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PEAT

Assessment of Thermal Comfort in Bus Station: A Case Study of Bentayan Bus Station, Muar

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Abstract

Public transportation facilities play a crucial role in urban mobility, offering convenience and sustainability. Ensuring thermal comfort within these facilities significantly impacts passenger satisfaction, well-being, and overall user experience. The Bentayan Bus Station in Muar, Johor, serves as a key transit hub but faces challenges in maintaining optimal thermal comfort levels, particularly in the waiting area, due to inadequate ventilation, excessive solar heat gain, and insufficient shading devices. This study assessed thermal comfort performance through on-site measurements of air temperature averaging 30.5°C, air velocity varied from 0.1 m/s to 1.5 m/s, and peak percentage for relative humidity 84%, using the LSI LASTEM Heatshield device. Passenger perceptions were collected via structured questionnaires from 101 respondents to gauge their comfort levels and overall experience. Data analysis aligned with ASHRAE Standard 55 revealed Predicted Mean Vote (PMV) values of 2.3 and Predicted Percentage Dissatisfied (PPD) at 84.1%, indicating significant thermal discomfort. Survey feedback highlighted the need for better air circulation and improvements to cooling systems and ventilation. The findings emphasize the necessity for interventions such as advanced mechanical ventilation systems, passive cooling techniques, and the integration of shading solutions to reduce solar heat gain. These measures are vital for enhancing user satisfaction, aligning the station's thermal environment with international standards, and supporting sustainable urban transit development. Overall, this research underscores the importance of thermal comfort in public transportation facilities to improve the passenger experience and operational efficiency.

1. Introduction

Public transportation systems are essential components of modern urban infrastructure, playing a pivotal role in providing affordable and efficient mobility solutions for urban populations. With rapid urbanization and population growth, the importance of public transport systems has intensified, especially in facilitating sustainable urban development. By maintaining a great-scale of thermal environment, it will enhance occupants' satisfaction and it will influence their overall well-being, and reduce the risk of discomfort related to health issues [1]. Thermal comfort, specifically, is a significant determinant of passenger satisfaction, directly impacting their health, well-being, and overall transit experience. In Malaysia, a tropical country characterized by high temperatures and humidity, ensuring thermal comfort in public transport hubs such as bus stations poses unique challenges. The Bentayan Bus Station in Muar, Johor, serves as a vital transit hub connecting various cities and towns, yet it struggles with thermal discomfort issues arising from insufficient ventilation, lack of shading devices, and excessive solar heat gain.

Extensive scientific research has been conducted on thermal comfort in various settings, emphasizing its importance in both building performance and occupant satisfaction. Standards such as ASHRAE Standard 55 and ISO 7730 provide comprehensive guidelines for assessing thermal environments by considering factors like air temperature, relative humidity, and air velocity [2]. From the previous studies underscore the importance of incorporating effective ventilation systems and architectural designs to mitigate thermal stress in tropical climates [5][6]. Despite these advancements, research on thermal comfort in bus stations remains limited, with most studies focusing on commercial buildings and airports. This lack of attention to smaller but equally critical transit hubs highlights a significant research gap, particularly in addressing the unique environmental and structural challenges faced by bus stations in tropical regions.

Thermal comfort is a critical factor in the design and operation of public spaces, particularly in transit hubs where large numbers of people congregate. It is defined as the condition of mind that expresses satisfaction with the thermal environment, influenced by various environmental and personal factors, including air temperature, relative humidity, air velocity, metabolic rate, and clothing insulation. Maintaining thermal comfort is essential in ensuring user satisfaction, health, and overall well-being, as prolonged exposure to uncomfortable conditions can lead to physical discomfort, reduced productivity, and even health risks such as heat stress. The findings are rigorously analyzed in accordance with ASHRAE Standard 55 to ensure a robust understanding of the thermal conditions within the station [4]. By integrating both quantitative measurements and user feedback, this research aims to provide a comprehensive assessment of thermal comfort at the station.

The primary research question driving this study are about the current thermal conditions at the Bentayan Bus Station, and what measures can be implemented to improve it in line with international standards. The thermal environment within transit hubs had an impact on the comfort level of passenger and influenced their overall experiences while using public transportation [7]. Through this research, actionable recommendations are proposed to address the identified shortcomings, contributing not only to the improvement of the Bentayan Bus Station but also to the broader discourse on sustainable urban transit solutions. By focusing on practical interventions, this study aims to improve the passenger experience, align the station's thermal environment with international standards, and promote sustainable practices in transportation infrastructure.

Thermal comfort is influenced by several key environmental and personal parameters, as outlined in Table 1. Air temperature (ta) and radiant temperature (tr) significantly affect heat exchange between the body and the surrounding environment, while relative humidity (RH) plays a role in perspiration efficiency and thermal regulation. Air velocity helps enhance evaporative cooling and influences perceived comfort levels. On the personal side, clothing insulation (clo) determines how much heat is retained by the body, and metabolic rate (met) reflects the heat produced by the body based on activity levels. To evaluate overall thermal comfort, indices such as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) are used, providing quantitative measures that help assess whether an environment meets thermal comfort standards.

Table 1: *Thermal comfort parameter*

Nomenclature is included if necessary	
t_a	Air temperature
t_r	Radiant temperature
RH	Relative humidity
clo	Clothing insulation
met	Metabolic rate
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied

2. Methodology

The evaluation methodology of this study is meticulously structured to ensure the achievement of its objectives, as depicted in the flow chart that outlines three critical phases. First phase involves an extensive literature review to establish a foundational understanding. Second phase focuses on the systematic collection of data relevant to the study and third phase encompasses a thorough analysis of the collected data to derive meaningful insights. This organized approach is essential for enhancing the effectiveness of the research and ensuring comprehensive results that contribute to the field of thermal comfort assessment in public transport environments.

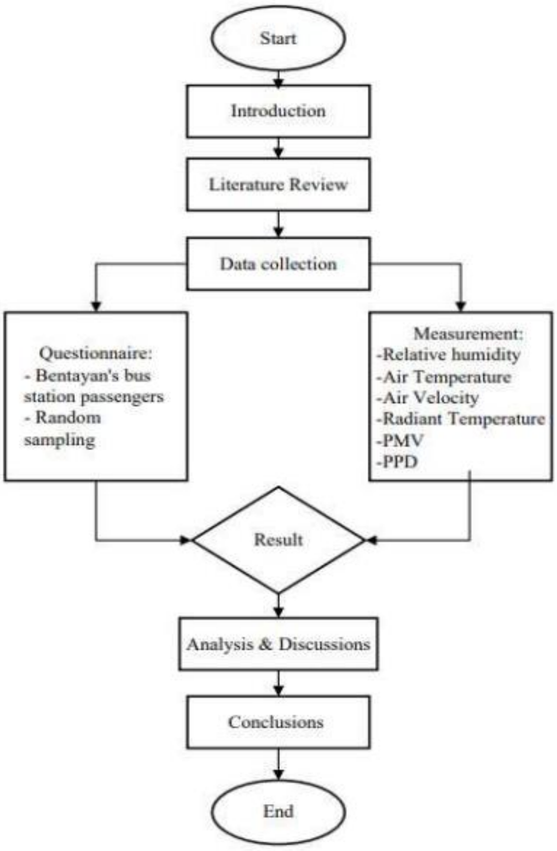


Fig. 1: Flow chart project

The CBE Thermal Comfort Tool have been used in this study. This tool allows users to input environmental parameters such as air temperature, relative humidity, air velocity, mean radiant temperature, clothing insulation (clo), and metabolic rate (met) to calculate Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) values. By using this tool, researchers can compare on-site measurements with standard thermal comfort ranges, ensuring that indoor and semi-outdoor environments meet acceptable comfort levels.

2.1 Human's Thermal Perception

The surveys of thermal comfort were evaluated through a questionnaire. The passengers' perceptions were analyzed and discussed and sought to gather the individual comfort levels on how environmental factors affect user experiences. The data was collected on 23rd October 2024 (Wednesday) and 25th October 2024 (Friday). There are 101 respondents based on two days of data collection on the weekday and weekend.

To assess passengers' thermal perception at Bentayan Bus Station, a structured questionnaire was developed, consisting of two main sections, as outlined in Table 2. Part A gathered demographic information such as age, gender, and ethnicity, recognizing that thermal comfort perceptions can vary based on personal characteristics, clothing, and metabolic differences. Part B evaluated thermal sensation using the Thermal Comfort Questionnaire and Bedford Comfort Scale, where respondents rated their experience from cold (-3) to hot (+3) to determine their level of discomfort. This section also examined key environmental factors such as air movement, humidity, and shading adequacy, which influence overall thermal comfort. By combining subjective feedback with objective thermal measurements, the study aimed to provide a comprehensive assessment of passenger comfort and identify potential improvements for the station's thermal environment.

Table 2: Questionnaire content

Part	Measured Constructs
A	A section are the common questions about respondent's demographic information.
B	B section is to assessed thermal sensation by using both the thermal comfort questionnaire and the Bedford comfort questionnaire.

2.2 On-site Data Measurement

There are several factors of thermal factors to be considered and measured in this research. It is a factor that will affect the thermal comfort which is, the air temperature, air velocity, and relative humidity. To collect data, the LSI LASTEM heatshield will be used to measure the factors. The clo was set 0.8 and met was set 1.2. This equipment can also provide physical parameters data such as temperature, wind speed, and humidity and it can be used to measure the PMV and PPD. With the capability of the machine, it will capture real-time data on humidity, air velocity, and air temperature.

Fig. 2: LSI Lastem Heatshield

The procedure for this study will based on ASHRAE standard 55 to identify and provide the reliable data that will be used in this research. On the other hand, with the PMV and PPD data that will be captured, it will refer to the CBE thermal comfort tool to compare with the CBE thermal comfort tool based on the indoor thermal parameter collected on-site. It is a developed tool that has an interface for thermal comfort predictions according to ASHRAE Standard 55.

3. Result and Discussion

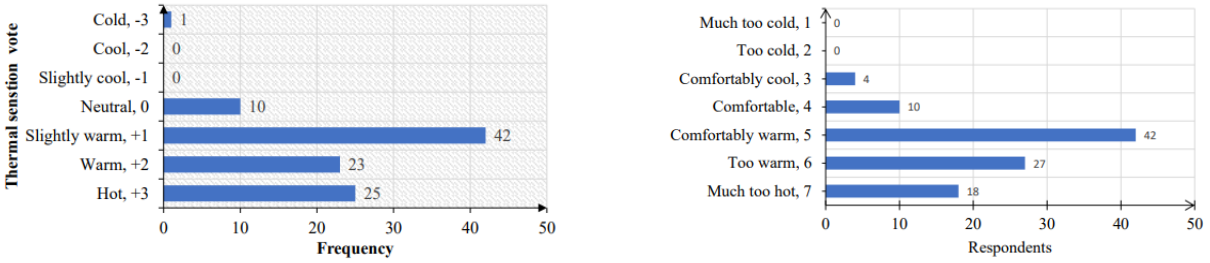
The questionnaires for this research were distributed to the respondents in the form of the Google Form method on 23rd October 2024 (Wednesday) and 25th October 2024 (Friday), representing weekdays and weekends, respectively. The data were gathered and extracted in a table form and graph and analyzed by using Microsoft Excel. The results from the on-site measurement and questionnaires were compared. The on-site measurement data alongside the passenger's perception from surveying are discussed to align with ASHRAE Standard 55.

3.1 Subjective measurement (Questionnaire)

The passenger questionnaire survey conducted at the Bentayan Bus Station provided valuable insights into user perceptions of thermal comfort. A total of 101 respondents participated, with data collected on both weekdays and weekends to capture a comprehensive understanding of varying passenger experiences. Demographic analysis revealed a balanced gender representation (51% male, 49% female) and diverse age groups, with the majority of respondents aged 19-25 years (53%) and a smaller segment aged above 31 years (33%). Ethnically, Malays constituted the largest group at 62%, followed by Chinese (16%), Indians (12%), foreigners (10%), and Kadazans (1%). This diverse respondent pool ensures a wide-ranging perspective on thermal comfort and user needs.Considering the common set of clothes worn by male respondents, which are trousers, T-shirts, socks, and shoes, will contribute 1.32 clo value. Meanwhile, females wearing trousers, long-sleeved shirts, hijabs, socks, and shoes will contribute to the 1.88 clo value.

A review from fig. 3 (a) of responses showed that 42 participants said they felt slightly warm (+1), which is moderately warm, while 25 said they felt hot (+3). This result shows that thermal discomfort is an almost universal human experience in the waiting area, where 90 out of respondents feeling hot sensation (+1 to +3).

While in the other hand, fig. 3 (b) showed a significant 42 respondents described their environment as comfortably warm, under which conditions they may have partial acclimatization to the warm conditions. However, the discomfort of being too warm and much too hot was endorsed by a total of 45 respondents, and this pin-points thermal stress during set peak hours. It was said that such conditions discourage the usage of the facility by passengers, hence the alteration of the very purpose for which it was established, as well as the satisfaction of users.



(a) (b)

Fig. 3: (a) The thermal sensation of respondents is based on surroundings (b) The contribution to the dissatisfaction of thermal sensation respondent

The survey results indicated significant thermal discomfort among passengers, with 85% expressing dissatisfaction with the current conditions. Common complaints included high temperatures, inadequate air circulation, and a lack of shading in the waiting area. A review of responses showed that 42 participants said they felt slightly warm (+1), which is moderately warm, while 25 said they felt hot (+3). This means that the thermal condition within the waiting area is high and does not suit most users. The discomfort of being too warm and much too hot was endorsed by a total of 45 respondents, and this pin-points thermal stress during set peak hours. It was said that such conditions discourage the usage of the facility by passengers, hence the alteration of the very purpose for which it was established, as well as the satisfaction of users.

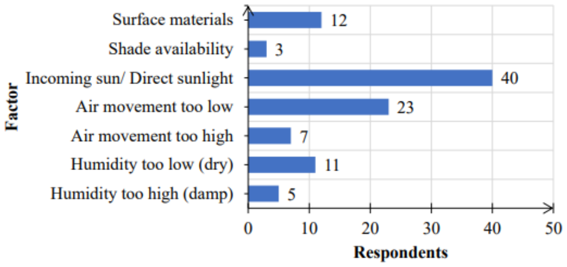
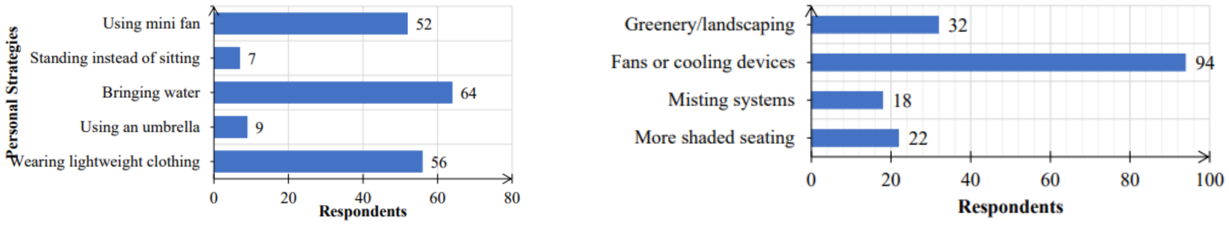


Fig. 4: The factors that affect comfort level

Fig. 4 showed 40 respondents expressed that they face problems with direct Sun exposure, and an additional three complained of inadequate structures for providing shade. 23 respondents identified insufficient air circulation as a critical factor affecting their comfort. Poor air movement creates stagnant conditions that exacerbate the build-up of heat, further amplifying discomfort. Out of all identified factors, low humidity was reported by 11 respondents.



(a) (b)

Fig. 5: Suggestions on How to Improve Thermal Comfort, (a) Personal strategies, and (b) Suggestion from the respondent

When asked about improvements, the most frequently suggested measures were enhanced ventilation systems (82%), increased shading (76%), and the introduction of passive cooling strategies (68%). These findings underscore the urgent need for targeted interventions to improve thermal comfort and align the station's conditions with user expectations and international standards.

3.2 Thermal Comfort Parameter Data Collection

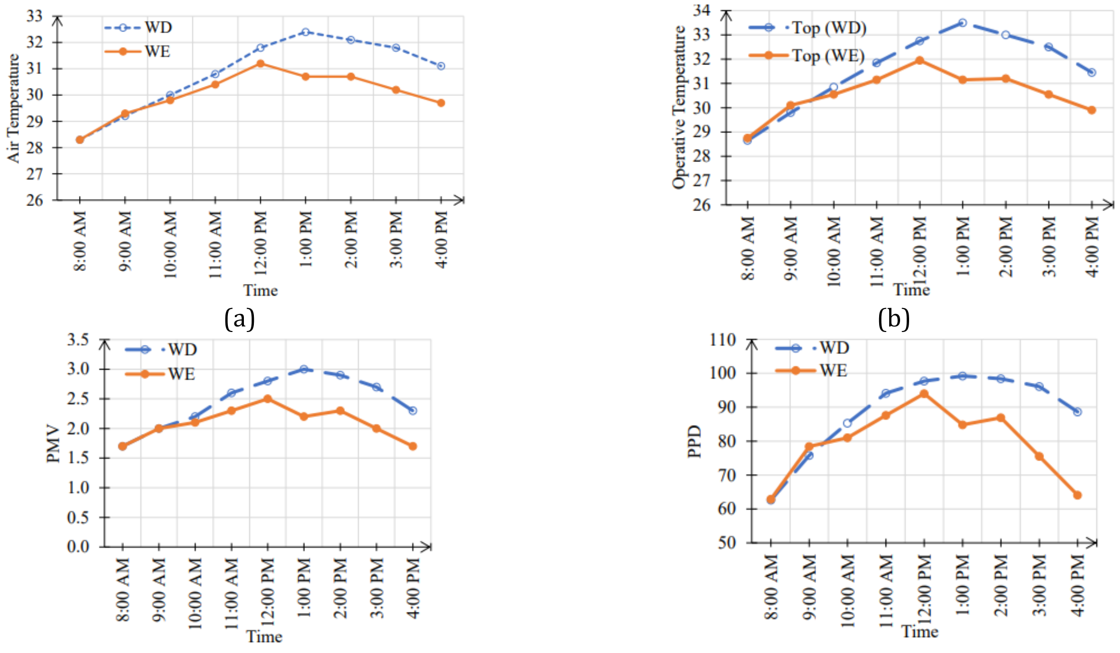
Bentayan bus station's thermal environment has been measured. Thermal comfort parameters measured are air temperature, air velocity, relative humidity, radiant temperature, PMV, and PPD. By using LSI Lastem Heatshield, the clo was set as 0.8, and for the met, it was set as 1.2. Data has been collected for 2 days, which is on 23rd October 2024 (weekdays) and on 25th October 2024 (weekend).

The measurements were conducted during different times of the day to account for variations in thermal conditions, specifically targeting peak operational hours (8:00 a.m. to 9:00 a.m. and 3:00 p.m. to 4:00 p.m.) and normal hours (12:00 p.m. to 1:00 p.m.) on both weekdays and weekends.

Based on fig.6, the recorded data highlighted significant thermal challenges within the station. The average air temperature was found to be 30.5°C, and can be peak to 31.2°C and it is conclude exceeding the comfort range specified in ASHRAE Standard 55, which recommends indoor temperatures between 23°C and 27°C for tropical climates. Air velocity was measured at an average of 0.1 m/s, significantly below the recommended levels for maintaining adequate air circulation. radiant temperature which ranged between 29 °C and 34 °C generally had a trend similar to that of the air temperature. For the weekdays, the peak radiant temperature is from 11 AM to 3 PM. It's between 33 °C and 34 °C. but for the weekdays, it peaks at 12 PM (32.7 °C) because the weather is overcast. Relative humidity averaged 72%, further exacerbating thermal discomfort by impeding effective sweat evaporation and natural cooling mechanisms.

Mean radiant temperature, along with air temperature, make up the operative temperature (top), which is considered an important factor for evaluating thermal comfort. On working days, the optimum working temperature increases to 33.5°C while on weekends, the highest of the temperatures recorded is slightly less than 31.95°C

For the figure (d) the PMV values varied between 1.7 and 2.9, and the range means that most passengers had a “warm to hot’ thermal sensation. These values are above the ASHRAE-recommended thermal comfort range of -0.5 to + 0.5, indicating that measures to change these conditions should be undertaken as soon as possible. The PPD value were between 62.6% and 99.2%, which indicates that passenger dissatisfaction is actually high. ASHRAE indicates that keeping values of PPD less than 10% is desirable as far as acceptability of comfort levels is concerned [4].



(a) (b)

(c) (d)

Fig. 6: On-site data collection (a) Air temperature vs time (b) Operative temperature vs time(c) PMV vs time (d) PPD vs time

3.3 Comparison of Thermal Condition with Standard and CBE Thermal Comfort Tool

Comparison of PMV and PPD result range, the collected data were benchmarked against ASHRAE Standard 55, which specifies acceptable ranges for PMV (-0.5 to +0.5) and PPD (<10%) to ensure thermal comfort PMV Compliance[3][4]. Based on table 3, the recorded PMV values were ranging from 1.7 to 2.9 these figures clearly depict the environment is beyond the acceptable standard in the thermal comfort model, thus the emphasis on thermal management to address this situation. PPD Compliance: Satisfaction indexes varying from 62.6% up to 99.2% are significantly different from an acceptable level according to the established standard of not more than 10%. The PMV from the questionnaire is 1.5 while the PPD is 47.52%. The combination of the results of temperature and humidity measurements and survey data gives a complex and comprehensive view of the problems with thermal comfort in the Bentayan Bus Station. The data also have been used in CBE Thermal comfort to compare with the on-site data. The result for PMV range between 0.82 to 2.07 while for the PPD is between 19.1% to 29.7% which did not compliance with AHRAE standard 55 Such results imply the need for improving thermal comfort interventions.

Table 3: Comparison of PMV and PPD result range

	Result range	**CBE Thermal Tool**	**PMV range (ASHRAE standard 55)**	**Questionnaire Result**
PMV	1.7 < PMV < 2.9	0.82 < PMV < 2.07	-0.5 < PMV < +0.5	1.5
PPD	62.6% - 99.2%	19.1% - 79.7%	<10%	47.52%

3.4 Summarize of On-Site Data Collection and Questionnaire Data Collection

The environmental assessment carried out at Bentayan Bus Station by measuring temperature and air humidity as well as air velocity with numerical data collection tools was complemented with the results of surveys assessing the perceptions of the passengers.

Table 4: The average of on-site data collection.

Parameter	Parameter data
Air Temperature (°C)	30.4
Mean Radiant Temperature (°C)	31.8
Relative Humidity (%)	75.7
Air Velocity (m/s)	0.7
Metabolic Rate	1.2 met
Clo	0.8
PMV	2.3
PPD (%)	84.1

Table 4 summarizes the average thermal conditions at the Bentayan Bus Station, revealing significant discomfort for passengers. The air temperature averaged 30.5°C, with a radiant temperature of 31.2°C, both exceeding the comfort range of 23°C to 27°C specified by ASHRAE Standard 55. Relative humidity was high at 72%, reducing the efficiency of sweat evaporation and intensifying the heat. Air velocity, at just 0.1 m/s, was insufficient to provide adequate cooling or circulation. The overall operative temperature was 31°C, reflecting the combined effect of air and radiant temperatures.

Table 5: Thermal sensation scale based on the questionnaire

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
1	0	0	10	42	23	25
Not satisfied = 1		Satisfied = 52			Not satisfied = 47	

Based on the table 5 questionnaire results, 47.52% of the respondents are not satisfied with the situation at the Bantayan bus station waiting area terms of from a questionnaire survey. According to Guan et al (2003), for PPD to be considered a good condition it should be less than 20%. Therefore, it can also be explained that the thermal conditions at the Bantayan bus station waiting area did not meet the standards and were not satisfied by the occupants.

Based on Fig. 7, the PMV from the questionnaire is 1.5 while the PPD is 47.52%. The combination of the results of temperature and humidity measurements and survey data gives a complex and comprehensive view of the problems with thermal comfort in the Bentayan Bus Station.

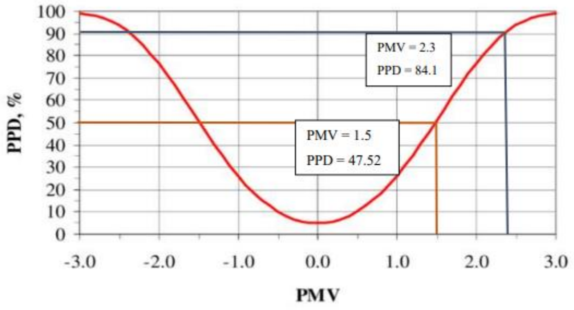


Fig. 7: The PPD vs PMV graph

4. Conclusion

The assessment of thermal comfort at the Bentayan Bus Station revealed significant challenges in maintaining a conducive environment for passengers. Key findings from on-site measurements showed high air and radiant temperatures, averaging 30.5°C and 31.2°C, respectively, along with high relative humidity levels at 72% and insufficient air velocity of 0.1 m/s. These factors, combined, contributed to an operative temperature of 31°C, well above the comfort thresholds outlined by ASHRAE Standard 55. Passenger surveys further highlighted widespread dissatisfaction, with 85% of respondents identifying the thermal conditions as uncomfortable, emphasizing inadequate ventilation, excessive heat, and insufficient shading as primary concerns.

Addressing these issues requires a multi-faceted approach that integrates enhanced mechanical ventilation systems, passive cooling strategies, and effective shading solutions to mitigate solar heat gain. By aligning with international standards and prioritizing passenger comfort, the proposed interventions can significantly improve the overall transit experience. This research not only provides actionable insights for the Bentayan Bus Station but also contributes to the broader discourse on sustainable design in tropical transit hubs. Enhancing thermal comfort in such facilities is essential for ensuring passenger satisfaction, promoting the use of public transportation, and fostering sustainable urban development.

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Conflict of Interest

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

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:
The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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