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Thermal comfort of multiple user groups in indoor aquatic centres

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ABSTRACT

Aquatic centres are popular recreational facilities in Australia and other developed countries. These buildings have experienced exponential demand over the past few decades. The growing desire for better indoor environmental quality in aquatic centres has resulted in a marked increase in energy consumption in this sector. With the existence of multiple user groups, achieving thermal comfort has always been challenging. Even though several thermal comfort studies are conducted in other building types, such studies are very limited with respect to aquatic centres. This paper analyses the thermal comfort conditions of various user groups in seven aquatic centres in Australia. Comfort measurements are performed through monitoring environmental parameters and surveying swimmers, staff and spectators. The results revealed the variation of air temperatures among the buildings, resulting in high level of thermal discomfort for the spectators and staff in some of the buildings. The thermal sensation of the staff and spectators had good correlation with the indoor temperatures and PMVs. Altering temperature settings according to the seasons will help to improve the comfort with respect to the adaptation and expectation of the occupants.

1. Introduction

Thermal comfort and well-being of the occupants are critical in assessing the quality of a building design. In fact, indoor thermal condition has serious implications on the health of the occupants [1,2]. Nowadays, people in developed countries spend more than 90% of their time indoors [3,4]. Among all the indoor facilities, aquatic centres have experienced exponential demand over the past few decades. Indoor swimming pools are the second most popular sport facilities worldwide [5]. According to Australian Bureau of Statistics [6], 263 million visitors have been attracted to 1900 aquatic centres annually, with 64% of Australians aged 15 and over participating there in physical activities for recreation or exercise. Although aquatic centres share some characteristics with offices and commercial buildings, due to different activity types, functions, ownerships, unique comfort requirements and complex environmental conditions, the level of energy consumption is significantly higher compared to a typical commercial building [1]. This is mainly due to the high indoor air temperatures, increased ventilation heat losses and the need to disinfect water. A recent study by the author found that aquatic centres are seven times more energy intensive than a commercial office building [7]. According to ASHRAE Handbook [8], for recreational natatorium, the temperature of the space and pool should be kept between 24 °C and 29 °C and the humidity level should be in between 50% and 60% to provide a thermally comfortable indoor facility.

Several studies have been conducted in naturally and mechanically ventilated office buildings to examine the relationship between the indoor environmental quality and occupant perceptions [9,10]. But studies on the indoor environmental quality of aquatic centres are very limited. Even though new advanced heating, ventilation and air conditioning (HVAC) systems have replaced old systems, the community expectation towards the overall indoor comfort in aquatic centres has not been adequately met. It is necessary to control the pool water temperature, air temperature, relative humidity, ventilation, lighting and water pumping, in order to provide a healthier indoor environment for different types of users such as swimmers, spectators and staff with different clothing types and various activity levels. Therefore, this study compares the thermal comfort in seven aquatic centres in Australia through occupant surveys and field measurements. Field studies are considered as an expensive and time consuming method in which the presence of several researchers in the building is necessary. Also, the process of filling the questionnaires is very sensitive to error. Still these two methods coupled together can offer valuable data from the different user's point of view [11]. Additionally, questionnaire results can either be used separately or in conjunction with the field measurement records [12]. The outcome of this study will provide insights about the current practices of indoor environmental operations in indoor aquatic centres. In addition, this study will

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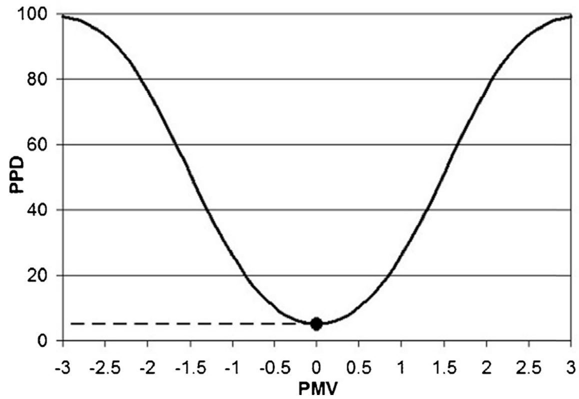

Fig. 1. PMV range.

help to propose recommendations for improving thermal comfort and optimizing the energy consumption of these buildings.

2. Literature review

2.1. Indoor thermal comfort research

Thermal comfort is defined as "the condition of mind which expresses satisfaction with the thermal environment when people are satisfied with thermal environment" [13]. The first comfort study was carried out by Gagge [14] in 1964. He considered the core temperature and skin temperature and proposed a "Two node model" to analyse the energy exchange between human body and its surrounding environment. Thermal comfort studies were improved and in 50s, "Effective temperature index" was developed which was defined as "the temperature of a fictitious room with 100% relative humidity". To clarify the relationship between the metabolic activity, clothing type and physical parameters of the environment, Fanger established predicted mean vote (PMV) index [15]. The indoor thermal comfort is generally assessed by means of the PMV by using a seven point scale ranging from cold (−3) to hot (+3) as shown in Fig. 1.

The PMV index is a function of six parameters. Four of them are ambient parameters and their measurement procedures are described in ISO 7726 [16]. The remaining two are personal factors, such as the clothing thermal properties and metabolic rate due to the activity. This methodology was validated in a controlled test chamber, so it is effective when applied to buildings provided with HVAC systems where occupants have little or no opportunity to adapt themselves, hence, application of this model in naturally ventilated settings leads to significant errors. Therefore a different approach based on an adaptive model was formulated by de Dear and Brager [17] for occupant controlled naturally ventilated buildings. There have been significant advances in the field of thermal comfort in the last 20 years, while most of them addresses office buildings. The new European Standard EN 1525175 distinguishes between building types such as kindergartens and department stores due to variation in activity levels and clothing [18].

Several studies were conducted to investigate the insulation achieved from clothing type, during various movements and different wind speeds [19,20]. ISO 9920 [21] provides a procedure to evaluate the clothing insulation with exhaustive tables of clo (m^2 K/W) values for several clothing types. Similarly ISO 8996 [22] provides metabolic rate with respect to various activities. Even though a number of studies were conducted to understand the relationship between thermal comfort and clothing type or activity levels, only few of them are conducted in the pool areas. In a study conducted much earlier in 1972, Lammers [23] indicated that the metabolic rate assigned to the wet swimmer, who is going out of the water immediately after the training, is considered equal to 1.8 Met, and it is 1.2 Met for the dry swimmer whose training is concluded at least 10 min before. It is to be noted that the PMV model is not applicable to occupants whose time-averaged metabolic rate exceeds 2.0 Met. A recent study in Italy evaluated the thermal comfort level in two sport facilities, a gym and a pool, by considering the impacts of activity level, indoor environment and clothing type [24]. Standardised and subjective measurements were applied to assess the thermal comfort using Fanger indices. The study concluded that by considering the specific personal factors, it would be possible to apply PMV model to assess the thermal comfort in sporting facilities. However literature shows that there are no studies reporting the assessment and comparison of thermal comfort conditions across a number of aquatic facilities.

2.2. Indoor environment in aquatic centres

There has been a consistent trend towards higher water temperatures in recent years, due to the substantial growth in aquatic leisure activities. A safe, comfortable and appealing internal environment is crucial to attract and sustain customers. There is no relevant regulation about the indoor swimming pool space temperature in many national standards. According to ASHRAE Handbook [8], air temperatures in public and institutional pools should be maintained 1–2 °C above pool temperature to reduce the evaporation rate and avoid chill effects on swimmers. Swimmers exiting the pool may expect and prefer higher temperatures as they are wet and with less clothing. With an 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 [25]. According to Australian Standards [26] and pool operators' handbook [25], recommended indoor temperature for indoor swimming pool is 27 °C and relative humidity range is 50–60%. The temperature of the pool hall air should normally be maintained at around the water temperature no more than 1 °C above. Higher temperature can cause discomfort to swimmers thereby limiting vigorous swimming. This increases the water pollution through sweat and body oil contamination. Higher water and air temperature increase direct and indirect energy cost. With higher temperature, moisture level in the pool increases, even when relative humidity is controlled at the same level. This causes risk of condensation, and possibly corrosion and deterioration of the building fabric, structure and equipment. This will also increase the rate of Chloramine formation [27].

When the difference between space temperature and pool water temperature is set at 2 °C, the pool water temperatures can be set at 26.2 °C, 27.8 °C, 25.8 °C and 26.6 °C on a spring day, summer day, autumn day, and winter day, respectively. These setting values are basically identical with the existing experiences and they are able to meet the design codes [2].

3. Methodology

In this study, the evaluation of thermal comfort in pool environment takes into consideration the situation of three user groups: swimmers, spectators who care for children undertaking swimming lessons and staff members who work as swimming attenders, through the use of PMV and Thermal Vote (TV). To study the influence of space temperature on the users, PMV was introduced as an empirical index, to quantify the occupant comfort, based on a steady-state model of thermal exchanges between the human body and the environment as described in