Thermal comfort mapping on Pasar Gedhe Hardjonegoro to obtain passive cooling strategy in warm humid tropics

V Soebiyan

1 Architecture Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

Corresponding author: Vivien.soef@binus.ac.id

Abstract. Sustainability energy in tropical climates based on passive cooling refers to a thin and slender shape building as the design strategy to obtain comfortable conditions inside the building. Therefore, thermal comfort problem would arise on a wide building with overcrowded people such as market building like Pasar Gedhe Hardjonegoro. The aim of this study is to examine the factors that influence the thermal comfort of a wide span building using passive cooling design. The tenants as the subject of this research are the main indicator in which the thermal comfort study of a building could be determined. The result of field studies indicates that there is a relation between the user’s thermal comfort with the different location in the building. Study showed that thermal comfort is influenced by the function of circulation.

Keywords: Thermal comfort, Passive cooling, Warm humid tropics

1. Introduction

The concept of sustainability energy in buildings in the humid tropical climate, refers to minimizing the energy used in buildings for cooling the room. While active cooling mostly dominated by the reliability of the electrical devices that consume energy, passive cooling is determined by the design of the building itself. Basically, the design concept for passive cooling aims to eliminate the heat of a building. A thin slender shape is likely to be the best solution for means of ventilation. Hyde describes several design strategies with natural storage in humid tropical climates, such as reducing the depth of the building plan, maximizing the permeability of the envelope through openings, increasing the openness of cuts or minimizing obstacles in the inner space, increasing exposure to wind flow and orientation of the room to the wind [1]. Furthermore, building design principle with consideration of building cooling in humid tropical climates aims to minimize the sun load and heat conduction received through the building envelope during the day to lower the temperature in the room and make natural ventilation effective [2]. In humid tropical climates where air temperatures are high, but have small daily temperature differences, passive cooling can be attained by ventilated cooling. But the decreasing temperature by passive control only by reducing the time and temperature [3].

Wide building with overcrowded people would arise the problem for thermal comfort as the accumulation of heat and the absent of cross ventilation for cooling the room. Pasar Gedhe Hardjonegoro is an old colonial building serve as a central city market of old Surakarta City. It is a building that represent the design typology as public service facility with wide span building with heat
accumulated from overcrowding people. The building consists of several long type space for selling called Los pasar. The market as wide space lined up extends to form a grid pattern on the inside of the market. On the second floor, the market booths forms a linear pattern that surrounds the market. The booths are covered by shops and offices, as a whole, it is a very large enclosed space.

This study purposes to examine the factors that influence the design of a building especially in this typology using passive cooling, based on thermal comfort.

A thermal sensation level is commonly used to define thermal comfort responses. ASHRAE determines the level of comfort uses 7 scales of thermal sensation, as Cold - Cool - Slightly cool - Neutral (comfortable) - Slightly warm - Warm – Hot [4]. Another scales used by several researchers, which depend on the location and object of the research conducted. Study conducted by Ballantyne in 1964 in Papua found that, local residents (Papuans) did not have the experience of feeling cold and cool as European respondents, so that it has difficulty in using 7 comfortable scales. In further research conducted in 1973, the comfort scale was changed from 7 scale to 5 scale. The use of the scale was adjusted based on race related to the location of the respondent. These studies, found a difference in the comfortable temperature field survey results to the comfortable equation (C.E., Comfort Equation) in Melanesians. Melanesians have a comfortable temperature of 2 °C higher than Caucasians. The comfortable temperature of Melanesians is 27.2 °C with C.E. 25.4 °C while Caucasians have a comfortable temperature of 25 °C with a temperature of C.E. 25.2 °C [5]. This shows that the experience of the temperature conditions will affect a person's comfortable temperature. Several studies on thermal comfort in warm humid tropics have been carried out in Singapore by Webb [6] and Jakarta by Karyono [7].

2. Method
The thermal comfort study of building temperature conditions is carried out using a scale on a qualitative approach. The study was conducted with descriptive research (descriptive research), namely the elaboration of thermal comfort conditions from observation / survey. In thermal comfort research, the data is the respondent's response to the thermal environment conditions of the building. In this study, users will conduct field observations to obtain data on respondents' responses to the thermal conditions of the building during market opening hours that illustrate the conditions and comfort scale at the Pasar Gedhe market area in the morning, afternoon and evening. Field observations were carried out for 7 days, with respondents filling out questionnaires.

Survey is designed with the Transverse method (Transverse design). With this method, a study is conducted on a number of respondents with one questionnaire, it will get more number of respondents. This method has the advantage of being able to broaden variations of individual responses and provide good predictions for populations [8]. According to studies conducted by Ballantyne, Barned and Spencer, the number of samples is the amount of data obtained from responses provided by respondents. In their study, the number of data obtained are 2843 data that used as a sample in the study from 16 respondents.

The comfort scale in the survey is a simplification of the ASHRAE comfort scale stratification, adjusted to the respondent's conditions based on climate location, education level and type of work considerations. Respondents are lowland residents who do not have difference experience of cold with cold - cool - slightly cool stratification and heat with slightly warm - warm - hot stratification, as intended by ASHRAE. The understanding of warm and cold will be ambiguous. Refer to the education level of the majority user, they will confuse to use foreign language terms that are not commonly used. The translation of the terms cold and warm in Bahasa literally into the word dingin and hangat will have a different perception.

3. Result and Discussion
The market area which is used for selling, is divided into three blocks, namely blocks I, II and III. Each of these blocks consists of longitudinal booths. Block I consists of booths E, F, G. Block II consists of I1 - I9 and Block III consists of booth H1 - H10. Los J is the place to sell between Block II
and III. While the upper parts used as tiered places are A, B, C and D. In general, the booth is arranged in a grid on the long side of the building which is divided into two blocks with a circulation room as a divider that connects the main door and the North gate. The third block is placed lengthwise on the short side of the building with a circulation passageway connecting the main door with the Southeast door. There are two open spaces located in front of the main door and the North door. Market stalls are spaces that consist of a series of market stalls that form a grid and are shaded by a roof, so this market stalls, semi open but covered by walls on all four sides and a roof at the top.

| Consideration      | Ashrae 7 scale | Modified 5 scale |
|--------------------|----------------|------------------|
| Tropical experience| Cold           | -3               |
| Education          | Cool           | -2               |
|                    | Slightly cool  | -1               |
|                    | Neutral / comfort | 0               |
|                    | Slightly warm  | +1               |
|                    | Warm           | +2               |
|                    | Hot            | +3               |
|                    | Agak dingin    | Nyaman           |
|                    | Panas          | Panas sekali     |

Table 1. Modified 5 scale in qualitative and Bahasa

The questionnaire resulted 173 data, involving 55 respondents and 14 control respondents, which can be categorized by gender, age, and location to determine responses to the thermal comfort of buildings. Classification based on ethnicity and type of clothing was not carried out because the majority of the seller's population in the market stalls were of Javanese ethnicity, while the clothes worn although varied, were generally still in the category of lightweight and thin clothing that was commonly worn on residents in the tropics such as blouses and shirts with value of 0.3 - 0.5 clo. Data obtained from the questionnaire sheet are grouped based on the selected comfort scale, to obtained thermal comfort sensation on each comfort scale.

To have a balanced number of results, it is necessary to control the distribution of respondents. The results are considered accurate if the distribution of respondents is the same. The distribution of samples at each time of taking plays a significant role in the accuracy of the comfort response, because convenience is closely related to the time variable. The number of respondents who accumulate at one particular time will provide a bias towards the comfortable response given. Although the distribution of respondents at the three times did not show the same amount, the number was still in a balanced percentage between morning, afternoon and evening as 32%, 37% and 31%, so that the results of the data collection were not expected to accumulate at one time which resulted in bias towards the results of user responses to the building temperature conditions.

Based on gender, the data sample was 61% female and 39% male, it actually represents the condition of the user population, which is the user majority are women. Related to the distribution based on male and female groups, the time variable will also affect the suitability of the results. It shows the level of a balanced sample spread between men and women in the morning, afternoon and evening, so that the distribution of respondents is quite relevant and appropriate. This is to avoid the accumulation of unbalanced responses such as the large number of heat responses in men because the largest number of male samples are taken during the day.

Table 2. Respondent and data sample

| Responent | 09.00 | Noon | Afternoon | Total | %  |
|-----------|-------|------|-----------|-------|----|
| Woman     | 33    | 40   | 33        | 106   | 61 |
| Man       | 22    | 24   | 21        | 67    | 39 |
| Total     | 55    | 64   | 54        | 173   |    |
| %         | 32    | 37   | 31        | 100   |    |
The results of field studies during market opening hours, are based on five comfort scales ranging from cool to warm, and there is no extreme cold response. Respondent data is based on the attached comfort scale. The most dominant temperature chosen by respondents on each comfort scale illustrated in figure 1. Figure 2b is a plotting of the respondent's location at a comfortable temperature above 28 °C. The map shows that comfort can be achieved at 29°C in the morning at East and West locations. In the plaza area, 19, 18, 17, north gate, J near the north plaza, respondents even still comfort at 30 °C – 32 °C.

The comfort responses map in figure 2 above indicate that comfort response will be perceived by respondents in locations near the plaza, around the Southeast door, block F-E, I1, I6, H5. At a temperature of 29°C respondents no. 12, 15, 59 can feel comfort in a location on the edge side next to the store. At a temperature of 30-31°C, respondents who gave a comfort response were at the corridor and around the door. While at 32°C, it is located in the plaza location and around the entrance area.

![Figure 1. Thermal comfort responses](image1)

![Figure 2. Thermal comfort mapping](image2)
With relatively the same temperature conditions with comfort response, the location is along the inner H block cannot perceive comfort conditions. 'Panas' in Bahasa translated as hot is a warm in a scale response. The warm responses can even be perceived by respondents who are in this area in the morning and evening. In warm responses (31-32 °C), humidity ranges from 79-86%. Response to heat, respondents felt 'panas' or warm at temperatures 26°C – 32 °C with humidity 60-98%. Based on the applicable heat temperature interval 30-31 °C, it shows that at that temperature humidity is recorded at 84 - 94%. These spaces are separated by the separation of the roof and plaza between the entrance and the booths.

The 'sejuk' response shows that the respondent will feel slightly cool at 27-29 °C at along the southeast side, in the plaza area and the Southeast entrance. Respondent code no. 2 and 46 feel slightly cool at 29 °C with 82% humidity, the same as the temperature interval for comfort respons. The slightly cool response map shows that respondents will feel slight cool at 27 °C with 92% humidity to 29 °C with 82% humidity.

4. References
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