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Thermal and Visual Comfort Analysis Using CBE Tools And Velux Simulation of Classroom in R.21 in Gedung Kuliah Bersama V University of Bengkulu

D Seftyarizki¹, A Prihatiningrum¹, and A Ramawangsa¹
¹Architecture Department, Universitas Bengkulu
debby.seftyarizki@unib.ac.id

Abstract. Thermal and Visual Comfort are two important subjects in building science. These two requirements also play important roles in creating good indoor environment quality. So does with R.21 in Gedung Bersama V Universitas Bengkulu, which used as a classroom. In a previous study, daylight visual comfort and mean radiant temperature for thermal comfort are already identified. However, the visual comfort of the previous study only defined the annual daylight. Meanwhile, thermal comfort was only defined by the mean radiant temperature obtained. In this recent study, different methods will be conducted to get more reliable results as well as upgrading the research quality. Thermal and Visual Comfort on August at 9 am, 11 am, and 1 pm and 3 pm will be identified. Thermal comfort quality will be measured with PMV standard from CBE calculation. Meanwhile, visual comfort quality will be interpreted using Velux daylight analysis and visualization. Weather data input is collected from Meteoblue. The result of the study showed that thermal comfort of the classroom is higher than standard, with PMV 1. Whereas visual comfort obtained already met the standard. Nevertheless, more output data obtained can improve the research map.

Keywords: Visual Comfort, Thermal Comfort, PMV, Illuminance.

1. Introduction
Designing a good building as a nice built environment means that full-filled several requirements are an essential thing to do. One of the requirements is comfort. Comfort is when the occupants of the building feeling at ease, when their body does not need to work hard to adapt to the surrounding environment. Comfort in a building can improve productivity as well as ensure the health of building occupants. Visual and thermal are two variables of comfort in terms of building science. Visual comfort is related to the ability of vision in a room, while thermal comfort is related to the thermal sensation perceived by room users. In most cases, the visual and thermal provision in a building is conducted by natural lighting and natural ventilation. So thus with the classroom, where most of them are still depends on the utilization of natural lighting and natural ventilation to obtain thermal comfort. It’s a possible thing to do especially in a tropical country, because natural light from the sun is available for almost 12 hours all day around the year, while annual temperature differences and thermal fluctuation between day and night are not much significant. Other than comfort, the utilization of natural lighting and natural ventilation also brings another benefit, which is minimizing the electricity or energy use in the building. Moreover, these two, artificial lighting and air conditioning, took first and second place in energy use in a building (1).
In a classroom, the availability of windows and openings is a common thing. So thus, with the academic facility at University of Bengkulu, especially in Gedung Bersama V, that engineering and natural science major for learning activity. Most of the classrooms are still use natural ventilation through wall opening with the help of an electric fan and provide natural lighting using numbered glass window installed face to the outside of the building. This study will examine the thermal comfort of the room, whether other approaches are still needed to optimize thermal comfort inside the classroom more. This study also examines the visual comfort of the room by the amount of light coming to the room, whether the light is too excessive or even the classroom is still lacks light.

1.1. Literature Review

Some Thermal comfort is the condition of mind that expressed the satisfaction of the thermal environment according to subjective evaluation (2). In detail, thermal comfort sensation takes place when there is a slightly low difference between human body temperature and surrounding environment temperature, so thus human body does not need to work hard to adapt. There are already a lot of studies about the thermal comfort of the room inside the building, especially a classroom. The common intention of thermal comfort study in the classroom is to improve student productivity, though it is not the only factor (3). One thing to be sure of is teenagers are founded more sensitive to the thermal sensation that they feel inside the classroom (4). Some of the thermal comfort studies in the classroom that ever done are to find the thermal comfort condition of the classroom that utilizes natural ventilation (5). Though people whose doing activity mostly in a naturally ventilated room are found to have a high tolerance of comfort in higher thermal conditions, some of them are still wanted the cooler thermal condition (5) (6). Several variables that have an effect on the thermal comfort inside the room are air temperature, humidity, airflow rate, and temperature from the wall surface that is exposed to the sun (mean radiant temperature) (7) (8) (9). These are the main variable to measure thermal comfort according to ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), besides activity and clothing that are used by the building occupants (10).

ASHRAE is a common standard that is used to maintain an indoor environment while preserving the outdoor environment. Though this standard comes from one specific country, this standard is widely used for thermal comfort research (5) (8) (11), because America also has a wide range of climate zones, so it can represent enough the variety of climate in another country. In calculating thermal comfort, ASHRAE depends on the psychrometric formula, using some variables as mentioned before. The measurement result of the ASHRAE thermal comfort standard produced several values. One of them is PMV (Predicted Mean Value). PMV is an index value of average thermal sensation prediction by a group that may experience the given space condition, within a scale of -3 to +3 that corresponding to “cold,” “cool,” “slightly cool,” “neutral,” “slightly warm,” “warm,” and “hot” categories (10). PMV index value is mostly used in thermal comfort-related studies to confirm the comfort of certain room conditions (4) (6) (11). PMV index also more reliable to measure classroom thermal comfort, and also have higher accuracy in predicting thermal comfort of tropic climate condition (11). One of the simple calculation tools to count PMV is by CBE Thermal Comfort Tool (6). CBE is a friendly tool because it can also show the comfort index in visual of the graphic. This makes the most impacted factor of thermal comfort in selected conditions are easier to understand. The neutral PMV index of CBE is between -0.5 and +0.5, representing 90% of satisfied occupants in the space (12).

Visual comfort is the condition of sufficient light quantity and quality that support the clear vision and not give harmful feeling when doing some activity. Good lighting is perceived when the light intensity reaches the minimum standard in the whole activity area, distributed evenly without significant bright-contrast differences (13). Visual comfort inside the room can be obtained by presenting natural lighting. Visual comfort obtained from natural lighting is believed to improve work productivity (14). The main source of natural lighting is the direct light of the sun and the light from the sky (skylight). Utilization of direct light from the sun is needed to be careful because the light should not exceed the limits. The excessive light intensity can disturb eyesight health, creating glare
and also bring along the heat. Therefore, a skylight is a more favorable design strategy to be used in most buildings. There are already several studies discussing visual comfort of light quantity-intensity rate and light quality-glare level in a classroom (15). Visual comfort is determined by the level of illuminance, luminance, and daylight factor (16) (17) (18). Luminance is the light brightness of the reflected surface from the light that strikes the unit area. Reflectance, roughness, and specularity of the surface play an important role in luminance. Illuminance is a total light incident falling onto the surface of the unit area. It is influenced by surface color and distance to the source of the light. The daylight factor is the percentage light amount of indoor related to the available light outdoor. Among them are opening size, opening position in the room, external and internal obstruction, indoor surface reflectance, room condition, and glazing type (19). Besides these factors, there some other aspect that influence lighting condition inside the classroom such as room dimension, room orientation, opening material, floor elevation, daylight condition, and the date and time simulation, opening degree, window wall ratio, room layout and furniture (16) (15) (18) (20) (21) (22). Several light level factors mentioned before with all the variables can be examined in a computer software called Velux. This software is already used by several studies about indoor natural lighting condition (16) (23), which one of them is a classroom (18).

1.2. Purposed study
To identify classroom visual and thermal comfort, R.21 in Gedung Kuliah Bersama V University of Bengkulu will be used as the case study. R.21 is located at the corner of the building, with 8m in wide and 6m in length, face 5 degrees to the north-east. R.21 has 8 windows faced to east and 4 windows faced to north, use glass door and also have a small window at the west side of the room connected to the indoor corridor (fig 1). R.21 use wall brick, concrete floor, and ceiling, and clear glass with alumn frame for windows and doors.

Last year, a previous study of this classroom was already conducted to examine visual and thermal comfort using Ecotect software simulation (24). The previous study showed that R.21 is not comforting in terms of thermal, but already have visual comfort with average light level annually 630 lux and 63% of daylight factor. However, it was limited by identifying the annual daylight and illuminance level to define visual comfort. While the mean radiant temperature inside the room on one day in April and September is used to defines thermal comfort. Moreover, the previous study used Kuala Lumpur climate data to run the simulation. Therefore, some new and different analysis methods are conducted as the new goal in this purpose study. First, Bengkulu climate data will be used as a controlled variable, especially for thermal comfort simulation. Then, a more detailed simulation time, which is 4 times a day for 15 days in August that represent the classroom schedule, will also be used as a controlled variable. Getting more various results, such as comfort in a certain time, with vary detailed input data, are the intention of this study to improve as well as upgrading the research quality.
2. Method
This research contains two analytical studies, thermal comfort and visual comfort. Both of these analytical studies are performed in two different simulation tools, CBE for thermal comfort, and Velux for visual comfort. Each analysis conducted in this study showed how to comfort R.21 in terms of thermal and visual occurred at a specific time of room usage on a daily basis, from 9 am until 3 pm with two hours interval. August 10, 2020, until August 14, 2020, August 17, 2020, until August 21, 2020, and August 24, 2020 until August 28, 2020 are chosen as the representative date of classroom usage, which is from Monday to Friday, for three weeks. Weather data condition of August is used for this study, when this study was conducted, in intention to get the latest condition result. Weather data used are collected from Meteoblue (25) using Bengkulu geographic location (3.8°S 102.27°E, 19m asl). After all the analysis results are already discovered, some interventions will be applied to see various possibility occurrence, so thus some recommendation will also be given to optimizing the comfort of R.21 for a classroom activity.

Thermal comfort analytical studies were performed using Center for The Built Environment (CBE) Thermal Comfort Tools by Berkeley (26). This analytics tool produced Predicted Mean Vote (PMV) as the thermal comfort index and thermal sensation. CBE thermal sensation which considers from the PMV index value of ASHRAE-55 standard, will be used as the standard of thermal comfort in this study. So thus, data input needed for this tool also use ASHRAE-55 standard for Psychrometric (air temperature), there is air temperature, mean radiant temperature, airspeed, relative humidity, metabolic rate, and clothing level. The metabolic rate and clothing level at this study are set to be the fixed variable. Metabolic rate is fixed in 1 met, an activity for Reading, seated, writing because this study assumed occurs during the class schedule. The clothing level at this study is 0.61 clo, Trousers, long-sleeve because it assumes as the common cloth wear by men and women student. Air temperature, airspeed, and relative humidity are adjusted variable with weather data condition according to selected date and time (fig. 2, fig. 3). Mean radiant temperature (Tmrt) data is obtained from Ecotect simulation using room model of the previous study (24) with Bengkulu location and Bengkulu weather data from Climate One Buildings’ website (27). Since there is a limitation of available weather data, mean radiant temperature on August 13, August 20, and August 27, which represent each week, will be used for these15 selected simulation dates (fig. 3).

Figure 2. Air temperature (processed from Meteoblue) and Mean radiant temperature (processed from Ecotect).
Figure 3. (a) wind speed and relative humidity (processed from Meteoblue); (b) Mean radiant temperature (processed from Ecotect).

Analysis of visual comfort was done by identifying numbered of day-lighting inside the room using Velux daylight visualizer. This simulation tool produced illuminance level and daylight factor inside the room. Since the object of the room is a classroom, 300-750 lux will be used as the standard of visual comfort (19). While the minimum standard for daylight factor is 2% (28). This standard is chosen because the previous study also used the same standard, so thus the evaluation of comparative output data results between the previous study and recent study can be conducted. Another output data of Velux simulation is luminance. 100-500 cd/m² will be used as the standard luminance amount on the room surface (29). Three dimensions modeling of the room was used to simulate the daylight condition. Modeling was created as closely as possible to the original room. Some data input to perform simulation besides 3d modeling form are location, surface material, and furniture. Velux daylight visualizer has a limitation in performing the simulation. Since there is no Bengkulu location, Singapore will be used as the substitute location due to the closest distance to the reallocation among other choices location provided. Input data for room surface materials are explained in table 5. Furnitures are not added in the modeling because there is no default furniture provided that suited the real classroom condition. Another limitation is the simulation date. Illuminance and luminance data can be simulated only one day in a month, August 21. Meanwhile, the daylight factor is the annual condition. The actual sky condition will be justified into 3 categories showed in figure 4. All the numbered output data obtained was in the height of 600 mm above the floor.

Figure 4. Cloud cover data

3. Findings and Discussion

3.1. Thermal Comfort

In general, the thermal comfort result of R.21 in GBV UNIB according to CBE Thermal Comfort analysis is still not comfortable with an average value of PMV in 15 days is 1. Most of the sensation feels in the room are dominated in slightly warmer conditions. Commonly, PMV is lower in the morning, then increases on the day, and goes lower slowly in the afternoon. PMV at 1 pm is found more consistent every week, which means that the sensation feels during that time is always nearly the
same, which is slightly warm. The most various sensation occurs in the morning (9 am). It also showed that during 15 days of study, three of the thermal sensations recorded occur at this time. PMV at week 1 is recorded as the higher PMV of the week among three weeks of study, which is 1.15. The highest PMV of the day also occurs at week 1, which is on August 14, with a daily PMV is 1.53. The lowest PMV of the day during 15 days of the study also occurs this week, on August 11, with a daily PMV is 0.78. Though PMV at week 3 is recorded as the lower PMV of the week among three weeks of study, which is 0.99. Week 2 has an average PMV of the week. Yet, at the same time, the most neutral and the highest warm sensation recorded at a certain hour also occurs this week.

Almost all of the neutral sensations in certain hours occur in the morning (9 am). It is happening in week 2 and week 3 of study. The most neutral sensation is PMV 0.02. It occurred on August 18 at 9am, when the air temperature is in 27.47 °C, MRT 31.07 °C, wind speed 1.55 m/s, and RH 81%. Though the RH is one of the highest categories in 15 days, the air temperature on this day is in the lowest category among 15 days. Moreover, the wind speed is also quite high. Though the higher PMV of the week occurs in week 1, the warm thermal sensation daily is mostly occurred at week 2. The highest PMV in 15 days is 2.26, on August 19 at 11am. Air temperature on that day is 29.87 °C, MRT 32.5 °C, wind speed 0.07 m/s, and RH 68%. Though air temperature and RH at this day are in the mean category for 15 days, the wind speed that occurred at that time is the lowest speed recorded for 15 days. Thermal comfort in 15 days of study never has cold sensation because there is no PMV lower than 0. Reasons assumption of this condition is the MRT data is relatively high (32.21 °C). From most neutral and warmest sensation recorded in this study showed that RH is not taking a really important part for thermal comfort when analyze using CBE thermal comfort tool which is used ASHRAE-55 standard for Psychrometric (air temperature). The highest and lowest PMV occurs in a row of two days. It is showed that thermal sensations have high fluctuation, or in other words, do not have a regular daily pattern.

![Graph showing PMV result every 2 hours for 15 days, Thermal sensation, and average PMV result every 2 hours](image)

**Figure 5.** (a) PMV result every 2 hours for 15 days; (b) Thermal sensation; (c) average PMV result every 2 hours

The thermal comfort result in this study shows a similar result, which is not comfortable and slightly higher than the standard. Though, each study, previous study (24) and this study use different standards as well as different methods and different analysis tools. Thermal data input at this study (August month with Bengkulu climate data) that different from the previous study (April and September month with Kuala Lumpur climate data) but show similarity in thermal comfort result. It
happens because both of these thermal data are for a tropical country. Moreover, the climate in the tropical country does not have a high difference every month and slightly constant in a year. In a previous study, thermal comfort that indicates by MRT in the room is 0.5 °C higher than standard. At this study, thermal comfort that indicates by PMV, is 0.5 point higher than standard. It shows that both of these studies showed relatively same result.

To optimize thermal comfort, average data will be used to find purposed thermal data condition, so thus thermal comfort could be obtained. With fixed clothing level (0.61 clo), metabolic rate (1 met), relative humidity (68.5%), MRT (32.21 °C), and wind speed in the range of 0.07 – 1.9 m/s, desired air temperature to reach thermal comfort is in 18 °C – 30 °C. and dry bulb temperature recommend is from 15 °C until 27 °C. When R.21 later planned to use an HVAC system, the operative temperature recommend for this condition is 24 °C – 30 °C. when lecture in a classroom requires various activities from sitting (1 met) to walking (1.7 met), suggested air temperature is in the range between 21°C to 29 °C, dry bulb temperature recommend is from 21 °C until 29 °C, and operative temperature recommend for this condition is 23 °C – 29 °C when R.21 latter planned to use HVAC system.

![Figure 6. Thermal comfort optimization](image)

3.2. Visuall Comfort

Sky condition for visual comfort with daylight simulation at this study plays an important role. In most simulation time, the sky is in clear condition, but the average cloud cover value is 41.89. In general, R.21 in GBV UNIB is already comfortable in terms of visuals. The simulation showed that the average illuminance value for 15 days of study in August is 454.605 lux, and the annual daylight factor is 4.35%. The maximum illuminance recorded is 1476 lux at 9 am in clear sky condition. Most of the overlit area is located at the corner of the room where window openings are installed on two sides of the wall, face to east and north outside. Despite that, on average, only 11% of the area receives more than 750 lux in 15 days of the simulation study. The minimum illuminance recorded is 98 lux at 3 pm in overcast sky condition. Overcast sky condition is mostly found at this hour. Most of the underlit area is located at the corner of the room near the door. This is the area that furthest from the window openings, even though this corner actually already has a glass door face to the indoor corridor. On average, as much as 68% area is still receiving more than 300 lux in 15 days of the simulation study.

There is not much various output data obtained in this study, because variable other than sky condition is set to be fixed variable, and sky condition is grouped into 3 categories only. Illuminance level in general is already high in the morning, then getting lower in the afternoon. However, morning sky conditions having more various conditions every week than afternoon sky conditions. It happens
because R.21 in GBV UNIB has several windows opening face to the east. So thus, afternoons’ daylight is more consistent every week. The highest daily illuminance is 503.793 lux. It occurs when the sky is always in sunny condition. This is the modus of sky condition, which appears 6 days among the total of 15 days of the simulation study. Meanwhile, the lowest daily illuminance is 347.8975 lux. It occurs when the sky is always in overcast, nearly cloudy condition. This sky condition rarely happens (only once) in 15 days of the simulation study.

Figure 7. (a) illuminance level every 2 hours for 15 days; (b) sky condition and illuminance level every 2 hours; (c) average illuminance level every 2 hours

The visual comfort result at this study is not much different from the previous study (24). However, the average illuminance and daylight factor are having a small difference with the previous study, about 180 lux lower and 2% DF smaller. It probably because there is not much light comes from the glass door face to the indoor corridor, which happens in the previous study. This situation in the current study is the closest to the actual situation. Therefore, it can be concluded that the current study is the correction from the previous study. Moreover, detailed results in every hour can be an improvement result of the previous study. The probability of glare mostly occurs on sunny morning days, where direct light comes into the room through the window opening, with up to 200 cd/m² of luminance level.

There is a lot of sky condition probability that always changes, no matter the season, month, and the hour is. By taking a look at these various sky conditions every hour, the best daylight condition can be identified. According to morning sky condition in August, most of them are in sunny condition. Daylight condition at 9 am in R.21 is nearly overlit throughout the room evenly. This 665.65 lux illuminance is the most maximum illuminance among other conditions. It makes the probability of visual discomfort and glare is high at this hour. It happens because R.21 has windows opening face to the east. Average condition is likely to happen when the intermediate sky and overcast sky occur at 11 am, overcast sky at 1 pm, and sunny sky at 3 pm. However, intermediate sky and overcast sky at 11 am, as well as the overcast sky at 1 pm are rarely and almost never happened in August. At 11 am, most of the sky is in sunny condition. It makes daylight condition at 11 am in R.21 is nearly overlit throughout the room evenly, and have visual discomfort and glare probability though just low. At 1
pm, it can be said it is the most preferable visual comfort for R.21 because the sunny and overcast sky mostly occurs at this hour in August. Meanwhile, at 3 pm in the afternoon, the sunny and cloudy condition mostly happens, but discomfort with too dark illuminance might happen.

| Sunny sky | Intermediate sky | Overcast sky | Daylight Factor |
|-----------|------------------|--------------|----------------|
| 9 am      | 665.65 lux       | 475.55 lux   |                |
|           | (Nearly overlit, maximum illuminance) | (Average illuminance) | (Underlit, distributed evenly) |
|           | 475.55 lux       | 295.56 lux   |                |
| 11 am     | 557.26 lux       | 437.43 lux   |                |
|           | (Nearly overlit) | (Average illuminance) | (Average illuminance) |
|           | (Distributed evenly) | (Average distribution) | (Average distribution) |
| 1 pm      | 448.68 lux       | 368.28 lux   |                |
|           | (Average illuminance) | (Nearly underlit) | (Average illuminance) |
|           | (Distributed evenly) | (Average distribution) | (Average distribution) |
| 3 pm      | 343.58 lux       | 294.1 lux    |                |
|           | (Average illuminance) | (Underlit, minimum illuminance) | (Underlit) |
|           | (Average distribution) | (Bad distribution) | (Bad distribution) |

DF = Average, meet standard, bad distribution.
4. Conclusion
R. 21 in GB V UNIB is still not comfortable in terms of thermal because the average PMV for 15 days of simulation is 1, which is 0.5 points higher than standard. It means that the common thermal sensation at R. 21 is slightly warm. The highest temperature mostly occurs at 1 pm. The thermal comfort result at this study is having similarity to the previous study, though using different methods and more detailed input data. For visual comfort, R. 21 in GB V UNIB meets the comfort standard, with 454 lux illuminance and 4.35% daylight factor. The most overlit condition happens in the morning because R. 21 having a window face to the east outside. Visual comfort result has similarity with the previous study, but slightly different in the value obtained, which is lower than the previous study. In this study, output data obtained is more detailed and has improved in the simulated visual condition of the room. From both of the studies, the uncomfortable condition between visual and thermal does not conduct at the same time. It means that when the lighting inside the room is too bright (in the morning), this room is not always showed a warm sensation, and vice versa. One recommendation to obtain thermal comfort is by setting the temperature inside the room to 23°C – 29°C. Other than using mechanical equipment, this intention can be obtained by creating shading to lowering MRT. So does with visual comfort, providing shading can be applied to anticipate excessive light and glare in the room. This study is limited only to an occasional month. Though the previous study conducted in April and September, and this recent study conducted in August, all showed relatively similar results, research in other months is also needed to get more reliable results.

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