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# The Impact of an Upgraded Ventilation System on Thermal Comfort in the Newly Renovated UTHM's Badminton Hall

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**Abstract**

This study investigates the impact of an upgraded natural ventilation system on thermal comfort within the newly renovated Universiti Tun Hussein Onn Malaysia (UTHM) badminton hall. Achieving sufficient thermal comfort is crucial for occupant performance and well-being, as athletic activities like badminton require a high metabolic rate. Previous assessments indicated that the original ventilation system failed to maintain appropriate indoor environmental conditions. This study aims to evaluate whether the upgraded system, which includes additional exhaust fans, improves thermal comfort. The findings showed that 90% of respondents experienced thermal conditions, with an average TSV of +0.5, that were within or close to the acceptable PMV range of -0.5 to +0.5. Compared to earlier studies, objective measurements indicated a reduction in extreme temperature fluctuations and a moderate improvement in air velocity. However, inadequate airflow persisted in certain localized areas. In conclusion, the upgraded ventilation system has contributed to improving the thermal comfort standards of the UTHM badminton hall. These results provide valuable insights for future enhancements in similar indoor environments and reinforce the importance of proper ventilation design and air flow in naturally ventilated sports facilities.

## 1. Introduction

Playing vigorous sports like badminton, which involves a high metabolic rate and intense breathing, demands excellent indoor air quality and proper airflow. Research, including insights from previous study, highlights significant health risks associated with exercising in poorly ventilated or confined spaces. These risks include respiratory problems such as asthma, coughing, shortness of breath, and migraines. This not only reduces oxygen availability but also heightens discomfort during physical activity. Thermal comfort refers to the state of satisfaction individuals experience with their surrounding thermal environment [1]. It is a vital aspect of indoor environmental quality (IEQ) and significantly impacts human health, well-being, and productivity. The air distribution system in a confined room or interior area is crucial as it significantly affects thermal comfort for the occupants. Thermal comfort refers to a state of mind that reflects satisfaction with the thermal environment, whereas the study of indoor air quality focuses on issues related to the healthiness of the indoor environment [2]. However, thermal sensitivity differs according to behaviour, age, gender, and other variables. In this case study, the user especially the students that plays at the badminton hall and also the sedentary spectators may take into account to determine the thermal sensitivity factor that may affect the thermal comfort level.

Physical parameters for thermal comfort, such as air temperature, relative humidity, air velocity, and mean radiant temperature, are measured using instruments like VelociCal meters and KIMO multifunction Instrument meters. Subjective assessments are conducted through questionnaires to gather occupant feedback on their thermal sensation, comfort levels, and perceptions of air quality. A systematic sampling strategy is implemented, involving the strategic placement of sampling points throughout the hall based on factors like layout and occupancy. Data collection occurs over three days, with two two-hour sessions daily (morning and evening) to capture variations in environmental conditions and user activity.

The collected data is then statistically analyzed using Microsoft Excel to determine minimum, maximum, mean, and standard deviation values. Results are compared against established standards such as ASHRAE Standard 55 to assess compliance and identify areas for improvement. Additionally, the CBE Thermal Comfort Tool is utilized to calculate comfort indices like Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD), providing a comprehensive understanding of thermal comfort levels in the hall. This study aims to provide practical recommendations for enhancing the indoor environment of the UTHM badminton hall, ensuring a comfortable and healthy space for its users.

## 2. Methodology

### 2.1 Study Location

The chosen model study for the research is the UTHM's badminton hall, where it is located at Parit Raja, Batu Pahat, Johor Malaysia. It is lies on the GPS coordinate of 1°51'20" North Latitude and 1°05'25" East longitudes. Fig. 1 shows the building of the UTHM's badminton hall and Fig. 2 displays the location of UTHM's badminton hall on map.

**Fig. 1** *The building of UTHM's badminton hall*

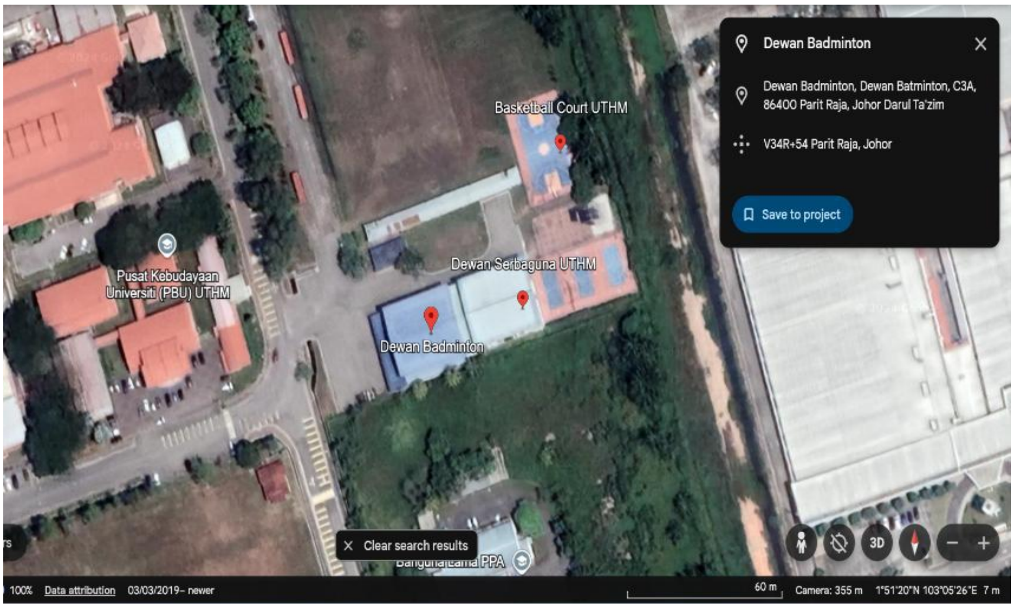



**Fig. 2** *The location of UTHM's badminton hall on map*

## 2.2 Data Collection

### 2.2.1 Subjective Measurements

The subjective measurement was carried out by giving questionnaires to respondents in each of the investigated spaces to obtain their thermal sensation values. The questionnaire was made through the ASHRAE 55 standard guideline. The questionnaire enquired about the respondent's age, gender, thermal sensation votes, clothing, activity level, and present health status. The ASHRAE seven-point thermal sensation scale, which is divided into the following categories: cold (-3) cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), and hot (+3), will be included in the thermal sensation questions. Thermal sensation votes (TSV), which ranged from (-1) to (+3) inclusive, were used to measure comfort and were then divided by the total number of votes. The subjective measurement was used to classify the thermal comfort inside the UTHM badminton hall. A total of 50 respondents answered the questionnaires for the subjective measurement.

### 2.2.2 Physical Measurements

KIMO Multifunction Instrument AMI 310 and TSI VelociCalc equipment Model 8386 were used to measure four parameters: air temperature, relative humidity, air velocity, and mean radiant temperature. Data was collected for the physical measurements in this study over the course of three days, from 9 am to 12 pm and from 2 pm to 5 pm. The key hours of expected occupancy were immediately identified as the measurement intervals. Five minutes or fewer must pass between measurements of air temperature, mean radiant temperature, and humidity, and three minutes or less must pass between measurements of air velocity. The apparatus was placed 1.1 meters above the ground floor as it was chosen as the most appropriate high level for the occupants in the badminton hall for both players and spectators.

## 2.3 Measuring Tools

The study utilizes three main instruments for physical measurements:

- VelociCalc Plus Model 8386: Measures air velocity and computes volumetric flow rate to ensure adequate airflow for indoor air quality, thermal comfort, and energy efficiency.
- KIMO Multifunction Instrument AMI 310: Measure air temperature and air speed temperature with a probe that can measure a sound level and radiant temperature.

## 2.4 Sampling Strategy

Strategic sampling locations are chosen within the badminton hall to accurately reflect environmental conditions, considering factors like geographical distribution, MVAC and HVAC proximity, occupant density, and activities. The minimum number of sampling points for physical measurements is determined based on the total floor area [3]. However, the experiment number of sampling is up to the researcher to decide, where the chosen number of sampling point for this study is 12 monitoring points. The sampling period consists of two two-hour sessions per day (morning: 9:00 a.m. - 12:00 a.m.; evening: 2:00 p.m. – 5:00 p.m.) over two days within a week, to capture variations in indoor ambient conditions and occupant behaviour. Monitors are positioned according to general guidelines, ensuring minimal disturbance and accurate data collection. Fig. 3 shows the location of measuring points in the study area.

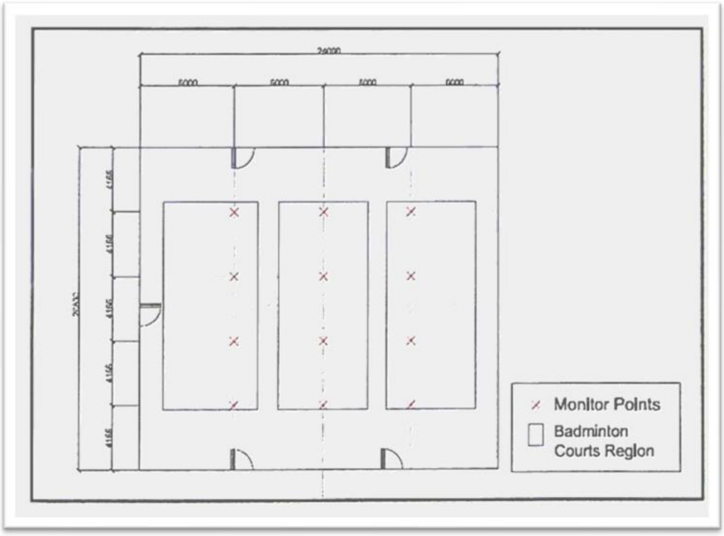



**Fig. 3** *The location of measurement points on the UTHM badminton hall*

## 2.5 Method of Analysis

Data collected from field measurements and surveys is analysed using statistical methods (minimum, maximum, mean, standard deviation) in Microsoft Excel to identify trends and compare results with established standards like ASHRAE Standard 55. The CBE (Center for the Built Environment) Thermal Comfort Tool, based on ASHRAE Standard 55, is used to predict thermal comfort levels by inputting personal and environmental variables and calculating comfort indices like Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD). The operative temperature is calculated using average air temperature and mean radiant temperature. The homepage of the CBE Thermal Tools to create adaptive chart for thermal comfort as shown in Fig. 4.


**Fig. 4** *CBE Thermal Comfort Tools*

# 3. Results and Discussion

## 3.1 Subjective Measurements Results

Out of a total of 50 responses, the demographic chart revealed a large male majority, with 78% identifying as male and 32% as female. This suggests that there is a gender disparity in the sample population of the survey [4]. The age distribution of the respondents is shown graphically in Fig. 5, which also shows that most respondents, a significant 60%, were between the ages of 24 and 26. This implies that those in their mid-twenties were the majority of those polled for the study. Following this, there was a noticeable presence of young adults, as 22% of the responders were between the ages of 21 and 23. The sample's slightly older demographic was represented by a smaller segment of respondents, 14% of whom were between the ages of 27 and 30. At only 4% of all responses, the youngest group 40 those between the ages of 18 and 20 made up the least percentage.

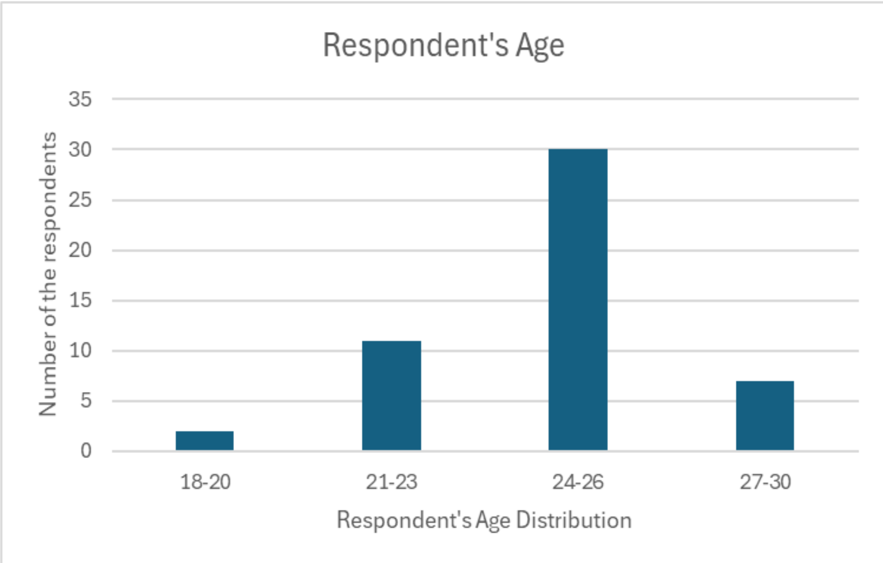



**Fig. 5** *Distribution of the respondent's age*

Table 1 shows the mean TSV value collected from the questionnaire. The TSV value for the badminton hall was +0.5 respectively. The TSV values were well within the recommended range of PMV by ASHRAE standard (-0.5 < PMV < +0.5). This result shows on the average all respondents were within the thermally comfortable condition.

**Table 1** *TSV Mean Value*

| ASHRAE 7-point | | Sedentary occupant |
|---|---|---|
| Hot | +3 | 0 |
| Warm | +2 | 5 |
| Slightly warm | +1 | 15 |
| Neutral | 0 | 30 |
| Slightly cool | -1 | 0 |
| Cool | -2 | 0 |
| Cold | -3 | 0 |
| Average TSV | | 0.5 |

In the questionnaire, respondents are required to answer how they feel about the temperature in the badminton hall. A total of 30 respondents chooses their thermal sensation on the neutral category, where the percentage is 60% from the overall respondents. On the other hand, 15 respondents choose their thermal sensation at the level of slightly warm, where the value of the percentage will fall to 30% from the overall data. Lastly, only 5 respondents choose their thermal sensation on the category of warm where it becomes 10% of the balance from the overall respondents. Fig. 6 shows that 60% of respondents feel neutral, 30% feel slightly warm, and 10% feel warm. The pie chart shows the total average of thermal sensation votes in the experimental badminton hall. It shows that 90% of the respondents feel comfortable because neutral and slightly warm are considered to be acceptable or comfortable [5]. According to ASHRAE Standard 55, thermal comfort is achieved when at least 80% of occupants find the thermal environment acceptable. This typically corresponds to a Thermal Sensation Vote (TSV) in the range of -0.5 < PMV < +0.5, which indicates people feel neutral or slightly comfortable.

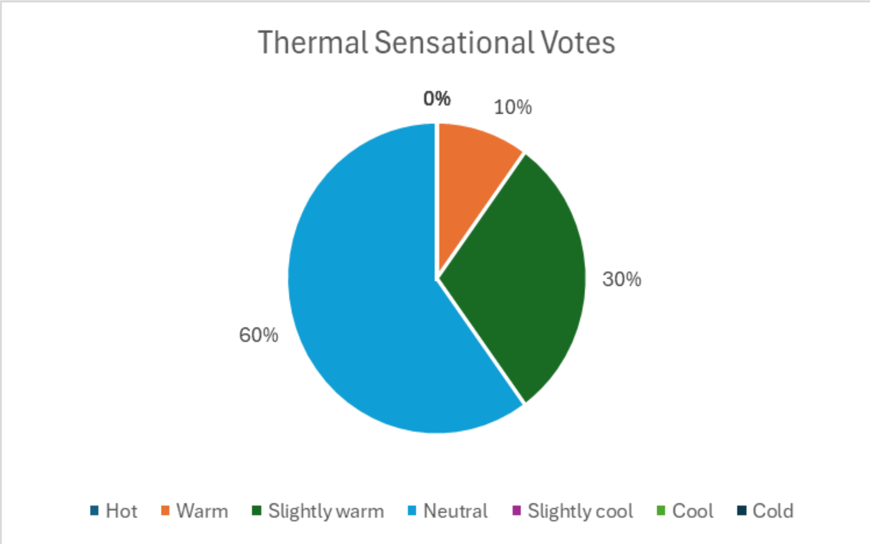



**Fig. 6** *Distribution of the respondent's thermal sensational votes*

## 3.2 Physical Measurements Results

Fi. 7(a) and Fig. 7(b) show the comparison of the air velocity between day 1 and day 2 respectively. Both sessions show a significant change over time, where the morning session shows a bit of an increase in value for day 1 compared to day 2. Meanwhile, for the evening session, the air velocity value for both days seems to be almost the same over time, especially at 5pm the value remains the same value of 0.19 m/s.

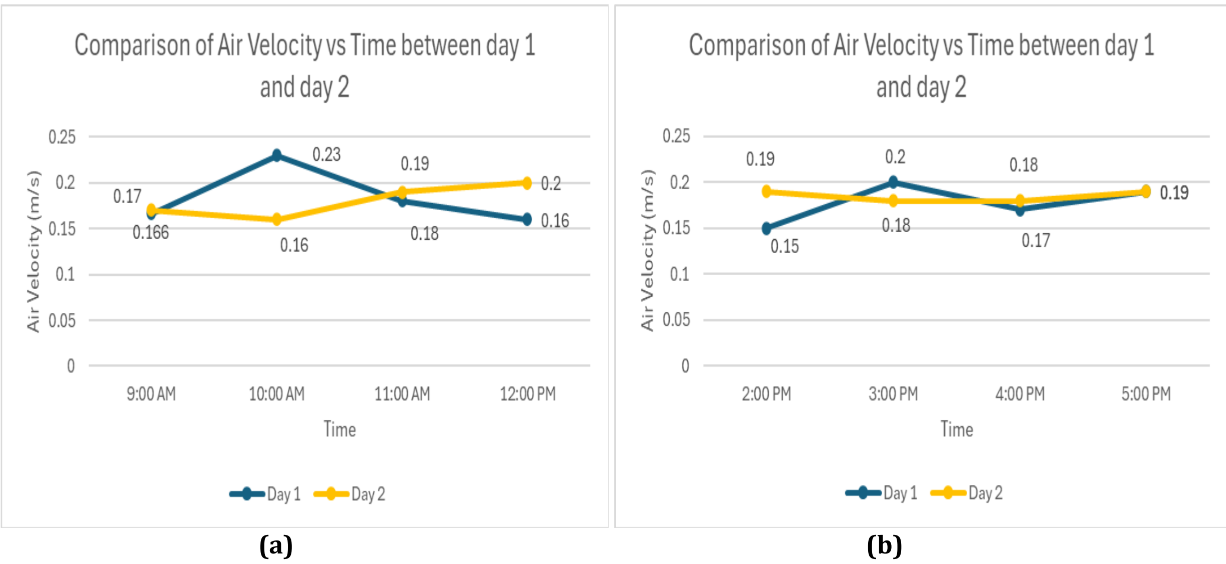
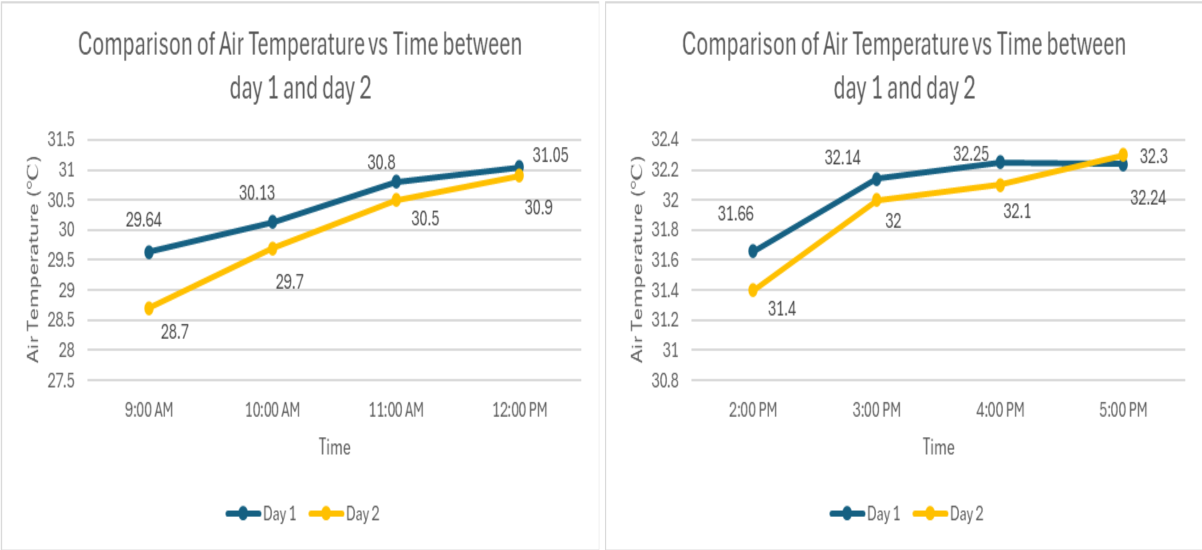



**Fig. 7** *The comparison of air velocity for (a) morning session and (b) evening session*

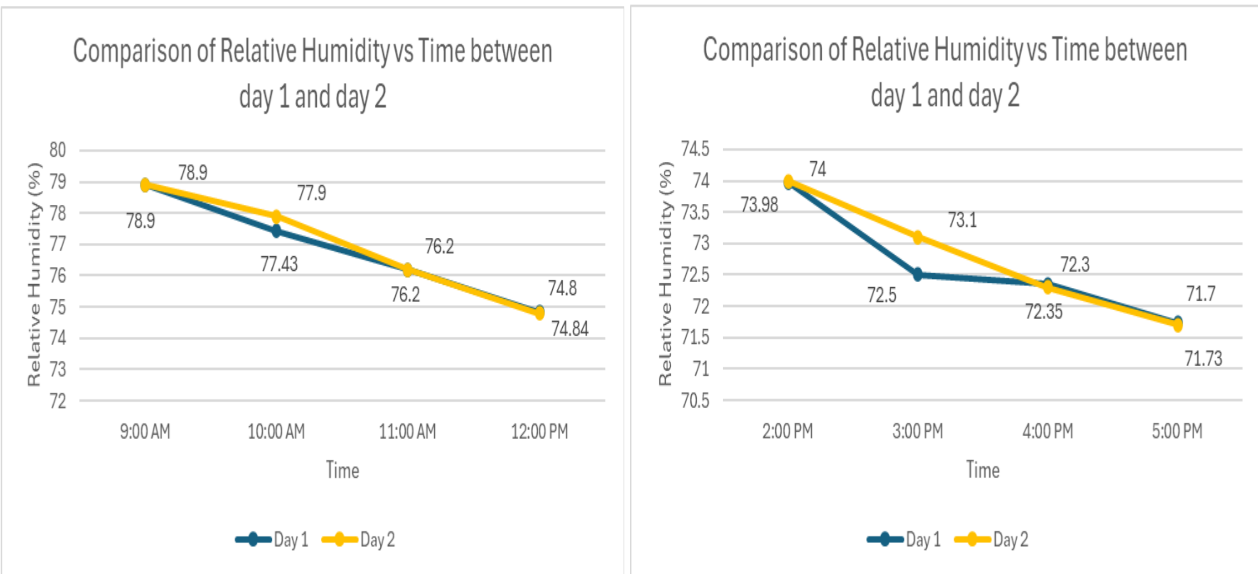
Fig. 8(a) and Fig. 8(b) display the comparison of the air temperature between day 1 and day 2 respectively. Both sessions show a significant change over time, where the morning session shows a bit of a decrease in the value of the air temperature for day 2 compared to day 1. Meanwhile, for the evening session, the air temperature for day 2 is slightly lower than day 1 for almost the whole part but at the last hour on 5 pm the air temperature increases a bit with the value of 32.24 ℃ to 32.3℃.




**(a)** **(b)**

**Fig. 8** *The comparison of air temperature for (a) morning session and (b) evening session*

Fig. 9(a) and Fig. 9(b) show the comparison of the relative humidity between day 1 and day 2 respectively. Both sessions show a significant change over time, where the morning session shows a bit of an increase in the value of relative humidity for day 2 compared to day 1. Meanwhile, for the evening session, the relative humidity for day 2 is slightly higher than day 1 for almost the whole part but at the last hour at 4 pm till 5 pm the relative humidity decreases a bit.




**(a)** **(b)**

**Fig. 9** The comparison of relative humidity for (a) morning session and (b) evening session

Fig. 10(a) and Fig. 10(b) show the comparison of the prevailing mean outdoor between day 1 and day 2 respectively. Both sessions show a slight change over time, where the morning session shows a bit of a decrease in the value of the prevailing mean outdoor for day 2 compared to day 1. Meanwhile, for the evening session, the prevailing mean outdoor for day 2 is slightly higher than day 1 for almost the whole time except during on 2 pm, where its temperature is lower than the day 1 with the value change from 31.65°C to 31.4°C.

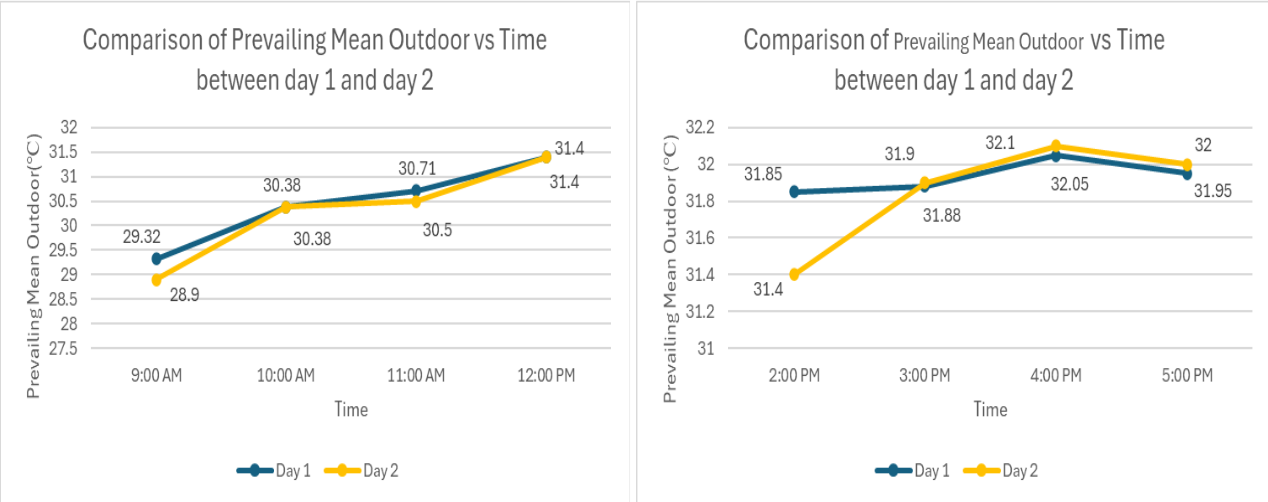



**Fig. 10** The comparison of prevailing means outdoor temperature for (a) morning and (b) evening sessions

Before the thermal comfort can be determined, the value of indoor operative temperature was calculated first for each point. The value can be calculated by using the equation. The value of A in the equation can be determined by using Table 2. The calculated values of indoor operative temperature are shown in Table 3.

**Table 2** *Values based on the function of relative air speed*

| Vr | < 0.2 m/s (40 fpm) | 0.2 to 0.6 m/s (40 to 120 fpm) | 0.6 to 1.0 m/s (120 to 200 fpm) |
|---|---|---|---|
| A | 0.5 | 0.6 | 0.7 |

Based on Table 3, Point 10 had the highest indoor operative temperature, which is 32.08°C, while point 1 was the lowest value of 29.5°C. The different time intervals during the experiment tend to affect the operative temperature of each point. The time taken during the measurement of physical data at point 10 was between 3.15 pm till 4.45 pm. This was the peak time where the operative temperature may be raised especially for a hot tropical climate area such as in Malaysia. Meanwhile, for point 1, where the lowest operating temperature was measured, the measurement was taken during the morning time at 9.15 am. The temperature level is still low therefore its level is slightly significant compared to other monitoring points.

**Table 3** *Indoor Operative Temperature*

| Monitoring Point | Indoor Operative Temperature (°C) |
|---|---|
| 1 | 29.5 |
| 2 | 29.84 |
| 3 | 30.4 |
| 4 | 30.65 |
| 5 | 30.93 |
| 6 | 31.16 |
| 7 | 31.6 |
| 8 | 31.81 |
| 9 | 31.62 |
| 10 | 32.08 |
| 11 | 31.93 |
| 12 | 32 |

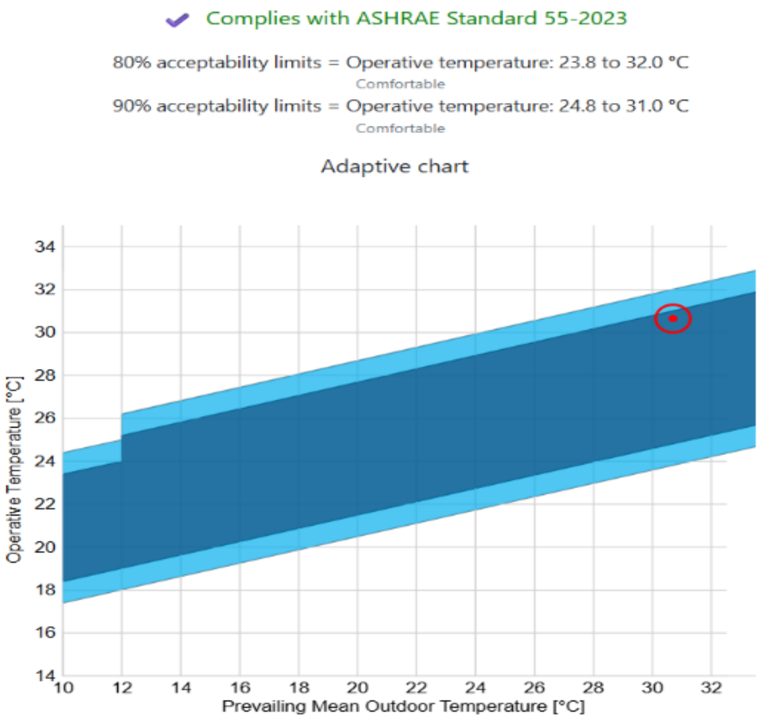



**Fig. 11** *Adaptive chart of naturally ventilated at monitoring point 4*

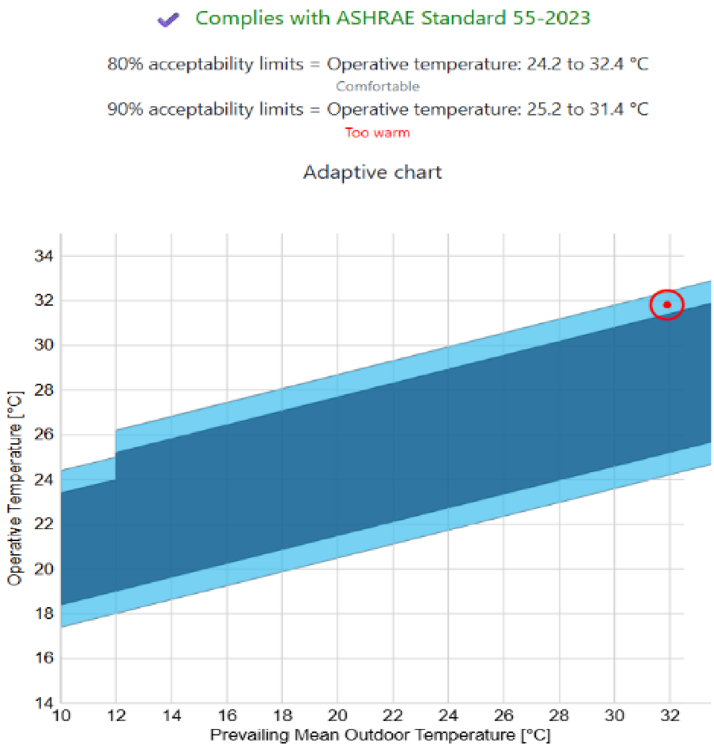



**Fig. 12** *Adaptive chart of naturally ventilated at monitoring point 8*

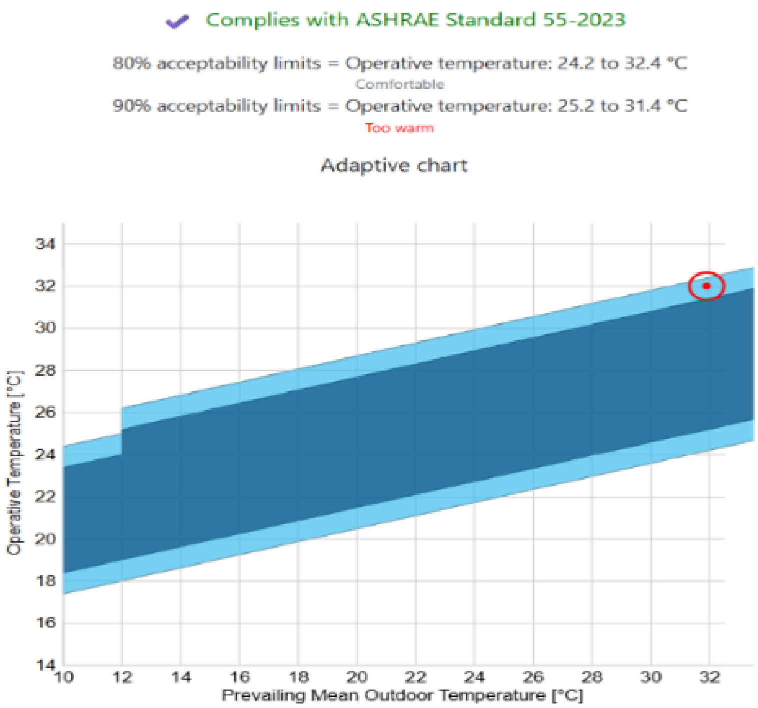



**Fig. 13** *Adaptive chart of naturally ventilated at monitoring point 12*

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The location of the 12 monitoring points scattered throughout the whole badminton hall space, where each court had four monitoring points placed according to the standard and guidelines in a straight line. There were three points that were located close to the spectators' areas which were monitoring points 4, 8 and 12. These monitoring points being placed on the right side of the badminton hall area. It was placed between the spectator's seat area and the end line of the badmintons court. Based on the adaptive chart from Fig. 11, Fig. 12 and Fig. 13, the monitoring point 4, 8 and 12 complies with the limit of thermal comfort standard. This implies that, while the temperature in the spectators' area is generally acceptable to 80% of occupants under the ASHRAE standard, it is likely on the warmer side. A significant portion of viewers between 10% and 20% may experience conditions slightly outside the "comfortable" range, perceiving the environment as "slightly warm" rather than thermally neutral [6]. This means that, while the temperature may not feel uncomfortably hot for most people, a noticeable minority could still experience some level of discomfort.

## 3.3 System Effectiveness

After obtaining the result for all models at different times with full mechanical ventilation and the light switched on at the badminton hall. The average temperature from the 12-monitoring point at different times were calculated for both new ventilation system and old ventilation system model. Fig. 14 shows the comparison of new ventilation systems against old ventilation systems for air temperature.

Over the course of the time, under observation, the new ventilation system continuously maintains lower air temperatures than the old ventilation system. For example, the previous system recorded 30.76 °C at 9:36 am, whereas the new system recorded 30.18 °C. Later in the day, this performance is more noticeable. The previous ventilation system reached a far higher 33.74 °C by 4:48 pm, whereas the new ventilation system recorded with 31.58 °C. This significant difference indicates that the new ventilation system is more successful in preventing heat buildup in the building, especially as the day goes on into the hotter afternoon and evening [7]. This result shown that the added unit of exhaust fans able to cool down the indoor air temperature of the badminton hall by the process of air flow ventilation where the hot air being pushed out of the indoor spaces.

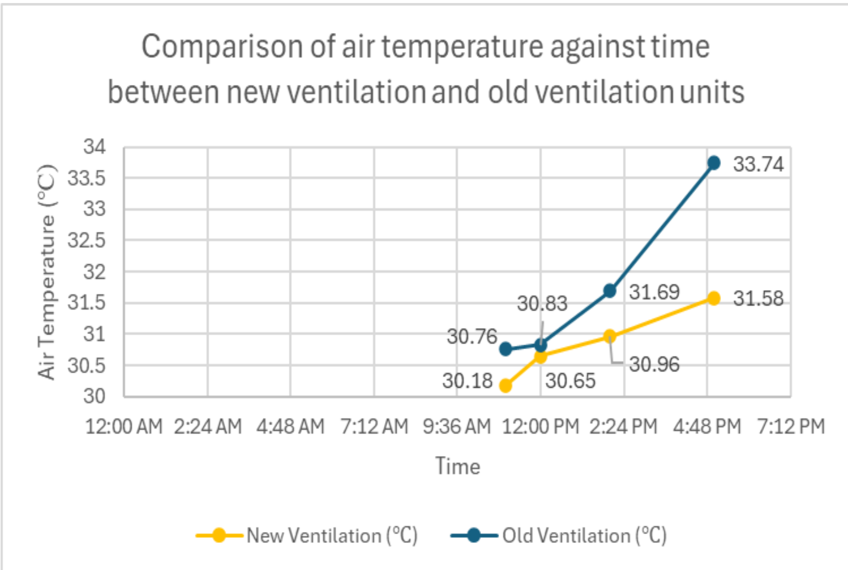


**Fig. 14** *Comparison of air temperature against time between new ventilation and old ventilation units*

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Based on the Fig. 15, the graph effectively illustrates the performance difference between the new and old ventilation systems in terms of air velocity over various time points. For instance, the air velocity recorded by the previous system at 11:00 AM was 0.04 m/s, whereas the new ventilation system recorded an air velocity of 0.23 m/s, which shown an improvement. This pattern is still there, with the old system sustaining very low levels, usually between 0.02 m/s and 0.05 m/s, while the new system maintains velocities between 0.15 m/s and 0.25 m/s. Airflow within the plant has significantly improved since the new ventilations units was implemented, as demonstrate by the clear distinction between the two lines on the graph and the new ventilation line's constant plotting considerably above the old ventilation line [8].

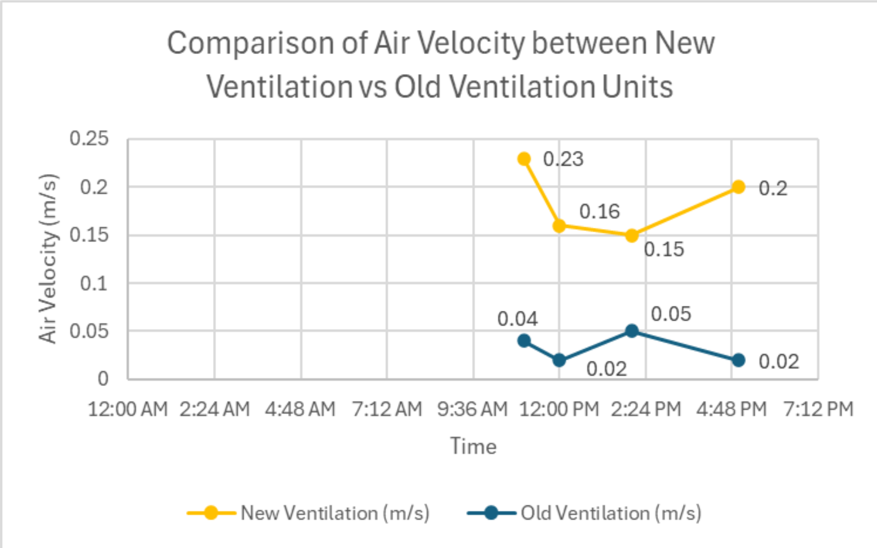


**Fig. 15** *Comparison of air velocity against time between new ventilation and old ventilation units*

## 4. Conclusion and recommendation

The As a result, the study fulfilled its objective of conducting an assessment and compare the thermal comfort conditions before and after the implementation of the upgraded ventilation system at the newly renovated UTHM badminton hall. The objective of assessing thermal comfort satisfaction and thermal sensation was achieved for the subjective assessment. Physical measurements were conducted in naturally ventilated UTHM badminton hall, where the variables that being gathered include the meant radiant temperature, air velocity, air temperature, relative humidity and prevailing mean outdoor. The subjective measurement was conducted through the questionnaires that include questions about the general information of the respondents and the subjective perception of thermal comfort.

Based on the finding, the air temperature in the morning for the physical measurement is less effective to be the data needed to determine the optimal thermal comfort in the badminton hall. This is because, in the morning, when indoor and outdoor temperatures are similar, the buoyancy-driven airflow is minimal. As the day warms and the indoor air becomes lighter, it naturally rises to the ceiling, allowing the ventilator to efficiently expel hot air consistent with documented stack-effect behaviour in tall, naturally ventilated spaces. Overall, the indoor air temperature decreased with the new ventilation units compared to the previous ventilation units. For instance, at 5 pm where the temperature was at peak, the air temperature in badminton hall was reduced from 33.74°C to 31.58°C. Hence, the new ventilation was able to reduce the temperature with the help of an additional number of exhaust fans compared to the previous units. Not only that, but a significant change in air velocity was also observed throughout the study. The results show a steady linear increase in air velocity for the new ventilation system compared to the previous one, with the average value rising from 0.15 m/s to 0.25 m/s, where the value of air velocity from before was ranging from 0.02 m/s to 0.05 m/s. Therefore, the effectiveness value of the air velocity was a significant finding for this study with the value of 18.29% on average.

Based on the CBE Thermal Comfort tool, the adaptive chart shows that all the monitoring points are within a comfortable range and suited for the occupant such as sedentary or spectator at the UTHM badminton hall. This is because the value obtained was complied with ASHRAE 55 standard for both 80% and 90% acceptability limits. From the subjective assessment, the thermal comfort votes obtained 90% of the students are comfortable in the badminton hall with the average indoor air operative temperature of 29.6°C.

## Acknowledgement

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## Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted independently, and no financial or personal relationships could have appeared to influence the work reported in this paper.

## Author Contribution

*The authors confirm contribution to the paper as follows: study conception and design: Teor Wee Hock, Azian Binti Hariri; data collection: Teor Wee Hock; analysis and interpretation of results: Teor Wee Hock, Azian Binti Hariri; draft manuscript preparation: Teor Wee Hock. All authors reviewed the results and approved the final version of the manuscript.*

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