Thermal Comfort Assessment in The Open Space in Bandung Case Study Dago Street and Riau Street

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Abstract. Bandung’s temperature has been higher since last years. This phenomenon affects the level of thermal comfort in open space. One indicator that determines the thermal comfort level is the type of activity performed by the open space user. Riau Street and Dago Street are corridors that are often used by the people for strolling, jogging, shopping. Dago Street has special event every Sunday namely car free day. Both corridors have different orientation; Dago Street is North to South corridor while Riau Street’s is West to East. The goal of the study is to compare people’s perception of thermal comfort in both corridors. This research uses two methods, namely qualitative method and quantitative method. Based on the results of qualitative analysis found that the thermal conditions in Dago Street more comfortable than the Riau Street. The result of quantitative analysis found that the average PET (thermal comfort indices) value of Dago Street was at 27.5 °C PET and Riau Street 28.6 °C PET. Dago Street is considered more convenient because it has a lower PET value than Riau Street. The people perception of thermal comfort is very important to start the steps for designing the orientation of street in urban design.

1. Introduction

The city is a gathering place in which humans live and perform various activities in a large collage [1]. A good city could provided comfort to every resident performing activities, one of which is thermal comfort. According to de Dear & Brager, thermal comfort is a condition in which there is satisfaction with the state of the existing environmental temperature so that it can be said comfort preference of every human and the thermal comfort level of every human is different [2]. Thermal comfort is closely related to air temperature, humidity, and wind [3]. These are factors that can affect thermal comfort. Some of these factors can be influenced by the development of the city such as building construction, energy generated by the building, and due to other factors such as the number of vehicles in a city [4].

Bandung is one of the fastest growing cities in Indonesia. Development of Bandung City is also accompanied by the construction of infrastructure such as streets with good pedestrian paths. One of the most well known corridors in Bandung is Ir. H. Juanda street or better known as Dago Street and L.L.R.E Martadinata street or known as Riau street. These two street corridors are notorious for their inner activity attracting the attention of the public both from within and outside the city.
Dago Street is one of the main streets in Bandung which is classified in secondary road collector level with a total length of 5.46 km, street width ± 12 meters, and pedestrian path ± 14 meters on both sides of the street. Dago street itself is one of the streets are very busy either through public or private vehicles, motorcycles, bicycles, and buses. On a typical day, the area is dominated by users who work in the area while on holidays, this area began to be visited by many tourists from out of town. Every Sunday, this street is used by the people’s of Bandung to conduct Car Free Day activities with activities such as selling food, gymnastics, cycling, exercising and for the promotions.

Riau Street is a secondary collector road that has a total length of 2.6 km and a width of ± 10 meters and a pedestrian line ± 2 meters on two sides of the street. Land use in this area is similar to Dago Street, which is a commercial and commercial areas. In additions, Riau Street is famous for its factory outlet. This is because the many functions of building factory outlets that dominate. This street has a street orientation from the West to the East. The main activities on the street are shopping, and offices. In contrast of Dago Street, Riau Street only has a busy time at certain hours, starting at 09:00 until 22:00. Outside of that time, the condition of Riau Street area can be quite quiet especially pedestrian user.

The high development of the city of Bandung, especially on the street corridor can affect factors related to thermal comfort such as wind, air temperature, and humidity in this street corridor. This can certainly affect the thermal comfort felt by the people who use this street corridor for daily activities. This research was conducted to know thermal comfort in both corridors of this street.

2. Research Methods

2.1. Thermal comfort responder’s preference
The Research method used in general is qualitative and quantitative methods. In the quantitative method using descriptive statistical analysis techniques. Descriptive statistical techniques are used to process data obtained by researchers from the results of questionnaires distributed to the public. Descriptive statistics are used that is by looking at the value of mode in the data obtained. In this analysis will describe quantitatively in the form of percentage of questionnaire results. These percentages explain the characteristics or profiles and preference of respondents regarding the level of thermal comfort according to their assumptions.

The data was collected during the Car Free Day (CFD) events on Ir. H. Juanda (Dago) Street at 08.00-09.00 and at the weekend at Riau Street. While the collection of data samples done by non-accidentally random sampling method is by bringing the form and conduct interviews on some people with certain gender, certain age range and certain activities.

2.2. Thermal comfort calculations
The data used to perform the thermal comfort calculations consist of Air Temperature (Ta), relative humidity (Rh%), Heat Stress (TG) and wind velocity (v, m / s). Data collection using the measuring tool is done parallel with the data retrieval process through interview respondents, with the division of tasks as follows: first, two researchers who each operated TR74Ui Data Logger and Anemometer digital take data air temperature, humidity and wind speed at one point ; Second, the researcher who operated the WBGT measurements took air temperature (Ta), humidity (RH) and Heat Stress (TG) data simultaneously with the researcher who collected interview data on radius about 500 meters from the first researcher point.

The further data that has been obtained will be processed through software Rayman. The software functions to know the value of the thermal comfort index in PET and PMV units. PET is defined as the temperature of air needed to reproduce in a space with a standard of body heat production and surface
heat of a particular human skin [5]. PMV is a thermal comfort index introduced by Professor Fanger from the University of Denmark in 1982 and has a standard ISO 7730. Here is the formula for calculating PMV.

\[
\text{PMV} = f(M, R_c, T_a, T_{mrt}, V, RH)
\]

M is the rate of metabolism (e.g., Lying = 0.8 met; sitting = 1.0 met; run = 8.0 meth); \( R_c \) is clothing resistance (e.g., shorts and shirts = 0.1 clo; trousers and coat = 1.0 clo; winter clothing = 3.0 clo); \( T_a \) is Air Temperature; \( T_{mrt} \) = mean radiant temperature; \( V \) ie Speed wind; \( RH \) is Relative Humidity.

3. Observation Results

In this research, the comparison between variables that affect the thermal comfort in the outer space in both street corridors. The comparison is based on community preference and tool measurement, while the variables comprised include activity (metabolic rate), air temperature, wind speed, humidity and clothing resistance.

Dago Street and Riau Street have similar characteristics of land use in the form of trade and services include offices, hotels, cafes and restaurants. The width of the street and the width of the street sidewalk in the two corridors of this street has almost the same width, Dago Street has a width of ± 12 meters and the width of the sidewalk ± 4 meters and Riau Street has a width of ± 10 meters street and ± 2 meter wide sidewalk.

To support the existing activities in both corridors there are various types of supporting facilities such as street furniture that can be used by street users to move in the outer space. These two street corridors have different street orientations, in which the Dago Street corridor has a north-south street orientation and the Riau Street corridor has an orientation of the East-West street. This difference in street orientation affects the movement of the winds in each street corridor thus also affecting the comfort of the outer space.

| Table 1. The comparison condition of Dago Street and Riau Street |
|--------------------------|--------------------------|--------------------------|
| Comparisons              | Dago Street              | Riau Street              |
| Street Width             | ± 12 meters              | ± 10 meters              |
| Width of sidewalk        | ± 4 meters               | ± 2 meters               |
| Street Orientation       | North-south              | West-East                |
| Land use                 | Trading and Services     | Trading and Services     |
|                         | Factory Outlet           | Factory Outlet           |
|                         | Café and Restaurant      | Café and Restaurant      |
| Building functions       | Hotel                    | Hotel                    |
|                         | Offices                  | Offices                  |
|                         | Residential Home         | Government Offices       |
|                         | Trading                  | Trading                  |
|                         | Offices                  | Offices                  |
| Activities              | Car Free Day             | Social interactions (open space in the garden) |

3.1. Responders Characteristic

Affect thermal comfort consists of two variables, the respondent's activity representing the metabolism value of the body and the clothing resistance that represents the respondents' adaptation index. At the time of the process of data collection, the most common activity of the community in both street
corridors is sport activity. Data collection conducted at Dago Street coincides with the weekly event of Bandung city that is car free day so that dominating activities include the activities of sports streets, cycling, gymnastics and running. The type of activities that people do on Riau Street is slightly different from Dago Street because on Riau Street there is no weekly car free day event, but people also do sports activities such as walking casual, running, waiting and shopping.

![Figure 1. Respondents Activities](image)

The clothing used by the respondents is also a variable that affects the thermal comfort preferences. The standard of clothing used in this research has a value of 0 clo to 3.0 clo which is where 0 clo means humans in the condition do not use clothes while 3.0 clo are in human condition wearing winter clothes. On Dago Street most of the respondents wear clothes with indexes of 1.5 are jackets or jackets and trousers, while for Riau street most respondents wear clothes with 0.5 clo indexes that are short sleeve and trousers.

**Table 2. Comparison of clothing types**

| Comparisons                        | Dago Street | Riau Street |
|------------------------------------|-------------|-------------|
| Not wearing clothes (0 clo)        | 0%          | 0%          |
| Short shirts and Shorts (0.3 clo) | 28%         | 29%         |
| Short Shirts and Trousers (0.5 clo)| 28%         | 38%         |
| Kong sleeves and trousers (1.0 clo)| 6%          | 33%         |
| Coat and jacket and Trousers (1.5 clo)| 38%     | 0%          |
| Winter Clothes (3.0clo)           | 0%          | 0%          |

3.2. **Thermal comfort preference**

In this research, the measurement of thermal comfort preferences is divided into three variables: humidity, wind sensation and solar radiation. Preference about humidity sensation in this research consist of 3 scale that is Dry, Ok and Humid. Overall the humidity felt by the respondents between the two street corridors is relatively the same. In Dago Street 69% of respondents felt that the humidity in
the street corridor was good enough, as did respondents in Riau Street. 66% of respondents also felt that the humidity in Riau Street was in good condition.

![Humidity Condition Preference](image)

**Figure 2. Humidity Condition Preference**

The differences in street orientation in Dago Street and Riau Street affect the wind conditions in each of the street conditions. The preferences of wind speed sensation consist of 4 scales: windy, Ok, Little Wind, and still water. Respondents located in Dago Street feel that wind speed in the street corridor is still less (little wind), different from respondents located in Riau Street who feel that wind speed is enough (windy). In addition to street orientation, the movement of the wind is also influenced by passing vehicles. Data retrieval on Dago Street is done at the time of car-free day, so that vehicles passing in the corridor are limited to bikes only so that the movement of the wind is not so great. On the other hand, on Jalan Riau, many vehicles cross the corridor causing high wind movement.

![Wind Speed Sensation Preference](image)

**Figure 3. Wind Speed Sensation Preference**

Solar radiation is the response of respondents related to how the sun exposure in each corridor to the comfort felt by the respondent during the corridor. Sun exposure is influenced by tree or canopy imagery in each corridor. Dago Street Corridor has a shade of trees that are more shady compared to Riau Street so that respondents who are on Dago Street mostly not directly exposed to sunlight. There are 5 scales used to measure the sun exposure: Too Strong, Little Strong, Ok, Little Weak, and Too Weak.
From the condition of several variables affecting thermal comfort obtained comparison of respondent's preference to thermal conditions in each street corridor. To measure the thermal sensation there are 7 comfort scales including cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3). The majority of respondents in Dago and Riau Street feels comfortable thermal sensation (neutral) with percentage of 65% and 44%. From the percentage, it is found that Dago Street has a more comfortable thermal sensation compared to Riau Street, this is because respondents in Dago Street are more comfortable compared to Riau Street.

| Scale         | Jalan Dago | Jalan Riau |
|---------------|------------|------------|
| Cold (-3)     | 0%         | 0%         |
| Cool (-2)     | 2%         | 22%        |
| Slightly Cool | 20%        | 22%        |
| Neutral       | 65%        | 44%        |
| Slightly Warm | 12%        | 6%         |
| Warm          | 0%         | 6%         |
| Hot           | 0%         | 0%         |

Thermal comfort measured affects thermal acceptability felt by respondents in each street corridor. In the street of Dago 98% of respondents felt that the thermal comfort level was ideal, and as many as 50% of respondents wanted no change to the current thermal conditions. While for Riau Street, 78% of respondents felt that thermal comfort in the street corridor was ideal, and 69% of respondents wanted no change to the current thermal condition.
3.3. Processing data of tool measurement

The data obtained from the three tools are TR74Ui Data Logger, Digital Anemometer, and WBGT measuring instruments put together in the table to simplify the PET search process. The PMV and PET search process included four Air Temperature (Ta), Relative Humidity (Rh%), Heat stress (TG), and wind velocity (m/s) data.

| Time  | TA   | RH  | m/s | TG  | Tmrt |
|-------|------|-----|-----|-----|------|
| 8:00  | 24.1 | 72.7| 0   | 29.2| 25.1 |
| 8:05  | 24.8 | 71.8| 0.5 | 31.5| 24.8 |
| 8:10  | 23.8 | 71  | 0.3 | 30.1| 25.3 |
| 8:15  | 25.85| 70.9| 0.9 | 36.1| 25.4 |
| 8:17  | 25.1 | 70  | 0.9 | 34.6| 25.6 |
| 8:20  | 25.5 | 72  | 0   | 29.5| 25.3 |
| 8:22  | 25.6 | 71  | 0   | 29.4| 25.8 |
| 8:25  | 25.9 | 70  | 0.3 | 27.8| 25.7 |
| 8:30  | 25.5 | 71  | 0.2 | 23.8| 26.2 |
| 8:35  | 26.9 | 68  | 0.1 | 23.2| 26.6 |
| 8:40  | 24.8 | 72.5| 0.8 | 32.5| 26.5 |
| 8:45  | 27.2 | 67  | 1.2 | 27.9| 26.9 |
| 8:50  | 28.7 | 62  | 0.3 | 28.1| 25.7 |
| 8:55  | 30.3 | 57  | 0   | 27.637| 25.7 |
| 9:00  | 33.4 | 47  | 0.3 | 22.9| 25.8 |

| Time  | TA   | RH  | m/s | TG  | Tmrt |
|-------|------|-----|-----|-----|------|
| 8.07  | 24.1 | 75.4| 0.77| 28.2| 34.1 |
| 8.08  | 23.9 | 75.1| 4.09| 27.7| 42.1 |
| 8.14  | 23.7 | 74.7| 3.50| 27.7| 38.8 |
| 8.17  | 23.6 | 74.5| 1.16| 28.3| 35.3 |
| 8.18  | 24.05| 75.3| 1.75| 28.83| 38.6 |
| 8.26  | 23.2 | 73.9| 1.76| 28.1| 36.7 |
| 8.28  | 22.1 | 71.8| 1.75| 28.5| 36.8 |
| 8.31  | 22.1 | 71.8| 3.11| 28.1| 38.4 |
| 8.35  | 21.6 | 71  | 0.97| 28.9| 34.7 |
| 8.37  | 21.05| 69.9| 4.09| 29.8| 45.3 |
| 8.42  | 20.7 | 69.3| 1.94| 29.4| 38.7 |
| 8.45  | 20   | 68.1| 1.95| 29.6| 38.3 |
| 8.52  | 21.05| 69.9| 4.29| 28.6| 43.3 |
| 8.55  | 21.7 | 71.1| 1.39| 27.7| 33.2 |
| 8.59  | 22   | 71.6| 1.40| 29.5| 39.2 |

After the data is collected, the data is processed using Rayman software to find out the value of the thermal comfort index such as PET and PMV. PET Defined as the air temperature required to reproduce in a space with the standard production of body heat and surface heat of a particular human skin (Matzarakis, 2008). The PMV is a thermal comfort index introduced by Professor Fanger of the University of Denmark in 1982 and is standard ISO 7730. The equation uses a steady-state heat balance for the human body and links between the deviation and the minimum load on the mechanism.

The results obtained from the data processing using Rayman, the following is :
Table 6. PMV and PET results on the Dago Street

| Time | PMV | PET |
|------|-----|-----|
| 8:00 | 1.3 | 28.4|
| 8:05 | 1.2 | 26.9|
| 8:10 | 1.1 | 26.3|
| 8:15 | 1.5 | 28.7|
| 8:17 | 1.3 | 27.4|
| 8:20 | 1.5 | 29.1|
| 8:22 | 1.5 | 29 |
| 8:25 | 1.2 | 26.6|
| 8:30 | 0.9 | 24.8|
| 8:35 | 1.1 | 25.6|
| 8:40 | 1.1 | 26.5|
| 8:45 | 1.2 | 26 |
| 8:50 | 1.6 | 28.4|
| 8:55 | 1.8 | 29.6|
| 9:00 | 1.8 | 28.8|
| **Average** | **1.3** | **27.5** |

Table 7. PMV and PET results on the Riau Street

| Time | PMV | PET |
|------|-----|-----|
| 8.07 | 1.3 | 27.6|
| 8.08 | 1.1 | 25.2|
| 8.14 | 1.1 | 25.4|
| 8.17 | 1.3 | 27.4|
| 8.18 | 1.4 | 27.9|
| 8.26 | 1.2 | 26.8|
| 8.28 | 1.3 | 27.3|
| 8.31 | 1.2 | 26.1|
| 8.35 | 1.5 | 28.2|
| 8.37 | 1.6 | 28.4|
| 8.42 | 1.5 | 28.4|
| 8.45 | 1.6 | 28.7|
| 8.52 | 1.3 | 26.5|
| 8.55 | 1.2 | 26.4|
| 8.59 | 1.5 | 28.9|
| **Average** | **1.6** | **28.6** |

Figure 7. PMV and PET of Dago Street
The averages PET on the Street of Dago corridor is 27.5 and the PMV is 1.3. This indicates that the thermal conditions of the Street Dago corridor are slightly above the thermal comfort standard index in hot-humid hotspots. While on the street of Riau found the average PET of 28.6 with a PMV of 1.6.

4. Conclusion
In generally, thermal comfort index values on both Dago Street and Riau Street are above the thermal comfort standard index for hot-humid climate countries. Some of the perceived preferences and sensations associated with the thermal conditions are influenced by the physical activity of the users of both street corridors. The difference in physical activity can cause differences that are influenced by clothing factors used during the move. On the Dago Street, thermal conditions are considered comfortable even though people do activities that are quite heavy such as running, gymnastics, and other sports. On the Riau street, thermal conditions are also considered to be comfortable even though the value of PET on Riau Street is higher than. This is due to the different activities that occur between Dago Street and Riau Street. The type of activity performed on Riau Street is lighter when compared to Dago Street.

Based on interviews, thermal comforts on Dago Street and Riau Street are considered to be sufficient to meet the comfort for the people who use both street corridors. With thermal comfort, the community can move outdoors optimally.

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