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The Assessment of Indoor Thermal Comfort of University Classrooms in Hot and Humid Areas

Rahmi Andarini[a,*], Muhammad Dzaky Al-Haidar[b], Vincentius Rayza Lee[c]

[a]Engineering Physics Department, Faculty of Engineering and Informatics, Universitas Multimedia Nusantara.
Email: rahmi.andarini@lecturer.umn.ac.id
[b]Engineering Physics Department, Faculty of Engineering and Informatics, Universitas Multimedia Nusantara.
Email: muhammad.dzaky1@student.umn.ac.id
[c]Engineering Physics Department, Faculty of Engineering and Informatics, Universitas Multimedia Nusantara.
Email: vincentius.rayza@student.umn.ac.id

Abstract

Thermal comfort is a description of the mental satisfaction experienced by humans regarding the temperature conditions in the surrounding environment. Appropriate thermal comfort conditions will have a positive influence on the occupant such as increasing productivity. This research was carried out to determine the level of thermal comfort in classrooms of the Universitas Multimedia Nusantara. There are two methods applied in this study: firstly, by measuring indoor air quality parameters, and the second method is by surveying the occupants' acceptance of the indoor air condition. The measurement of indoor air parameters consists of two different methods those are by installing Internet of Things monitoring systems and manual measurement. There were 2 classrooms and 1 student lounge surveyed, and the measured parameters were indoor air temperature and relative humidity. The results of the measurements show that the average indoor air temperature of the conditioned classrooms was $26^{O}C$ and the average temperature of the student lounge during unconditioned was $29^{O}C$. In the same condition, the measured relative humidity in the classrooms was found to be 55%, and the student lounge was at 70%. Regarding the thermal comfort condition, 68% of occupants of the Student Lounge felt just comfortable, 17% felt very comfortable, and 15% felt uncomfortable. The opinion regarding this choice is affected by the sitting position of the respondents. In classrooms D1509 and D1510, 64% of the respondents felt just comfortable, 28% felt very comfortable, and 8% felt uncomfortable, meaning that most of the respondents felt comfortable.

Keywords: Indoor air condition; measurement; thermal comfort

1. Introduction

A university is a formal educational institution that functions as a means of creating a generation that has knowledge, attitudes, and skills. Apart from preparing learning that is appropriate to educational institutions, universities must provide conducive and comfortable learning spaces that comply with Indonesian National Standards [1]. Several aspects that can be considered before creating a comfortable classroom consist of comfort, flexibility, and the use of communication technology. Aspects like this are essential in order to increase the effectiveness of learning in the classroom [2].

Thermal comfort is a state of mind and satisfaction that can be expressed in a thermal or comfortable state in the surrounding environment. This means that thermal comfort is greatly influenced by human conditions and their environment. Clothing and activities are the main human factors that determine the thermal comfort conditions in a room. Meanwhile, the environment has several factors such as: air temperature, relative humidity of the air flow, and surface temperature [3].

Thermal comfort refers to the subjective satisfaction or dissatisfaction of an individual with the thermal environment they are in. Each person has their own unique preferences and tolerances for thermal conditions around them. In recent years thermal comfort has been emphasized as one of the important factors when planning or maintaining a building. Especially in educational settings, providing optimal thermal comfort plays an important part in ensuring students' productivity and concentration [4].

The impact of thermal comfort cannot be neglected. It can affect various aspects such as productivity, concentration, and the wellbeing of an individual. Indoor air quality has become very important considering that the majority of our time is spent indoors, and especially for the education sector, indoor air quality conditions can affect student stress levels [5]. Previous research showed that when people are in a thermally comfortable environment, their performance, concentration, and productivity increase. The incapability to provide a thermally comfortable environment can lead to

*Corresponding author. Tel.: +62-812-3300-726
Engineering Physics, Universitas Multimedia Nusantara, Tangerang, Indonesia, 15810

discomfort, reduced productivity, concentration, and performance, and can cause health issues such as fatigue and stress [6].

Maintaining conducive and comfortable conditions is an essential factor of a university environment, specifically the thermal comfort condition of the classrooms, as indoor comfort condition has a significant impact on users' health, productivity, and psychology [7] [8]. Factors that can maintain conducive and comfortable indoor conditions are the buildings' indoor air condition that comply with Indonesian National Standards and installing artificial cooling, such as air conditioning system and mechanical ventilation [2]. The air conditioning system must satisfy the occupants' thermal comfort requirement [9], which is recommended by the Indonesian National Standard [10], that the indoor air temperature is maintained at 25.5ºC ± 1.5ºC and relative humidity of 60% ± 5%. The recommendation for indoor air conditioning is shown in Table 1.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers developed the standard for thermal environmental conditions, known as ASHRAE Standard 55. A method used to calculate and assess the thermal comfort level experienced by occupants in a particular environment, such as inside a room or building, and following set by ASHRAE Standards [3]. This standard establishes guidelines for indoor thermal comfort parameters, such as temperature, humidity, air speed, and other factors.

ASHRAE also provided a psychrometric chart that can be used to analyze the relationships between various properties of air, including temperature, humidity, and enthalpy. By utilizing the psychrometric chart [12] it can determine whether the thermal conditions in a room or building are within the acceptable comfort level, as shown in Fig. 1.

Table 1. Recommendation of indoor air condition [11]

Category	Air Temperature (TE)	Relative Humidity (RH)
Cool Comfortable	20.5^{O}C – 22.8^{O}C	50 %
Upper Threshold	24^{O}C	80 %
Comfortable	22.8^{O}C – 25.8^{O}C	70 %
Optimal Upper Threshold	28^{O}C	
Warm Comfortable	25.8^{O}C – 27^{O}C	60 %
Optimal Upper Threshold	31^{O}C	

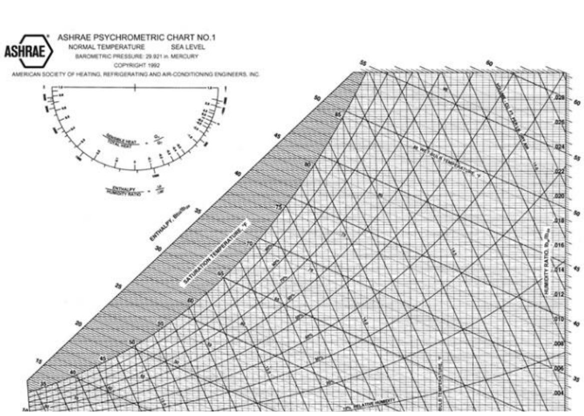

Figure 1. Psychrometric chart

Predicted Mean Value (PMV) is a method used to calculate and assess the thermal comfort level experienced by occupants in a particular environment, such as inside a room or building. PMV models take into account various factors, including air temperature, relative humidity, air velocity, activity level, radiant temperature, clothing insulation, and personal presence. This index used a scale ranging from -3 to +3, where negative values indicate a feeling of cold and the positive value indicates a feeling of warmth a person felt. The PMV model can predict the average thermal sensation felt by a group of people and determine the Predicted Percentage of Dissatisfied (PPD). Predicted Percentage of Dissatisfied is the prediction of the percentage of people who feel dissatisfied with the condition of the room [13].

The indoor air condition of Universitas Multimedia Nusantara has already been monitored in some places such as the library [14], classrooms and corridors [15] using the Internet of Things (IoT). The monitored parameter consists of indoor air temperature, relative humidity and CO_2 level. The developed intelligent system consists of several components, namely: Internet of Things (IoT) based sensors and smart thermostat using ESP32 board, MQTT broker using Raspberry Pi 4 board, MERN (MongoDB, Express JS, React JS and Node JS) Stack, and intelligent controller. In this stage, the system functions to monitor the condition of the room and its environment.

This research was carried out by taking manual measurements of the classrooms that have been installed in the monitoring system and distributing questionnaires to occupants of the classrooms. The measurement of indoor air conditioning was carried out in 3 (three) classrooms, namely D1509, D1510, and Student Lounge. The results of measurement will be compared to those of monitoring system values to ensure that the data logged by the monitoring system are accurate. The occupants' survey was carried out to confirm that the indoor thermal condition of the classrooms was acceptable.

The objective of this research is to assess the indoor air condition of classrooms of Universitas Multimedia Nusantara and to gather the occupant satisfaction level regarding indoor air condition. The occupant survey results regarding the comfort levels in the classrooms will be compared with the measured parameters.

2. Method

The methods applied in this research consist of 3 (three) main activities, such as

- measuring indoor air condition parameters (temperature and relative humidity) of the classrooms
- comparing the measured parameter with the data collected by the monitoring system with the purpose to ensuring that the data collected by the monitoring system are accurate
- Conducted occupant survey by distributing an electronic questionnaire to the students who previously had lectures in the classrooms of D1509, D1510, and Student Lounge.

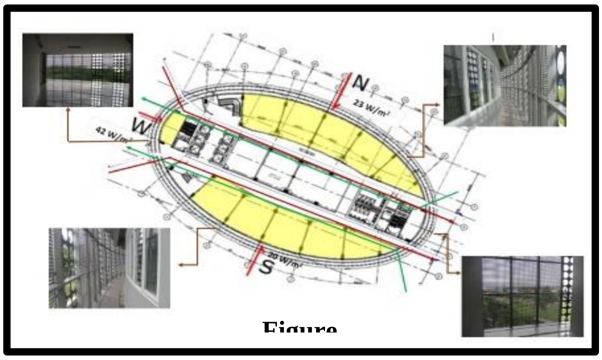

Figure 2. The layout of classrooms at the 15th level of Building D Universitas Multimedia Nusantara

2.1. Characteristics of the classrooms

The location measurement was carried out in the classrooms on the fifteenth floor of Building D of Universitas Multimedia Nusantara, as shown in Fig. 2. The building's mass orientation is designed by considering the sun's trajectory, which is how sunlight affects the building. Hence, solar radiation can be reduced. The shape of the building is an ellipse, and the outside wall is a double façade.

The air conditioning system for Building D uses a centralized chiller, which serves the needs of Building D. However, there is a thermostat installed in each classroom. Hence, the occupant is still able to turn the AC off or on as needed. In addition, the occupant can still set the air temperature and the fan speed. Usually, the AC will be on when there is a lecture in the classrooms, specifically for the Student Lounge, as shown in Fig. 3; it often functions as an event room, such as events by student organizations or lecturers' frequent meetings.

The measurement process and occupants' survey in the Student Lounge were carried out both when the room was conditioned and unconditioned. However, due to the low occupancy of the Student Lounge, most of the indoor air conditioning measurements were taken while the room's air conditioning was off. As the occupants' survey was performed using an e-questionnaire, therefore the respondents were still able to answer outside the measurement time.

Student Lounge is located in the middle of the 15th floor. The west and east walls are made of glass. The length, width, and height of the Student Lounge are 7.5 meters, 25.5 meters, and 3.5 meters, respectively.

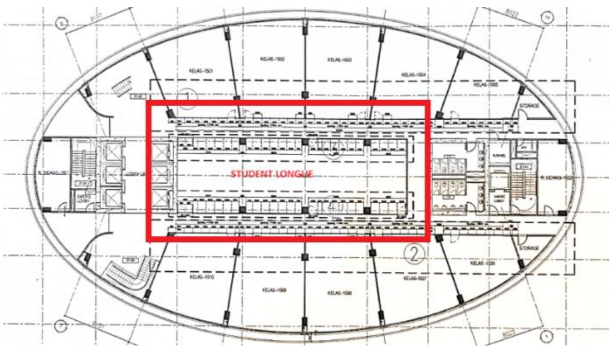

Figure 3. Location of student lounge

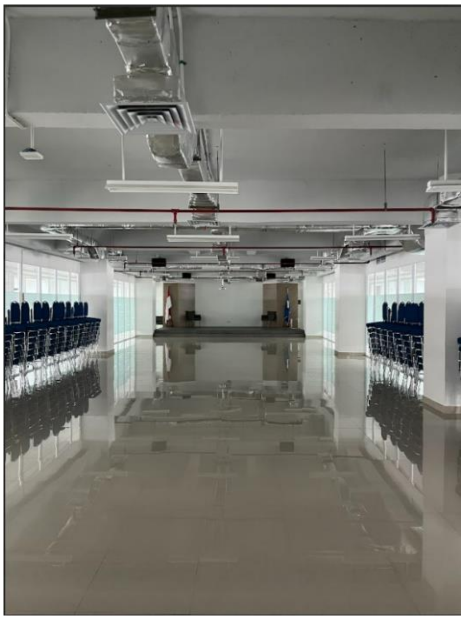

Figure 4. Interior condition of student lounge

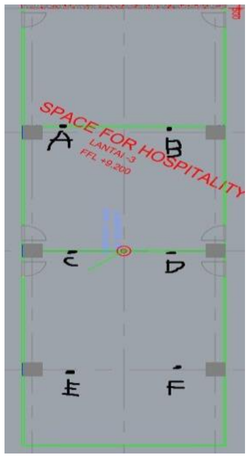

Figure 5. Points of measurement of student lounge

The total room area is 191.25 m^2, with a capacity of occupants of up to 100 students. The interior condition of the Student Lounge is shown in Figure 4. It can be seen that there is still a possibility of maximizing the use of natural lighting in the Student Lounge even though it is located in the middle of the floorplan.

There are two points of sensors of the monitoring system in the Student Lounge. They are installed in the front and back sides of the room. This monitoring system measured the indoor air temperature, relative humidity, and carbon dioxide level. The monitoring system logs the data every five minutes.

The measurement points of the Student Lounge are shown in Figure 5. There are 6 (six) points of measurement of Student Lounge, namely points A, B, C, D, E, and F. For every point, 10 (ten) measurements were carried out.

The classrooms D1509 and D1510 are located on the southwest side of the building, as depicted in Fig. 6. The dimensions of rooms D1509 and D1510 are 11 meters long by 7.5 meters wide by 3.5 meters high. There are windows on the south side and a glass wall on the north side. Hence, these classrooms have the opportunity to maximize natural lighting entering the rooms. The capacity of each room is 40 students.

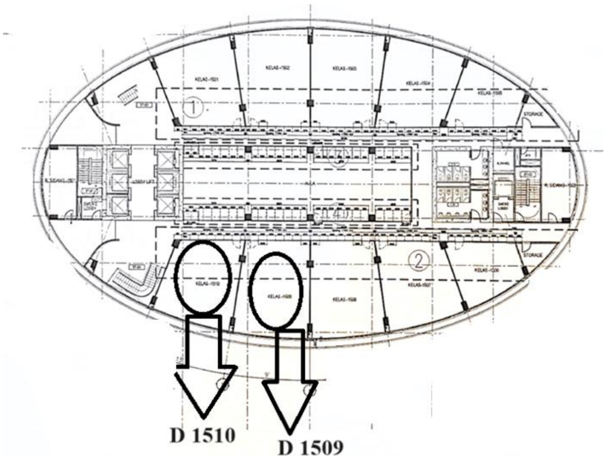

Figure 6. Position of classroom D1509 and D1510

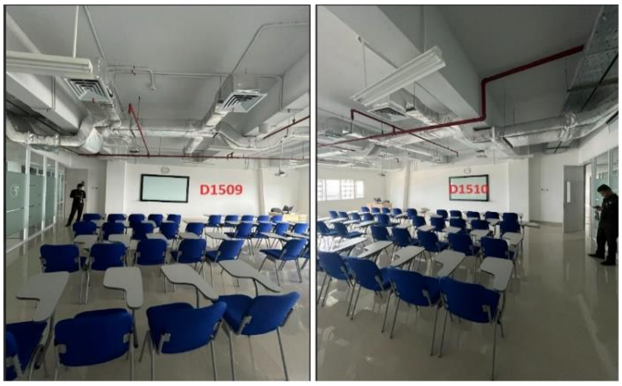

Figure 7. Interior Condition of Classrooms D1509 and D1510

The interior condition of classrooms D1509 and D1510 is shown in Figure 7. The monitoring system is attached to the ceiling, in the front side of the classroom.

The measurement points of classrooms D1509 and D1510 are shown in Figure 8. There are 4 (four) points of measurement in each classroom, namely points A, B, C, and D. For every point, there were 10 (ten) indoor air temperature and relative humidity measurements carried out. The measurements and occupant survey were done while the rooms' air condition was on and the setting temperature was 24^{O}C.

2.2. Monitoring System

The monitoring system that utilizes the DHT22 temperature and humidity sensor, which is a digital temperature and humidity sensor [15]. To monitor the condition of CO_2 levels, the type of CO_2 sensor used is MH-Z19B, which is an infrared gas sensor module. The circuit of monitoring system is depicted in Fig. 9.

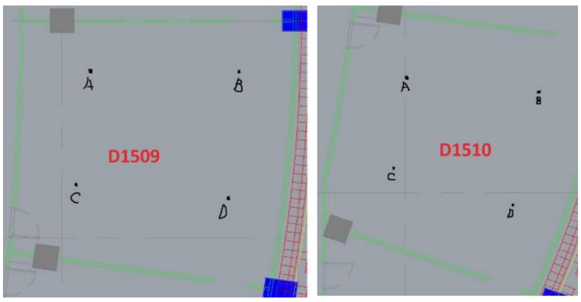

Figure 8. The measurement points of D1509 and D1510

Figure 9. Monitoring system

Figure 9. Calibration

Prior to the installation of the monitoring system, the calibrations were performed in order to ensure that the system worked properly. The calibration method applied was by comparing the reading of the calibrated room thermometer and hygrometer. For the CO_2 level, the type of the sensor is self-calibrating sensor. Figure 9 shows the calibration for temperature and relative humidity sensors.

The calibrations were carried out during 72 hours, with the data logged every 10 minutes. Figure 10 shows the calibration results of temperature and relative humidity sensors. There were 10 sensors calibrated, and the results shows that the sensors work properly and demonstrate similar results of reading. According to previous research [16], the characteristic of DHT22 sensor shows that the allowable average error is 3% for relative humidity and 2.3% for temperature or $\pm$ 5^{O}C.

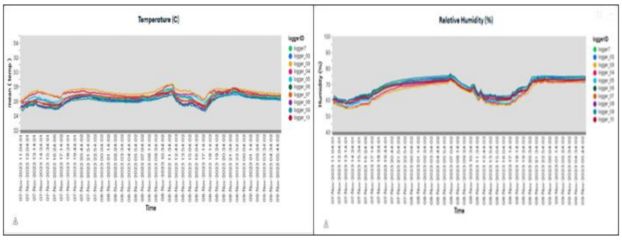

Figure 10. The calibration result

Figure 11. The position of monitoring system [15]

The circuit of the monitoring system is installed at the ceiling with the reason of being close to the electric plug and for security reasons.

2.3. Occupant survey

Occupants' survey was performed with the purpose to confirm the occupant's acceptance regarding the thermal comfort condition of the classrooms. The questionnaire consists of several question such as

- Gender – Male/Female
- Age - < 18 years; 18-25 years; >25 years
- Duration in the classrooms - < 1 hour; 2-3 hours, > 4 hours
- The position of the occupant during in the classroom (select the point)
- The impression regarding indoor temperature condition (-3 = cold; -2 = cool; -1 = slightly cool; 0 = neutral; +1 = slightly warm; +2 = warm; +3 = hot)
- The impression regarding relative humidity (-2 = very dry; -1 = dry; 0 = neutral; +1 = humid; +2 = very humid)
- Overall, how is the occupant's impression regarding the indoor thermal comfort (very comfortable – just comfortable – uncomfortable)

The target respondents for this survey were the students who had experience staying in the selected classrooms within the month of February until May 2024. The e-questionnaire was distributed so that it would be more flexible for the respondent to answer the questions. Some assumptions taken into consideration were consists of clothing value and respondents' activity. The dress worn by the occupants is a casual dress (trousers, short-sleeve shirt) with the clothing value of 0.57 [3]. As most of the respondents are students, light activity it is considered as reading and seated with a metabolic rate of 1.0 met [3].

3. Results and Analysis

3.1. Measurement of indoor air condition

The results of the measurement of indoor air parameters of the Student Lounge during unconditioned, as depicted in Fig. 13, show that the indoor temperature ranges between 28.4^{o}C to 29.5^{o}C, and the relative humidity was between 71.9 – 73.9%.

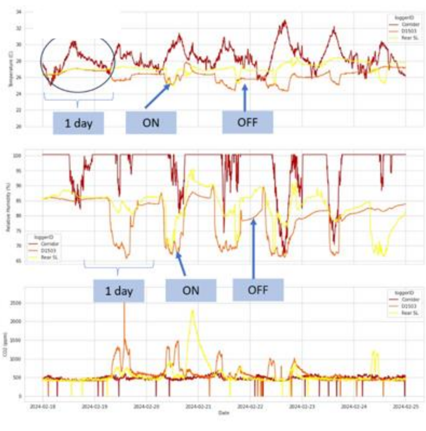

Figure 13. The results of monitoring systems

Figure 14. The data logged resulted by monitoring system

In the classrooms, it is found that the indoor temperature ranges between 25.69^{O}C to 26.43^{O}C and relative humidity was between 48.42% to 60.34%.

Figure 14 shows that during unconditioned, the temperature of Student Lounge was constant at 27^{O}C throughout the day and the relative humidity was 80%. The air temperature in the classrooms reported at the average of 24.5^{O}C and the relative humidity of 65%.

During occupied hours where the air conditioned was on, the average indoor air temperature of the Student Lounge was reported at 24^{O}C and the relative humidity of 68% as depicted in Fig. 14. The temperature of the classrooms was around 25^{O}C and relative humidity was between 60% to 75% when there was activity in the classrooms.

From the results of the comparison between data logged by the monitoring system and manual measurement, it is found that there is a 1-2OC difference in indoor air temperature conditions. This difference is still below the allowable error range of 5^{O}C, which means that the data logged by the monitoring system is acceptable [16]. For the relative humidity, there is a 4% difference or 1% higher than that of the sensor data sheet's allowable error range. The difference that occurs between measured data and logged data by the monitoring system is most probably caused by the position and the number of measurement points. There are only two monitoring system sensors installed in the Student Lounge, whereas there are four measurement points. In addition, the position of the sensor is also different. The sensor of the monitoring system is located at a height of about 3.5 m from the floor, and the sensor of the manual environment meter was about 1 m. This situation has also occurred during the measurement process of classrooms D1509 and D1510.

3.2. Occupants' Survey

- Student Lounge

The number of people who answered the survey was 47 respondents, which consists of 33 males (70%) and 14 females (30%). The age of all respondents ranged between 18 and 25 years old. From the survey result, there are 33 respondents who usually stay inside for 2 to 3 hours, 6 respondents stay for 1 to 2 hours and 8 respondents stay more than 4 hours. This finding supports the previous statement that the room is usually functioned as a meeting room or seminar venue.

The likert scale is very useful in determining how or on what scale a person feels regarding the indoor air temperature and relative humidity conditions.

Figure 12 and 13 show the Likert scale of the occupants' impression regarding the indoor air temperature condition. 13 respondents felt slightly cool (-1), and 13 respondents chose neutral (0). There are 10 respondents agreed that the indoor air temperature was slightly warm, 8 respondents felt slightly cool and only 2 respondents felt warm.

Regarding the condition of relative humidity, based on survey results that graphed in Figure 13, most of the respondents felt neutral (0). That is, 33 respondents (70%), 4 (9%) felt dry (-1), and 4 people (9%) felt very dry (-2). There are 5 people (11%) felt humid (+1), and only 1 person felt very humid (+2).

The average temperature and humidity levels, according to the survey, are -0.3 and -0.1, respectively. This means that the occupants felt slightly cool and slightly dry. According to the ASHRAE standard, this value is within the comfort level.

Figure 14 shows that 68% of occupants of the Student Lounge felt just comfortable,17% felt very comfortable, and 15% felt uncomfortable. The opinion regarding this choice is affected by the sitting position of the respondents.

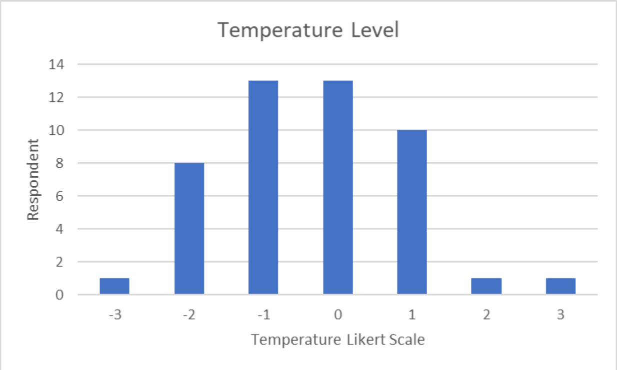

Figure 12. The number of respondent vs impression on the indoor air temperature of student lounge

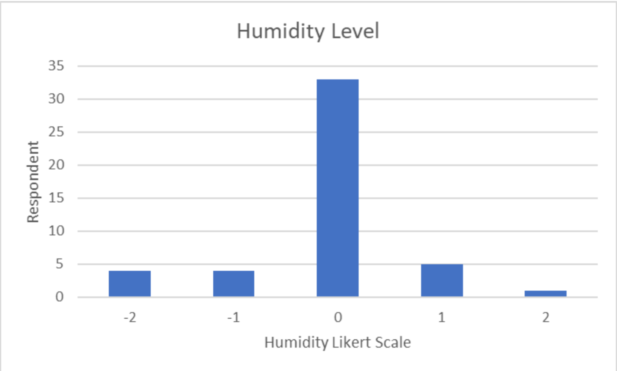

Figure 13. The number of respondent vs impression on the relative humidity of student lounge

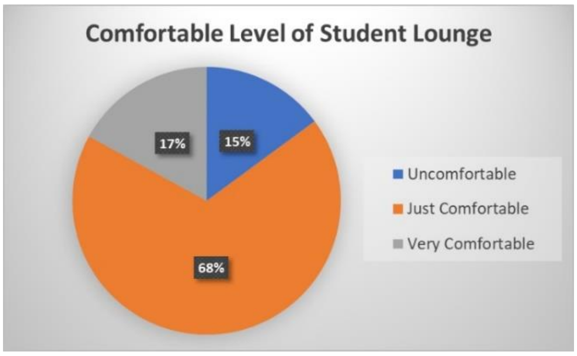

Figure 14. Percentage of comfort level of the occupants of student lounge

Figure 15. Sitting position at student lounge

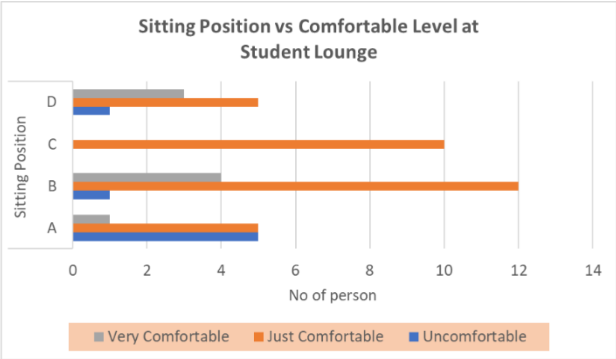

Figure 16. The sitting position vs comfortable level

The sitting position of the respondents at the Student Lounge is depicted in Figure 15. There 4 (four) segments that define the sitting area. The respondents were asked about their position during their activity in the Student Lounge.

Referring to Figure 16, it can be seen that the most "very comfortable" area is area B, followed by area D, and uncomfortable sitting position is area A. This situation occurs most probably caused by the position of area B and area D are the closest position from the entrance doors, of which according to the average PMV, indoor air condition of Student Lounge is cold and dry, thus, area near the entrances will be slightly warmer as the outdoor of Student Lounge is unconditioned.

Figure 17 shows the Likert scale of the occupants' impression regarding the indoor air temperature condition of classrooms D1509 and D1510. There are 24 respondents felt cool (-2) and 19 respondents choose slightly cool (-1). There are 6 respondents felt neutral (0) and 1 person agreed that the room was cold also 1 person felt hot.

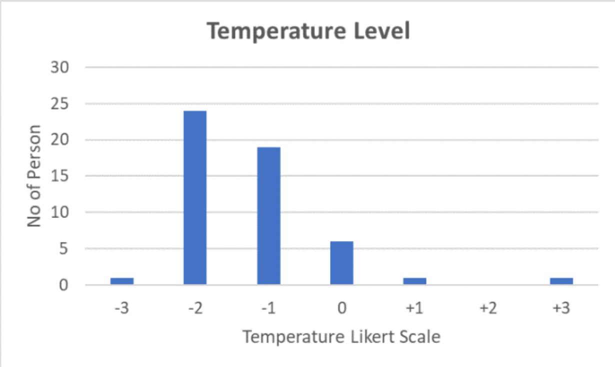

Figure 17. The number of respondents vs impressions on the indoor air temperature of Classrooms D1509 and D1510

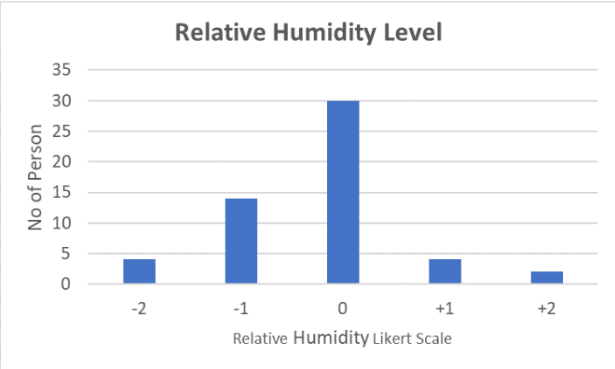

Figure 18. The number of respondent vs impression on the relative humidity of Classrooms D1509 and D1510

According to the survey results related to the relative humidity, graphed in Figure 18 shows that most of the respondents felt neutral (0) that is 30 respondents (56%), 14 (26%) felt dry (-1) and 4 person (7%) felt very dry (-2) and humid, each. There are only 2 person (4%) felt very humid (+2).

Figure 19 shows that 64% of occupants of classrooms D1509 and D1510 felt just comfortable, 28% felt very comfortable, and 8% felt uncomfortable. There was no further observation regarding the seating position of the occupants of the classrooms.

Based on the PMV analysis, the average temperature and humidity levels according to the survey are -1.2 and -0.2, respectively. This means that the occupants felt cold and slightly dry.

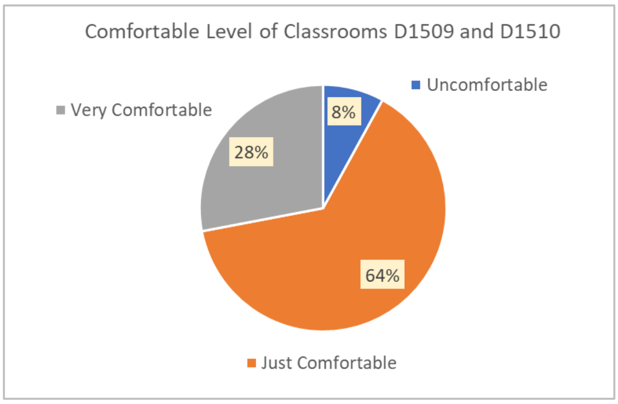

Figure 19. Percentage of Comfort Level of the Occupants of Classrooms D1509 and D510

4. Conclusion and Recommendation

There are some points that can be concluded from the analysis of the results of indoor air condition measurements and occupants' survey:

- From the results of the comparation between data logged by monitoring system and manual measurement, it is found that there is 1-2^{O}C difference of indoor air temperature condition. This difference is still below the allowable error range of 5^{O}C, which means that the data logged by monitoring system is acceptable. For the relative humidity, there is 4% difference or 1% higher than that of sensor data sheet's allowable error range. The difference occurs between measured data and logged data by monitoring system most probably caused by the position and the number of measurement points.
- The average temperature and humidity level according to the occupants' survey at Student Lounge are -0.3 and -0.1, respectively. This means that the occupants felt cold and dry. According to the ASHRAE standard this value is within the comfortable level.
- Regarding the thermal comfort condition, 68% of occupants of Student Lounge felt just comfortable, 17% felt very comfortable and 15% felt uncomfortable. The opinion regarding this choice is affected by the sitting position of the respondents. At the classrooms D1509 and D1510, 64% of the respondents felt just comfortable, 28% felt very comfortable, while only 8% felt uncomfortable. It can be concluded that the majority of the respondents felt comfortable.
- Based on PMV analysis, the average temperature and humidity level according to the survey at Classrooms D1509 and D1510 are -1.2 and -0.2, respectively. This means that the occupants felt cold and slightly dry which shows the temperature condition is considered uncomfortable.

Based on the abovementioned conclusion, it is recommended to add more sensors installed in the rooms so that the results of monitoring systems are more accurate. It is also important to conduct measurements on the CO2 level and compare it to the results of the monitoring system, as this parameter is also significant in determining the indoor comfort level.

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