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STUDY ON THERMAL COMFORT FACTORS IN CONVERSION-ADAPTIVE BUILDING, CASE STUDY IN SURAKARTA INDISCHE HOUSE

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ABSTRACT

Traditional buildings are one type of structure that can adapt to a dynamic environment. Some functions of the building's spaces have been changed to the new requirements, but the building's overall shape has been preserved. The purpose of this study was to examine and determine the differences in perceived thermal comfort values between occupants and visitors inside the building. Using the observation method and analyzing the data through PMV-PPD and correlating with the Adaptive method in the Center for the Built Environment (CBE) Thermal Comfort Tool Website, it shows that there are differences caused by the environmental climate that do not match the PMV standard from ASHRAE. This study also has shown a difference of 18% between the PMV value of visitors to occupants, where there are past factors that influence this difference, and also a difference of 0.58 between the PMV value of Fanger and Sugini theory (comparison between general theory that is often used with the local theory that has been researched), because of Indonesians' heat tolerance. In this study, it was found that there are variables that are not needed in the adaptive method approach of naturally ventilated buildings, namely the humidity in buildings that are in tropical and humid areas. The reason for this is that the effect of moisture on the thermal sensation is insignificant, and it can be neglected.

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1. Introduction

Traditional architectural buildings serve as benchmarks that can adapt well to the surrounding natural conditions and can utilize energy resources appropriately and efficiently. Buildings that provide a balance between activity patterns in the building and the natural surroundings can provide maximum comfort.

The Indische building in Laweyan Batik Village is an example of a tropical building that is still able to survive in this ever-growing era. The shape of the building is still maintained even though the function of some of the space in the building has been replaced to suit the new needs of a showroom and other businesses. Laweyan District in Surakarta City has been designated as a location for creative industries, history, and traditional values, shopping tourism, cultural heritage tourism, and dense residential areas under the Surakarta City Spatial Planning (RTRW) 2011–2031 (Surakarta, 2012).

With the growth of the hybrid economy in Laweyan, it is feared that Kampung Laweyan will change from a residential area to a commercial area. This study plays a crucial role for researchers in understanding the behavior change processes of the Laweyan people that influence where they live for economic benefits as a result of tourism destinations. In order to maintain it as a cultural site, the Laweyan people must work together side by side.

Indische building owners try to adjust the thermal comfort felt by visitors in response to shifting building activity patterns without significantly changing the building's distinctive architectural style. It is also necessary to study the tropical architecture in these traditional buildings and whether the use of natural light and natural ventilation can work in harmony and meet the thermal comfort of current activities. Consideration of energy savings and preservation of tropical architecture are the main concepts that must be adhered to in overcoming the problem of the times that will indirectly change the surrounding climate and can affect the comfort of the building.

The objective of this study is to determine the thermal comfort between the visitors and the occupants of the building on two factors (human factors and environmental factors) and discover the value suitability of thermal comfort inside the building against ASHRAE comfort standards. From this goal, it is expected that it can contribute to the development of knowledge about Traditional Indische Buildings and Thermal Comfort which can change according to the needs of new activities in that place.

2. Literature Review

2.1 Thermal Comfort

According to Satwiko (2009), comfort and feeling comfortable are a person's comprehensive assessments of his environment. Humans judge environmental conditions based on stimuli that are not only in the form of physical biology but also feelings. External environmental factors such as sound, temperature, light, aroma, etc., are processed simultaneously by the brain, then the brain will provide a relative assessment of determining these conditions, including whether they are comfortable or uncomfortable. One type of comfort is thermal comfort in buildings which is needed to provide comfort for users or building occupants. Thermal comfort has several factors based on the 2010 ASHRAE Standard published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ("ASHRAE Standard 55," 2010). There are four environmental factors and two human factors that can affect the thermal comfort:

a. air temperature;
b. radiant temperature;
c. wind velocity;
d. humidity;
e. clothing insulation;
f. metabolic rate.

The standards referred to by this study to calculate clothing insulation based on clothing type with units of clo; and metabolic rate based on their activity in units of met units then converted into W/m^2, can be seen in Table 1. Clothing Insulation Value and Table 2. Metabolic Rate Value.

Table 1. Clothing Insulation Value

Clothes	Insulation Value (clo)
T-shirts	0.09
Shirt	0.22
Jacket	0.37
Cardigans/sweaters	0.17
Dresses/Gamis	0.7
Sock	0.01
internal	0.05

Table 2. Metabolic Rate Value

Activity	Metabolic Value	
	(Met Units)	W/m^2
Visit (standing)	1.4	80
Field Practice	2.1	120
Visit (seated)	1	70
Shopping (Walking about)	1.7	100
Consultation (Writing, typing)	1.1	6.5

In research that has been conducted by Wong et al., (2020) and Bassoud et al., (2021), temperature is a major factor in their comfort and adaptive behavior, but high humidity does not have a significant impact on thermal comfort. In the case of this study, Indonesia's climate is classified as a hot and humid tropical climate which is characterized by a high average annual temperature and a relatively small amplitude between day and night. The idea underlying the adaptive thermal comfort model is that the thermal conditions outside the building affect the thermal conditions inside the building and each individual can interact and adapt to various existing thermal conditions. Adaptive thermal comfort models are based on unique predictions of thermal conditions in the environment, which in turn are based on behavioral patterns, memories and existing environmental thermal conditions.

2.2 Laweyan Village-Indische House

The city of Solo as a whole is an old city that is known both in terms of history and as a cultural site. The villages in Solo are descended from the social structure of the Kasunanan Surakarta government, which functions as the epicenter of community activities or professions. One of them is Kampung Laweyan, which has a long history as a village, including its transformation from a city and trade center in Lawe. Then, in the early 20th century, it developed into a center for the "stamped batik" industry, and finally became "Batik Tourism Village". The Surakarta City Government has a program called "Kampoeng Wisata Batik Laweyan" which aims to revitalize cultural sites.

The building has an architectural style that emerged during the Dutch colonial period in Java called "Indische Architecture", which is a blend of architectural influences from the Middle East, Java (Indonesia), Europe, and a bit of China. The architectural style known as Indische is considered a transitional style, because it only lasted a relatively short period of time (1890-1915). The case study that will be observed in this study is one of the buildings in Laweyan which has an Indische architectural style, Laweyan Crown Batik is a generation of "Batik Puspowidjoto" which existed in 1965. Where the building's authenticity is still preserved by the owner of the building even though generations have changed.

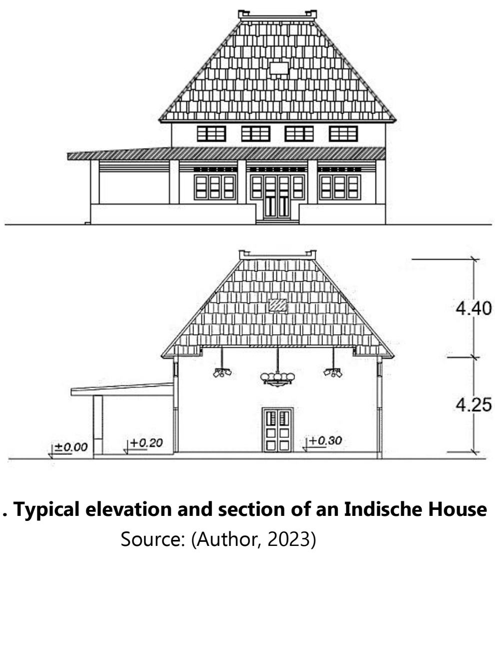


Figure 1. Typical elevation and section of an Indische House
Source: (Author, 2023)

The appearance of the building conditions has been modified to suit Indonesia's humid tropical climate. In Figure 1. Typical elevation and section of an Indische **House** show a large room volume with a high ceiling that can minimize the heat in the room caused by radiation. The deep and wide "overhang" can be used to collect rainwater runoff and shade walls in direct sunlight. As an adaptation of traditional architecture, an open verandah or passage can function as a place for people to gather and chat.

The appearance of the "Indische House" building consists of wide lattice windows and wide eaves, ventilation holes at the top and bottom of the walls, and thick walls (average one stone), accompanied by high ceilings. With a temperature difference of up to 8°C between day and night, the massive walls of this Indische building can retain four times more heat than ventilation walls in traditional Javanese houses (Samodra, 2004 and Syamsiyah, 2013).

In addition, previous research (Vella et al., 2020) stated that the comfort of old buildings can be affected by local building materials and thermal wall inertia. From various studies, the most effective variation for increasing cross ventilation in order to maximize temperature changes inside the building is through the height of the roof and the width of the circulation area in the middle of the building (Wong et al., 2003).

3. Research Method

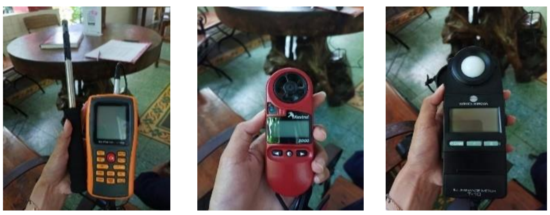
This research aims to investigate and describe how the performance of ventilation and natural lighting in traditional Indische buildings affects the thermal comfort felt by occupants and visitors inside the building.

Primary data was obtained by searching literature from books and journals that are still related to the object of study as well as direct field observation activities. In-depth interviews were also carried out with trusted sources who are the owners of the house. In addition, there are calculations in the form of research instruments or research tools:

a. GM8903 2.6 inch LCD Screen Digital Handheld Hot Wire Wind Anemometer with a measurement range of air velocity 0-30 m/s,
b. Kestrel 3000 Pocket Handheld Weather with Patented Quick-Response RH Sensor, and
c. Konica Minolta Illuminance Meter T-10A with a measurement range of Illuminance 0.01 to 299,900 lux.

The above tools can be seen in

Figure 2. Tool-research **tools** are necessary to be able to conduct research that is efficient, accurate, and valid. Field data was collected by using specific tools when the weather was sunny, overcast, cloudy, or rainy.



a. b. c.

Figure 2. Tool-research tools

Source: (Author, 2023)

It is necessary to know the field conditions and how comfortable the visitors and occupants feel, then the results will be compared between the two. This research was carried out on February 28-March 6, 2022 by measuring thermal comfort and administering a questionnaire, where the implementation time was adjusted to the showroom opening hours, namely 09.00 AM - 05.00 PM, Monday to Saturday. Time distribution includes: morning at 9 to 10 AM, noon at 12 to 1 PM, and afternoon at 3 to 4 PM.

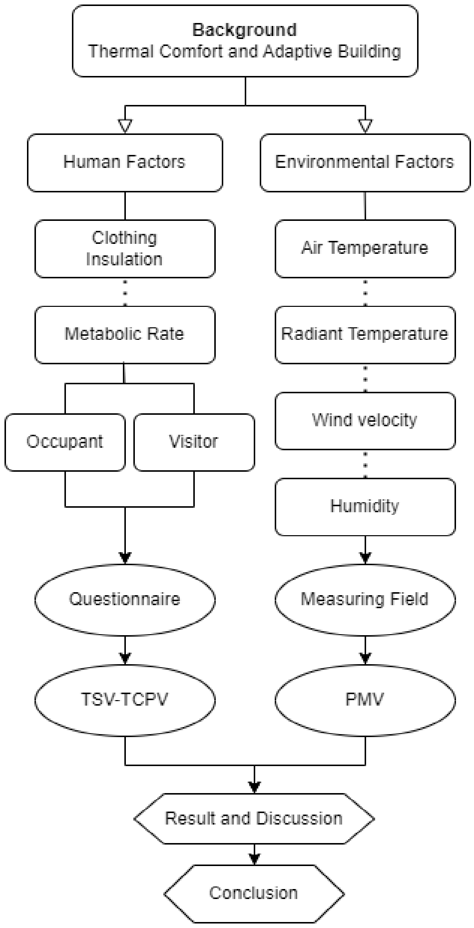


Diagram 1. Framework Methodology and Analysis

Source: (Author, 2023)

Furthermore, the data will be analyzed through PMV and PPD using the CBE (Center for the Built Environment) Thermal Comfort Tool with the Adaptive Method approach because the case study will be examined using natural ventilation. This measurement value was originally initiated in 1975 by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE-55) (Tartarini et al., 2020), and now it has been widely adopted as a standard and regulation by various countries, especially in Southeast Asia with its hot and humid climate (Hassan & Nasir, 2017).

After these phases, the result will be produced as a whole by employing environmental elements and human aspects to determine whether their comfort is still relatively comfortable or not.

4. Results and Discussions

In this research, there are parameters used including clothing insulation, air velocity, relative humidity, radiation, and air temperature, as well as metabolism (visitor activity) and the level of visitor satisfaction with the thermal comfort of the room, based on information obtained from a questionnaire.

4.1 Field Data

4.1.1 Air Temperature

There are several factors that affect the value of the air temperature in a building, namely, weather and temperature outside the building. This idea is in line with research (Gunawan, 2019), which reveals that the indoor air temperature can decrease along with the occurrence of rain due to tarring sunlight covered by rain clouds, as seen in Figure 3. Air Temperature Distribution Plan during the day the temperature is higher.

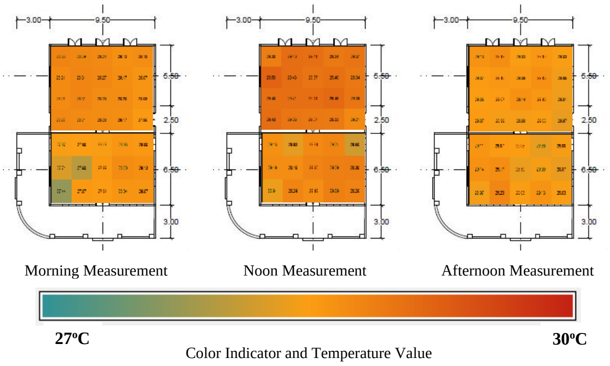


Figure 3. Air Temperature Distribution Plan
Source: (Author, 2023)

More details can be seen in Figure 4. Air Temperature Chart, where the temperature value line is the highest during the day, followed by the afternoon and then the morning. The difference between average temperature and times was 0.95-1.04, in the morning 28.06°C, afternoon 29.26°C, and evening 29.04°C.

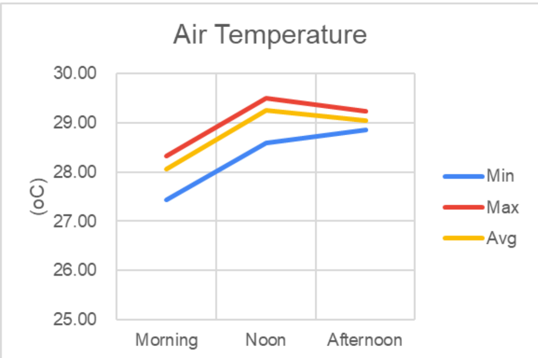


Figure 4. Air Temperature Chart
Source: (Author, 2023)

Diagrams in the Figure 5. Outside Air Temperature Chart is the range of the outdoor temperature (during the research period) that can have an impact on indoor comfort. The average outside temperature from February to March 2022 is 27.393°C with a minimum-maximum range of 23.8-31.6°C.

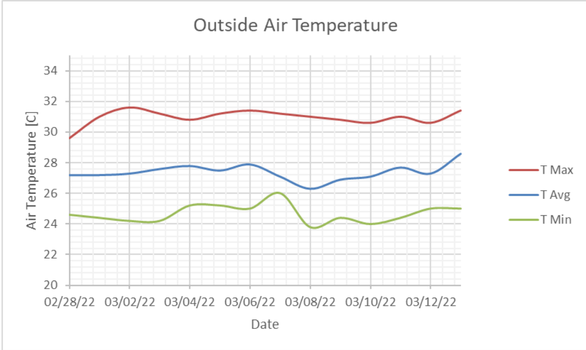


Figure 5. Outside Air Temperature Chart
Source: (Author, 2023)

4.1.2 Air Humidity

The average relative humidity data ranges from 82.04% to 83.61%, where this relative humidity is high. According to data collection results, the average humidity inside the building ranges from 81.55-83.63%. This is because March is the rainy season. Therefore, when the weather starts to get cloudy or it rains, it will cause an increase in relative humidity in the room (BMKG, 2022). This statement is in line with the findings (Sipayung, 2012), which reveal that cloudy and rainy weather can cause the concentration of water vapor in the air to increase.

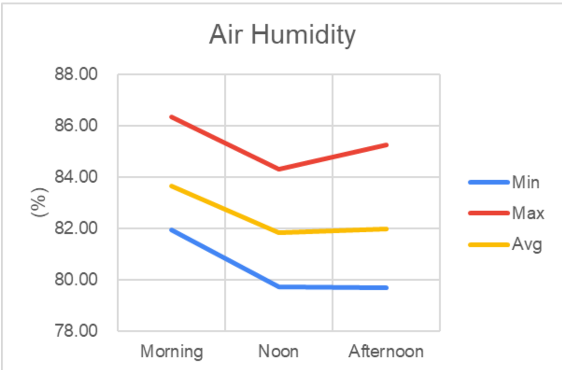


Figure 6. Air Humidity Chart
Source: (Author, 2023)

4.1.3 Wind Speed

Air velocity between 0.6 m/s-1.5 m/s is required to maintain thermal comfort in Indonesia's hot and humid tropical environment. When the wind speed exceeds this threshold, it will cause problems because it will feel stronger. It can also be problematic when the air velocity is getting closer to 0 m/s, because it will be slower and more difficult to exchange air with high temperature and humidity with air that has a lower temperature and humidity, making it more difficult to achieve thermal comfort. The Figure 7.Wind Speed Chart shows that the maximum average value found in the afternoon is 0.28 m/s, and the overall average is still relatively low at that place.

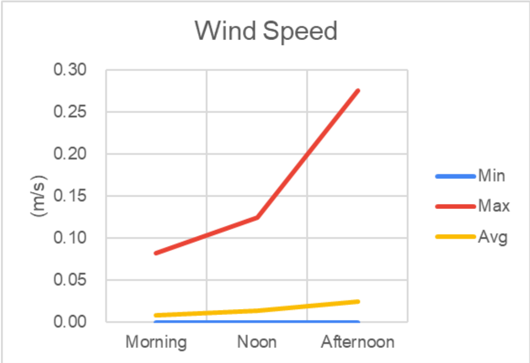


Figure 7.Wind Speed Chart
Source: (Author, 2023)

4.1.4 Temperature Radiants

Radiation temperature is the heat emitted by heat-producing objects. Radiation temperature is higher than the air temperature in relation to the way heat is emitted or received from or to the environment. Radiant temperature can be calculated by the following formula:

Radiant Temperature =

$$(0.7 \times T_{wb}) + (0.3 \times (1.36 \times T) - 2.358)$$

Notes:
Twb : Wet Bulb Temperature (°C)
T : Air Temperature (°C)

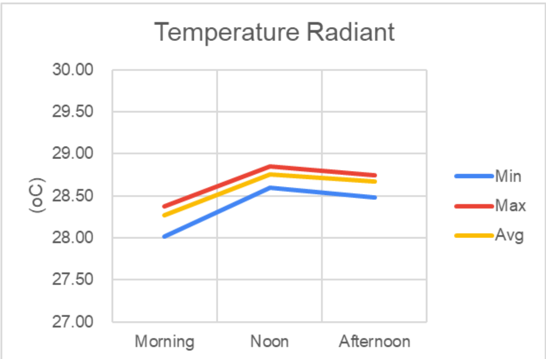


Figure 8. Temperature Radiant Chart
Source: (Author, 2023)

The calculation results in the radiant temperature in Figure 8. Temperature Radiant shows that the highest time was at noon, and the average value was closer to the maximum value than the minimum value. This means that the average radiant temperature value was high.

The radiation temperature inside the building can be reduced using thermal insulation. Thermal insulation can be achieved by planting plants and choosing materials that absorb less heat (Auliciems, A., & Szokolay, 2007).

4.2 Questionnaire Data

The validity test in this research is intended to determine whether a questionnaire is valid or not to measure the variables to be studied. In this research questionnaire, there is a distribution of questions for occupants and visitors, including:

a. Personal data of visitors/occupants: age, gender, origin, and last education
b. Data on visitor/occupant comfort factors: time of visit, type of activity, type of clothing, weather, and temperature (cold-cool-normal-warm-hot) outside the building
c. Comfort data inside the building: natural ventilation and daylighting

From the total data of visitors and occupants who have filled out the questionnaire, there are 36 people (of which 30 visitors and six occupants or a ratio of 6:1 between visitors and occupants). There were some difficulties in getting the maximum sample because, at that time, the data collection had occurred during a pandemic that could affect the number of visitors who came to that place. However, the data obtained was considered to meet the requirements because the sample obtained was even in terms of time distribution.

From the total number of respondents, 83% are women, 50% are aged 18-29 years, 56% have the last D3-S1 education, and 86% come from Central Java. According to Dosumu and Aigbavboa (2019), the characteristics examined were considered to be most suitable for a building's indoor environmental quality (IEQ). On the other hand, inferential statistics demonstrate that the respondents' responses varied in terms of some IEQ characteristics based on their age, gender, ethnicity, and building unit. Based on the results, the study concludes that the factors impacting the indoor environmental quality (IEQ) of buildings vary depending on the age, gender, and type of occupied building units. The above statement means that these parameters (age, gender, ethnicity) have an effect on comfort, but as many other factors can be more influential, the parameter is not used in this study. According to Artino et al., (2014), although education level can affect the results of questionnaire research, in consequence, it is important to consider other factors that can be interrelated.

The distribution of the number of occupants and visitors at three different times can be seen in Figure 9. Visit Time Chart.

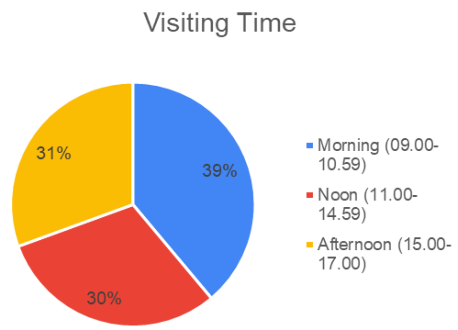


Figure 9. Visit Time Chart
Source: (Author, 2023)

Human factor variables (visitors and occupants) are obtained through questionnaire data collection. In these results, there is a significant difference in the variables of Clothing Insulation and Metabolism Level by occupants and visitors can be seen in Figure 10. Metabolic Rate Chart and scale division on the type of clothing and metabolic rate in Table 1. Clothing Insulation Value and Table 2. Metabolic Rate Value derived from the ASHRAE-2010 standard ("ASHRAE Standard 55," 2010).

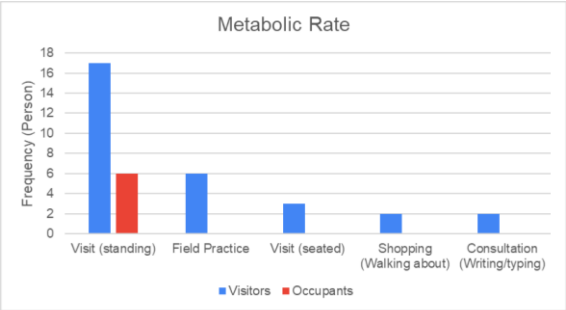


Figure 10. Metabolic Rate Chart
Source: (Author, 2023)

The average value obtained between the two variables is 80 W/m2 and 0.18 clo for occupants; 1.50 Met Units or 93.6 W/m2 and 0.34 clo by visitors. This can be interpreted that the average value of the type of clothing occupants is smaller than visitors, the difference is around 0.18 clo, and the difference in the average metabolism is 13.6 W/m^2.

4.3 Calculation Analysis of Adaptive Thermal Comfort

From the results of processing field data using Adaptive Thermal Comfort analysis for buildings that use natural ventilation, it shows that overall visitors and occupants feel comfortable, as can be seen in the diagram below. The points on all three times are in the 90% zone of acceptance (comfort).

Provisions on the Adaptive Method value using the Center for the Built Environment (CBE) Thermal Comfort Tool using the 2020 ASHRAE-55 Standard (Tartarini et al., 2020) as the main reference for calculating thermal comfort.

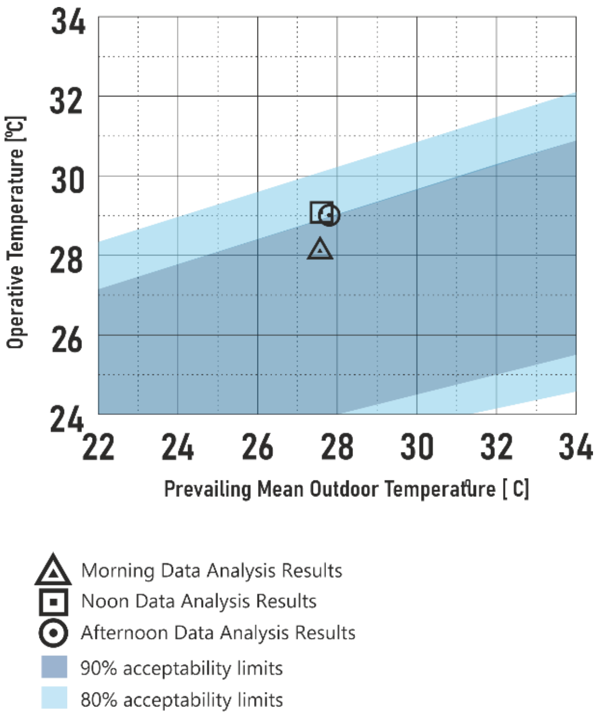


Figure 11. Adaptive Method Result Diagram
Source: (Author, 2023)

These tools require air temperature (maximum value, minimum value, and average), mean radiant temperature, prevailing mean outdoor temperature, and air speed. In using this method, there are provisions of criteria, including:

a. There is no mechanical cooling system installed. No heating system is in operation.
b. Metabolic rates ranging from 1.0 to 1.3 met.
c. Occupants are free to adapt their clothing to indoor and/or outdoor thermal conditions within a range of at least as wide as 0.5-1.0 clo.

The results of thermal analysis comfort (Figure 11. Adaptive Method Result Diagram) using CBE showed that in the morning, it was classified as comfortable with 90% acceptability limits, while in the afternoon and evening, it was still comfortable but with 80% acceptability limits or on the threshold of comfort. It can be interpreted that morning is the best time to get comfortable inside the building, compared to afternoon and evening.

When associated with the comfort variable in this study, apart from the air temperature and radiant temperature values, there is a wind speed variable that affects the comfort value. If the wind speed value increases, the area/zone of the maximum 90% acceptability limits in the diagram above will increase by 0.6-1.2°C every 0.3 m/s (59 fpm).

In another case with the variable air humidity, according to Enteria et al. (2019) in their research on comfort in tropical and humid environments, it was found that high humidity did not have a significant impact on thermal comfort.

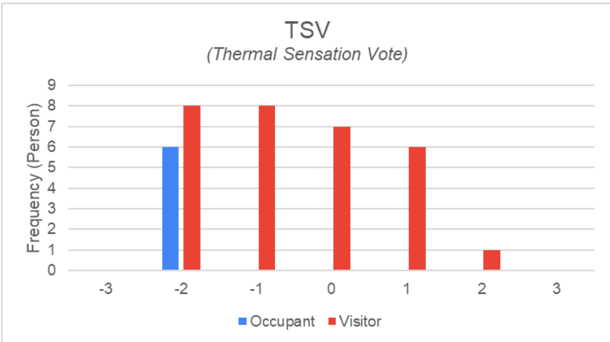


Figure 12. TSV Chart
Source: (Author, 2023)

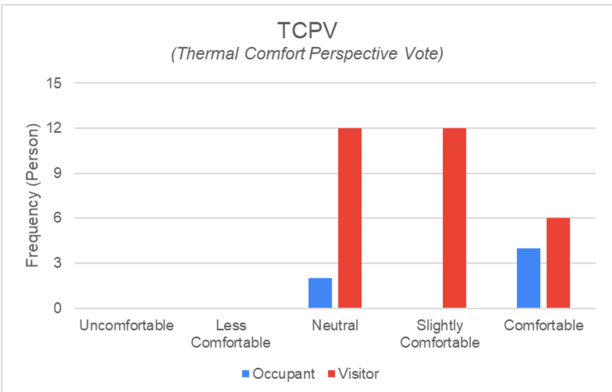


Figure 13. TCPV Chart
Source: (Author, 2023)

In the analysis of the questionnaire data shown by the TCPV (Thermal Comfort Perspective Vote) diagram in, occupants were found to feel more comfortable than visitors, as seen in the TSV (Thermal Sensation Vote) diagram in Figure 12. TSV Chart, evaluation visitors and occupants feel the situation when inside the building is cool to neutral. This is in line with the findings in Sugini's study (2014) that say when buildings in Indonesia with natural ventilation converted from comfort standards according to Fanger (1982), the estimated PMV thermal value is added 0.58 because the Indonesian population is more tolerant of heat, as shown by the findings in Figure 14. PMV and PPD .

As a result of the PMV analysis with an average assessment of TSV and TCPV, the comfort felt by occupants and visitors is categorized as slightly comfortable with a warm feeling (-1).

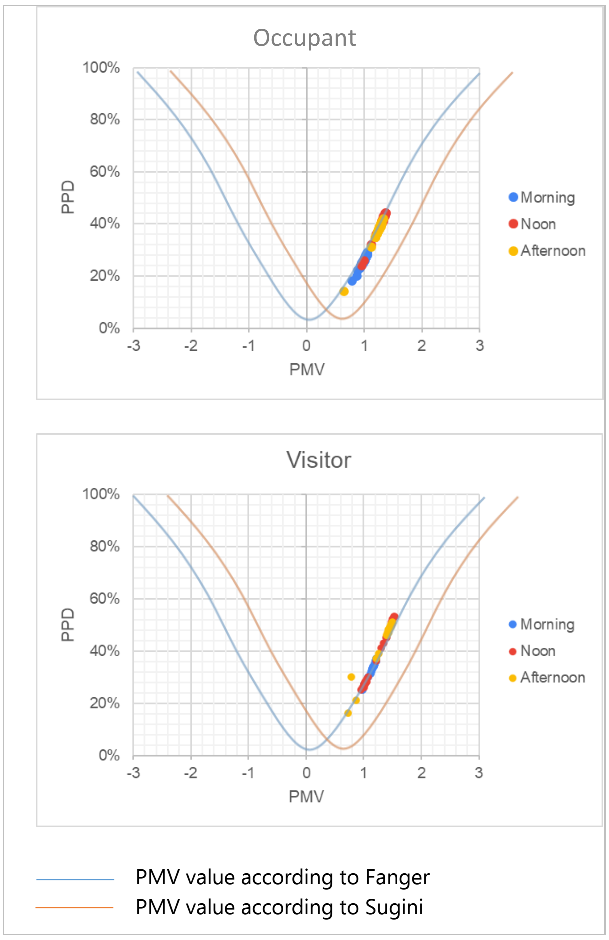


Figure 14. PMV and PPD Chart

Source: (Author, 2023)

In addition, according to the paradigm of thermal comfort through "thermo-adaptive-psychological", factors that influence a person's thermal comfort depend not only on differences in individual physiology and climatic conditions in the environment but also depend on individual psychological differences. This psychological difference is related to how a person processes thermal stimuli in their environment. This process is related to one's past thermal experiences, which can be influenced by social and contextual situations in one's past. This is following the results of the data obtained, shown in the assessment of occupants who feel more comfortable compared to the ratings of visitors who are more varied and tend to feel neutral/ordinary to somewhat comfortable (Figure 13. TCPV Chart).

5. Conclusion

Judging from the characteristics of heritage buildings, using natural ventilation can dissipate heat and provide good-quality fresh air. On the other hand, air movement in a large room volume with high ceilings can minimize the heat in the room caused by radiation. Deep and wide overhangs can be used to collect rainwater runoff and shade walls that are exposed to direct sunlight. Therefore, the air temperature, radiation temperature, and humidity are still protected and can increase the perception of comfort through tolerance to higher air temperatures and from evaporation resulting in an average temperature in the three-time is maintained, namely an average of 28.06-29.26°C with a difference of fewer than 2 degrees Celsius. According to the adaptive chart on the CBE Thermal Comfort (ASHRAE Standard 55-2020) the comfortable conditions for occupants and visitors are at a temperature of 23.8-28.8°C (90% acceptability limits) and up to a temperature of 29.8°C (80% acceptability).

Based on the questionnaire data, visitors who come to the place feel that the conditions inside the building are cool to warm (Figure 8. TSV Diagram). In this case, occupants can take adaptive actions by controlling openings or accelerating air movement in the mechanical system, but (personally) visitors can only exercise control by adjusting clothing to suit the comfort they want to achieve.

There are variables that are not needed according to previous studies, explained in this discussion and emphasized in the CBE Thermal Comfort Tool for the adaptive method approach for naturally ventilated buildings not using humidity variables in thermal comfort in buildings located in tropical and humid areas. The reason for this is that the effect of moisture on the thermal sensation is so small that it can be neglected.

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