Air temperature and CO₂ concentration in naturally ventilated classrooms in hot and humid tropical climate

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Abstract. Students at the public primary schools in Medan city, Indonesia, complete 90% of their learning activities in the same classroom, which, in order to save energy, utilises natural ventilation to obtain thermal comfort and fresh air for indoor air quality, which is the physical school environment that impacts the students’ achievement. Air temperature is a crucial factor that influences thermal comfort, while the CO₂ concentration determines the quality of fresh air. This paper aims to describe air temperature and the CO₂ concentration in an occupied naturally cross-ventilated classroom in a hot and humid tropical climate, in Medan city, Indonesia. The air temperature and CO₂ level were simultaneously monitored for four days during the students’ lesson hours in a school classroom that complies with the regulations of the Ministry of Education of Indonesia about the infrastructure standards for elementary, junior high, and senior high schools. The results of this study showed that air temperature in the classroom exceeded the comfortable temperature, while the median CO₂ concentration was below 1000 ppm as recommended by ASHRAE and WHO.

Keywords: ASHRAE, comfort temperature, CO₂ concentration, natural ventilation, school classroom

1. Introduction
Thermal comfort and air quality form the majority of the elements of the physical school environment, which impact various aspects of student achievements, such as [1]; performance of schoolwork [2]; and the effect on health, comfort, and the cognitive performance of students [3]. Various methods were used to obtain thermal and air quality comfort in the school classroom, using natural ventilation [4,5], mechanical ventilation [6], and a hybrid system that combines natural and mechanical ventilation systems [7]. Using natural ventilation to obtain thermal comfort and indoor air quality is better way to conserve energy.

The thermal comfort zone of the ASHRAE standard 55–1992 in school classrooms using natural ventilation in a hot, humid tropical climate is difficult to achieve [8], even with mechanically ventilated with the help of fans [9]. Several thermal comfort studies in naturally ventilated classrooms in tropical climate in Indonesia have been carried out. Students in a high school in Makassar felt comfortable in a temperature ranging between 28.2 °C in the morning to 33.6 °C midday, with the air humidity ranging between 44 % to 73 % [10]. The comfortable temperature in a naturally ventilated classroom without fans during the learning and teaching activities between
7:00–12:00 am in Manado was the temperature being lower than that of Makassar, namely 26.3 °C with a relative humidity of 84.6 % [11]. High school students in classrooms without a fan in Padang reported that they felt uncomfortable during learning and teaching activities between 7:00 am to 2:00 pm in the temperature range between 27–30 °C, with relative humidity range between 68–80 % [12]. Other studies about thermal comfort in a classroom mechanically ventilated by fans in Singapore concluded that pleasant temperatures ranged between 27.1 °C to 29.3 °C [9], higher than the comfortable temperature without a fan in Manado and Padang, Indonesia. The maximum acceptable operative temperature in the naturally ventilated classroom during the students’ lesson hours between 2 pm to 6 pm in Malaysia was 26.5 °C [13]. The students in the classrooms that used natural ventilation in Hawaii were tolerant of a broader range of operative temperatures, between 22.0 °C to 29.5 °C, with relative humidity range of 40 % to 60 % [14].

In addition to the air temperature, the concentration of CO₂ in the classroom also affects the students’ learning at school. The CO₂ concentration in a school classroom can reach over 1000 ppm, higher than the outdoor CO₂ level, if the ventilation is inadequate, since the process of human respiration produces 4.4 % of the CO₂ volume. Meanwhile, children are more susceptible for air pollutants and require more oxygen for their growth. The indoor CO₂ concentration over 1000 ppm will affect the students’ health [15], concentration levels [16], and academic performance [17]. These causes for the increase in the CO₂ level are often used as indicators of the need for adequate ventilation in order to ensure the entry of fresh air and to maintain the condition of the indoor air quality in classrooms. Occupancy densities and activities [18], occupancy periods [19], and ventilation rates [5] are the various factors that influence the CO₂ concentration in the school classrooms. Previous studies have shown that the CO₂ concentration in the school classrooms, which used natural ventilation, was lower that of the classrooms, which used mechanical ventilation split units [20].

Indoor air quality, according to the CO₂ concentration in occupied school classrooms used natural ventilation with the help of fans in Malaysia below 1000 ppm [21,22], according to the daily threshold recommendations by ASHRAE and the Malaysian DOSH [23]. A study conducted in a naturally ventilated single-sided classroom of a primary school located in the Nordic climate, Canada, showed an increase in the temperature from 30 % to 56 % with the air temperature being under 24 °C and the CO₂ concentration being below 1000 ppm [3]. This study proved that a comfortable temperature, as well as indoor air quality that meets the health standards, could be obtained by saving energy through the use of a natural ventilation system.

There are no standards or policies to set a comfortable temperature in the classrooms of educational buildings in Indonesia. Even the concentration of CO₂ is not used as an indicator of the indoor air quality. Meanwhile, the WHO [24] and many other countries mentioned the CO₂ concentration below 1000 ppm as an indicator of indoor air quality in occupied classrooms. Most of primary public school classrooms in Medan city use natural ventilation with large windows to obtain thermal comfort, and fresh air by manually operable windows, combined with horizontal or vertical jalousie/louvre as permanent ventilation for saving the building operational costs with regard to the use of energy. The results of studies as mentioned above concluded that the comfortable temperature and indoor air quality in the occupied classroom are required for the students’ health, their learning and performance abilities at school, and conservation of the building operation energy. For that reason, it is crucial to study the indoor temperature and the CO₂ level in school classrooms in Medan city. This study aims to describe the air temperature and indoor air quality condition regarding the CO₂ concentration in naturally cross-ventilated school classrooms in Medan city.

2. Methods
Considering that primary schools should be located in the residential area as mentioned in SNI 03-1733-2004 [25], the study was completed in SDN 066046 in the same area with school buildings SDN 064982, both being public primary schools at Jl, Tanjung Perumnas Helvetia, a residential
area in the district of Helvetia Medan. The building configuration layout was shaped in a closed courtyard plan (Figure 1).

2.1. Selected classroom

The selected classroom was considered with regard to its occupation density (the ratio of the number of students to classroom size), its ventilation with regard to opening area, and its occupancy period (students' lesson hours). The number of students in SDN 066046 is 307 students, who were divided into 10 study groups. The school building SDN 066046 has nine classrooms, where each floor has an area of 52 m² (7.4 m x 7.0 m), and the height from the floor to the ceiling is 3.25 m. The study was conducted in a fifth-grade classroom, as seen in Figure 3 and 4.

2.1.1. The number of student and classroom density

The maximum room density to maintain the air quality in the classroom is two m²/student [26,27] while the Ministry of Health, Republic of Indonesia, established a standard of 1.75 m²/student [28]. There are two different policies setting the number of students for each study group (classroom) in primary schools in Indonesia. The Ministry of National Education No. 24 in the Year 2007, with regard to the School facilities and infrastructure standards, established a standard where the number of students would be a maximum of 28 students in 7 m x 8 m or a total area 56 m² classroom size [27]; while the Minister of National Education No. 15, in the Year 2010, with regard to the Minimum Services Standards for Basic Education in District/City, established a standard that the number of students would be a
maximum of 32 in the same classroom size. The floor area of the observation classroom floor was 52 m$^2$, occupied by 30 students. Thus, occupancy density of the classroom was found to be 1.73 m$^2$/student.

2.1.2. Opening area for ventilation. There are a few policies about ventilation for education building in Indonesia. The openings in primary school classrooms are meant to accommodate the needs of natural lighting and ventilation [29]. SNI 03-6572-2001, with regard to the procedure for design ventilation and air conditioning system in a building with natural ventilation, setting the permanent opening area (windows, doors, or other means that can be open) to at least 5% of the floor area. Appendix II PermenDikbud No. 32 the Year 2011, according to the standards and technical specifications of the rehabilitation of damage in schools, and the development of new classrooms along with the furniture and development of the library along with the furniture for SD/SDLB established the widespread exposure of 20% of the total floor area of a building, 6–10% of the total area as permanent ventilation: cross ventilation or single-sided ventilation. The Health Ministerial Decree No. 1429/Menkes/SK/2006, regarding the guidelines for the implementation of school environmental health set the total ventilation area to ensure a steady flow of fresh air in the classrooms in the school environment as 20% of the floor area with a minimum of 1.75 m$^2$ of density and minimum ceiling 3 m of height above the floor.

Based on the observation, classrooms used a combination of top-hung windows, which were manually operated, and the light windows. Both were completed with jalousie as permanent ventilation on the upper side. The window on the corridor side was 1.20 m height from the floor, while on the opposite side was at 0.90 m height from floor. The total opening areas, which consisted of top hung windows, fix light windows, jalousie and door were 16.02 m$^2$ or 31% from the total classroom floor area, with only 18.7% functioning as ventilation when the study conducted.

2.1.3. Occupancy period of the classroom (students’ lesson hours). With regard to the Indonesian Minister of National Education Regulation No. 15 of 2010, concerning Minimum Services Standard for Basic Education in Regency/City [30], students at the public primary schools in Indonesia organised learning process for 34 weeks per year, 18 hours per week for the first and second grade, 24 hours per week for the third grade, and 27 hours per week for students from the fourth to the sixth grade. Lesson hours at SDN 066046 school for 4th–6th grade were between the range time 07:30–12:05 pm with two breaks at 09:15–09:30 and 10:40–10:55 (each time break was for 15 minutes), from Monday to Thursday; 07:30–10:40 for Friday; and 07:30–10:00 for Saturday. The study was conducted in a fifth-grade classroom between 07:30–12:05 pm where the students spent 90% of their learning activities in the same class.
2.2. Monitoring and placement of measuring instrument

Monitoring was conducted using a CO₂ data logger Trotec BZ 30 (Figure 8). At the same time, it could automatically record the air temperature, relative humidity, and CO₂ concentration every two seconds. The instrument has a data memory 50,000 values and the sampling rates being measured every two seconds: and temperature with a measuring range between -5–50 °C, resolution 0.1 °C, and accuracy ±1 °C; relative humidity (RH) with a measuring range 0.1–99.9 % RH, resolution 0.1 % RH, and accuracy ±5 % RH; and CO₂ concentration with a measuring range 0–9,999 ppm, resolution 1 ppm and accuracy 75 ppm or ±5 % of the measured value. Measurements in situ were carried out in April 2016 during the students’ lesson hours between 7:30–12:05 pm, for four days in order to obtain accurate data. Instruments were located in the centre of the classroom about 1.20 meter above the floor (Figure 9). Referring to a study for classroom area up to 100 m² measurement was conducted at one point in the middle of the room at the height of the student breathing zone in seating condition [31]. The instrument checked for calibration by using similar equipment.

![Image](image.png)

**Figure 8.** The instrument for physical measurements.

**Figure 9.** Classroom situation during break times, and placement of measuring instrument.

3. Results and Discussion

3.1. The measurement result of indoor air temperature and relative humidity.

Medan city is located at the 3°27′–3°47′ north latitude and the 98°35′–98°44′ east longitude, and has hot and humid tropical climate, with the temperature ranging between 23.1–34.3 °C and the average relative humidity ranging between 78–85 % [32]. The measurement of the monitoring data for four days showed that indoor air temperature in observation classrooms increased with time (Figure 10) while the outdoor air temperature fluctuated and became higher than the indoor air temperature.

![Figure 10](image.png)

**Figure 10.** Classroom indoors and outdoors air temperature for four days.

Table 1 shows the statistical data of indoor and outdoor climate. The measured data showed that indoor air temperature for four days during the teaching and learning process was between 30.5 °C
and 34.5 °C, with a relative humidity between 57.2 % and 74.6 %. The maximum air temperature inside the classroom varied slightly between 33.3 °C and 34.5 °C, with a relative humidity between 71.7 % and 74.6 %. Average ranges of the indoor air temperature were between 32.3 °C and 32.8 °C, and the average ranges of relative humidity were between 67.7 % and 70.3 %. The differences between the maximum and minimum temperature in the classrooms were between 2.7 °C and 3.7 °C. The maximum outdoor air temperature had reached between 35.2 °C and 36.6 °C, with a relative humidity between 65.9 % and 78.5 %.

| Measure | Ti | Temperature (°C) | RH (%) |
|---------|----|-----------------|--------|
|         | Max| Min | Mean | To | RH in | Rh out |
| 1st day | 33.3| 30.6 | 32.3 | 2.7 | 35.2 | 30.0 | 32.9 | 74.6 | 65.4 | 78.5 | 59.3 |
| 2nd day | 34.5| 30.8 | 32.8 | 3.7 | 36.6 | 30.5 | 34.5 | 73.7 | 57.2 | 72.4 | 49.2 |
| 3rd day | 34.1| 30.6 | 32.5 | 3.5 | 35.8 | 30.4 | 33.2 | 73.7 | 64.6 | 72.8 | 57.8 |
| 4th day | 33.6| 30.5 | 32.5 | 3.1 | 36.3 | 31.2 | 34.3 | 71.7 | 62.4 | 65.9 | 55.5 |

Ti = indoor temperature, To = outdoor temperature, RH_{out} = outdoor relative humidity, RH_{in} = indoor relative humidity.

3.2. The measurement result of the indoor and outdoor air CO₂ concentration.

Figure 11 shows the fluctuation of the measuring data of the indoor air CO₂ concentration of classroom for four days. The measurement of three out of the four days showed indoor air CO₂ concentration exceeding 1000 ppm, namely 0.6 %, 1.4 %, and 1.9 % of the data record. However, the median CO₂ level for four days ranged between 602–637 ppm, below the legal standard for health (1000 ppm). Figure 12 shows that the CO₂ concentration of outdoor air during the measurement period exceeded the CO₂ level according to ASHRAE standard for outdoor air, which is 400 ppm, and the maximum outdoor air CO₂ concentration for four days was the same, namely 767 ppm. The median out-door air CO₂ concentration was 498–520 ppm.

**Figure 11.** Ranges of indoor CO₂: minimum 457–484 ppm; maximum 872–1631 ppm; and median 602–637 ppm.

**Figure 12.** Ranges of outdoor CO₂: minimum 443–453 ppm; maximum 767 ppm; and median 498–520 ppm.
4. Conclusion
Results of the study in an occupied classroom using natural cross ventilation, which is in the ratio of the total opening area to the floor area at 18.7 % (function as ventilation), and the occupancy density being at 1.73 m$^2$/student, showed that indoor air temperature between 30.5 °C and 34.5 °C, exceeded the comfortable temperature zone in the classrooms, with regard to the previous studies of the same nature in tropical climate in Indonesia, Singapore, Malaysia, and Hawaii. The relative humidity in the classroom was between 57.2 % and 74.6 %. In contrast, the median CO$_2$ concentration between 602 ppm and 637 ppm was lower than 1000 ppm, as permitted of ASHRAE and WHO, although the median of the outdoor air’s CO$_2$ concentration was between 498 ppm and 520 ppm or even exceeding 400 ppm. The results of the study are required for the future experiments to examine the relationship of air temperature and relative humidity with the CO$_2$ level in natural cross-ventilated classrooms.

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