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THERMAL AND VENTILATION PERFROMANCE OF A MULTI-FUNCTIONAL SPORTS HALL WITHIN AN AQUATIC CENTRE

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ABSTRACT

There has been an increasing demand for sports facilities in urban areas recently. As a result of this, more attention is drawn towards not only the energy performance of these building typologies, but also creating a healthy indoor environment for the users. This Study investigates the thermal and ventilation performance of a sports hall within an aquatic centre using computational fluid dynamics (CFD) simulations. IES Virtual Environment software was used to perform the simulations. A number of scenarios were tested by changing the position of extract fans as well as by incorporating natural ventilation strategies. A high level of discomfort was observed in the space. Better comfort condition was achieved by changing the location of exhaust fans ad openings. The results help to recommend some guidelines to inform the proposed refurbishment plans of the site.

INTRODUCTION

As the society becomes more affluent and living standards improve, there has been a growing demand for top quality recreational facilities all over the world (Lam and Chan, 2001). The indoor sports hall has become one of the favourite venues for sport activities. Traditionally, sports in Australia has been an outdoor pastime. But in recent times, an increased awareness of skin cancers and other health risks, coupled with a broadening of the range of sports being played, has seen an upsurge in indoor recreational pursuits and a trend towards multi-purpose facilities. The growing desire for better indoor environmental quality in the indoor sports centres has resulted in a marked increase in energy consumption in this building sector. While current research on indoor environmental quality mainly focuses on residences and offices, few studies are concerned with the indoor environment of large enclosures (Stathopoulou et al., 2008). Studies regarding sports centres mainly deal with ventilation issues in terms of energy cost and saving, while indoor air quality is not directly addressed (Trianti-Stourna et al., 1998). Indoor air pollution profiles were assessed during three concerts and one ice hockey game carried out in three different halls for recreational activities in Switzerland. Sharp increases in pollution concentrations were observed when visitors enter the halls and an exponential decrease in concentration after the event has ended (Junker et. al., 2000). Studies conducted by Chow et al. (2002) illustrated that many mechanical ventilation and air conditioning systems in big halls were not designed properly, leading to lots of complaints on poor ventilation performance. The amount of fresh air supplied to a space was observed to be sufficient, but distribution of air was not considered carefully. As a result, it was difficult to provide a comfortable thermal environment with good indoor air quality, this wasting energy on operating the environmental control systems. Research about the energy performance of sports centres or aquatic centres is very limited in Australia. The key issue for Australia in coming decades is the achievement of greenhouse gas emission reduction targets. The Government's targets are equivalent to a reduction in every Australian's carbon footprint of nearly one third to one half (Department of climate change, 2010). In order to achieve the 2020 target of 5% below 2000 greenhouse gas emissions, there is a need to undertake aggressive energy efficiency measures. At the end of June 2005, there were 9,256 businesses/organisations operating in Australia whose main activity was the provision of sports and physical recreation services. This included 600 government organisations. The number of fitness centres increased from 667 in 2000-01 to 824 in 2004-05 - an increase of 24% (Australian Bureau of Statistics, 2005). Victoria has in excess of 500 aquatic facilities with 277 (55%) belonging to local government. The remaining 233 (45%) include private swim schools and educational institutions (ARV Industry database, 2009). In Western Australia there are 120 public aquatic centres that provide significant benefit in terms of community development, sport, recreation, health and fitness. Total annual expenditure in aquatic centres is estimated to be $57,989,307 (Leaversuch and Gibbs, 2010).

Due to the age of the existing building stock, a large number of the aquatic centres are about to be refurbished. The thermal conditions were measured using MABEL (Mobile Architecture and Built Environment Laboratory) equipments. A high level of discomfort was observed in this space. IES Virtual

Environment software was used to perform Computation Fluid Dynamics (CFD) analysis and to predict the airflow and thermal performance of the space and to recommend some guidelines to inform the proposed refurbishment plans of the site.

THE BUILDING

The construction of the aquatic centre is typical of many commercial buildings built in the 1980s and exhibits facades that are generally light metal to brick veneer. The sports hall is 62 m long, 36 m wide and 10 m high with the total volume of 22,320 m^3. There are 19 small vents of size 950 mm x 950 mm at one side of the wall. Figures 1 and 2 show the view of the sports hall and the vents at the western façade respectively. There was no cooling system in the hall and the ventilation was achieved with the help of three exhaust fans installed at the roof. The fans were turned off most of the time.

Figure 1: View of the sports hall

Figure 2 : Open vent along the west wall

METHODOLOGY

IES Virtual Environment software is used for the simulation. This programme has been used widely for different types of building performance simulation. k-ε turbulence model was adopted to enable the effect of turbulence to be predicted. The basic equations describing the indoor airflow consist of the conservation equations of continuity, momentum, and energy for a turbulent, buoyancy-affected incompressible fluid, together with two additional transport equations for the turbulent kinetic energy and its dispersion rate. The *k-ε* model assumes that the turbulence viscosity (μ_t) is linked to turbulence kinetic energy *(k)* and dissipation *(ε)* via the relation $\mu_t = C_\mu \rho (k^2 / \varepsilon)$ where $C\mu$ is a constant and ρ is the fluid density.

The boundary conditions data including the surface temperature of the façades were measured using an infra-red camera. The average surface temperature of the façades were recorded to be around 30°C and the external air temperature was recorded as 25°C. Mean measured surface temperature was used for simplification and subsequent investigation using parametric variations. The fans at the top of the roof was used as an extract boundary condition. The speed of each fan was noted as 9000 l/s. The heat output from artificial lights were estimated as 60 kW.

The base case scenario was validated using the measured parameters including thermal comfort indices and air change rate. Also, a survey of the occupants were conducted. Different scenarios were tested after validating the base case.

WEATHER CONDITIONS

The MABEL weather station was positioned on the rooftop of the building in order to receive the best possible solar exposure. Weather condition was monitored using a weather station. The weather conditions are representative of a pre-winter season where non-overheating periods are expected. Figure 3 shows the general weather conditions, external air temperature and solar energy parameters.

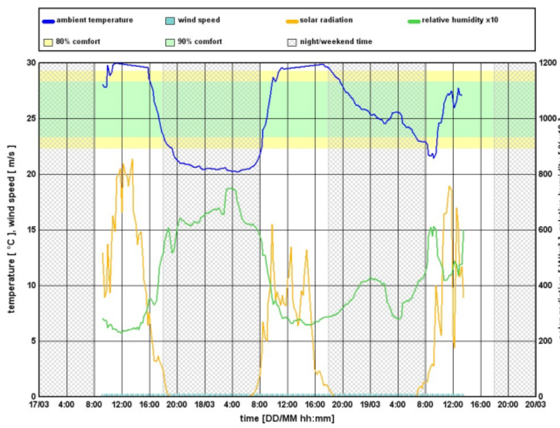

Figure 3: Weather Conditions

COMFORT PARAMETERS MEASURED

The ISO 7730 thermal comfort model is the predictive model used in this research. Here the prediction assesses how comfortable people would be at a given period in time at a specific location in the building. This allows the calculation for the Predicted Percentage Dissatisfied (PPD) to be made along the lines of the ISO 7730 standard. Comparing this data to local (on site) weather station information for the same period of time allows an assessment of the building space comfort performance and can be applied to the new 'adaptive comfort' models (Brager and deDear).The instrumentation used is the Comfort Cart which has been designed according to the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). The carts measure the dry-bulb (DB) temperature, the globe temperature (Tg) and the air velocity at 0.1 m, 0.6 m and 1.1 m heights. An additional relative humidity sensor is also included at a central location on the cart. More recently the carts have been developed into an ADPI (air diffusion performance index) ASHRAE-113 standard Instruments include a 1.7m velocity and additional temperature sensor as well as a CO_2 meter. Figures 4 and 5 show that a high degree of discomfort was experienced in the sports hall. Under the light clothing levels and the high activity level, some degree of discomfort would be expected during this course of the day. Natural ventilation (external conditioning) might remedy this problem if the exterior temperatures allow this. The air change rate was measured using tracer gas method and it was found that the average ACH was 0.4 in natural ventilation mode and 2.7 when the exhaust fans were turned on.

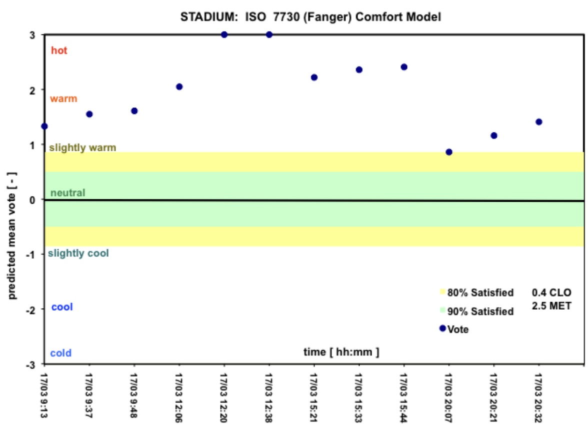

Figure 4: Sports hall thermal comfort

A thermal imaging camera was used internally during the daytime periods to analyse the areas of the building envelope that excessively heat up. These problematic areas of the building envelope should be considered with respect to the resulting interior comfort conditions and in some cases where excessive air temperatures occur. Figure 6 explains why the sports hall experiences dramatic interior overheating during midday external solar radiation and higher temperatures.

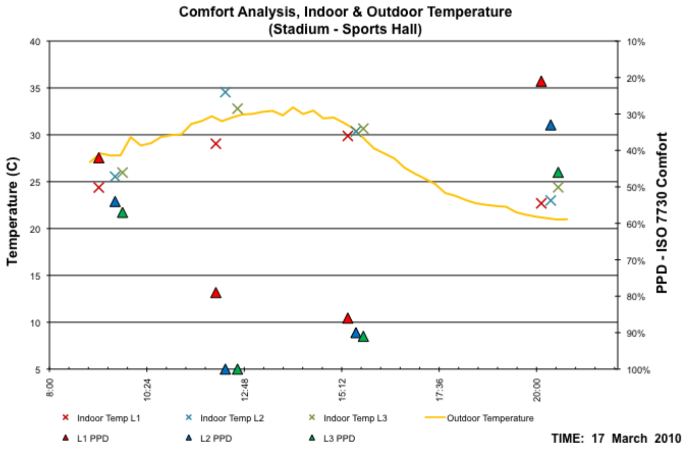

Figure 5: Sports hall Occupant air temperature levels

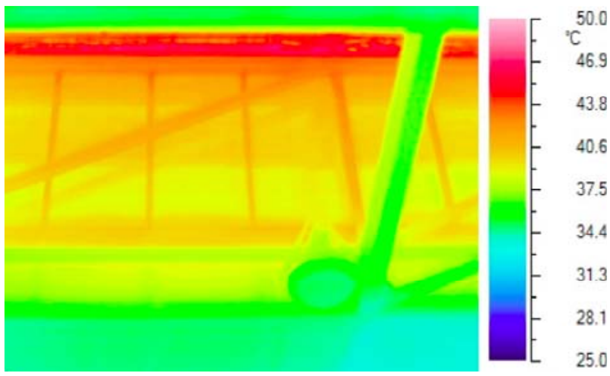

Figure 6: Infra red image of the sports hall clearstorey

Figure 7 gives some indication of stratification during the overheating periods of the space. The exhaust fan was turned off during the morning and activated in the later afternoon. Due to the natural ventilation assistance of the exhaust fans, it is apparent that the stratification level is diminished. Overheating particularly takes place at the 4.0m above floor level.

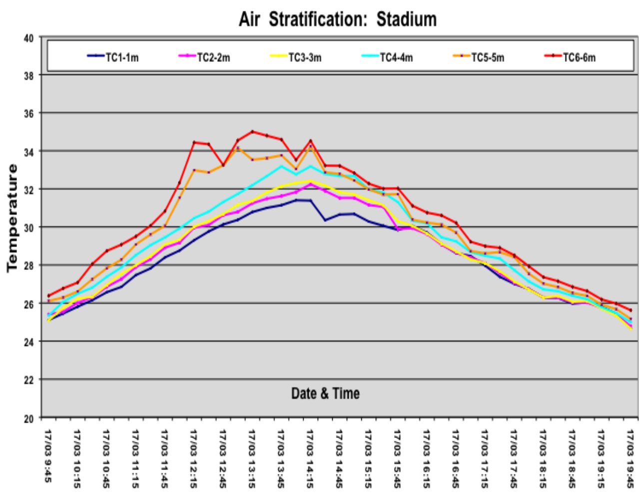

Figure 7: Air Temperature Stratification

BASECASE SCENARIO

A simplified model of the sports hall was created in modelIT. The total number of grid elements in the model were around 178,000. The thermal comfort parameters including PMV and PPD as well as the velocity and air change effectiveness were analysed. A number of different scenarios were tested. They include: changing the fan location to Position 2 and Position 3, incorporating another outlet at Position 2, 3, 4 and 5. Varying the inlet wind speed can predict the natural ventilation effectiveness for different wind conditions. Also, the effect of stack ventilation in the absence of wind was tested. Table 1 summarises the different scenarios tested. Figure 8 shows the location of the openings as well as outlets. The location of exhaust fans as well as outlets are shown as "positions".

Table 1 Different Scenarios tested

Scenarios	Position of fans, inlet and outlet
Base Case	3 Exhaust fans at Position 1 Ceiling
Scenario 1	3 exhaust fans at Position 3
Scenario 2	3 exhaust fans at Position 2
Scenario 3	No exhaust fans, outlet at Position 2, external wind speed 1m/s
Scenario 4	No exhaust fans, outlet at Position 4, external wind speed 1m/s
Scenario 5	No exhaust fans, outlet at Position 2 and 4, external wind speed 2m/s
Scenario 6	No exhaust fans, outlet at Position 2 and 5 external wind speed 2m/s
Scenario 7	(Stack effect), outlet above position 3

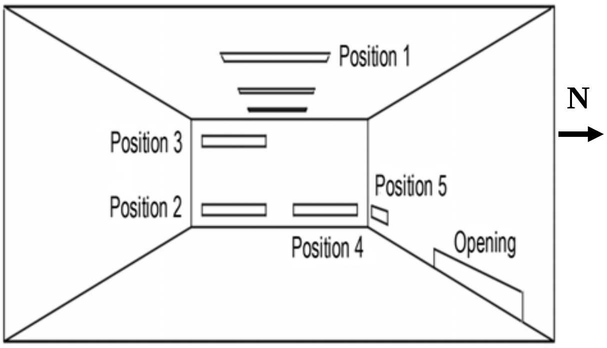

Figure 8 Position of exhaust fan, vents and outlets for different scenarios

SIMULATION FINDINGS

Basecase model

The velocity vectors, PMV, PPD and air change effectiveness for each of the scenario were analysed in detail. These parameters at a height of 1.75 m (to represent people standing) were considered for initial comparison. PMV and PPD were calculated for 2 different types of activities and clothing levels: vigorous sports with sportswear and medium light work with light office wear. Figure 9 shows the vector profile for the basecase scenario. It can be seen that there is some air movement in front of the vents, but the rest of the room is found to be stagnant with effectively no air movement.

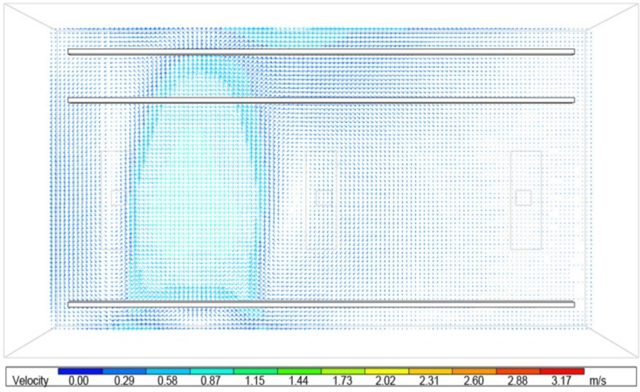

Figure 9: Velocity vectors for the basecase

Figure 10 shows the air change effectiveness. The maximum air change effectiveness of 1.1 was found next to the inlet whereas around 0.5 was observed at most of the other areas. Figures 11 and 12 show the PMV for the two levels of activities and clothing levels. With rigorous sports activities, the PMV was found to be very high which is in the range of 3.

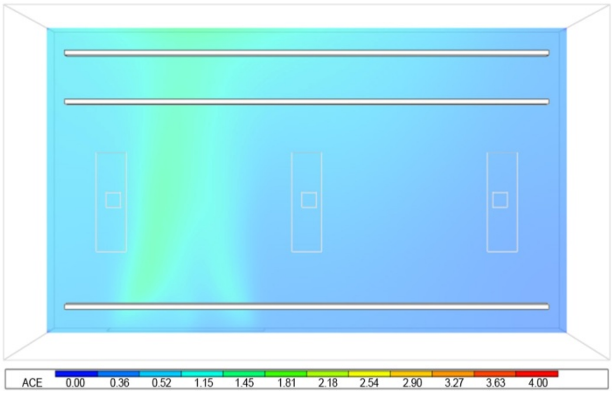

Figure 10 :Air change effectiveness

This is expected for such high level of activity especially on a hot day. With light activity (for eg in the case of spectators), PMV ranged from 0.9 to 1.5 where it was 0.9 next to the inlet and 1.4 at most of the other locations.

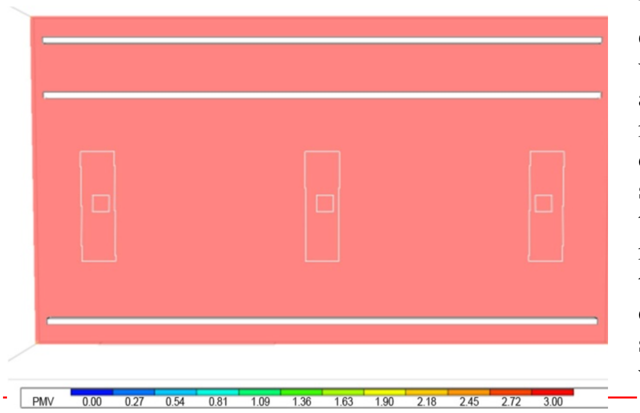

Figure 11: PMV with rigorous sports activity

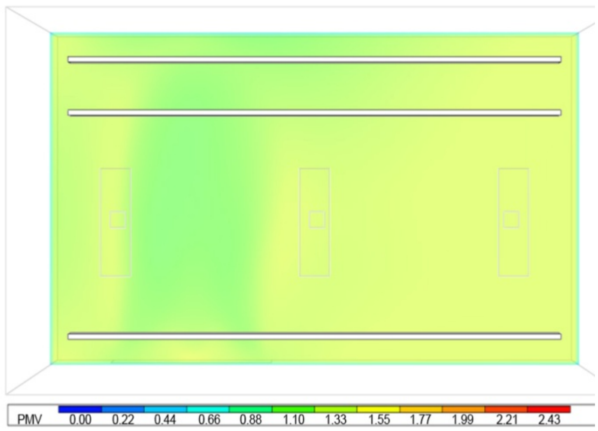

Figure 12: PMV with light office work

Velocity Profile

Comparing scenarios 1 and 2, it was found that more air movement occurred for scenario 2 when the exhaust fan was at a lower level. Scenario 2 showed a clear improvement compared to the basecase, but there was still some stagnant area in the south-west side (see Figure 13).

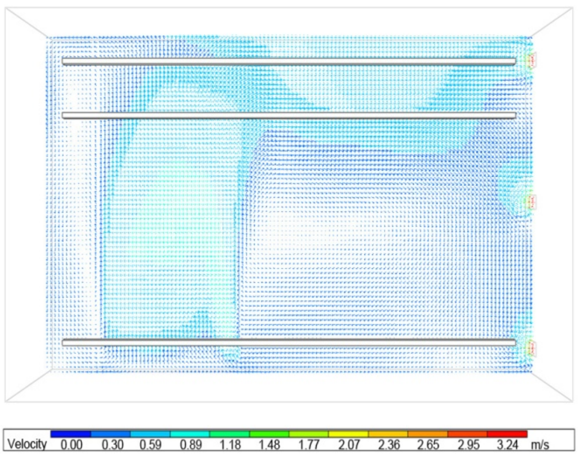

Figure 13: Velocity vectors for scenario 2

The next scenario tested includes replacing the exhaust fans with opening as an outlet for natural ventilation. Figure 14 shows the velocity vectors. The air movement profile is much better even though the magnitude of velocity is lower. The low velocity is due to low external wind speed. When the outlet was shifted to position 4, more air movement occurred in the south-west part of the room (see Figure 15). A number of simulations were conducted with varying the wind speeds to study the effect during windy conditions. It was found that when the external wind speed was higher, more air velocity was observed within the space.

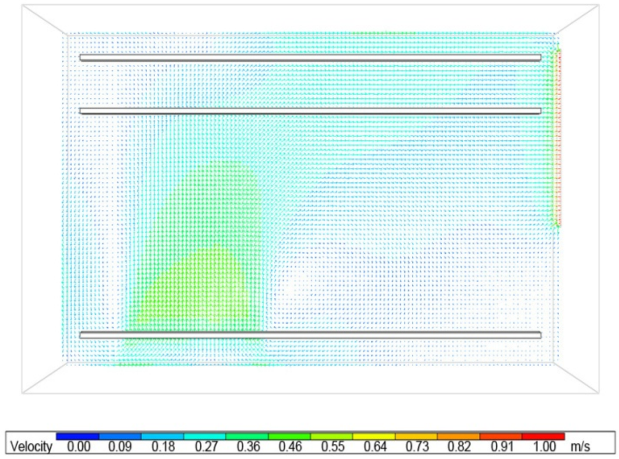

Figure 14: Velocity vectors for scenario 3

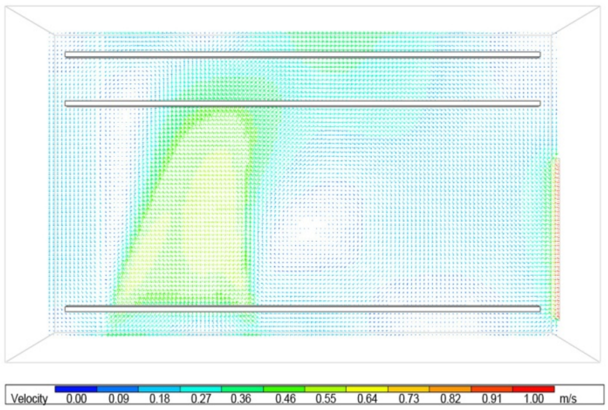

Figure 15: Velocity vectors for scenario 4

Scenarios 5 and 6 have two smaller outlets instead of one as shown in figure 8 and Table 1. Figures 16 and 17 show the indoor air velocity profile for scenario 5 and 6 respectively. External wind speed of 2m/s was used as the boundary conditions to represent moderate windy condition. Scenario 6 shows better distribution of air and slightly higher wind velocity compared to scenario 5.

For stack effect, the inlet wind speed was assumed as 0.1m/s in order to simulate very low wind conditions. The opening was placed at the top of the wall near position 3. The results were then compared to another scenario with same inlet wind speed, where the opening is at lower level. Some air movement was observed at higher levels near to the outlet compared to absolutely no air movement at lower levels.

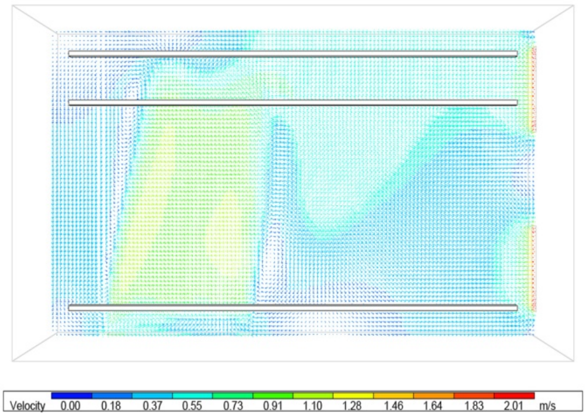

Figure 16: Velocity vectors for scenario 5, inlet wind = 2m/s

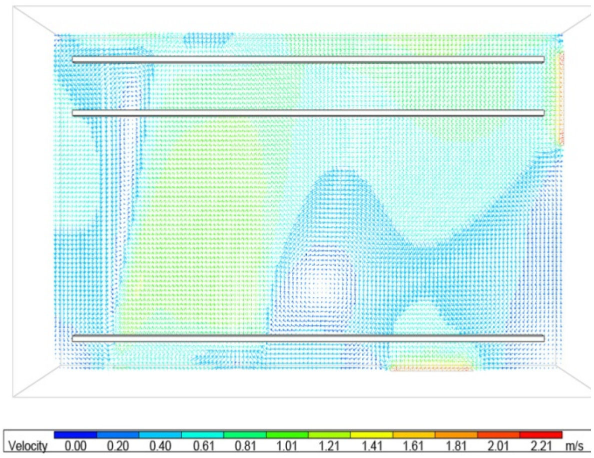

Figure 17: Velocity vectors for scenario 6, inlet wind speed 2m/s

Air change Effectiveness and Thermal Comfort Parameters

The air change effectiveness and comfort indices were analysed further. With the presence of exhaust vents, air change effectiveness was found to be slightly better for scenario 2 where the vents are at a lower location. The air change effectiveness was more even for scenario 5 compared to scenario 6. The stack ventilation did not have much significant improvement in the air change effectiveness as well as thermal comfort in the occupant zone. Figure 18 shows the temperature stratification in a vertical plane. The airflow induced due to stratification was not very significant as the temperature difference between the lower level and higher level is only around 4°C (see Figure 7).

PMV for medium light work was slightly improved for scenario 2. However, there was no significant change in PPD. With scenario 3, PMV was around 1.4-1.6 at most of the locations which indicates hot conditions (Figure 19). For scenario 4, When the outlet was located towards the south-west side, the PMV was found to be around 0.9 which represents slightly hot but better conditions (Figure 20). Scenario 6 provided slightly better thermal comfort conditions compared to scenario 5. With the existing high temperature outside, it is expected that PMV will remain above the comfort temperature levels. However, when the external air temperature is lower, it is possible to have better comfort levels. Figure 21 shows the PMV contours when the external air temperature is 20°C. The PMV range was in between 0 and 0.6 which is within the range of neutral temperatures and considered acceptable. It was very hard to achieve comfort conditions with activity such as vigorous sports. Comfort can only be achieved with lower external air temperature in such cases.

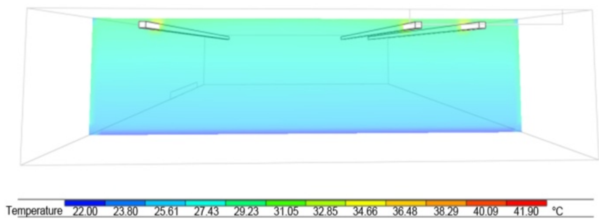

Figure 18: Temperature stratification due to stack effect

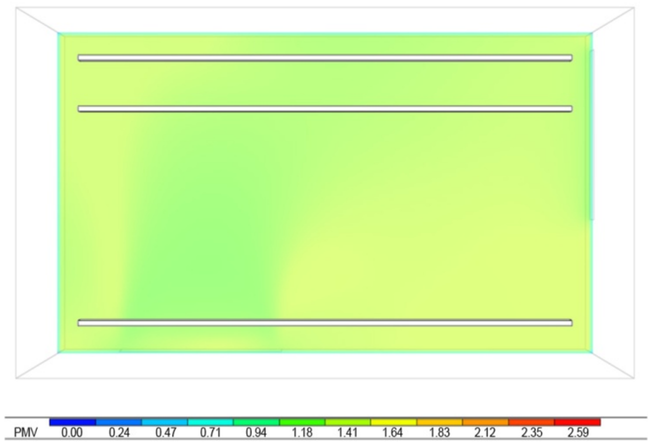

Figure 19: PMV for scenario 3

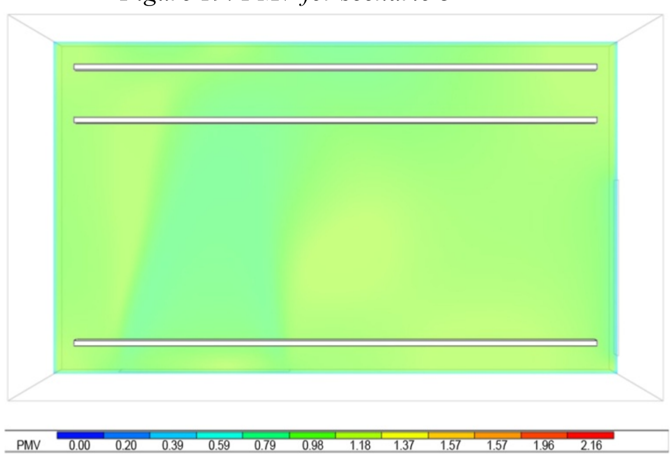

Figure 20: PMV for scenario 4

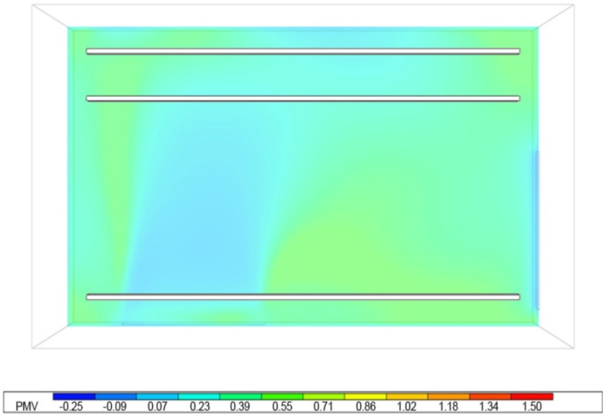

Figure 21: PMV for external temperature 2 0°C

CONCLUSION

The thermal and ventilation performance of a sports hall within an aquatic centre were investigated using CFD simulations. The results were validated with field measurement. Various scenarios were tested and analysed by changing the position of the exhaust fans as well as incorporating natural ventilation strategies. The air change effectiveness was found to be good even though a high level of thermal discomfort was experienced in the space. Lower level exhaust fans give better comfort conditions at the occupant level compared to exhaust fans located at the roof. Also natural ventilation performance was better when the openings were located at a lower level. Changing the location of openings towards the south-west side improved the air movement and comfort conditions. Uniform velocity profile and relatively better thermal comfort was obtained with two smaller openings each positioned at different walls (scenario 6). Stack ventilation did not have significant impact on the air movement and thermal comfort of the occupied zone. With the existing external air temperature, it was very hard to achieve comfort conditions when the occupants are involved in vigorous sports activities. Studies are ongoing by changing the capacity of the exhaust fans and varying the external air temperature in order to find the optimum thermal comfort conditions.

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