIONS

This benchmarking guideline was based on the results of a detailed study of six aquatic centres in Victoria. These buildings represent the wider population of modern aquatic centres in Victoria in relation to a number of factors, including floor area, area of functional spaces and number of visitors (see Table 1).

Table 1: Range of floor areas and visitors

	Range
Floor area	2,944 to 8,500 m^2
Water surface area	640 to 1,650 m^2
Pool hall area	1,300 to 3,300 m^2
Annual visitors	168,000 to 1,200,000 people

Each facility considered in this study had two or more water bodies within the pool hall, such as a lap pool with multiple lap lanes (either 25 metres or 50 metres in length), a programme pool for swimming lessons, a leisure pool or a wellness pool. Programme pools are separate pools less than one metre in depth and have a large surface area to volume ratio. In addition, two facilities had outdoor swimming pools and multi-purpose sports halls. On average, the swimming pools occupied up to 35 per cent of the gross floor area of the facilities. Conversely, the area for gymnasiums and group fitness classes occupied up to of 19 per cent of the gross floor area. For a detailed description of each building see Appendix 1.

This study was subject to a number of limitations that should be taken into consideration:

- A limited number of samples;
- The contribution of each of the energy efficiency features was difficult to assess and varied from centre to centre;
- Differences in the type of fuel used influenced the energy and emission profile of the centres; for example, centres using cogeneration system used more gas and less electricity; and
- The IEQ was measured for two days at each centre during the winter months; no measurements were taken in summer.

4 METHODOLOGY

A comprehensive methodology was adopted for this study (see Figure 1). Methods included collecting energy bills to analyse monthly consumption patterns, collecting interval data of various systems using sub-metering and detailed IEQ monitoring of the pool hall areas. The measurements were taken in winter, representing an energy intensive period. The data collected were processed and verified to examine integrity and accuracy. The instrumentation applied included thermal comfort carts designed in accordance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 (2013). The carts measured the Dry Bulb (DB) temperature, the globe temperature (Tg) and the air velocity at heights of 0.1 m, 0.6 m and 1.1 m. Additional sensors measured relative humidity and CO_2 levels. The International Standard Organisation (ISO) 7730 (2005) thermal comfort model was applied. Further, a simple questionnaire (see Appendix 2) was distributed to the occupants of the six aquatic centres to evaluate the thermal comfort sensation. Procedures outlined in ASHRAE Standard 55 (2009) were adopted.

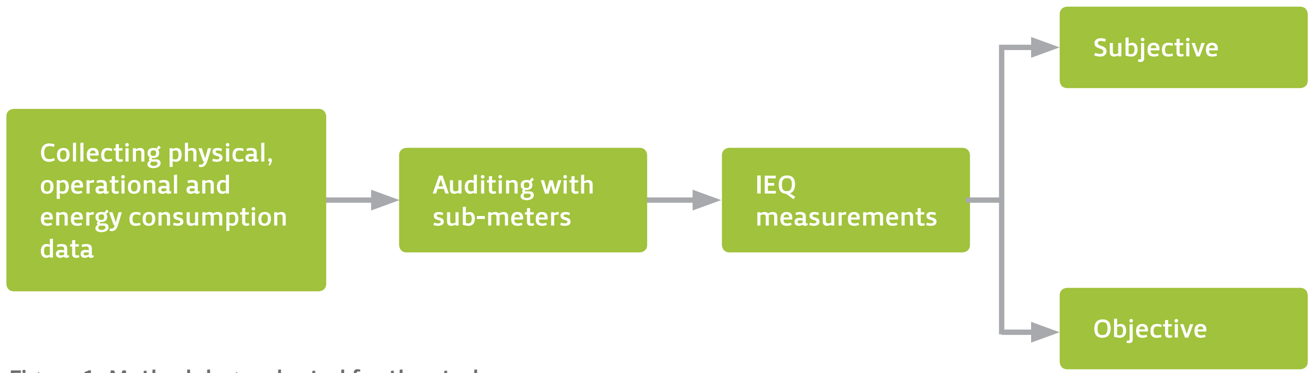


Figure 1: Methodology adopted for the study

A weather station was positioned on the rooftop of each building (unobstructed by other neighbouring building structures) to record weather data. Figure 2 shows air temperatures, relative humidity, solar radiation and wind speeds measured over a two-day period. The weather conditions are representative of the winter season. These results were considered in analysing the data collected from inside the pool hall. Temperatures ranged from 10 to 15 °C (with an average of 12°C). Relative humidity ranged from 42 to 93 per cent. The maximum solar radiation was 320 W/m².

The measured data was analysed to understand the inter-relationships between numerous factors contributing to the energy consumption of these facilities and determine the significant drivers of building energy use on a site energy basis.

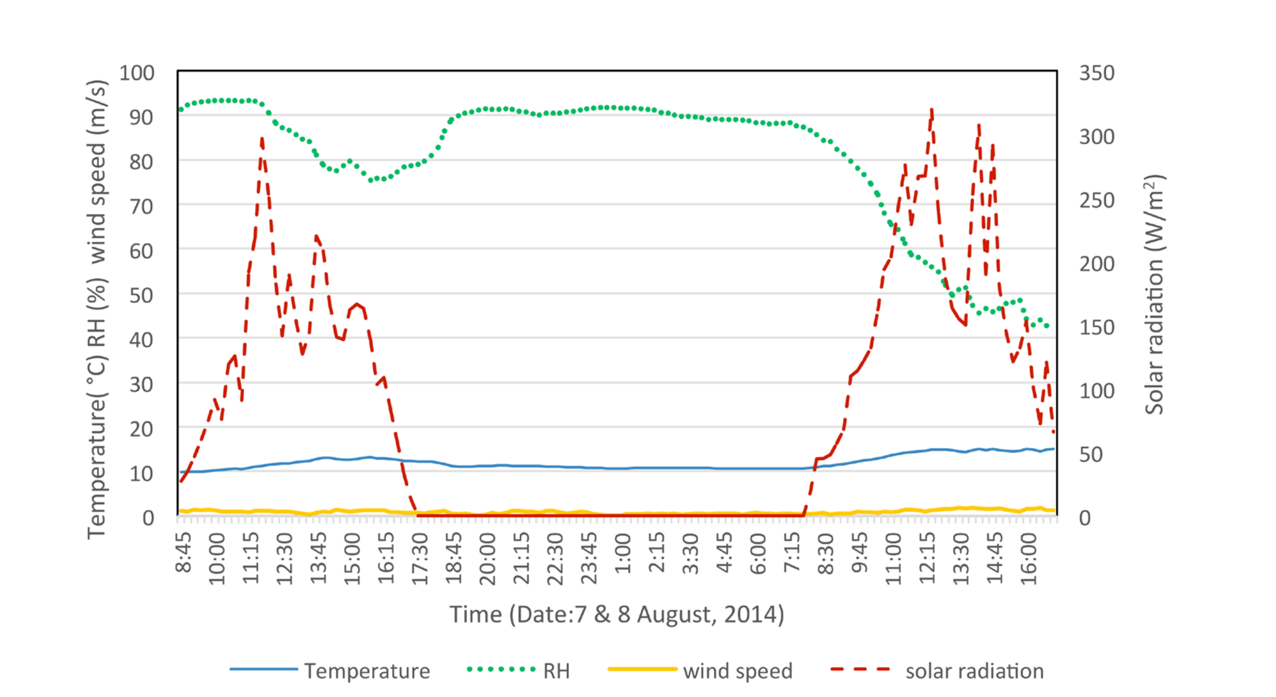


Figure 2: External weather data

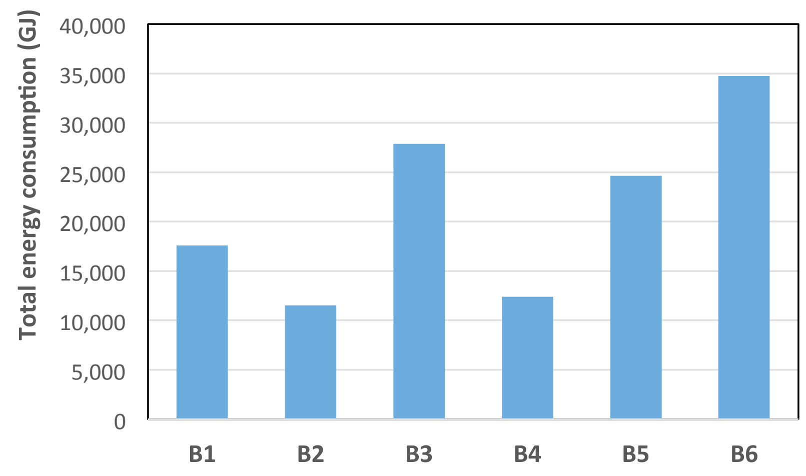
5 OPERATIONAL BENCHMARKS

5.1 Energy Consumption

Aquatic facilities, like most other building types in Australia, use both electricity and gas. Electricity is used for lights, gym equipment, pumps, fans while gas is used for space and pool heating. Motors, fans and pumps were used widely throughout the swimming pool buildings for water treatment and ventilation systems. The average proportion of gas to electricity was approximately 75 to 25 per cent. Most of the electricity generated in Australia is derived from coal and gas with black coal, brown coal and gas constituting 55 per cent, 22 per cent and 15 per cent of the total electricity, respectively. There are different emission factors for electricity and gas that vary from state to state. Eighty-five per cent of the electricity generated in Victoria is fuelled by brown coal, making it a huge contributor to the state's total greenhouse gas emissions. The remainder is sourced from natural gas and renewable energy sources (e.g., hydro, wind and solar).

The method used to heat pool water is an important consideration. Different options include electric resistance heaters, electric heat pumps, gas-fired boilers, solar thermal and the use of waste heat. Electric resistance heaters are the most expensive to operate. Most of the energy load of a swimming pool is used to heat the pool water and pool hall air. To control pool hall air quality, a large quantity of heated moist air must be expelled from the hall. Heat from the pool water is also lost during the backwashing of filters or when make-up water is added. Figure 3 shows the total annual energy consumption, including electricity and gas, for the six centres. The total annual energy ranged from 11,542 to 34,747 GJ. The average consumption of the six centres was 19,375 GJ (5,382 MWh). Figure 4 shows the breakdown of energy consumption in relation to electricity and gas. For Building 1 (B1) and Building 3 (B3), gas consumption comprised approximately 85 per cent of the total energy expended. This is because these two buildings used gas to run cogeneration plants to generate energy on site.

Figure 3: Total annual energy consumption



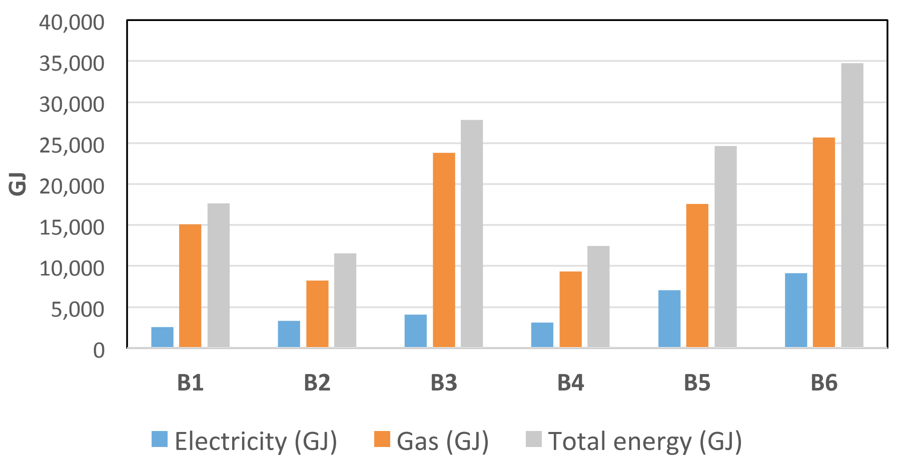


Figure 4: Electricity, gas and total energy consumption

5.2 Normalised Energy Consumption

Energy use per unit area or Energy Usage Intensity (EUI) is the most commonly used indicator in benchmarking studies. However, a lack of clarity exists as to how to determine the best indicators. Some studies have used usable area and water surface area as performance indicators. Using water surface as a performance indicator makes energy comparisons between aquatic centres and other types of building difficult. As a performance indicator, water surface area might be appropriate if only indoor swimming halls are being considered in the benchmarking. However, most aquatic centres include several amenities and dry areas (e.g. gymnasiums, sport halls and cafés). The number of visitors also has an impact on the energy consumption of centres. A statistical analysis involving more samples would help to determine the indicator that best predicts energy usage.

5.2.1 Annual energy per gross floor area

Figure 5 shows the total energy consumption along with gross floor area. Gross floor area includes conditioned and unconditioned areas. The unconditioned floor area includes storerooms, plant rooms, multi-purpose sports halls and basketball stadiums. Outdoor swimming pools were not included in the gross floor area calculation. It should be noted that B3 and Building 6 (B6) had outdoor swimming pools of 25 m and 50 m, respectively. The gross floor area of the buildings ranged from 2,944 to 8,500 m^2. Figure 6 shows the total energy consumption normalised with gross floor area. The EUI per floor area values ranged from 1,824 to 5,983 MJ/m^2.

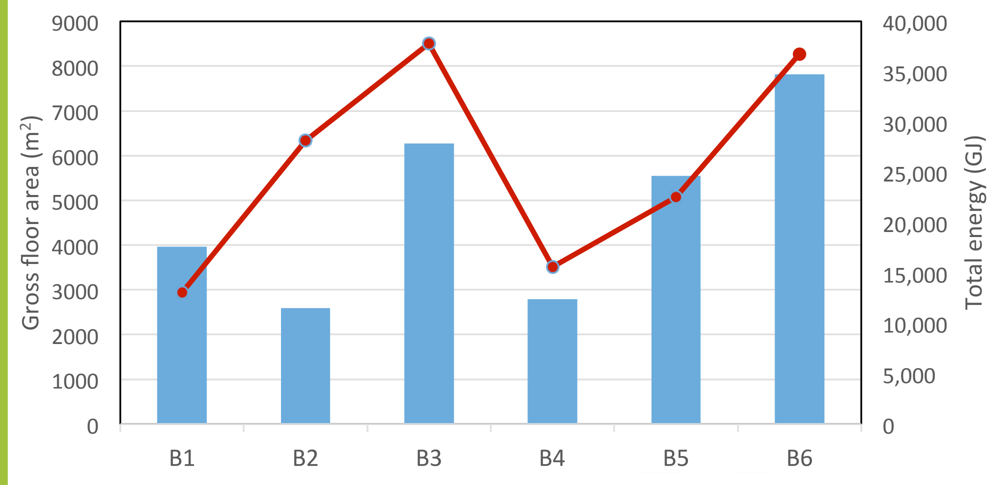


Figure 5: Total energy and gross floor area

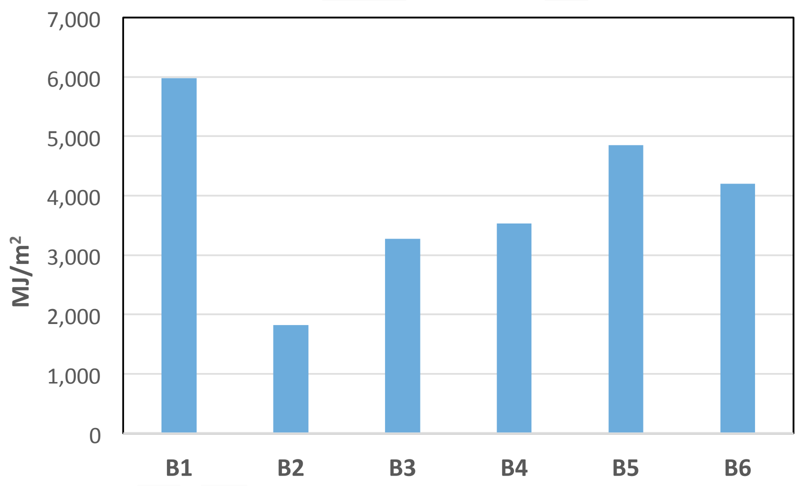


Figure 6: Total energy normalised with gross floor area

5.2.2 Annual energy per visitors

Visitors used the dry amenities (e.g., gymnasiums, sport halls and childcare facilities) and the swimming pools. Visitors that use swimming pools contribute to the bather load and will use more energy and water compared to visitors using dry amenities. Thus, energy consumption should be analysed separately in relation to the total number of visitors and the number of bathers. However, most of the centres did not separately record the number of visitors using the swimming pool; thus, the total number of visitors had to be used in the analysis. The number of annual visitors at the six centres ranged from 168,000 to 1,200,000 people. Figure 7 shows the total annual energy consumption and the number of visitors. The number of visitors correlated with energy consumption. Figure 8 shows total energy consumption per visit. There was a considerable variation among the values (ranging from 25 to 76 MJ/visit). Building 4 (B4) had the highest energy consumption per visit and B3 the lowest.

Figure 7: Annual energy along with the number of visits

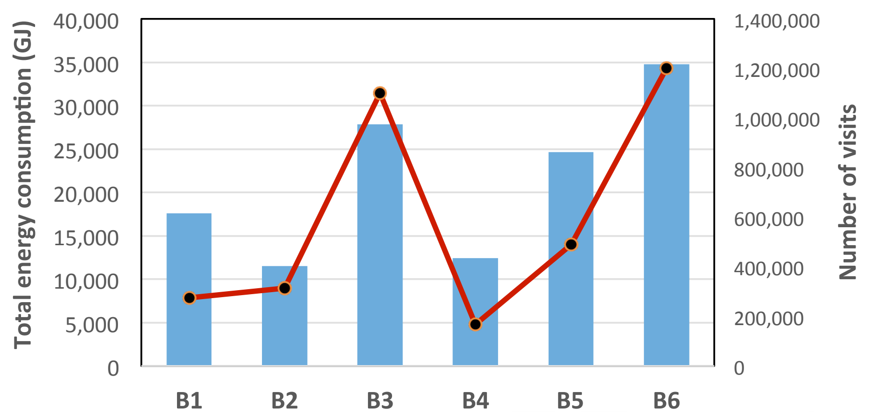
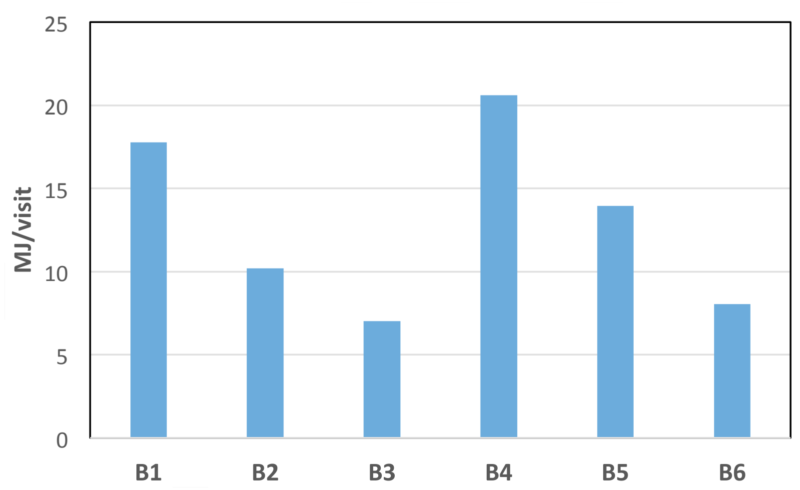


Figure 8: Annual energy per visit



5.2.3 Annual energy per water surface area

As a performance indicator, water surface area is appropriate for studies focusing on indoor pool halls only. Figure 9 shows total energy consumption and water surface area. B3 and B6 had large water surface areas, including both indoor and outdoor swimming pools. Figure 10 shows the total energy normalised to water surface area.

Figure 9: Energy consumption along with water surface area

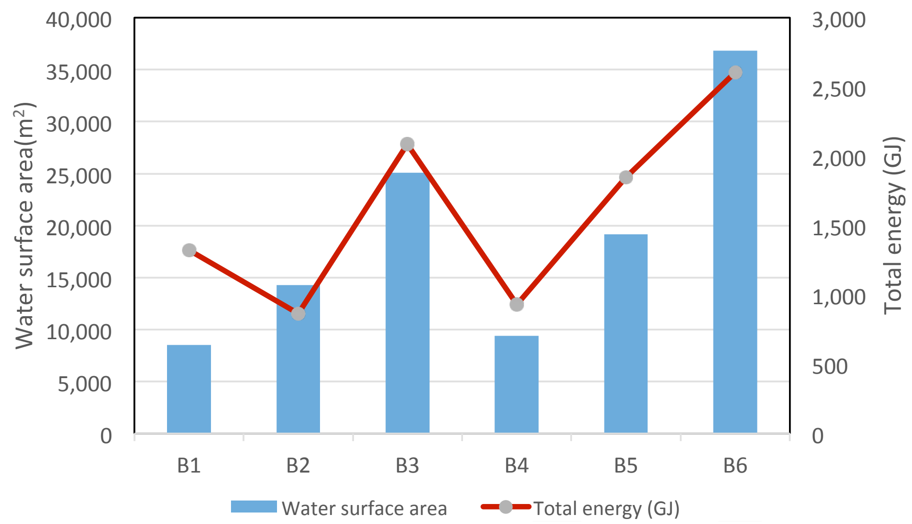
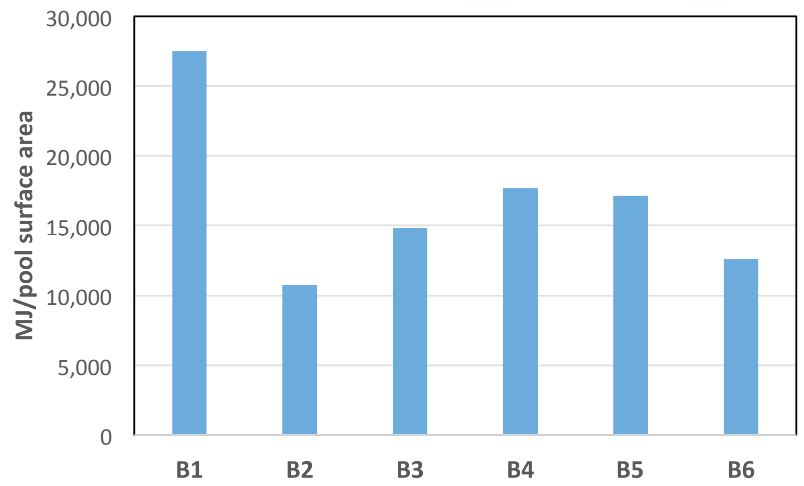


Figure 10: Total energy per water surface area



5.3 Carbon Dioxide Emissions

Depending on the energy profile of the facility, a number of technologies can be used to meet the heating and/or cooling needs of a site. The environmental effects of different fuel options should be taken into account. Electricity is not a primary fuel and its production and distribution result in substantial energy loss and CO_2 emissions. In Victoria, the emission factor for electricity in Victoria is currently 1.18 $kgCO_2$-e/kWh and for gas, it is 3.9 $kgCO_2$-e/GJ (Australian Government Department of Industry, Innovation and Science 2014).

Figure 11: Carbon Dioxide emissions

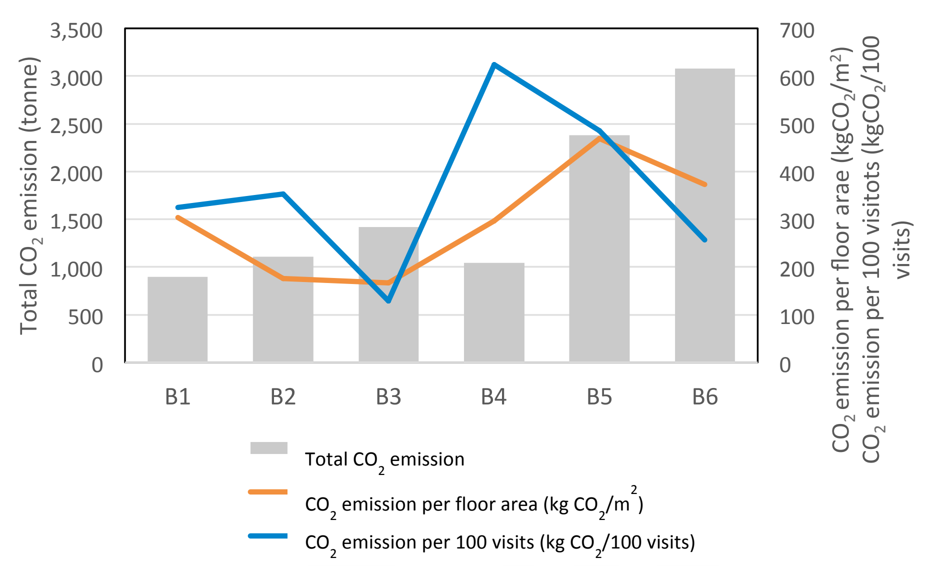


Figure 11 shows the total CO_2 emissions and normalised CO_2 emissions. B6 had the highest CO_2 emissions and B1 the lowest. B4 had lower CO_2 emissions than other buildings; however, its normalised emissions in relation to the total number of visitors and total floor area were very high. Building 5 (B5) had the highest emissions per floor area. B1 had the highest energy consumption per floor area (see Figure 6); however, its CO_2 emissions per floor area were not very high because its cogeneration system used significantly less electricity than gas. B3 also used a cogeneration system and had the lowest CO_2 emissions in relation to the number of visitors and total floor area.

5.4 Water Usage

The real cost of water to a business is more than the water meter charges (Sydney Water Corporation, 2011). Efficient water use can also result in energy savings. Figure 12 shows the water consumption of the six facilities. The water consumption ranged from 11,000 kL to 36,600 kL. B6 used the highest amount of water and had the highest number of visitors (i.e., 1.2 million a year). The number of visitors has a significant effect on water consumption. Visitors using fitness and sporting facilities used less water than swimming pool patrons. Water use per person (per visit) is a more appropriate indicator than water use per swimming pool patron (i.e., bather), as it also includes patrons using dry amenities such as gymnasiums, sport halls, childcare facilities.

Figure 13 shows water usage per number of visitors. B4 had the highest water usage per visitor (at 96 L/visitor) and B3 had the lowest water usage per visitor (at 22 L/visitor). A study on the water usage of aquatic centres in New South Wales showed that water usage ranged from 20 L/bather to 60 L/bather (Sydney Water Corporation, 2011). The number of bathers was generally lower than the number of total visits. Thus, the water usage of aquatic centres in Victoria was higher than that for aquatic centres in New South Wales.

Figure 14 shows that the water usage per pool surface area ranged from 1,000 to 2,100 kL. The Best Practise Tracker developed by Sustainability Victoria used water surface area to compare energy use across centres. Pool water heating, pool hall heating and ventilation were generally the largest components of energy use in aquatic centres; thus, pool surface area relates directly to water and energy consumption for these components. However, the energy consumption of dry facilities and respective floor areas must be taken into consideration in any comprehensive analysis.

According to the Sydney Water Corporation (2011), aquatic centres waste an average 22 per cent of the total water used through leaks and base flows. Monitoring the use of water can aid understandings of a facility's water use patterns and allow leaks to be identified that may have otherwise remain undetected, incurring unnecessary costs. Data loggers fitted to gas metres can store water usage data. Online monitoring systems also enable the data to be monitored 'live'.

Figure 12: Annual water consumption

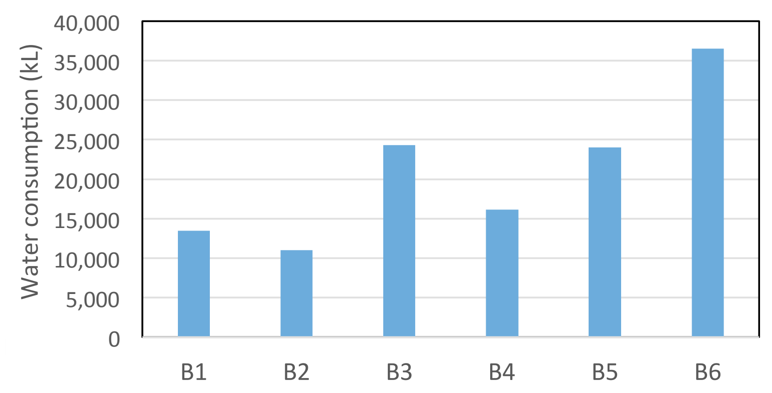


Figure 13: Water consumption in relation to number of visitors

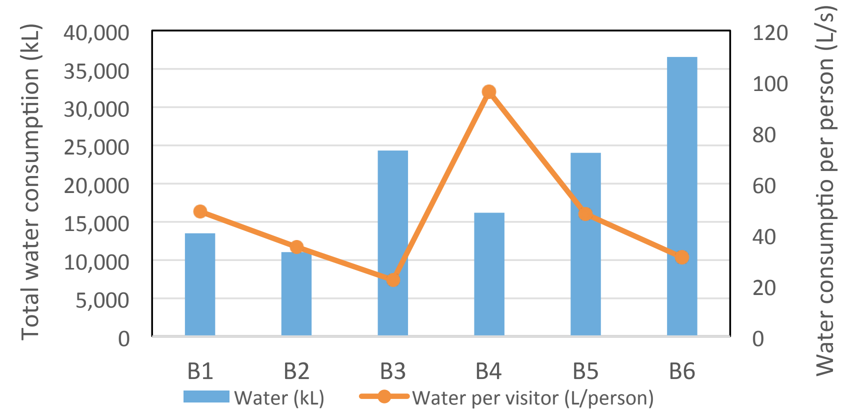
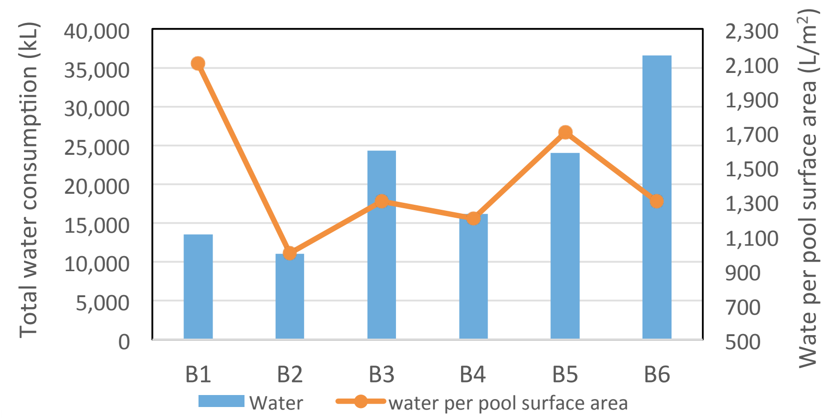


Figure 14: Water consumption in relation to pool surface area



6 INDOOR ENVIRONMENTAL QUALITY

Several studies have been conducted in naturally and mechanically ventilated office buildings to examine the relationship between IEQ and occupants' perceptions. However, very few studies have been conducted on the IEQ of aquatic centres. Today, new advanced Heating, Ventilation and Air Conditioning (HVAC) systems have replaced old systems; however, community expectations towards the overall indoor comfort of aquatic centres have not been adequately met. Pool water temperature, air temperature, relative humidity, ventilation, lighting and water pumping must be controlled to create healthier indoor environments for different users (e.g., swimmers, spectators and staff) each of whom wear different types of clothing and engage in various levels of activity.

6.1 Thermal Comfort

A safe, comfortable and appealing internal environment is crucial to attract and sustain customers. Under Australian Standard 1668.2 (2002), indoor DB temperature should be maintained between 22.5 and 25.5 °C and the average relative humidity should not exceed 70 per cent for any building (when an air-conditioning system is in operation. According to the ASHRAE Handbook (2003), air temperatures in public and institutional swimming pools should be maintained at 1–2°C above the pool temperature to reduce the evaporation rate and avoid chill effecting swimmers. Table 2 sets out the recommended indoor environmental conditions as per the Pool Operators' Handbook (Victorian Government Department of Human Services, 2008) and the Australian Standards (2002). In this study, comfort levels of the pool halls were generally observed to be warmer. Higher temperatures may be expected and deemed quite acceptable by visitors exiting pools, as they are wet and wearing less clothing. Visitors will also experience evaporation as they dry that creates a cooling effect. Additionally, visitors' activity levels may be significantly reduced after swimming, dropping their comfort levels towards a neutral temperature. Given the increasingly wide variety of pool uses and flexible pool operations, it is difficult to select a single appropriate or optimum operating temperature for any particular pool (Victorian Government Department of Human Services, 2008). Higher temperatures can cause discomfort to swimmers and, consequently, limit vigorous swimming and increase water pollution through sweat and body oil contamination. Higher water and air temperatures also increase direct and indirect energy costs. With higher temperatures, moisture levels in the pool increase even if relative humidity is controlled at the same level. This causes a risk of condensation and, possibly, the corrosion and deterioration of building fabrics, structures and equipment. It can also increase the rate of chloramine formation (Pool Water Treatment Advisory Group (PWTAG), n.d.).

Table 2: Recommended indoor environmental conditions

Air Temperature	Humidity	Pool Water Temperature (°C)	Ventilation (l/s)	Lighting Levels (lux)	Sound Levels (DB(A))
27°C in the pool hall, not more than 29°C	50–60%	26–30 for lap pools	10 l/s for sports hall 10 l/s for pool and deck areas 15 l/s for spa and hydrotherapy	300 for recreation and training 500 for competition 600 for international, national or state competition	45 – 50 with coaching 50-55 without coaching

Evaluations of the thermal comfort of swimming pool environments consider three user groups: swimmers, spectators (who care for children undertaking swimming lessons) and staff members (working as swimming pool attendants). It should be noted that thermal comfort is very sensitive to clothing and activity levels. Clothing levels change according to the seasons; visitors may wear more clothes in winter to adapt to outside conditions. Figures 17, 18 and Table 3 show the results of measured indoor environmental parameters and user surveys. Approximately 100 completed surveys were collected from the six centres resulting in total 721 samples. The survey (see Appendix 2) comprised 15 short questions, including questions on the age and gender of the visitors, purpose of visit, time and frequency of visit(s), number of hours spent at the facility on each visit and clothing. Survey participants were able to choose from list of clothing that cover various body parts such as the head, upper body, lower body and feet. The clothing values were calculated using ISO 9920 (2007).

Swimming pool users could belong to one of three categories: staff (who normally spend approximately 4–5 hours inside the pool hall), swimmers (who spend 1–2 hours inside the pool hall) and carers of young children attending swimming lessons (who spend approximately 1 hour inside the pool hall on each visit). The metabolic rate of each of the user groups was determined using ISO 8996 (2004). Survey participants were asked to record their thermal feeling on that day using a seven point scale ranging from cold (−3) to hot (+3). Survey participants were sitting, standing or walking inside the pool hall when they were approached and asked to complete the survey. The thermal feelings recorded by the survey participants were considered to be equivalent to their average feeling during the overall time they spent inside. Simultaneously, thermal comfort measurements were conducted at various locations in the pool hall using a movable thermal comfort cart. The cart was fitted with various sensors to measure air temperature, mean radiant temperature, humidity and wind speed at occupant levels.

6.1.1 Thermal comfort measurement

Figure 15 sets out thermal comfort measurements in the pool halls using comfort cart. Table 3 shows the mean air temperature, relative humidity and water temperature measured at the six facilities. The temperatures measured were above 29°C in B3 and B4 and approximately 24°C in Building 2 (B2). B3 had the highest average relative humidity (i.e., 72 per cent) and B1 the lowest (i.e., 52 per cent). B5 also had low relative humidity (i.e., 54 per cent).t

Figure 15: Comfort cart thermal comfort measurements

Table 3: Indoor environmental parameters setting

	Mean Air Temperature (°C)	Mean RH (%)	Water Temperature (°C)
B1	28.06	52.21	31
B2	24.26	69.53	27
B3	29.07	72.04	27
B4	29.16	61.26	29
B5	26.74	54.03	28
B6	27.57	64.39	28

Figure 16 shows the thermal comfort scale where comfort feeling is represented as a Predicted Mean Vote (PMV) ranging from -3 to +3. The right hand of the scale shows slightly warm to hot conditions, whereas the left hand side shows slightly cool to cold conditions. The middle of the scale (zero) represents a neutral thermal condition. When the PMV was within the range of -0.5 to 0.5, participants perceived their environments as thermally comfortable.

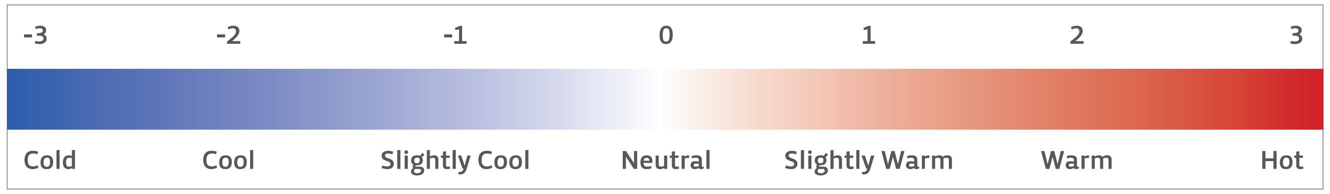


Figure 16: Thermal comfort scale

Figure 17 shows the thermal comfort of swimmers, staff and spectators and pool hall temperatures. The results ranged from 0 (neutral) to 2 (warm). Mean PMVs for B3 and B4 were 1.69 and 1.64, respectively. It should be noted that the mean air temperatures of B3 and B4 were set at 29°C (a temperature that was quite high compared to the temperatures of the other buildings). The PMV for staff and spectators were very similar. In relation to B1, B3, B4 and B6, the PMVs for spectators ranged from 'slightly warm' to 'warm'. B5 had a reasonably satisfactory PMV range within the slightly warm zone (i.e., 0.92 for staff and 0.85 for spectators). Overall, B5 with its set point temperature of 26°C–27°C and humidity of 50–58 per cent provided a comfortable thermal environment for all the three groups. However, it should be noted that lower relative humidity levels increase the evaporation rate, thus increasing energy and water consumption.

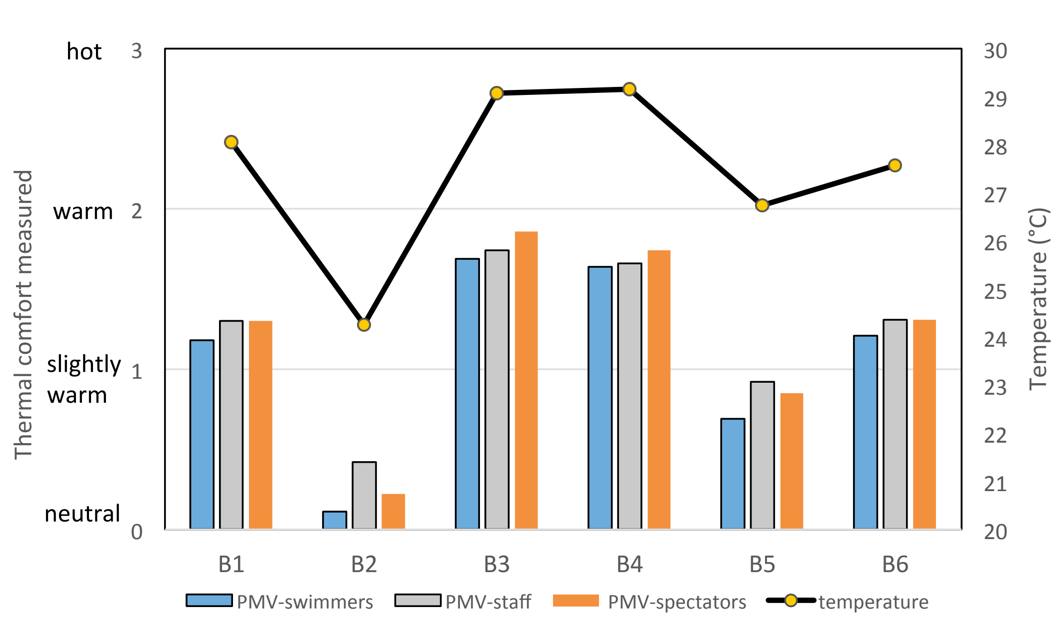


Figure 17: Thermal comfort levels (PMV) measured in the pool hall

6.1.2 Thermal comfort survey

Upon receipt of the completed surveys from each facility, they were grouped according to whether they were completed by swimmers, spectators and staff. Spectators comprised the largest group of participants, followed by swimmers. The total number of staff who completed the survey was quite small in comparison to swimmers and spectators. Figure 18 shows average thermal comfort rates and the set point temperatures inside the pool halls for each facility. The survey results showed that occupants' thermal comfort correlated well with the temperature of the pool hall. The thermal comfort experienced by spectators and staff generally ranged from 'neutral' to 'warm', whereas the thermal comfort experienced by the swimmers ranged from 'neutral' to 'slightly warm' in all buildings except B4. The thermal comfort experienced by staff was in the range of warm in B3 and B4. It should be noted that staff spend more time (i.e., 4–5 hours) inside the buildings compared to other user groups.

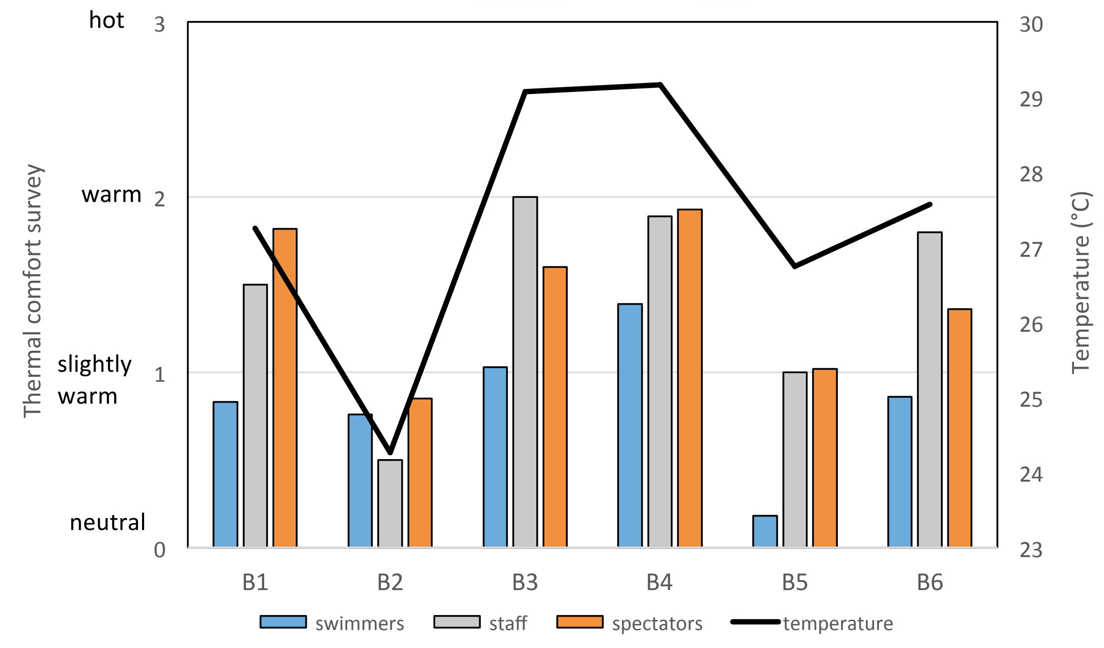


Figure 18: Thermal comfort results from the survey

6.2 Air Quality

6.2.1 Carbon dioxide levels

CO_2 levels below 1,000 ppm in indoor environments indicate adequate air circulation. CO_2 concentrations in outdoor air typically range from 300 to 500 ppm. Figure 19 shows the CO_2 levels measured over the two-day period. B1 and B2 had higher levels of CO_2 with concentrations increasing up to 1,600 ppm during certain periods. Most of the facilities used CO_2 to reduce the pH level of water. Uncontrolled CO_2 use in the water resulted in high CO_2 levels in the pool hall air. B6 had the lowest level of CO_2 (< 600 ppm) for the entire measurement period.

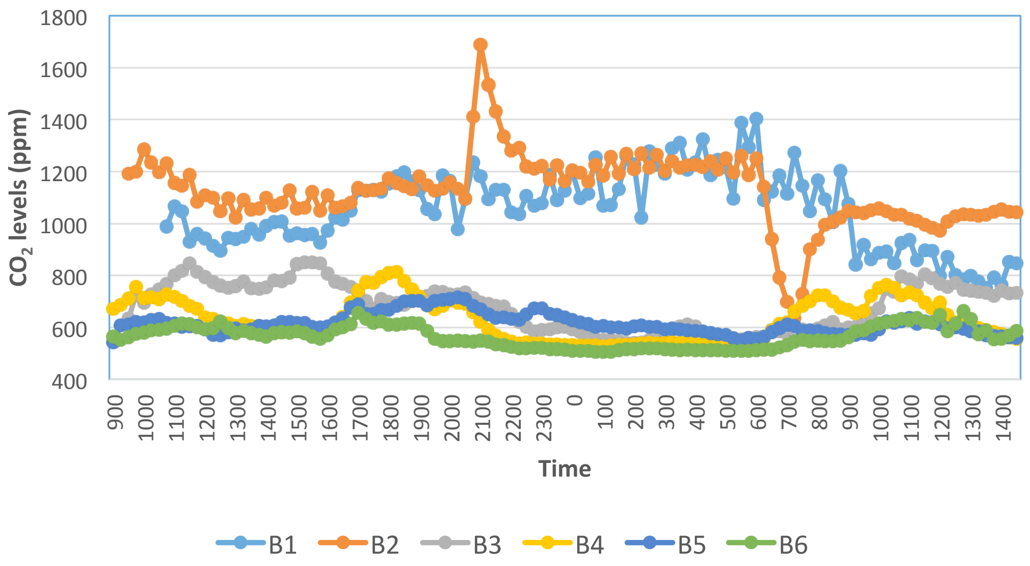


Figure 19: Carbon dioxide levels

6.2.2 Chloramines

Aquatic centres require a considerable disinfection to avoid microbiological pollution; however, paradoxically, disinfection by-products can create health hazards. Individuals commonly walk into indoor swimming pool facilities and perceive a smell 'chlorine', but this odour is not caused by excess chlorine; rather it is caused by a chlorine compound called chloramine that is formed in the water and released from the surface of the pool. Several studies have shown that associated increases in asthma and respiratory illnesses in swimming pool patrons, lifeguards, coaches and observers are the result of exposure to disinfection by-products. Further, these by-products are also the primary cause of facility corrosion.

It is well recognised that chlorine discharging agents such as calcium or sodium hypochlorite are frequently used to disinfect water in swimming pools. These chemicals give rise to chloramines that are inorganic compounds. There are three types of chloramine: monochloramine, dichloramine and trichloramine. Trichloramine is toxic and a major cause of swimmer discomfort. Physiological responses to trichloramine exposure include sneezing, coughing, irritated eyes, difficulty breathing, tightness in the chest, chest congestion and increased risk of asthma.

Over the past few years, research has focused on the quality of pool hall air quality and, in particular, the effects of chronic lung exposure to chlorine and its by-products, especially in young children (Bernard et al., 2003). Respiratory symptoms and asthma is more prevalent in competitive swimmers than other athletes (Goodman & Hays, 2008). Thickett et al. (2002) found that trichloramine can be a cause of occupational asthma in swimming instructors and lifeguards. A study of Jacobs et al. (2007) showed an elevated prevalence of respiratory symptoms in Deutsch swimming pool workers compared to the general Dutch population. Parrat et al. (2012) showed that even relatively low exposures to trichloramine (i.e., up to 0.3 mg/m^3) could cause health problems. Predieri and Giacobazzi (2012) noted that the most sensitive populations to environmental factors are babies and young children, as at these ages, organisms are more vulnerable to toxins because immunological and lung development is not yet complete. Additionally, fluctuation of relative humidity levels can be an even greater concern, as relative humidity levels outside the normal range can result in increased human susceptibility to diseases from bacteria, viruses, fungi and other contaminants and potentially lead to respiratory problems (Baxter, 2012).

The quantity of trichloramine emitted from pool water depends on various factors such as water temperature, water agitation, bather load, the concentration of urea and free chlorine as well as air ventilation conditions. However, the chemical composition of swimming pool air is extremely complex and how these factors are associated with trichloramine levels in the air is poorly understood (WHO, 2000). Due to energy costs, the fresh air ratio is often reduced, leading to insufficient by-product reduction (Parrat et al., 2012). Swimming pools need large amounts of outside air to offset the amount of water in the atmosphere. Air circulation systems should be able to distribute air effectively over the whole of the pool hall area to eliminate any chlorine odours, risk of condensation and uncomfortable drafts. As a result of a few studies conducted in late 1990s, the World Health Organization (WHO) (2006) recommended a reference value of 0.5 mg/m^3 of trichloramine in the air.

Despite the considerably different heating ventilation and air-conditioning systems used in Australia, to date, no studies have been published on the level of trichloramines in the Australian aquatic centres. A proper balance of chloramine control, air distribution, outdoor air and room exhaust air along with air movement at the water surface is crucial to ensure good indoor air quality. Chloramines also corrode handrails, ladders, exposed steel structural elements and HVAC components.

Measurements were conducted at two facilities (i.e., B3 and B6) to investigate the airborne trichloramine concentrations and determine whether staff and users were at any risk from trichrloramine exposure. It should be noted that B3 and B6 were recently constructed in 2014 and 2012, respectively. Table 4 shows the trichloramine levels measured at B3 and B6. Samples were collected from six locations within each pool hall. Monitoring was undertaken in accordance with the method outlined by Hery et al. (1995). Sampling points were selected based on atmospheric concentrations that were likely to be high, including areas close to return air and areas of water agitation (e.g., around spas and play pools). The average levels were 0.45 and 0.54 mg/m^3 in B3 and B6, respectively. B3 and B6 had 100 per cent fresh air intake. Also a heat wheel and cross flow ensured full heat recovery.

Table 4: Trichloramine levels

	Minimum (mg/m^3)	Maximum (mg/m^3)	Average (mg/m^3)	Location of Highest Concentration	<WHO Recommendation
B3	0.35	0.65	0.45	Wellness pool hall	< 0.5 mg/m^3
B6	0.44	0.61	0.54	Main pool hall	

6.3 Implication of Comfort Parameters on Energy

The results of the objective measurement and occupant survey showed that indoor parameters across the seven buildings varied significantly. Consequently, comfort experiences varied between buildings. Each of the parameters had implications for the energy consumption of the building, particularly the energy required for heating. The energy required to heat the pool water depended on the evaporation rates. Every gram of moisture evaporated in the space is a load that must be dehumidified and also represents heat lost by the pool water.

Managing the rate of evaporation is an important part of indoor pool environment care. Evaporation is a function of the water temperature, the higher the water temperature, the greater the evaporation rate. The evaporation rate was also influenced by differences in temperature between water and air, water surface area and humidity. Higher relative humidity resulted in lower energy use; however, humidity must not be so high that it causes indoor air problems or structural damage.

7 PERFORMANCE OF BUILDING ENVELOPE

The building envelope permeability rating is a measure of the amount of air that permeates through gaps, cracks and leaks in a building envelope when driven by an external force such as the wind or the thermal stack effect. It is expressed as the cubic metres of air per hour that passes through each square metre of a building's façade ($m^3/hr/m^2$). A permeability rating is obtained using air pressure testing. The results of the tests show the integrity of the building envelope in relation to leakage through penetrations, joints in the building façade and around door seals and windows.

Uncontrolled air movement has a significant impact on energy consumption, especially heating energy, as HVAC systems need to work harder to treat the air. Table 5 shows the envelope construction of the six buildings. Notably, buildings constructed after 2006 must comply with Building Code of Australia (BCA) Section J requirements for the envelope. Thus, new buildings must be well insulated with double glazed windows. Conversely, many old buildings are poorly insulated and have many gaps between joints, window frames and mullions.

Table 5: Type of building envelope

Facilities	Age of Buildings	Building Fabric	R Value (m^2K/W) /SHGC	Energy Efficiency Rankings	Permeability Rating ($m^3/hr/\ m^2$)
B1	20	Insulated walls with no sealing, single glazed windows and air gaps in mullions/window frames	1–1.2 for walls, 0.9 for windows/SHGC 0.8	4	Not measured
B 2	35	Minimal insulation with single glazed windows and air gaps in mullions/window frames	1–1.2 for walls, 0.9 for windows/ SHGC 0.8	5	Not measured
B 3	1	Part J compliant, well-sealed walls and roofs, double glazed windows	1.8–2.8 for walls, 1.6–1.8 for windows/SHGC 0.6	1	10
B 4	11	Insulated walls and no sealing, single glazed windows with air gaps in mullions/window frames	1–1.2 for walls, 0.9 for windows/SHGC 0.8	4	Not measured
B 5	18	Insulated walls reasonable sealing and single glazed and sealed windows	1.2–1.5 for walls, 0.9–1.2 for windows/SHGC 0.8	3	22.5
B 6	3	Part J compliant, well-sealed walls and roofs, double glazed	1.8–2.8 for walls, 1.6–1.8 for windows/SHGC 0.6	2	Not measured

Table 6 shows the different permeability rates as specified by the Air Tightness Testing and Measurement Association (Air Tightness Testing and Measurement Association (ATTMA) TSL2 Standard, 2010). ATTMA is a professional association based in the UK, dedicated to promoting technical excellence and commercial effectiveness in all air tightness testing and air leakage measurement applications. Previous studies have shown that air leakage rates in Australia are much higher than those reported in Europe and the United States (Egan, 2011).

Constructed in 2014, B3 had an air permeability rating of 10 $m^3/hr/m^2$ (see Table 5). Of medium age, B5 had a permeability rating of 22.5 $m^3/hr/m^2$. If leakage is to be reduced from 22.5 $m^3/hour/m^2$ to below 15 $m^3/hour/m^2$, careful sealing of all air gaps is required. The permeability ratings of the other four buildings were not measured. Correlating the permeability rating with the façade construction, it can be deduced that B1, B2 and B4 may have much higher values for their permeability ratings compared to B3 while B6 may have a permeability rating closer to 10 $m^3/hour/m^2$. For simple rankings for energy efficiency based on façade construction see Table 5.

Table 6: Permeability rating ($m^3/hr/m^2$) as per ATTMA TSL2 standard

Type of Facility	Air Permeability (best practice)	Air Permeability (good practice)
New Leisure and Aquatic Centre	2	5
20 year+ Old Leisure and Aquatic Centre	5	15

8 DESIGN GUIDELINES

Design guidelines were developed based on the analysis of energy consumption and IEQ measurement (as described above). These guidelines should help architects, engineers and facility owners to set targets for optimum energy and IEQ when designing new facilities and improve environmental performances. The guidelines comprise six sections: building fabric, air side mechanical, water side mechanical, HVAC heating, pool heating and lighting. The prescriptive and performance measures for each section have tabulated below from best practice (top) to worst practice (bottom).

8.1 Building Fabric

8.1.1 Wall construction

Ranking criteria	
Part J compliant and air tightness with permeability rating under 10	Best practice
Part J compliant	
Insulated walls, reasonable sealing	
Insulated walls, no sealing	
Minimal insulation, air gaps in wall	Worst practice

8.1.2 Roof construction

Ranking criteria	
Part J compliant, well-sealed and air tightness with permeability rating under 10	Best practice
Part J compliant	
Insulated, but gaps	
Minimal insulation with gaps and no insulation on gutters	Worst practice

8.1.2 Window construction

Ranking criteria	
Part J compliant, well-sealed and air tightness with permeability rating under 10	Best practice
Part J compliant	
Insulated, but gaps	
Minimal insulation with gaps and no insulation on gutters	Worst practice

Note:

- To be Part J compliant, buildings require a certain level of insulation in their walls and roofs and minimum R values for glazing in accordance with the climate zones in which they are located.
- Roofs, walls, floors, windows and doors to the envelope of a conditioned space must be sealed to minimise air leakage. Windows and doors must be fitted with edge seals. Edge seals may be compressible or fibrous strips.
- Victoria has three climatic zones: zones 6, 7 and 8. The following rule applies:

  R value for wall = 1.8 m^2K/W (zones 6 and 7); 2.8 m^2K/W (zone 8)

  R value for roof = 3.2 m^2K/W (zone 6); 3.7 m^2K/W (zone 7); 4.8 (zone 8)

8.2 Air Side Mechanical

8.2.1 Air distribution

Ranking criteria	
Non-condensation experiences	Best practice
Air directed to glass and other surfaces, condensation evident, but not severe	
Minimal or no distribution, evidence of condensation	Worst practice

Note: Proper air distribution is also important in addition to how much outside air is introduced. Airflow over the pool surface and deck area should be minimised to reduce drafts on swimmers and the rate of evaporation, as this increases with air velocity. Considering the locations of supply air diffusers may also help; for example, locating supply air diffusers to blow dry air into the faces of spectators may make them feel more comfortable.

8.2.2 Fans

Ranking criteria	
All variable speed fans	Best practice
No variable speed fans	Worst practice

Note: Variable Air Volume (VAV) systems can manage changing load requirements by varying the airflow to keep the temperature constant. The advantages of VAV systems over constant-volume systems include more precise temperature control, lower fan energy consumption and reduced fan noise.

8.2.3 Heat recovery

Ranking criteria	
Full heat recovery heat wheel	Best practice
Run-around heat coil	↕
No heat recovery	
No Heat recovery	Worst practice

Note: There is considerable scope for the use of heat recovery systems. The most important means of heat recovery in a pool is usually the sensible heat recovery. There are three main types of heat recovery systems (Building Research Energy Conservation Support Unit (BRECSU), 2001):

(a) In a cross flow heat exchanger, the two fluids usually move perpendicular to each other, allowing a heat exchange of warmer extract air to cooler inlet air. Supply and extract routes must be immediately adjacent to each other.

(b) Run-around coils are probably the most flexible heat recovery system. Two heat exchange coils, one in the supply duct and one in the extract duct, are linked by pipework carrying a heat transfer fluid. The fluid is pumped between the two coils, transferring heat from the warmer extract air stream to the cooler inlet. The supply and extract systems do not need to be close to each other; thus, this system is particularly flexible and especially suitable for refurbishment and improvement projects.

(c) The thermal wheel system uses a rotating disc-shaped heat-retentive honeycomb matrix, through which air can pass to achieve heat transfer. The disc rotates through both supply and extract air streams at approximately 20 rpm. Heat is transferred via the wheel from the warmer extract duct to the cooler supply air system. The system requires that the supply and extract ducts are close to each other and occupies more space than other systems. Heat transfer efficiencies of up to 75 per cent have been achieved using this type of system. However, because of its moving parts, this system generally requires more maintenance than others types of heat recovery systems. Previously regarded as a high cost specialist heating component for very large space applications, the thermal wheel is now seen as a highly economical form of energy saving and is rapidly becoming popular in new buildings where large volumes of air need to be handled and high efficiency is required.

8.2.4 Fresh air percentage

Ranking criteria	
100 per cent fresh air with heat recovery	Best practice
100 per cent fresh air with no heat recovery	↕
50:50 recycled air	
100 per cent recycled air	Worst practice

8.3 Waterside Mechanical

8.3.1 Circulation pumps

Ranking criteria	
VSD ramp speed reduced by 20–30 per cent based on turbidity, Nephelometric Turbidity Unit (NTU), provided chlorine, chloramines and pH levels are within the limits	Best practice
VSD fitted, but speed fixed to achieve constant turnover rate when open (timer controlled for after hours slow down)	↕
VSD fitted, but speed fixed to achieve arbitrary and constant turnover rate	
VSD not fitted or fitted and not used for speed control	Worst practice

Note: Maintaining the quality of swimming pool water requires pumps that consume electricity. 'Turnover' is the rate at which the swimming pool water needs to be filtered. Properly sized multi-speed demand-controlled pumps can improve the efficiency of the pumping system.

8.3.2 Heat recovery

Ranking criteria	
Heat recovery	Best practice ↕
No heat recovery	Worst practice

Note: Heat can be recovered from backwash using heat exchangers.

8.3.3 Filtration and backwash

Ranking criteria	
Ultrafine Filtration (UFF), no backwash, closed loop pre coat, mechanically assisted candle, filter aid Diatomaceous Earth (D.E) cake during regeneration	Best practice
UFF, backwash, single pass pre coat, gravity based candle, filter aide D.E cake during regeneration	↕
Medium rate sand	
Gravity sand	Worst practice

Note: Water filtration is very important to pool water treatment at aquatic centres. Swimming pool water is continually circulated through filters to capture contaminants. Unnecessary filter backwashing wastes water, energy and chemicals due to the need to heat and treat the incoming make-up water. The frequency and volume of the water used in each backwashing cycle depend on the filter type, filter media and operation of the filters during backwash (Sydney Water Corporation, 2011). For convenience and simplicity, filters are often backwashed to a schedule for a set period. Best practice filter operation is to backwash only as necessary.

8.3.4 UV treatment plant

Ranking criteria	
Auto power control based on chloramines with override if chlorine is below set point	Best practice
Auto power control based on stepless UV level	↕
Auto power control based on stepped UV level	
Manual lamp power control	
No lamp power control	Worst practice

8.3.5 Water disinfection

Ranking criteria	
Calcium hypochlorite (granular)	Best practice ↕
Sodium hypochlorite	Worst practice

Note: Water quality is the most important aspect of an aquatic centre's operation. Clean, clear and healthy water attracts bathers and ensures bather safety (Sydney Water Corporation, 2010). Chlorination is widely used to disinfect pool water. It is generally achieved by adding sodium or calcium hypochlorite to the water. Relatively large volumes of sodium hypochlorite are needed to maintain water quality and a sufficient residual. However, chlorination can quickly lead to the build-up of Total Dissolved Solids (TDS). Compared to sodium hypochlorite, a smaller proportion of calcium hypochlorite is required. Thus, it builds up more slowly and less diluted water is required to mitigate TDS. Some aquatic centres supplement chlorination with Ultraviolet (UV) light irradiation or ozone treatment for extra protection and to reduce chemical use. UV and ozone treatment have no effect on pH or water balance and do not contribute to TDS levels. However, they do help to reduce volatile gases and smell. Ozone plants may have high on-going operational and maintenance costs.

8.3.6 Total dissolved solids levels

Ranking criteria	
Set point maximised for site specific chemical treatment regime, water supply, etc.	Best practice
Set point fixed arbitrary 3,000 ppm	↕
Set point fixed arbitrary 2,000 ppm	
Set point fixed arbitrary 1,500 ppm	Worst practice

Note: As chemicals are continually added to pool water, residual salts or TDS built up. TDS measure the total amount of dissolved matter in the water (e.g., calcium, magnesium, chlorides, sulphates). A normal range is 1,000 to 2,000 ppm. TDS values above 2,500 ppm can damage pipes, filters and pumps and result in a loss of water clarity.

8.4 Heating

Selecting type of heating

There are many issues to consider when selecting a pool heating system, including capital and running costs, fuel tariffs, the space allocated for the equipment, the location of heating equipment, the availability of energy, energy costs and budgetary restraints (e.g. capital and operating budgets).

(i) Combined heat and power (cogeneration)

Cogeneration (also known as Combined Heat and Power (CHP)) is the simultaneous production of electricity and heat from a single fuel source, commonly natural gas. In principle, cogeneration uses a relatively low cost fuel (usually gas) to generate heat for the swimming pool and electricity (e.g., for lighting and pool pumps). Producing electricity and heat together using cogeneration should be cheaper than producing electricity and heat separately. Facilities that are most likely to benefit from cogeneration are those that simultaneously use large quantities of thermal loads (e.g., hot water, heat, steam or chilling) and electricity. The relative amounts of electricity and heat produced can be tailored to the needs of a site. Cogeneration involves burning natural gas in an engine that in turn spins a generator to create electricity. As the engine is powered by gas rather than coal, it produces electricity that has significantly less greenhouse gas emissions than coal fired electricity. The initial cost of this system can be very high.

(ii) Electric heat pump

A heat pump transfers heat from a low-grade temperature source and upgrades it to a higher and more useful temperature. Electric heat pumps are highly efficient and (when used with the correct electrical tariff) cheap to run. As the energy required to operate the equipment is less than the energy produced, heat pumps are considered energy efficient. These units are expensive to purchase; however, installation costs are low provided that there is a suitable incoming power supply.

(iii) Gas-fired boilers

The source of heat for a boiler is the combustion of fuels such as wood, coal, oil or natural gas. A heat exchanger must be installed to isolate the boiler from the pool water. This heat exchanger allows the transfer of heat from a hot fluid to a cooler fluid, but keeps the two fluids separate as they pass through the device. Boilers require a heat exchanger, two pumping systems and control valves. Thus, they have high installation costs.

(iv) Condensing boilers

Condensing boilers are fuelled by gas and are highly efficient as they use the waste heat in flue gases to pre-heat cold water entering the boiler. Water vapour produced during combustion is condensed into liquid form and leaves the system via a drain. Due to this process, a condensing boiler is able to extract more heat from the fuel it uses than a standard efficiency boiler. Further, less heat is lost through the flue gases.

8.4.1 Swimming pool heating

Ranking criteria	
Condensing boiler with cogeneration + solar	Best practice
Condensing boiler with cogeneration	
Condensing boiler with solar	
Heat pumps with solar	
Condensing boiler	
Heat pumps	
Boiler—standard boiler with solar	
Boiler—standard boiler	
Direct pool boiler	Worst practice

8.4.2 Swimming pool covers

Ranking criteria	
Automatic swimming pool cover or swimming pools with Bauer control system	Best practice
Manual swimming pool cover	
No swimming pool cover	Worst practice

Note: Evaporation is the major source of heat loss for swimming pools. Covering a swimming pool when it is not in use is the single most effective way of reducing pool heating costs. A swimming pool cover limits the exposure of the swimming pool surface to the surrounding air by providing a physical barrier between the swimming pool surface and the atmosphere. Approximately 70 per cent of the heat energy lost by swimming pools is due to water evaporating. Swimming pool covers conserve make-up water by 30-50 per cent and can reduce chemical consumption. The set point temperature can be reduced when the swimming pool is covered and the swimming pool is unoccupied. The set back temperature is normally between 23°C and 24°C and allows a significant amount of energy to be saved. Properly designed swimming pool covers have the following benefits:

- Reduce water losses by 30–50 per cent;
- Reduce heat losses by 70–90 per cent;
- Reduce HVAC running costs; and
- Reduce the effect of condensation on the building structure, fabric and fittings (Sydney Water Corporation, 2011).

8.4.3 Heating, ventilation and air-conditioning systems

Ranking criteria	
Condensing boiler with cogeneration + solar	Best practice
Condensing boiler with cogeneration	
Condensing Boiler with solar	
Heat pump boiler	
Standard boiler with solar	
Standard boiler	Worst practice

8.5 Lighting

Ranking criteria	
LED lighting with light sensors	Best practice
LED lighting	
Standard lighting with control system	
Standard lighting, manual switching	Worst practice

8.6 Energy Management and Control System

Bauer control system is an energy efficient system that works particularly well in humid environments. It improves the mixing of the air at a molecular level and significantly decreases the effect of inversion layers within a space. Inversion layers produce a significant temperature difference between the top and bottom of a tall space. The system creates a very small positive pressure in a space by controlling the speed of the supply fans and the position of the dampers within the system. The slightly positive pressure then allows the air to mix at a partial pressure level.

Conventional HVAC systems cause temperature layering within an occupied zone where hot air rises towards the roof and cold air falls. A Bauer system monitors zone and duct pressure, temperature, humidity, IAQ and/or CO_2 levels and supply and return damper positions to determine the volume and quality of air required. Temperature stratification was minimum in pool halls (e.g., B3) using the Bauer system. Further, the CO_2 levels measured were very low.

REFERENCES

Air Tightness Testing and Measurement Association (ATTMA) (2010), Measuring air permeability of building envelopes, ATTMA, British Institute of Non-destructive Testing, Technical Standard L2, available at https://www.bsria.co.uk/download/asset/attma-tsl2.pd, Last accessed, 20 April 2015.

American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc (ASHRAE) (2003), HVAC applications. ASHRAE, Atlanta, GA, United States.

Aquatic and Recreation Victoria (ARV) (2009), ARV industry database, available at www.aquaticsandrecreation. org.au, last accessed 20 December 2011.

ASHRAE (2013), Standard 55, thermal environmental conditions for human occupancy. ASHRAE, Atlanta, GA, United States.

Australian Government Department of Industry, Innovation and Science (2014), National greenhouse account factors, available at http://www.environment.gov.au/system/files/resources/b24f8db4-e55a-4deb-a0b3-32cf763a5dab/files/ national-greenhouse-accounts-factors-dec-2014.pdf, last assessed 10 December 2015.

Australian Standards 1668.2 (2002), The use of mechanical ventilation in buildings, Standards Australia, Sydney.

Baxter, R. C. (2012), 'Designing for IAQ in natatoriums', American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Journal, vol. 54, no. 4, pp. 24–32.

Bernard, A., Carbonnelle, S., Michel, O., Higuet, O., de Burbure, C., Buchet, J. P., Hermans, C., Dumont, X. & Doyle, I. (2003), Lung hyperpermeability and asthma prevalence in schoolchildren: unexpected associations with the attendance at indoor chlorinated swimming pools, Occupational and Environmental Medicine, vol. 60 (6), 385–394.

Building Research Energy Conservation Support Unit (BRECSU) (2001), Energy Consumption Guide, 78, Energy use in sports and recreation buildings, available at http://targ.co.uk/other/ guide78.pdf, last accessed 10 October 2013.

Carbon Trust (2006), 'Sports and leisure: Introducing energy saving opportunities for business', available at www.carbontrust.com/media/39352/ctv006_sports_and_leisure_sector_overview.pdf, last accessed 12 August 2012.

Egan, A. M. (2011), Air tightness of Australian offices buildings: Reality versus typical assumptions used in energy performance simulation, Proceedings of the 12th Conference of International Building Performance Simulation Association, Sydney.

Goodman M. & Hays S. (2008), 'Asthma and swimming: a meta-analysis', Journal of Asthma, vol. 45, pp. 639–647.

Hery, M., Hecht, G., Gerber, J. M., Gendre, J. C., Hubert, G., & Rebuffaud, J. (1995), 'Exposure to chloramines in the atmosphere of indoor swimming pools', Annals of Occupational Hygiene, vol. 39, no. 4, pp. 427–439.

Howat, G., Murray, D. & Crilley, G. (2005), 'Reducing measurement overload: rationalizing performance measures for public aquatic centres in Australia', Managing Leisure, vol. 10, p. 128-142.

International Centre for Energy and Environmental Technology (IECU) (1994), 'energy efficient technologies in sports facilities', A thermie programme action, European Commission, Directorate General for Energy.

ISO 7730 (2005), Ergonomics of the thermal environment—Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, International Organization for Standardization, Switzerland.

ISO 9920 (2007), Ergonomics of the thermal environment estimation of thermal insulation and water vapour resistance of a clothing ensemble, International Standard Organization, Geneva, Switzerland.

ISO 8996 (2004), Ergonomics of the thermal environment—Determination of metabolic rate, International Standard Organization, Geneva.

Jacobs, J. H., Spaan, S,. van Rooy, G. B. G. J., Meliefste, C,. Zaat, V. A. C., Rooyackers, J. M., & Heederik, D (2007), 'Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers', European Respiratory Journal. vol. 29, pp. 690–698.

Lam, C. J. & Chan, L. S. A. (2001), 'CFD analysis and energy simulation of a gymnasium', Building and Environment, vol. 36, no. 3, pp. 351–358.

Ma, X., Jian, Y. & Cao, Y. (2006), 'A new national design code for indoor air environment of sports buildings', Facilities, vol. 2, no. 11/12, pp. 458–464.

Parrat, J., Donze, G., Iseli, C., Perret, D., Tomicic, C. & Schenk, O. (2012), 'Assessment of occupational and public exposure to trichloramine in Swiss indoor swimming pools: A proposal for an occupational exposure limit', Annals of Occupational Hygiene, vol. 56, no. 3, pp. 264–277.

Pool Water Treatment Advisory Group (PWTAG) (n.d.) Pool temperatures, available at http://www.pwtag.org/Pool%20 temperatures.php, last accessed 22 January 2015.

Predieri, G. & Giacobazzi, P (2012) 'Determination of nitrogen trichloride (NCl3) levels in the air of indoor chlorinated swimming pools: an impinger method proposal', International Journal of Environmental Analytical Chemistry, vol. 92, no. 6, pp. 645–654.

Sharp, T. (1996), Energy benchmarking in commercial office buildings, Proceedings of the American Council for an Energy-Efficient Economy (ACEEE) 1996: summer study on energy efficiency in buildings, pp. 4,321–4,329.

Sharp, T. (1998), Benchmarking energy use in schools, Proceedings of the ACEEE 1998 summer study on energy efficiency in buildings, pp. 3,305–3,316.

Stathopoulou, O. I., Assimakopoulos, V. D., Flocas, H. A. & Helmis, C. G. (2008), 'An experimental study of air quality inside large athletic halls', Building and Environment, vol. 43, no. 5, pp. 834–884.

Sydney Water Corporation (2011), 'Best practice guidelines for water management in aquatic leisure centres', available at https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/ zgrf/mdq1/~edi sp/dd_045262.pdf, last accessed 25 August 2014.

Trianti-Stourna, E., Spiropoulou, K., Theofilaktos, C., Droutsa, K., Balaras, C. A. & Santamouris, M. (1998), 'Energy conservation strategies for sports centers: Part B: swimming pools', Energy and Buildings, vol. 27, no. 2, pp. 123–135.

Thickett K. M., McCoach J. S. & Gerber J. M. (2002) 'Occupational asthma caused by chloramines in indoor swimming pool air', European Respiratory Journal, vol. 19, pp. 827–832.

Victorian Government Department of Human Services (2008). Pool operators' handbook, available at https://www2.health.vic.gov.au/getfile/?sc_itemid={7EB2A1F1-77D2-4130-BA0D-EEBB00E88449}&title=Pool%20 operators%27%20handbook, last accessed 20 December 2015.

World Health Organization (WHO) (2000), Guidelines for safe recreational water environment. Volume 2: Swimming pools, spas and similar recreational water environments, WHO, Geneva, Switzerland.

WHO (2006), Guidelines for safe recreational water environments, Volume 2, Swimming pools and similar environments, WHO, Geneva, Switzerland.

APPENDIX 1

PHYSICAL AND OPERATIONAL PROPERTIES OF THE FACILITIES

	B1	B2	B3	B4	B5	B6
Total floor area (m²)	2,944	6,327	8,500	3,518	5,079	8,260
Number of visitors	275,420	314,514	1,100,000	167,607	490,532	1,200,000
Year constructed	1995	1980	2014	2004	1997	2012
Water surface area, including outdoor pools (m²)	640	1,072	1,882	703	1,438	2,760
Type of pools	25 m pool, toddlers' pool, learners' pool, spa, sauna, water slide	50 m pool, toddlers' pool, baby play, spa and steam room	25 m pool, toddlers' pool, tipping bucket, dive board, spa	25 m pool, leisure pool, toddlers' pool, spa, steam room	50 m pool, learn to swim pool, toddlers' pool, wave pool, spa, sauna, steam room	25 m pool, leisure pool, programme pool, spa, sauna, steam room
Other pool areas	NA	NA	Warm water pool, 25 m outdoor pool	NA	NA	Warm water pool, 50 m outdoor pool
Other areas	Squash court, basket ball stadium	Sports stadium	Basket ball stadium			basket ball stadium
Heating method	Condensing boiler with cogeneration	Electric heat pump	Gas from cogeneration	Gas boilers	Gas boilers	Gas boilers
Air distribution	No variable speed fans	All variable speed fan	No variable speed fans	All variable speed fans	Gas boilers	Gas boilers
Fresh air	50% fresh air	100% fresh air	100% fresh air	50% fresh air	100% fresh air	100% fresh
Fresh air	50% fresh air	100% fresh air	100% fresh air	50% fresh air	100% fresh air	100% fresh air

	B1	B2	B3	B4	B5	B6
Heat recovery	No	No	Full heat recovery with heat wheel	No	Run-around heat coil	Full heat recovery cross flow
Building management and control system	Bauer control system		Bauer control system			
Water circulation pumps	No variable speed drive (VSD)	No VSD	VSD fitted	No VSD	VSD fitted	VSD fitted
Filtration and backwash	UFF (Ultra fine Filtration)	Medium rate sand	UFF	UFF	UFF (Ultra fine filtration)	UFF (Ultra fine filtration)
Water disinfection	Sodium hypochlorite	Chlorine	Sodium hypochlorite	Calcium hypochlorite	Chlorine	Onsite chlorine generation, UV treatment plant, auto power control based on chloramines
Other Environmentally Sustainable Design (ESD) features	Automatic pool cover, rainwater for toilet flushing, evacuated tubes for solar hot water	Rainwater for toilet flushing and pool filling	Rainwater for toilet flushing only	Manual pool cover, rainwater for toilet flushing and pool filling, lighting control system, solar hot water with black matt panels	Rainwater for toilet flushing only	Manual pool cover, Rain water for toilet flushing and pool filling, lighting control system, solar hot water with black matt panels

APPENDIX 2—SURVEY QUESTIONNAIRE

ENERGY AND INDOOR ENVIRONMENTAL QUALITY OF AQUATIC CENTRES

You are invited to participate in a survey and support the research 'Energy and Indoor Environmental Quality of Aquatic Centres' in the School of Architecture and Built Environment, Deakin University. Please see next page for more details about this project.

1. Your Age

(Select only one.)

☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ 66-75 ☐ 76 or more

2. Your Gender

(Select only one.)

☐ Female ☐ Male

3. How long have you been visiting this swimming pool?

(Select only one.)

☐ less than a month ☐ 1-3 months ☐ 3-6 months ☐ 6 months-1 year ☐ 1-2 years
☐ 2-5 years ☐ more than 5 years

4. How often do you visit this swimming pool?

(Select only one.)

☐ twice every day ☐ once every day ☐ 3-5 days a week ☐ 2-3 days a week ☐ once every week

5. How long do you usually spend here during each visit

☐ 30 minutes ☐ 30 minutes to 1 hour ☐ 1- 2 hours ☐ 2-3 hours ☐ more than 3 hours

6. Purpose of visit

☐ swimming lesson ☐ lap swimming ☐ recreational /leisure swimming
☐ carer of swimming children ☐ staff in this centre

7. Which pool do you normally use?

☐ indoor lap ☐ learn to swim pool ☐ leisure pool ☐ warm water pool ☐ others

8. What are you wearing now?

☐ swimwear

Or please tick items from (a), (b) , (c) and (d) below

(a) Head	☐ hat			
(b) Upper body	☐ T shirt (short sleeve)	☐ T shirt (long sleeve)	☐ vest (no sleeve)	☐ Jacket
(c) Lower body	☐ shorts pants	☐ long pant	☐ skirt	
(d) Feet	☐ socks	☐ shoes	☐ thongs	

9. Please rate the pool/pool hall according to your experience today.

Pool hall Temperature	Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
Feeling							
Preference							
Pool hall humidity	**Very humid**	**Humid**	**Slightly humid**	**Neutral**	**Slightly dry**	**Dry**	**Very dry**
Feeling							
Preference							
Pool hall ventilation/air movement	**Very stuffy**	**stuffy**	**Slightly stuffy**	**neutral**	**Slightly airy**	**airy**	**Very airy**
Feeling							
Preference							
Pool hall air quality	**excellent**	**Very good**	**good**	**neutral**	**bad**	**Very bad**	**Really bad**
Feeling							
Preference							
Pool water temperature	**Cold**	**Cool**	**Slightly Cool**	**Neutral**	**Slightly Warm**	**Warm**	**Hot**
Feeling							
Preference							

Please record the date and time you completed this questionnaire

Date: _____/_____/_____ Time: _______________

Any other comments:

AQUATICS &
RECREATION
VICTORIA