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Study of thermal comfort and CO_2 concentration in air-conditioned children's rooms during the Covid-19 Pandemic

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ABSTRACT

The government's implementation of online learning for students during the Covid-19 pandemic since March 2019 has impacted thermal comfort and CO_2 concentration in the rooms where children engage in activities at home. This study aims to investigate the thermal comfort and CO_2 concentration in air-conditioned children's rooms during the Covid-19 pandemic. The research method was carried out through field measurements consisting of collecting external climate data, internal room data, and CO_2 concentration levels. Temperature, air humidity, and CO_2 concentration levels were recorded every minute for four days. In addition, surface temperatures of the floor, ceiling, and walls were recorded every 15 minutes between 06:00-18:00 Central Indonesia Time (CIT). The results showed that the average room air temperature was 26.2 °C, with the AC thermostat set at 26 °C. However, uneven air distribution was caused by the furniture arrangement that hindered uniform air distribution. CO_2 concentration levels increased above the normal limit when more than three people were in the room, especially at night. To quickly reduce CO2 levels to meet the standards, it is recommended to open windows or doors to facilitate air circulation.

Introduction

The Covid-19 pandemic has affected various sectors of life, including the education sector, experienced by various countries, including Indonesia, since the beginning of 2019. Since March 16, 2020, the President of Indonesia has urged people to carry out activities from home (Zamroni 2020). This policy is expected to reduce social mobility, including for students. The education sector has also made adjustments through the Circular Letter of the Ministry of Education and Culture Directorate of Higher Education No. 1 of 2020 regarding preventing the spread of Covid-19 in the education sector (Handarini et al. 2020). The Ministry of Education and Culture instructed distance learning in this circular letter and advised students to learn from their respective homes. Since March 2020, school children have started to get used to learning online from home. A healthy and comfortable learning space is needed for their learning activities to run normally.

One important factor for a comfortable learning space is thermal comfort, and the CO_2 levels in the air must meet the standard. Considering that Indonesia's climate cannot continuously provide thermal comfort for a full day (Latif 2020), mechanical devices are needed to provide thermal comfort in a room such as an air conditioner (AC). Children's activities, from studying and playing to sleeping, are done longer in air-conditioned rooms than in other rooms. This new habit of children is to avoid the heat conditions in rooms that do not use air conditioning (AC).

The hot conditions in the interior of tropical climates have been confirmed by previous researchers (Latif et al. 2019a; 2019c). This information shows a heat problem experienced by residential homes in tropical climates such as Indonesia, especially during the day, caused by climatic influence.

The thermal environment is closely related to the quality of residential comfort. Currently, studies on the thermal environment in indoor spaces are more numerous than in outdoor spaces (Fan et al. 2017). One important consideration is that the thermal environment in outdoor spaces has higher complexity than indoor spaces. Especially in the outdoor thermal environment, it is influenced by solar radiation, which is not considered in the indoor thermal environment.

Efforts to achieve thermal comfort in a room affect economic factors through increased electricity consumption. Indonesia has experienced high economic growth, around 4.6-6.2% in recent years, accompanied by an increase in population with an annual growth rate of 1.1-1.4% (Bank 2020). This economic growth has led to increased energy use in the household sector (Luckyarno et al. 2019).

The factors responsible for the high energy consumption of buildings in tropical climates are the climate which has both summer and rainy seasons. In tropical and humid areas of Indonesia, the daily maximum temperature is usually above 30°C with high humidity throughout the year, around 70-90% (Latif et al. 2019b). This condition encourages building occupants to use air conditioning (AC) to address thermal comfort issues (Santamouris et al. 2018). However, other strategies can be applied in this climate to achieve thermal comfort, namely through passive design, especially natural ventilation (Latif et al. 2019d, Hamzah et al. 2018).

Previous studies reported that in humid tropical climates, open windows during the day would increase indoor temperature, even if the airflow in the room is improved. Cooling ventilation systems directly affect occupants through sweat evaporation and convective heat transfer, usually considered a traditional ventilation strategy in tropical areas (Sangkertadi et al. 2008). Recent studies show that in Southeast Asia, most occupants tend to open their windows during the day to allow for natural ventilation. Still, AC is commonly installed in bedrooms during the daytime and nighttime. (Zaki et al. 2018).

In addition to thermal comfort, the level of CO_2 concentration in a room, especially a sealed room with air conditioning used for extended periods, must be considered. Growing evidence shows that an increased CO_2 concentration relevant to the environment (<5,000 ppm) can pose direct risks to human health. Increased CO_2 concentration in a room can cause harmful exposure due to the increased time spent indoors. Evidence regarding the potential health risks of chronic exposure to increased environmental CO_2 levels can affect health, such as inflammation, decreased high-level cognitive abilities, bone demineralization, kidney calcification, oxidative stress, and endothelial dysfunction. Early evidence shows potential health risks from CO_2 exposure above 1,000 ppm (Hviid et al. 2020).

Productivity will decrease for occupants in a room with poor air quality. Sun et al. (2018) explained that increasing ventilation openings could dilute contaminants and reduce the risk of sick building syndrome (SBS) symptoms. A room with a ventilation rate of less than 10 L/second per person produces poor air quality perception and SBS symptoms (Sun et al. 2018). It is recommended that the ventilation rate of a room be greater than 25 L/second to reduce SBS symptoms and health problems. Carbon dioxide (CO_2), a contaminant in the room originating from human respiration, can be diluted by replacing fresh air intake from outdoor air by applying accurate levels of home ventilation systems. The level of CO_2 concentration in a room can exceed 1000 ppm due to low ventilation rates and high occupant density (Hviid et al. 2020).

The lack of fresh air intake channels will decrease the level of ventilation in the room, also resulting from a lack of awareness of fresh air intake channel operation. Such conditions, combined with the high number of people in the room, cause an increase in CO_2 levels (Shriram et al. 2019, Yang et al. 2022).

Zune et al. (2020) stated that the combined effect of air temperature and humidity would affect the thermal performance of buildings in climate scenarios. Extreme heat waves and increasing average air temperatures require adequate building responses to protect their occupants. The effect of heat on occupants can be quantified by an index known as the heat index (HI) (Suparta et al. 2017). The level of heat-related discomfort can be classified based on temperature and relative humidity and their impact on health issues (Barradas et al. 2022, López-Pérez et al. 2019, Gopalakrishnan et al. 2021). The levels of heat discomfort can be classified into four categories: caution, extreme caution, danger, and extreme danger. The standard heat discomfort index is obtained from the National Weather Services (NWS) Heat Index (Opitz-Stapleton et al. 2016, Suparta et al. 2017).

Research on air conditioning (AC) use for cooling small residential spaces has not been extensively studied in Indonesia. At least in the past ten years, there has been little research data specifically focused on the thermal comfort of AC-cooled rooms in small residential homes. This condition is also caused by the fact that regulations for small residential sectors have not been included in building energy regulations. Generally, research on rooms with AC focuses on larger buildings with a significant energy impact. In contrast, according to the above explanation, household energy consumption is more than 50% (Hariadi et al. 2018). For middle and high economic class households, energy consumption for cooling the room ranges from 20-32% (Luckyarno et al. 2019). In addition, according to the predicted impact of the COVID-19 pandemic on the energy sector in Indonesia in 2020, the Large Scale Social Restrictions (LSSR) policy that limits outdoor activities will increase household energy consumption (BPPT 2020).

Based on the above explanation, this proposed research aims to fill the gap in research on thermal comfort in homes that use AC, linked to several building comfort indicators such as CO_2 levels and heat index. Therefore, this study aims to investigate the existing conditions of room usage and the external climate's influence on internal thermal conditions, CO_2 levels, and heat index in a case study of a child's room during the COVID-19 home learning period.

Method

The study was conducted in a children's room in Kapasa Raya, Makassar city, as shown in figure 1. A children's room was selected as the case study for this research. The room is at the front of a single-story house, facing east. It has an area of 25.38 m2 (7.15 x 3.55 m), a ceiling height of 3.10 m, and two windows on the east side measuring 2x06x1.2 m (area 1.44 m^2), as shown in figures 2 and 3.

Figure 1. Research location map

This children's room uses an AC unit with an inverter capacity of 1.5 horse power (HP). Operates continuously with a thermostat setting of 26 °C. Before using the air conditioner for measurements, wash it first to operate with the best performance.

This study used survey and measurement methods. Climate data in the external environment (macro/external climate) was obtained from a Misol instrument whose sensors were placed outside the house from October 4 to 8, 2021. The parameters of the interior room climate (micro/internal climate) were also measured using a Misol instrument, measuring temperature and relative humidity of the air, with sensors placed at several points at the height of 75 cm and recording the duration of every minute for 24 hours. The measuring points were designated by the symbol numbers 1 to 5 (in circles); see Figures 2-3. The data were then input into Excel and compared to the Indonesian National Standard (INS) thermal comfort standards. The standard temperature range is between 20.5-27.1°C, with a relative humidity of 40%-60%, and indoor air velocity between 0.15-1.5 m/s; the recommended air velocity directly affecting the skin should not exceed 0.25 m/s (Latif et al. 2019a; SNI 03-6572 2001). In addition to temperature and relative humidity measurements, the concentration of CO_2 in the room was also measured, with a recording duration of every minute. The thermal air measurement data from the internal and external climate determined the heat index value using a commonly used formula, see equation (1) (Opitz-Stapleton et al. 2016).

$$HI = c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6R^2 + c_7T^2R + c_8TR^2 + c_9T^2R^2 \quad (1)$$

In this formula, HI = heat index in Fahrenheit, T = temperature in °F, and R = Relative humidity (%). Then the constants c_1 to c_9 are as follows:

c_1 = - 42.379
c_2 = - 2.04901523
c_3 = - 10.14333127
c_4 = - 0.22475541
c_5 = - 6.83783 × 10^{-3}
c_6 = - 5.481717 × 10^{-2}
c_7 = - 1.22874 × 10^{-3}
c_8 = 8.5282 × 10^{-4}
c_9 = - 1.99 × 10^{-6}

The surface temperature measurement on the floor, ceiling, and four sides of the walls was conducted for two days on November 3-4, 2021. Recorded every 15 minutes between 06:00-18:00 Central Indonesia Time (CIT). The treatment used in this measurement was with the air conditioner turned on with a thermostat position of 26 °C. Two instruments were used, namely thermocouples and a thermometer gun, with measurement points indicated by symbols A, B, C, D, E, and F (in triangles), as shown in figures 2-3.

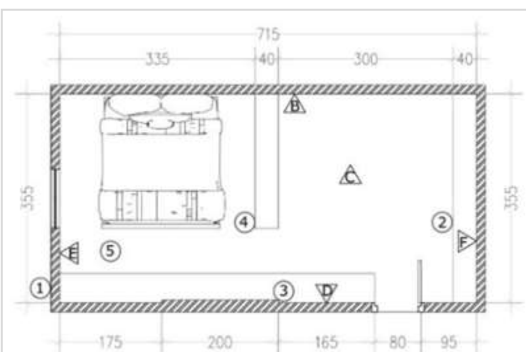

Figure 2. Child's room floor plan

In this study, other instruments used as measurement tools were the Misol data logger Wireless Weather Station, CO_2 data logger HT-2000, and Thermocouple 4 Channel Type K HT-9815.

Figure 3. Child's room cross section

The analysis of macro/external and internal climate measurement results was compared to the SNI thermal comfort standard. Meanwhile, the temperature measurement results for each surface will be compared to the average temperature of the interior climate/microclimate to determine the AC load value.

Result and discussion

The results of this study consisted of four measurement variables, namely measurements of temperature, relative humidity (RH), heat index, and CO_2 concentration.

Temperature

The results of temperature measurements in the case of the children's room were translated into three measurements, namely external temperature measurements outside the house, internal temperature measurements in the room, and surface temperature measurements for the floor, ceiling, and four sides of the walls.

Exterior temperature

The results of the exterior and interior air temperature measurements in figure 4 shows the difference between the outside/exterior temperature T1 (blue line) and the inside, which can be seen in graphs T2, T3, T4, and T5.

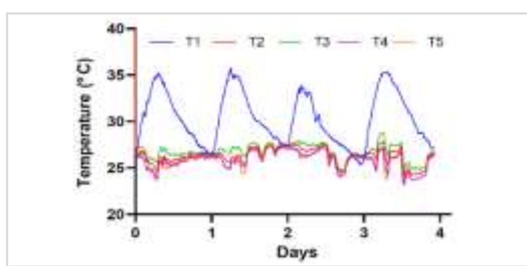

Figure 4. Interior and exterior temperature graph

Explanation:
T1 = Exterior temperature, location of point 1 device; T2= interior temperature, location of tool point 2; T3 = interior temperature, location of tool point 3; T4= Interior temperature, location of tool point 4; T5 = interior temperature, location of point 5. For measuring tool points, see figure 2.

The results of exterior climate measurements show an average day and night temperature of 30.4 °C with a maximum temperature of 35.8 °C and a minimum temperature of 25.3 °C.

The average temperature during the day is 32.0 °C from 06.00-18.00 CIT. The highest temperature during the day is 35.8 °C, and the lowest is 25.4 °C. This means that measurements are taken when the weather is sunny. This value is high, which can have the effect of giving heat pressure to the interior space. This condition can potentially cause thermal discomfort in the children's room and can negatively affect the productivity of the occupants' performance. (Brink et al. 2021). At night it was recorded from 18.00-06.00 CIT. The highest temperature at night is 33.1 °C, and the lowest is 25.3 °C. The average difference in external air temperature in 24 hours is 3.3 °C, with the maximum temperature difference during the day and the minimum temperature at night being 10.5 °C

Interior temperature

Interior measurements show that the average room temperature day and night are 26.2 °C. The average value is the room temperature that is considered comfortable for learning, playing, and sleeping in the child's room. The average temperature is included in the temperature thermal comfort interval (Latif et al. 2019a; SNI 1993). The highest temperature during measurement was 28.8 °C, and the lowest was 23.1 °C. High temperature in the room usually occurs due to changing the AC (air conditioner) thermostat to a high-temperature setting. If the room is uncomfortable because of the heat, usually the thermostat is set to a cooler temperature below 26°C on the AC remote control thermostat indicator.

Based on the measurement data for each sensor, there is a temperature difference based on the location of the measurement point. The sensors at points T4 and T5 are close to the flow of cold air from the AC, so they have lower temperature records than other sensor points. The air temperature distribution is uneven in this room, caused by the furniture layout affecting the flow direction. However, this position benefits energy savings because the cold area is where the occupants move or rest (effective area).

Surface temperature

The measurement results shown in figure 5 measure the surface temperature of the floor, ceiling, and four side walls on November 3, 2021.

The position of the measurement point is indicated by the letter symbol in the triangle in figure 2-3. Measurement point A is located on the surface of the gypsum ceiling, with an average temperature from morning to evening of 29.4 °C with a maximum temperature of 33.5 °C and a minimum of 25.9 °C. Measurement point B is located on the surface of the south wall, a double-sided plastered half-brick wall with a thickness of about 15 cm. The average temperature was recorded from morning to evening of 26.0 °C with a maximum temperature of 26.6 °C and a minimum of 25.4 °C. The C measurement point is the surface temperature of the tiled floor, which averages 27.7 °C with a maximum temperature of 28.0 °C and a minimum of 27.3 °C.

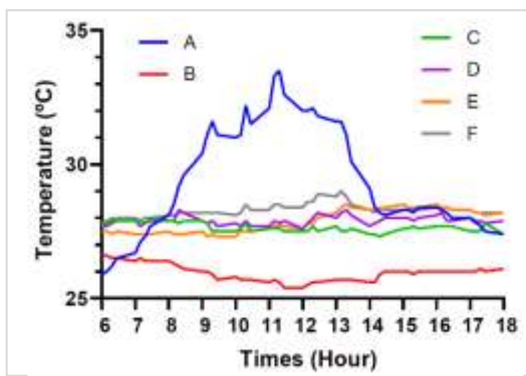

Figure 5. Graph of the surface temperature of the field of measurement on the first day

Explanation:
A = ceiling surface temperature; B = South wall surface temperature; C = floor surface temperature; D = North wall surface temperature; E = East wall surface temperature; F = surface temperature of the west wall. For measuring tool points, see figures 2 and 3.

Measurement point D is the surface temperature of the north wall made of double-sided 10 cm thick gypsum, with an average surface temperature of 27.9 °C, a maximum temperature of 28.3 °C, and a minimum of 27.6

°C. Measurement point E is the surface temperature of the east wall, the only room wall with direct contact with the outside. The double-sided plastered half-brick masonry wall material recorded an average surface temperature of 27.9 °C with a maximum temperature of 28.5 °C and a minimum of 27.3 °C. Measurement point F is the surface temperature of the western wall, made of 10 cm thick double-sided gypsum, recorded with an average surface temperature of 28.3 °C with a maximum temperature of 29.0 °C and a minimum of 27.8 °C.

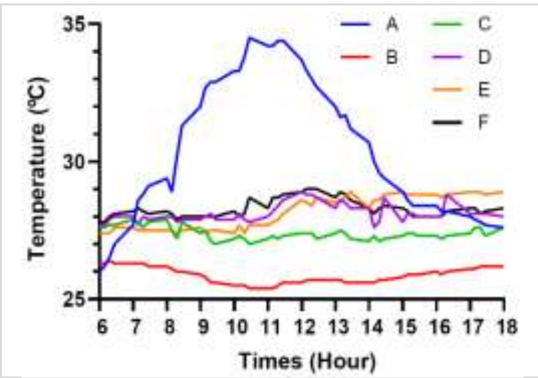

Figure 6. Graph of the surface temperature of the second day of measurement

The measurement results shown in figure 6 measure the surface temperature of the floor, ceiling, and four side walls on November 4, 2021.

The position of the measurement point is indicated by the letter symbol in the triangle in figure 2-3. Measurement point A is located on the surface of the gypsum ceiling, with an average temperature from morning to evening of 30.4 °C with a maximum temperature of 34.5 °C and a minimum of 26.0 °C. Measurement point B is located on the surface of the south wall, a half-brick masonry wall plastered on both sides, with an average temperature from morning to evening of 25.9 °C with a maximum temperature of 26.4 °C and a minimum of 25.4 °C. The C measurement point is the surface temperature of the tiled floor, which averages 27.4 °C with a maximum temperature of 27.9 °C and a minimum of 27.0 °C. Measurement point D is the surface temperature of the north wall made of 10 cm thick double-sided gypsum, recorded with an average surface temperature of 28.1 °C with a maximum temperature of 28.9 °C and a minimum of 27.6 °C. Measurement point E is the surface temperature of the east wall, the only room wall with direct contact with the outside. The double-sided plastered half-brick masonry wall material recorded an average surface temperature of 28.9 °C with a maximum temperature of 28.1 °C and a minimum of 27.4 °C. Measurement point F is the surface temperature of the western wall, made of 10 cm thick double-sided gypsum, recorded with an average surface temperature of 28.3 °C with a maximum temperature of 29.0 °C and a minimum of 27.8 °C.

Based on the measurements of the surface temperature of the ceiling, floor, and four sides of the walls in the children's room from 06.00 in the morning to 18.00 in the afternoon when the room was using air conditioning, the average temperature was recorded at 26.2 °C. Based on the results of surface temperature measurements for two days, it was found that the hottest surface areas were on the ceiling (measurement point A) with an average of 29.9 °C. Several other plane surfaces, such as the floor (point C) and walls points D and F, have relatively the same temperature ranging from 27.5-28.4 °C.

An interesting phenomenon from the measured data is the measuring point in plane B (red line on the graph), which has an average plane temperature of 25.9 °C lower than other surfaces. Wall area B, made of 1.5 brick thick red bricks plastered on both sides, is noted to be cooler when compared to wall areas D (Northside) and F (West side), made of gypsum material.

The wall's surface in the east room (measurement point E) has an average surface temperature measurement for two days of 28.4 °C. The wall material is made of 1.5 brick-thick red bricks plastered on both sides. It can be concluded that the average measurement of the east wall is quite low even though the outer surface of this wall is in direct contact with the very hot outside air. Therefore, the data from this study can be concluded that the red brick masonry wall material is very good for giving a cold effect to interior rooms.

Relative humidity

Along with temperature measurements, relative humidity (%) measurements were carried out, interior and exterior/external.

Figure 7 shows the results of measuring relative humidity for four days from 4-8 October 2021. The data recorded is the measurement of the external space of the building and the interior of the room.

The results of external measurements show that the average relative humidity for the four days and nights is 70%, with a maximum humidity of 86% and a minimum of 46%.

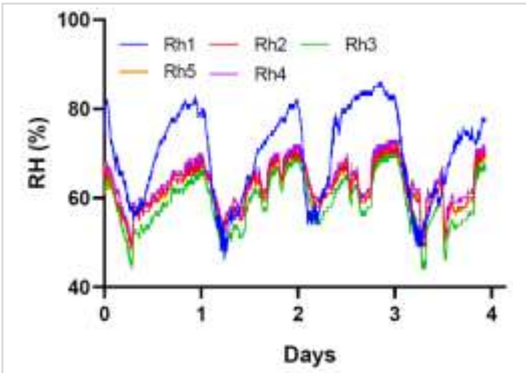

Figure 7. Relative humidity graph

Explanation:
Rh1 = Exterior temperature, location of point 1 device; Rh2 = interior temperature, location of tool point 2; Rh3 = interior temperature, location of tool point 3; Rh4= interior temperature, location of tool point 4; Rh5 = interior temperature, location of point 5. For measuring tool points, see figure 2.

The measurements of the interior of the room show that the average relative humidity for four days and nights is 61.7%, with a maximum humidity of 73% and a minimum of 44%.

The relative air humidity data shows the average air humidity outside the house is above the thermal comfort standard for the air humidity variable. Using air conditioners in bedrooms helps reduce air humidity to reach the threshold of thermal comfort for room air humidity. Air conditioners in humid tropical climates such as Indonesia generally can dry the air. Although the average relative humidity measurement results in the children's room are 61% which is above the standard for thermal comfort of air humidity of 40-60% (SNI 03-6572 2001), the occupant's perception of feeling comfortable with the results of the average air humidity measurement is 61, 7%. Temperatures above the thermal comfort standard may not feel hot if the relative humidity is low. In contrast, temperatures above the thermal comfort standard may feel uncomfortable if the humidity is high (Sobolewski et al. 2021).

The relationship between the daily average exterior temperature is 30.4 °C, and the interior is 26.2 °C, so there is a difference of 4.2 °C, which becomes the AC cooling load. Likewise, the relationship between the daily average exterior relative humidity is 70% and interior 61.7%, so that there is a difference of 8.3% which is the AC load. Based on this data, the performance of the air conditioner to lower the room temperature to a comfortable standard is effective. However, the air humidity must still be reduced by another 1.7% to meet the standard (SNI 03-6572 2001). The temperature conditions in the children's bedroom are acceptable to the occupants, including the humidity above the standard of 1.7%.

The relationship between surface heat and the average interior room temperature (26.2 °C) can be described as follows. Surface heat which is higher than the average room temperature, becomes a source of heat for the room, then becomes the workload of the AC to reduce it. The average (two days of measurement) surface temperatures during the day are: 1) point A, ceiling 29.9 °C; 2) point B, south wall 25.9 °C; 3) point C, floor surface 27.5 °C; 4) point D, North wall 28.0 °C; 5) point D, East wall 28.4 °C; 6) point D, West wall 28.3 °C. Almost all plane surfaces have heat above room temperature so that it becomes a cooling load for the AC except for the South wall, which is thought to be due to the influence of the type of brick wall material.

Heat index

This study also calculated the heat index (HI) for conditions outside the house and in the room. Heat index measurement is commonly used to determine the condition of potential heat stress in a room due to the influence of conditions outside the building.

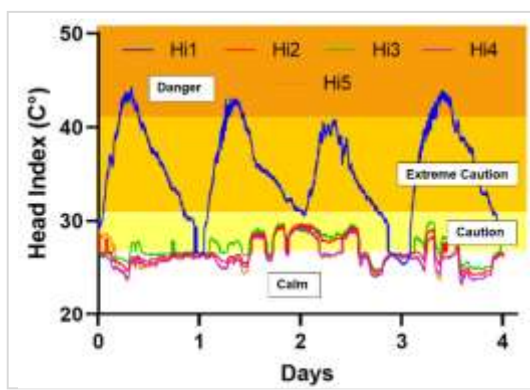

Figure 8. Heat index graph

Explanation:
Hi1= Exterior temperature, location of point 1 device; Hi2= Interior temperature, location of tool point 2;

Hi3= Interior temperature, location of tool point 3; Hi4= Interior temperature, location of tool point 4; Hi5= Interior temperature, location of point 5. For measuring tool points, see figure 2.

There are many formulas for calculating HI, but in this study, we use the general HI formula, also used by Opitz-Stapleton et al. (2016), as presented in Equation (1). The data from the calculation of the heat index in the children's room is presented in figure 8.

The temperature and humidity data in the children's room were measured for 24 hours in 4 days; then, the results were compared with the heat index chart to assess the danger level of heat disturbance. As a standard, heat disturbance is obtained from the National Weather Services (NWS) Heat Index, as shown in figure 9.

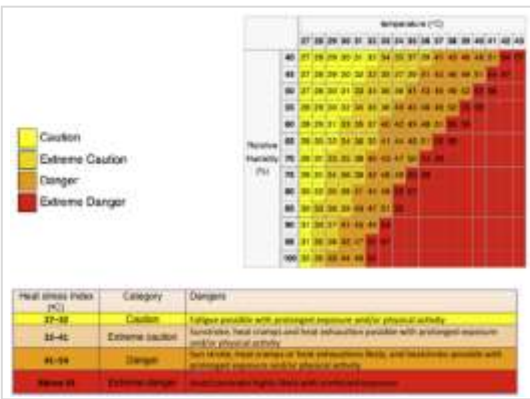

Figure 9. NWS heat index table and health impact (Opitz-Stapleton et al. 2016)

The results of heat index measurements, in general, show that the condition of the children's room during the day is safe from heat disturbance (calm) because the average daily interior temperature is 26.2 °C (Opitz-Stapleton et al. 2016). Some data shows that indoor conditions are in the caution category and outdoor conditions are in the extreme caution to danger category. This indicates that air conditioning effectively reduces the risk of health problems during hot weather, figure 9.

CO_2 concentration

The research results presented in figure 10 show that the children's room with a volume of 78.68 m3, if occupied by 3 to 4 people, has a CO_2 concentration that meets the standard during the day because the occupants often enter and leave the room, resulting happen air exchange due to the frequent opening of the door. Due to human respiratory activity, the CO_2 concentration rises above the required standard of 1000 ppm at night because the room is closed. For this room size, if occupied by more than three people, the nighttime CO_2 concentration level may exceed the 1000 ppm standard, which could potentially affect health but does not pose an immediate risk to human health since the concentration is <5,000 ppm (Hviid et al. 2020).

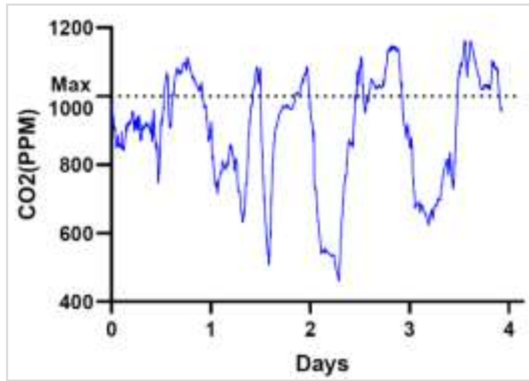

Figure 10. CO_2 concentration graph

The number of people in the room influences the high or low concentration of CO_2 in a child's room. Also influenced by natural air circulation because fresh air rich in O_2 enters, reducing high air CO_2 concentrations. The results of this children's room research strengthen the results of previous studies (Shriram et al. 2019; Yang et al. 2022).

This research has not analyzed the door and window openings model, so it has not been determined how much the recommended opening value is. However, based on the results of previous studies, it is known that to reduce the level of CO_2 concentration in the room is to increase ventilation to>10 L/s per person (Sun et al. 2018).

Conclusion

This investigative study found that the results showed that the average air temperature in the room was 26.2 °C with the AC thermostat setting at 26 °C. However, the air distribution is not evenly distributed due to the placement of furniture, which prevents air distribution evenly. The level of heat disturbance, as measured using the Heat Index, is classified as safe from heat disturbance (calm). The CO_2 concentration increases above normal limits if more than three occupants are in the room, especially at night. Although in this study, an in-depth study of the window and door opening modes has not been carried out. Based on previous findings, it is suggested to reduce CO_2 levels quickly to meet standards, namely by opening a window or door so that air circulation occurs.

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Sahabuddin Latif contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

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Sri Wahyuni contribute to methodology, supervision, and validation.