Adaptive thermal comfort in colonial building classrooms

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Abstract. The thermal sensation experienced by humans is a function of climatic factors such as air temperature, humidity, and wind velocity as well as individual factors such as the level of activity related to the body metabolic rate and the type of clothing worn. Moreover, adaptive thermal comfort assumes the occupants of a building are the main factors determining thermal comfort. The physical parameters measured showed the colonial classrooms buildings in State Senior High School 3 Bandung fulfill the thermal comfort standards. This was further established with the comfortability reported by most of the students to have experienced while conducting learning activity in the classroom.

1. Introduction
Teaching and learning activities are part of the educational processes conducted in the classroom. They are conscious and planned efforts towards realizing the appropriate atmosphere and learning process to ensure students actively develop their potential. Moreover, students' ability to study effectively depends on a comfortable learning environment and one of the ways to achieve this is through thermal comfort.

The shape and character of a classroom indirectly depend on the curriculum applied in the school and government policies. For example, in the colonial era of the early 19th century, the Dutch government built several schools in Indonesia with European style and these schools are still functional and visible in the country. One of these is the Hoorgere Burger School (HBS), now State Senior High School 3 and 5, built in 1916 in Bandung. The school was designed by CP Wolff Schomaker, an architect reported to have designed many private and public buildings in Bandung for decades [1].

The classroom for the teaching and learning process requires a design with the ability to adapt to climatic or environmental conditions. Geographically, Indonesia is located in 6° North Latitude to 11° South Latitude and this led to its classification as a humid tropical climate with high solar radiation intensity, relatively high air temperature, air humidity, rainfall, and cloudy sky [2].

The human environment is influenced by several natural factors including climate quantities such as solar radiation, temperature, humidity, precipitation, and others [3]. These factors individually or simultaneously create a less suitable environmental condition for human habitation, for example, hot mixed moist or very cold one accompanied by strong winds. The most important factors affecting thermal comfort in a closed room are air temperature (T) in degrees Celsius, relative humidity (RH) in %, solar radiation (MRT) in degrees Celsius, and wind velocity (V) in m/sec [4].

Adaptive thermal comfort theory has, however, been used as a basis for research by several researchers up to date with the focus on climate variables, user perceptions, and personal factors such as occupant habits [5]. This study was, therefore, conducted to determine the variables perceived to be influencing thermal comfort.
2. Literature review

The thermal comfort process involves physiological, psychological, and physical conditions. It is, subsequently, the result of an individual’s satisfaction in a thermal environment [6]. The concept has also been defined to be the derivation of satisfaction in the surrounding thermal conditions [7]. It is also an environmental condition affecting humans [8]. This, therefore, means thermal comfort can be defined as an empirical formulation of an experience or feeling with the perceived conditions observed to be different from one person to another. It is possible to determine the thermal comfort of a zone by assessing the dominant perception observed among a group of samples in the area.

The International Standard for Thermal Comfort (ISO 7730) recommends the use of an index from Professor Fanger known as the Predicted Mean Vote (PMV) and Predicted Percentage of Discomfort (Predicted Percentage Dissatisfied, PPD) as the parameters to indicate the extent to which a group of people feels thermally comfortable or uncomfortable. PMV has the ability to predict the average thermal sensation in a group of people with similar clothes, activities, and in a certain room while PPD predicts their inconvenience percentage [9].

The comfortable temperature for humans is obtained based on the average air temperature from outside and inside the building [10]. Meanwhile, Standard Effective Temperature (SET) is a thermal index describing the thermal sensation conditions associated with the definite climate factors of air temperature (Ta), mean radiant temperature (MRT), relative humidity (RH), wind velocity (V) affecting humans at a certain level, affected by cloth, and some activities conducted to produce the body's metabolism [11].

Some studies have proved the comfort threshold to be different depending on the geographical location and human subjects or ethnic groups studied as shown in the following table 1.

| Author | Location | Country | Comfort Limits |
|--------|----------|---------|----------------|
| ASHARE | South USA (30°NL) | India (without AC) | 20.5°C - 24.5°C |
| RAO    | Calcutta (22°NL)  | Malaysia (without AC) | 20°C - 24.5°C |
| WEBB   | Singapore Equator | Chinese (without AC) | 25°C - 27°C |
| MOM    | Jakarta (6°SL)  | Indonesia (without AC) | 20°C - 26°C |
| ELLIS  | Singapore Equator | Europe (without AC) | 22°C - 26°C |

3. Methods

The research was conducted using a quantitative method with a descriptive presentation at the State Senior High School 3 which was built in the form of a colonial building in 1916 as shown in Figure 1. The data was sourced from the students, environment, and by assessing the classroom condition where the teaching and learning processes are conducted [1]. Moreover, data were collected by measuring all the required physical environmental variables and students’ perceptions of the thermal comfort in the classroom at the same time and place using a questionnaire [15].
Figure 1. Environmental and classrooms conditions at State Senior High School 3 Bandung [1,16].

The physical environment variables include indoor and outdoor climatic conditions such as air temperature, relative humidity, and air velocity and the questionnaire was designed to determine students' perceptions of the thermal comfort level in the classroom.

The data were analyzed using descriptive statistics which involves describing the average thermal conditions and thermal comfort index. The results of the index calculated were compared with the standard values while students' perceptions were described by grouping their responses towards the thermal comfort in the classrooms.

4. Results and discussion

Data were collected from the historic building of Senior High School 3 Bandung School located on Belitung Bandung street with a connection to the historical development of colonial architecture in Bandung. The building was constructed in 1916 at the beginning of Dutch colonialism after a new ethical policy was enacted in 1900-1920 and this raised suspicions on the influence of Indo-European architectural culture and Nieuwe Bouwen which were the colonial architectural styles [17].

This place was selected because its functions have not changed much from the way it worked since its inception. The building is located directly adjacent to Belitung Street in the north, Kalimantan Street in the west, Bali Street in the east, and colonial residential buildings which now belong to the Army in the south as shown in Figure 2.

Figure 2. Research objects location [17,18].

The mass shape of the school building is oriented towards the North-South with form extending from the East-West direction which is a method of responding to the sunlight direction. The school building’s mass formation is broadly rectangular and thinly designed to ensure the effective utilization of the natural light and airflow. The mass is divided into three parts including the core which is the largest, the middle located between the core and the back which is the third and smallest of all. The formation was observed to have followed a tread-like shape by getting smaller backward or towards the South.
The building was observed to be old with two floors, ground and top, having five classrooms each, and only two classrooms, XII SCIENCE 6 located on the ground and XII SCIENCE 5 on the upper floor, were assessed by distributing questionnaires to the students in them. The research was conducted in the 2011/2012 school year and the parameters were measured in the morning between 07.00 - 10.00 and afternoon between 11.00 - 14.00 WIB for three days with a cloudy sky and two days with a clear sky. The points where the thermal comfort measurements were made are shown in Figure 3.

![Diagram of thermal comfort points](image)

**Figure 3.** Point of thermal comfort.

The results from the three days assessment made in January 2012 produced the average temperature, humidity, and air movement in each classroom as shown in the table 2.

| Aspect                  | Time             | Old Building Ground Floor | Old Building Upper Floor | Criteria                                                                 |
|-------------------------|------------------|---------------------------|--------------------------|---------------------------------------------------------------------------|
| Average Temperature (°C)| (07.00 – 10.00)  | 24.6                      | 24.8                     | a. Cool, comfortable, between effective temperatures 20.5 °C - 22.8 °C |
|                         | (11.00 – 14.00)  | 26.2                      | 26.8                     | b. Optimal, comfortable, between effective temperatures 22.8 °C - 25.8 °C |
| Average Humidity (%)     | (07.00 – 10.00)  | 72.1                      | 71.4                     | c. Warm, comfortable, between effective temperatures 25.8 °C - 27.1 °C    |
|                         | (11.00 – 14.00)  | 70.8                      | 69.4                     | d. Humidity of 30-70%                                                     |

The classrooms on the ground floor have an average temperature and humidity of 24.6°C and 72.1% respectively in the morning and 26.2°C and 70.8% in the afternoon. The temperature was observed to be increasing during the day but still in the warm comfortable category while the air movement or wind inside the classroom was felt when the students are close to the window.

Air temperature is the most influential factor determining human thermal comfort conditions and the temperature of the human being used as a sample in the experiment was observed to have increased when the room temperature increased to approximately 21°C without any effect on the skin temperature but causes the skin to sweat [19].
Humidity was observed not to have much influence on the room climate (in buildings) compared to air temperature \( (T_a) \) or average radiation temperature \( (T_{mrt}) \). For example, at \( T_a = T_{mrt} = 20 \, ^\circ\text{C} \) and wind velocity \( V_a = 0.05 \, \text{m/s} \), the RH was observed to have changed from 30% to approximately 75% causing an average increase in the skin temperature \( (T_s) \), by 1°C. In real conditions, people from dry climates tend to be uncomfortable, even sick, when visiting humid climates [20].

Wind velocity was also discovered to have a different effect on thermal comfort in comparison with other climatic factors. A higher value of this parameter causes a reduction in the average skin temperature \( (T_s) \) as observed in the reduction of \( T_s \) value by approximately 2°C when the air velocity increased from 0.00 to 0.002 m/s. This is, however, only applicable to environments where the air temperature is below the skin's temperature. Meanwhile, in a situation the air temperature is higher than the skin temperature, the airflow effect is expected to be the same as observed for other climatic factors which means causing an increase in the skin temperature [21].

The adaptive approach to thermal comfort is based on field surveys and this includes collecting thermal data and, at the same time, measuring respondents' thermal responses in real situations, with minimum researcher intervention [10]. In recent years, adaptive thermal comfort models are being used to determine the neutral temperature as a function of both indoor and outdoor temperatures [22].

The thermal comfort perception questionnaire data were analyzed using a trend test with the tendency of variables obtained by grouping the score acquisition data based on ideal scores and ideal standard deviations. The percentage of score acquisition was calculated to describe the percentage of comfort aspects achieved based on the respondents' scores acquisition compared to the ideal values.

The student responses to thermal comfort in classrooms at the upper floors of the old buildings were found to have a score of 82.79% while the lower floors had 81.06% and this means 82.79% of those learning in upper floors feel comfortable and the same was observed for 81.06% of those on the lower floors. The difference in the level of comfort between the classes is relatively small and recorded to be less than 1%. This, therefore, shows most students learning in both classes feel they fulfill the required thermal comfort.

These findings are in line with the experimental results which showed comfort to be related to skin temperature and not to environmental or clothing variables. The desired temperature at a steady work and light clothing was found to be close to 25.6°C and no effect was recorded on age, gender, race, and others. Moreover, the difference in the desired temperature is often more determined by the type of clothing [23].

5. Conclusion
Microclimate was found to be influenced by four factors including air temperature, solar radiation, humidity, and wind velocity, and the one with the most dominant effect on thermal comfort was discovered to be the air temperature due to its impact on the occupant's condition. The physical parameters measured also showed the classrooms in the colonial building at State Senior High School 3 Bandung fulfill thermal comfort standards. This is in line with the comfortability recorded to have been felt by most students in the classroom while conducting learning activities.

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