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A Study on Thermal Comfort Performance in Shared Facility Multi-Purpose Hall (MPH), Pagoh Educational Hub

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Abstract

Thermal comfort significantly affects students' productivity and health in university's environment, particularly during examinations. This study focuses on evaluating thermal comfort in the Multi-Purpose Hall of the Shared Facility in Pagoh Educational Hub, addressing student complaints about excessively cold conditions during exams. The objectives of this study are to evaluate occupants' perception of thermal comfort and to assess the thermal conditions of the Multi-Purpose Hall. There were two method approach was employed, integrating physical measurements (air temperature, humidity, air velocity) with subjective data from questionnaires. Thermal comfort parameters were analyzed and compared against ASHRAE Standard-55, MS 1525-2014 and ISO 7730 guidelines. The PMV and PPD values from the thermal environment measurement at the multipurpose hall fall within the acceptable range specified by ASHRAE 55 and ISO 7730, with a PMV of -0.1 and a PPD value of 5.7%, indicating that the measured thermal conditions are within the comfort zone. However, the PMV and PPD values obtained from the questionnaire survey show a PMV of -1.5 and a PPD value of 53%, which exceed the upper limits recommended in ASHRAE Standard 55 and the acceptability criterion in ISO 7730. In conclusion, the Multi-Purpose Hall's thermal conditions are aligned with comfort standards but in term of occupant's survey, the value exceed the upper limits recommended in ASHRAE Standard 55 and the acceptability criterion in ISO 7730.

1. Introduction

Thermal comfort plays a critical role in enhancing the well-being of building occupants and optimizing energy usage in indoor spaces. The importance of maintaining appropriate thermal conditions in architectural design has been widely acknowledged in building science and engineering. With the rapid urbanization and the increasing demand for multifunctional spaces, such as the Shared Facility Multi-Purpose Hall at the Pagoh Educational Hub, ensuring thermal comfort in such spaces has become essential for creating conducive environments for occupants. This aspect of building design is not only vital for health but also for improving productivity and user satisfaction. Considering the growing concerns over energy efficiency and sustainable building design, achieving a balance between comfort and energy use remains a significant challenge in modern architecture. The rising influence of climate change, building occupancy patterns, and technological advancements in HVAC systems are reshaping how thermal comfort is addressed in shared spaces. The need for systematic studies to assess and optimize indoor thermal conditions has, therefore, gained momentum in recent years.

The relationship between indoor environmental parameters and human perception of comfort is complex and influenced by various factors, including air temperature, humidity, air velocity, and individual preferences. Thermal comfort models, such as the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), have been employed to quantify occupant satisfaction in indoor spaces. However, while these models offer valuable insights, they may not always capture the full range of occupant experiences in spaces with varying uses and environmental conditions. To date, several studies have focused on thermal comfort in educational buildings and multi-purpose halls. These studies often highlight the challenges posed by fluctuating occupancy, variable weather conditions, and the limitations of conventional HVAC systems in maintaining a consistent indoor climate. While some studies have suggested that passive design strategies can improve indoor thermal comfort, others have pointed to the shortcomings of these methods in highly dynamic environments such as the Pagoh Educational Hub's Shared Facility Hall.

Despite the growing body of research, gaps remain in understanding how different environmental parameters interact and how occupant behavior influences perceived comfort. Taken together, it remains an open question whether the existing thermal comfort models are universally applicable in multi-use buildings. The complexity of occupant feedback, which can vary significantly depending on age, gender, and cultural background, further complicates the development of universal guidelines for thermal comfort. Furthermore, the role of adaptive strategies, such as clothing choices and the ability to personalize thermal settings, has not been fully explored in the context of multi-purpose halls. The research indicates that adaptive behavior, such as the use of layered clothing, can have a significant impact on thermal perception, but this aspect has often been overlooked in conventional thermal comfort studies (2). Moreover, external factors like air velocity, solar exposure, and seasonal changes in temperature have not been sufficiently incorporated into existing studies, particularly in relation to their impact on thermal comfort in educational hubs and public buildings.

The goal of this study is to address these gaps by evaluating thermal comfort in the Shared Facility Multi-Purpose Hall at Pagoh Educational Hub, focusing on the interaction between environmental parameters and occupant preferences. It is hypothesized that while the indoor air temperature and relative humidity fall within acceptable limits, thermal discomfort can still occur due to fluctuations in air velocity and external weather conditions. To test this hypothesis, A study involving 87 occupants was conducted to assess their thermal perceptions through surveys, coupled with direct measurements of air temperature, relative humidity, globe temperature, and air velocity. This study aims to provide new insights into the role of adaptive behavior, including clothing adjustments, in improving comfort levels in multi-purpose spaces. The study also aims to explore the influence of different weather conditions, such as sunny, cloudy, and rainy, on indoor thermal comfort, particularly in relation to HVAC system efficiency. By focusing on both subjective and objective measures of thermal comfort, this paper seeks to fill the gap in the existing literature regarding the optimization of indoor environments in shared facilities. The primary hypothesis is that occupant satisfaction can be significantly improved by incorporating adaptive strategies, such as educating users on the benefits of layered clothing, and by considering dynamic weather patterns in building design and operation. To answer this question, A comprehensive approach was employed, including thermal measurements, occupant surveys, and the application of PMV and PPD indices. This paper is structured as follows: first, the methodology used to collect data on environmental parameters and occupant perceptions is described. Second, the results of the analysis are presented, focusing on the correlation between environmental factors and thermal comfort. Finally, we discuss the implications of our findings for building design and HVAC system optimization.

2. Methodology

The methodology flowchart presents the sequential steps taken to address the research question, starting from the data collection phase, followed by thermal comfort assessment, and concluding with statistical analysis. The chart highlights the key stages including site selection, instrument setup, respondent survey, and data analysis. Each step was designed to ensure the accuracy and reliability of the findings, with a clear framework for validating the results.

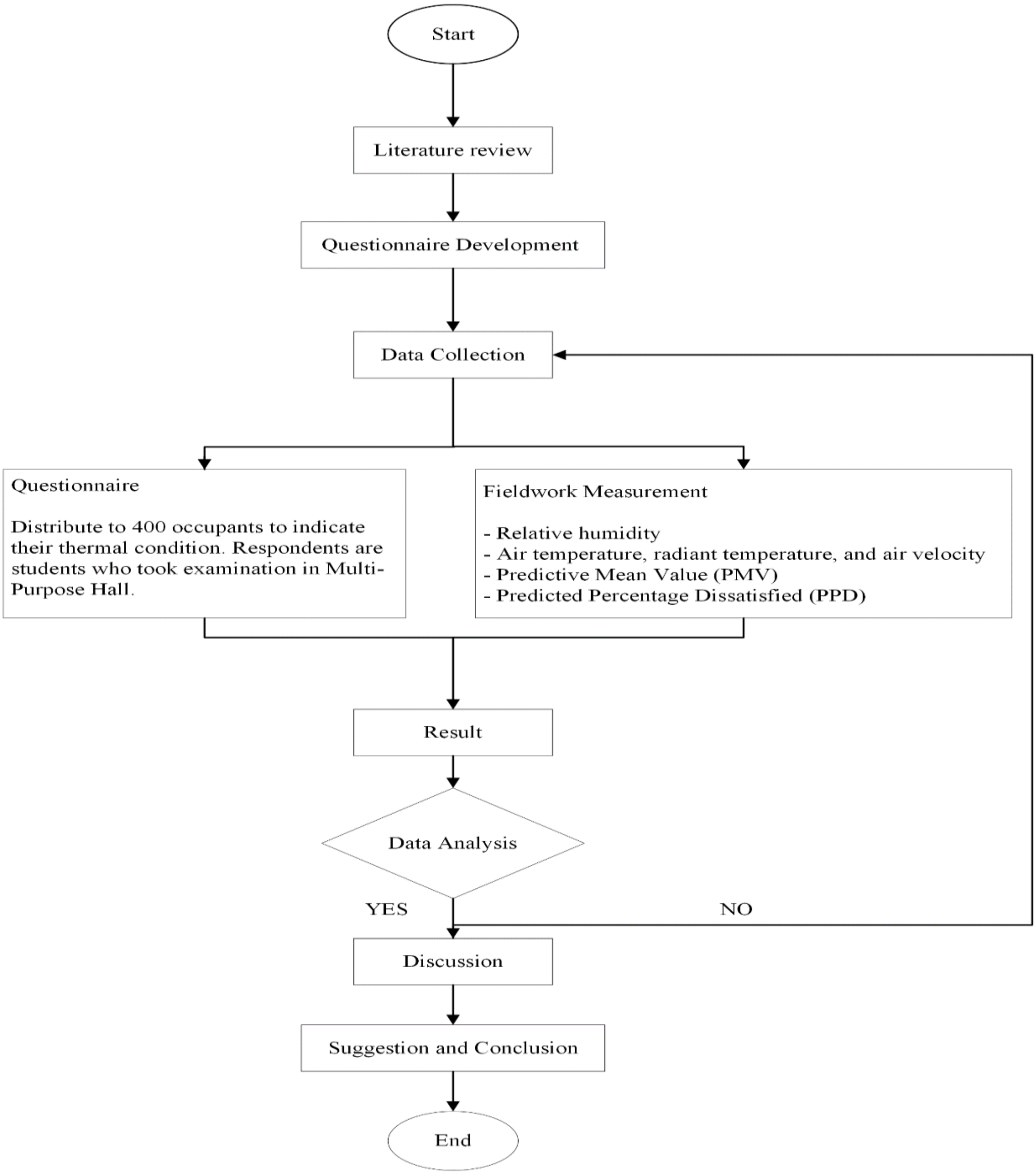


Fig. 1: Overview of Methodology Process

2.2 Measurement Method

The measurement methods employed in this study were designed to capture both subjective and objective data related to thermal comfort. Objective data were obtained through the use of a thermal comfort kit, while subjective data were collected through a detailed questionnaire administered to the occupants. The integration of both approaches allowed for a comprehensive analysis of thermal comfort levels across different environmental and personal variables.

2.2.1 On-site Measurement

The thermal comfort kit used in this study consisted of instruments to measure environmental parameters such as air temperature, humidity, air velocity, and radiant temperature. The kit was calibrated according to the standards set by ASHRAE Standard 55-2021 (3), ensuring accuracy in the measurement of thermal conditions. It was configured for a clothing insulation value (CLO) of 0.8 and a metabolic rate (MET) of 1.2 to simulate typical indoor activity levels and attire. These measurements were taken in the Shared Facility Multi-Purpose Hall to assess the indoor environmental quality and its influence on thermal comfort (4).

Fig. 2: On- site measurement using thermal comfort kit (LSI Lastem heatshield)

2.2.1 Questionnaire

In parallel with environmental measurements, a questionnaire was administered to occupants to gather data on their perceptions of thermal comfort and their responses to the indoor environmental conditions. This tool was designed to assess subjective aspects of thermal comfort, such as comfort perception, preferences, and adaptive behaviors. The questionnaire was structured in two parts to capture both demographic information and thermal comfort responses. Section A of the questionnaire aimed to collect demographic data from respondents, including their age, gender, clothing type, and activity level. This section also included questions related to the individual's typical comfort range and any known health conditions that might influence their thermal comfort perception. The information gathered in this section was essential for understanding potential variations in comfort perception across different respondent groups in their work on adaptive thermal comfort (5). Section B focused on the respondents' subjective perceptions of thermal comfort in the multi-purpose hall. Using a scale, occupants were asked to rate their level of comfort, from "very uncomfortable" to "very comfortable," based on the temperature, air quality, and overall environmental conditions of the space. This section also included questions about the impact of ventilation, lighting, and the presence of any thermal discomfort symptoms such as fatigue or difficulty concentrating. The data from this section were critical in understanding how environmental factors affected thermal comfort (6).

2.3 Method of Analysis

Data collected from the thermal comfort measurements and questionnaires were analyzed using Microsoft Excel. For the environmental measurements, an average was calculated for each parameter (air temperature, relative humidity, mean radiant temperature, air velocity, PMV, and PPD) over the survey period to represent the overall thermal conditions in the multi-purpose hall. For the subjective data, a frequency analysis was conducted to determine the percentage of respondents who reported being "comfortable" versus those who reported thermal discomfort. Cross-tabulation was also used to assess the relationship between demographic variables (such as age and activity level) and reported thermal comfort. Finally, regression analysis was performed to identify which environmental factors (temperature, humidity, velocity, mean variant temperature.) were most strongly correlated with the respondents' comfort levels (7)(8).

3. Result and Discussion

This section presents the results of the research, followed by an in-depth discussion of the findings. The results were obtained through a combination of occupant surveys and environmental measurements. The discussion will interpret the results, highlight key patterns, and relate them to existing research while addressing potential limitations and their implications for future research.

3.1 Questionnaire Result

The questionnaire provided valuable insights into the occupants' perception of thermal comfort and demographic characteristics. It consisted of sections aimed at understanding the respondents' demographic information and their subjective experiences with thermal comfort in the multi-purpose hall during examination periods. This data is essential for interpreting the environmental measurements in the context of occupant comfort.

3.1.1 Demographic Information

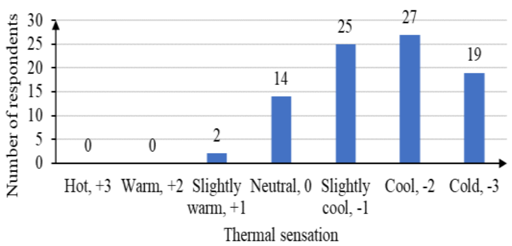
A total of 87 respondents participated in the survey, comprising 53% females and 47% males, with 46% aged between 22 to 24 years, 36% aged between 18 to 21 years, and 18% aged 25 years and above. This information is critical in understanding the thermal comfort preferences of different user groups in the multi-purpose hall. In terms of racial distribution, 76% identified as Malay, 14% as Chinese, 8% as Indian, 1% as Bidayuh, and 1% as Iban, reflecting the cultural diversity that influences thermal comfort preferences due to variations in diet, metabolism, and other lifestyle factors.

Additionally, 83% of respondents in healthy conditions, 10% of respondents reported experiencing fever, and 7% respondents experiencing flue, which may increase sensitivity to thermal discomfort. 41.4% of respondents wore sweaters, 12.6% respondents wore jackets, and 33.3% respondents wore long-sleeve shirts, indicating a preference for moderate to high insulation. This suggests that the indoor thermal environment may be cooler, prompting occupants to layer their clothing for warmth.

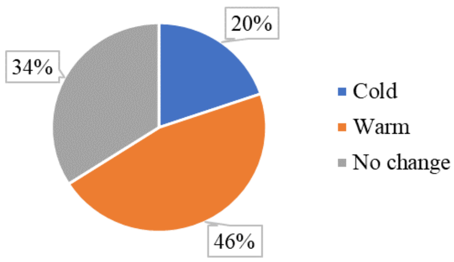
The majority of respondents wore trousers (52.9%), socks (66.7%), and shoes (72.4%). On the other hand, only a small percentage opted for lighter options such as short sleeves (17.2%), shorts (1.1%), sandals (3.4%), or slippers (2.3%), reflecting that some occupants might perceive the environment as warmer or prefer less insulation. Cultural factors, such as the use of hijabs (29.9%), also contribute to variations in clothing insulation These demographic insights provided a comprehensive context for evaluating thermal comfort perceptions across different groups.

3.1.2 Occupant Thermal Comfort Perception

When inquired about their thermal sensation during examination periods, 25 respondents felt "slightly cool," and 27 respondents reported feeling "cool." The discomfort was primarily associated with higher temperatures, particularly during peak hours of examination. This aligns with the findings of Nicol and Humphreys (2002), who found that high indoor temperatures negatively impact occupants' comfort during focused tasks such as exams. Regarding temperature preference, 46% of the respondents preferred a warm temperature. This preference is consistent with existing studies, which suggest that the majority of occupants in indoor environments feel most comfortable within the range between temperature range 22°C and 24°C (9).



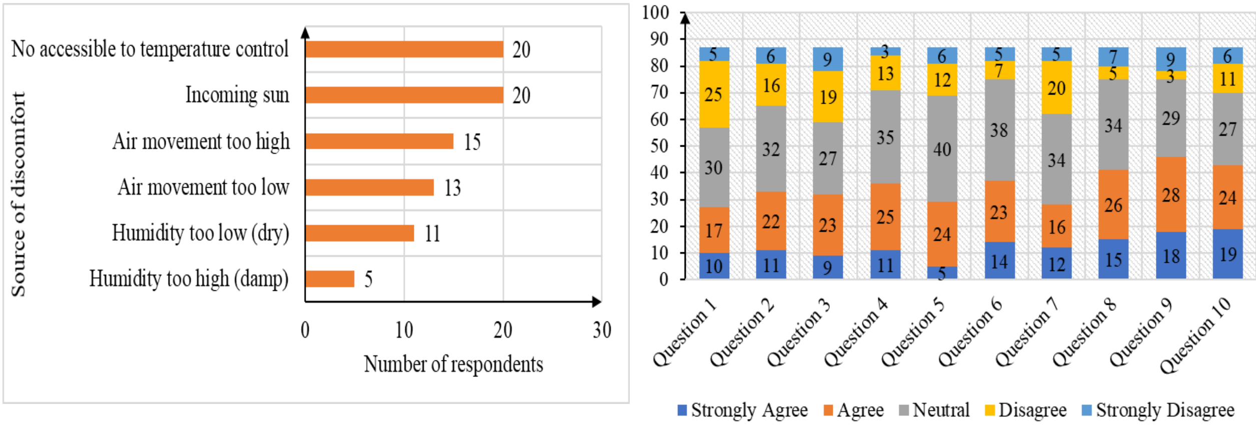
(a)



(b)

Fig. 3: Thermal sensation during examination time (a) Occupant's temperature preference (b)

The primary sources of thermal discomfort reported were incoming sun with 20 respondents, same with no accessible to temperature control. This finding suggests that poor temperature control, coupled with ventilation inefficiencies, is a common cause of discomfort, which has been documented in similar studies on thermal comfort (6). Based on Appendix A, 30 respondents felt comfortable, with 27 of respondents preferred cooler temperatures for better focus, while warmer conditions (35 respondents) were seen as disturbing. The temperature significantly affected many occupants, with more than half of the respondents agreeing that it reduced their performance, ability to stay awake, and concentration level. Moreover, some occupants responded that temperature increased stress levels and provided different temperature preferences, meaning they were dissatisfied with the current temperature. Several respondents indicated that the temperature of the multi-purpose hall was affected physically in terms of sweating or feeling cold at times. The experience in the hall was described by respondents as being too cold, with the need to go to the toilet frequently being mentioned.



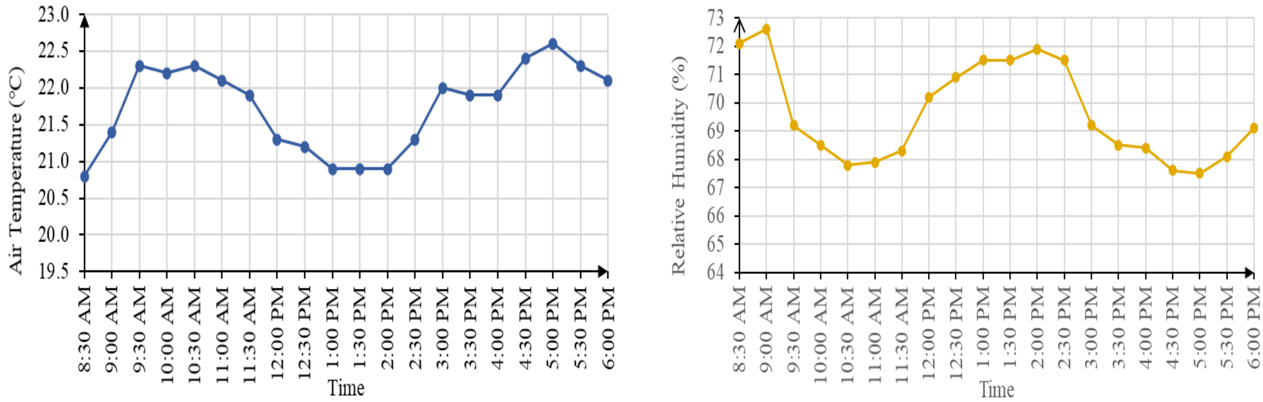
(a) (b)

Fig. 4: Source of discomfort (a) Occupant's perception during examination in Multi-Purpose Hall (b)

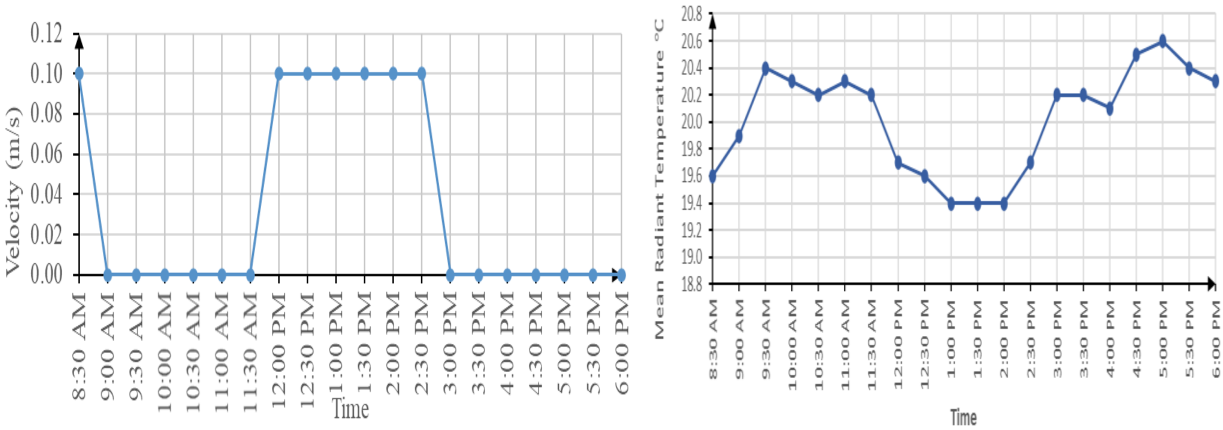
3.2 Thermal Comfort Parameter

The environmental data collected, including air temperature, relative humidity, air velocity, PMV (Predicted Mean Vote), and PPD (Predicted Percentage of Dissatisfied), were analyzed to determine the indoor thermal conditions and how they align with occupant perceptions. The temperature in multi-purpose hall starts at 21°C in the morning, rises to a peak of 22.5°C by 9:30 a.m., and maintains around 21.5°C until midday. The temperature gradually increases in the afternoon, reaching a maximum of 22.8°C by 4:30 p.m., before slightly dropping to 22.5°C in the evening. These fluctuations indicate that the multipurpose hall is slightly cool during the morning but experiences a rise in temperature in the afternoon. The humidity in the multi-purpose hall starts high at 72% in the morning, drops to its lowest point at 67%, and then gradually increases to peak again at 70%. Afterward, it steadily decreases, reaching around 68% by late afternoon, and rises slightly to 69% by 6.00 PM. High humidity in the morning is common due to cooler temperatures. The midday drop results from increased indoor heating and air movement, reducing moisture levels. The gradual increase in the afternoon is due to accumulated heat and moisture from examination inside the hall or external conditions.

The air velocity starts at 0.1 m/s at 8:30 AM, drops to 0 m/s by 9:00 AM, and remains at 0 m/s until 11:30 AM. From 11:30 AM to 2:30 PM, the air velocity increases and stabilizes at 0.1 m/s before dropping to 0 m/s and staying constant for the rest of the day. The changes in air velocity result from the presence of students in the multipurpose hall. The zero velocity periods indicate times when occupants entered or exited the multi-purpose hall.



(a) (b)



(c) (d)

Fig. 5: Air temperature vs time (a) Relative humidity vs time (b) Air velocity vs time (c) Mean radiant temperature vs time (d)

The PMV values from questionnaire survey data show the fluctuation slightly around the neutral line, with values ranging from -0.35 to 0.10. This indicates that occupants might feel slightly warm or cool at different times of the day. PPD values remain below 5%, indicating that a small percentage of occupants are dissatisfied with the thermal environment. The PMV values indicate minor fluctuations around the neutral comfort level, experiencing slight variations in warmth and coolness. Despite these fluctuations, the PPD values remain below 5%, indicating high occupant satisfaction with the thermal environment.

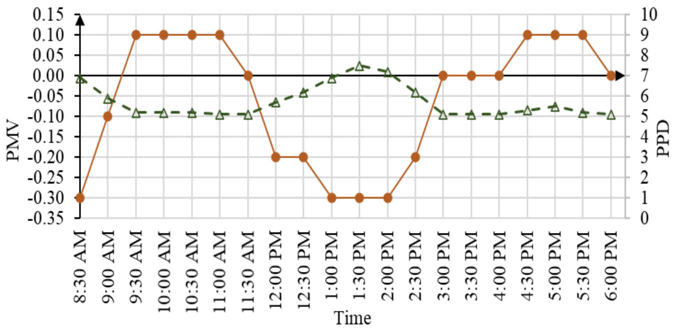


Fig. 6: PMV vs PPD

3.3 Thermal Comfort Evaluation

When comparing the measured thermal parameters with the established comfort standards, it was found that the indoor temperatures in multi-purpose hall fell within the acceptable limits outlined in ASHRAE Standard 55-2021. The PMV (Predicted Mean Vote) value is -0.1, which falls outside the acceptable range of -0.5 to +0.5 specified by ASHRAE 55-2017. This indicates that the thermal environment is not within the comfort range for most occupants according to the ASHRAE standards. The PPD (Predicted Percentage of Dissatisfied) value was 5.74%, well below the 20% threshold set by ASHRAE 55-2017, suggesting that a small percentage of people are dissatisfied with the thermal environment. However, it is still within the acceptable limit. Therefore, both PMV and PPD values align with the ASHRAE 55-2017 standards, indicating that the thermal conditions are generally comfortable for most occupants.

Table 1: The average of on-site data collection.

Parameter	Average Data
Air Temperature (°C)	21.7
Mean Radian Temperature (°C)	22.7
Relative Humidity (%)	69.6
Air Velocity (m/s)	0.04
Metabolic Rate (met)	1.2
Clothing Insulation (clo)	0.8
PMV	-0.1
PPD (%)	5.7

Based on Table 1, the PMV (Predicted Mean Vote) value is -0.1, which falls outside the acceptable range of -0.5 to +0.5 specified by ASHRAE 55-2017. This indicates that the thermal environment is not within the comfort range for most occupants according to the ASHRAE standards. The PPD (Predicted Percentage of Dissatisfied) value was 5.74%, well below the 20% threshold set by ASHRAE 55-2017, suggesting that a small percentage of people are dissatisfied with the thermal environment. However, it is still within the acceptable limit. Therefore, both PMV and PPD values align with the ASHRAE 55-2017 standards, indicating that the thermal conditions are generally comfortable for most occupants.

Thermal Sensation Vote (TSV) is a subjective measure in thermal comfort studies to assess an individual's perception of their thermal environment. It is typically collected through a questionnaire survey where respondents are asked to rate their thermal sensation on a predefined scale. Based on the questionnaire survey, a thermal sensation vote (7-degree scale) should be used in environments involving PMV and PPD. The correlations between the PMV, PPD, and thermal sensation are shown in Table 1. Thermal satisfaction for a population is an important step to determining comfort instead of whether people are going to be happy or not (10). According to the requirements of the International Standard, thermally dissatisfied people are those who will vote hot, warm, cool, or cold on the 7-point thermal sensation scale (ISO 8996, 2004).

Table 2: Thermal sensation vote (TSV) through questionnaire survey

Thermal sensation vote						
Cold	**Cool**	**Slightly Cool**	**Neutral**	**Slightly Warm**	**Warm**	**Hot**
19	27	25	14	2	0	0
Dissatisfied = **46**		Satisfied = 4**1**			Dissatisfied = **0**	

$$PPD = \frac{\textit{the number of quetionnaires having discomfort lable}}{\textit{total number of questionnaires in any section}} \times 100 \quad (1)$$

$$= \frac{46+0}{87} \times 100$$

$$= 53\%$$

From the results obtained through the questionnaire survey, 53% of the occupants are dissatisfied with the thermal condition of the multipurpose hall. According to Guan et al. (2003), for PPD to be categorized as a good condition, it was noted that it has to be below 20%. Hence, it can also be explained that the multipurpose hall's thermal condition does not meet the standard and the occupants are dissatisfied.

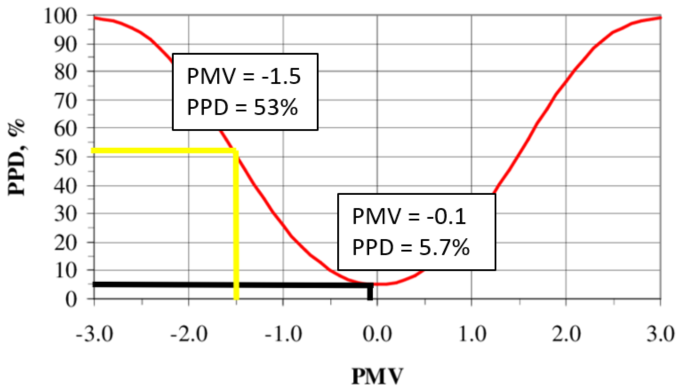


Fig. 7: Comparison graph between PPD vs PMV

Fig. 7 shows the graph of PPD against PMV. Of the occupants, 53% are dissatisfied with the thermal environment of the multipurpose hall. The result of PMV, determined by the mean vote of the respondents in the building, is -1.5 and is located between the thermal conditions slightly cool and cool. It is lower than the upper limit of -0.5, as recommended by the ASHRAE Standard-55. The PMV and PPD values from the fieldwork measurement are 0.1 and 5.7, while the values from the thermal sensation vote are -1.5 and 53%. It can be concluded that the PMV model tends to classify the thermal environment as being cooler than the actual thermal sensation of the user. This is because there are variations of clothes that influence the experience of thermal comfort. The kind of cloth used, the thickness of the cloth, and even the fit of the cloth can influence a person's perceived thermal comfort in various weather conditions.

3.4 Comparison Data with Standard

The thermal measurement result of air temperature and air velocity was lower than the MS 1525-2014 guidelines but meet with AHSRAE 55-2017 standard. The air velocity falls below an acceptable range with the standard. In order to create an optimum comfortable indoor environment, these three parameters should be considered and maintained.

Table 3: The comparison between the measured result and the standard

Parameter	Data collected	MS 1525-2014	ASHRAE 55 -2017
Air temperature (°C)	21.74	24-26°C	19-28°C
Relative humidity (%)	69.62	50-70%	30-60%
Air velocity (m/s)	0.04	0.15-0.50 m/s	< 0.8 m/s

Table 4: Comparison between calculated PMV and PPD with ASHRAE Standard-55 and ISO 7730-2005.

Data	Thermal environment measurement	Questionnaire survey	ASHRAE Standard-55	ISO 7730-2005
PMV	-0.1	-1.5	0.5<PMV<+0.5	0.5<PMV<+0.5
PPD	5.7%	53%	<10%	<10%

Table 4 compares calculated PMV and PPD with two international standards, ASHRAE Standard-55 and ISO 7730-2005. According to Table 4, both PMV and PPD values from the thermal environment measurement at the multipurpose hall fall within the acceptable range specified by ASHRAE 55 and ISO 7730, with a PMV of -0.1 and a PPD value of 5.7%, indicating that the measured thermal conditions are within the comfort zone. However, the PMV and PPD values obtained from the questionnaire survey show a PMV of -1.5 and a PPD value of 53%, which exceed the upper limits recommended in ASHRAE Standard 55 and the acceptability criterion in ISO 7730. This suggests that the occupants perceive the thermal environment as too cool, highlighting a discrepancy between the measured conditions and the subjective comfort responses.

ASHRAE 55 and ISO 7730 define comfort based on a model that assumes steady-state conditions and a uniform thermal environment. In reality, environmental conditions fluctuate, and occupants may experience localized discomfort due to drafts, uneven radiant heat sources, or humidity variations, which are not always reflected in the PMV-PPD calculations. The PMV model averages the thermal sensation of a large group, but individual preferences and sensitivities vary significantly. Some people may feel warmer or colder than the predicted PMV value due to psychological and physiological differences.

Conclusion

The study successfully evaluated occupants' perceptions of thermal comfort, assessed thermal conditions, and analyzed optimal temperature settings in the Shared Facility Multi-Purpose Hall. It was found that occupants generally reported "cool" to "slightly cool" thermal sensations, while their thermal preference leaned toward a "warm" environment. Demographic factors, including gender, age, and race, showed slight but notable influences on thermal sensation, preference, and acceptability. Thermal condition assessments revealed that the air temperature and velocity were below the MS 1525-2014 standards, although relative humidity complied with the guidelines. For optimal thermal comfort, it is recommended to maintain an indoor temperature range of 23-26°C and relative humidity levels between 40-60%. The PMV (Predicted Mean Vote) of 0.1 and PPD (Predicted Percentage Dissatisfied) of 5.7% further validated that the thermal environment provided a generally acceptable comfort level for the occupants.

To ensure thermal comfort in the Multi-Purpose Hall, a few recommendations should be implemented. Encouraging adaptive clothing among occupants, such as wearing light but layered clothing, can help individuals adjust to varying indoor temperatures, enhancing personal comfort while reducing reliance on the HVAC system. This strategy promotes energy efficiency and supports sustainable thermal management. Additionally, environmental parameter measurements should be conducted under varying weather conditions, including sunny, cloudy, and rainy days, to gain comprehensive insights into how external weather influences the indoor environment.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper

Author Contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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Appendix A: Question on Occupants' Perceptions

Question	
Question 1	I feel comfortable during examinations in the Multi-Purpose Hall.
Question 2	The overall thermal environment in the Multi-Purpose Hall during examinations allows me to concentrate better.
Question 3	I am able to focus better on my exams when the temperature is cooler.
Question 4	I am able to focus better on my exams when the temperature is warmer.
Question 5	The temperature in the Multi-Purpose Hall during examinations affects my performance negatively.
Question 6	The temperature in the Multi-Purpose Hall during examinations affects my ability to stay alert and focused.
Question 7	The temperature in the Multi-Purpose Hall during examinations impacts my stress levels.
Question 8	I would prefer a different temperature setting in the Multi-Purpose Hall during examinations.
Question 9	The temperature in the Multi-Purpose Hall during examinations affects my physical comfort (e.g., sweating, feeling cold).
Question 10	I often go to the toilet during exam because the temperature in Multi-Purpose Hall is too cold.